The Toyota production system : an example of managing complex social/teaching systems : 5 rules for designing...

Article · January 1999

Source: OAI

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THE TOYOTA PRODUCTION SYSTEM: AN EXAMPLE OF MANAGING COMPLEX SOCIAL / TECHNICAL SYSTEMS

5 RULES FOR DESIGNING, OPERATING, AND IMPROVING ACTIVITIES, ACTIVITY-CONNECTIONS, AND FLOW-PATHS

A thesis presented
by
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In partial fulfillment of the requirements
for the degree of
Doctor of Business Administration

HARVARD UNIVERSITY
GRADUATE SCHOOL OF BUSINESS ADMINISTRATION
George F. Baker Foundation

May 26, 1999

ABSTRACT

The Toyota Production System:
An Example of Managing Complex Social/Technical Systems
5 Rules for Designing, Operating, and Improving
Activities, Activity-Connections, and Flow-Paths

Steven J. Spear

Researchers have established that Toyota enjoys advantages in cost, quality, lead-time, and flexibility when compared to its competitors in automobile assembly. Differences in generating value have been attributed to differences between the Toyota Production System ("TPS") and alternative management systems. Distinctive tools and practices have been associated with TPS. However, evidence suggests that merely copying these does not generate the performance advantages enjoyed by Toyota. This has prompted several questions: how is TPS used in actual practice; under what circumstances and why does it lead to performance advantages; how is TPS propagated and why is it difficult to imitate?

I have three primary conclusions. The first is that the tools and practices that have received attention are not fundamental to TPS. Rather, they are responses to site-specific challenges in production and delivery of goods and service. The unstated, implicit but nevertheless pervasive guidelines that govern the design, operation, and improvement of individual activities, connections between activities, and flow-paths for production and delivery are fundamental. I have codified these as five "Rules-in-Use."

Second, the five Rules-in-Use promote distinctive organizational features. These are nested, modular structure; frequent, finely-grained self-diagnostics; and frequent, structured, directed problem-solving that is the primary mechanism for training and process improvement. These are advantageous when people both design and perform value-adding activities; information relevant to the design, coordination, and improvement of activities is inextricably linked to doing the activity; and the system's performance as a whole is affected by the form, timing, and quantity with which goods, services, and information are passed between activities. Bureaucracies, M-form corporations, light-weight and heavy-weight project management, and other approaches have been used to manage organizations with these characteristics. Toyota has invented -- through decades of experimentation -- a novel approach that contrasts with these others both in methods and in the fundamental, underpinning assumptions.

My third finding follows from these two. The Rules are fundamental to TPS. They are learned through frequent, structured, directed problem-solving. Therefore, people who know the Rules-in-Use and mechanisms to teach the Rules through frequent, structured, directed problem-solving are both necessary if an organization is going to learn TPS. Both are barriers to imitation.

These Rules were developed from field data, collected during 176 days working or directly observing others work at 33 sites in Japan and North America, over a 3 1/2 year period. Data was gathered across a variety of products, processes, functional specialties, and stages in the supply chain.

Dedication

To my family.

-- With gratitude and love

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ACKNOWLEDGMENTS

I am an extraordinarily fortunate person. For the better part of the last four years -- as has been true throughout my life, I have been the student of very many people who have gone to great lengths and have made great efforts to teach me what they know. This research would not have been possible without their selflessness, and I would be less of a person today had I not benefited from their influence. In these next few pages, I thank some of those to whom I am deeply indebted. In truth though, this work as a whole is a testament to the dedication, skill, passion, and commitment that all of those who have taught me have brought to what they do. Through my association with them, I am richer, and I hope that this work shows, in some measure, the appreciation that I owe to them.

This research had three purposes: to discover how the Toyota Production System is used in practice to manage the production and delivery of intermediate and final goods, services, and information; to discover why and under what circumstances the Toyota Production System is a greater source of value than alternative management systems; and to discover how Toyota promotes TPS expertise and to learn what prevents non-Toyota organizations from acquiring a similar capability. This dissertation reports my answers to these questions.

In particular, two people are responsible for the successful conduct of this research. First and foremost is Harvard Business School Professor H. Kent Bowen. He accepted me into the doctoral program, took responsibility for me as his student, guided my research efforts, challenged and greatly improved the interpretations I was making, and throughout guaranteed that I would have the opportunities, resources, and mentoring necessary to complete this undertaking. I cannot overstate the importance of his role, nor can I fully repay his kindness.

Hajime Ohba, manager of the Toyota Supplier Support Center, directed me to fruitful learning opportunities, provided access to people within plants that I could not have gained on my own, and patiently taught me. In word and deed, Mr. Ohba embodies the principle of a manager as learner-leader-teacher. He possesses the unusual combination of tremendous knowledge with an unrelenting willingness to be challenged to learn more. I am immeasurably in his debt, both for what he did on by behalf and for the example that he set.

I owe many thanks to the people at Toyota and at its supplier plants. They have produced, through inspiration and exertion, a magnificent creation. It was my privilege to study the product of their collective efforts. In addition to Mr. Ohba, I am also in debt to other people at the Toyota Supplier Support Center who allowed me to observe their work, explained what they were doing with great thoughtfulness, and made a deliberate investment in teaching me to understand the production environment. These include Toshi Kitamura, Olivier LaReau, Lisa Nichols, Christine Parker, Bryant Sanders, and Cindy Voss with whom I worked at great length. I am also greatly indebted to the Mr. Nakayama, Mr. Hayashii, and other senior members of Toyota's Operations Management Consulting Division for their hospitality and help in creating learning opportunities during my three research visits to Japan. I must also thank the OMCD members who guided and instructed me during these visits, including Mr. Akioka, Mr. Aoyama, Ms. Kitano, Mr. Numa, and Mr. Takeda. I would be derelict if I did not thank Mr. Fujio Cho, Toyota's president, who has shown interest in and provided encouragement to our research efforts.

I conducted this research by gathering data in 33 plants, in the United States and in Japan. Many of the people who contributed their time, expertise, interest, and enthusiasm are mentioned in this thesis. Many others are not, but they too were essential to the successful completion of this work.

I received enormous support at Harvard Business School. Professors Clayton Christensen and Amy Edmondson guided, instructed, and challenged my work, making it much better than it would have been otherwise. I was extremely fortunate to have them as advisors on my thesis committee.

As you will see clearly, I also am in debt to Professor Carliss Baldwin. Much of the discussion in this thesis rests squarely on definitions and constructs of modularity that she and HBS Dean Kim Clark developed. Beyond providing a conceptual grounding, Professor Baldwin engaged me in an ongoing conversation about this work and so contributed enormously too it. Professor Steven Wheelwright too played an integral role in making this a much better work than it would have been otherwise.

During my studies, several classmates offered consistently valuable advice on research methods, data analysis, and interpretation. Moreover, they provided friendship, encouragement, direction, and support. These include Tom Eisenmann, Alan MacCormack, Andrew McAfee, and Raul Velarde.

I don't think that I could have undertaken this research in a doctoral program other than that of the Harvard Business School. From my first days at HBS, I was trained in the art and science of doing field-based, grounded research that was motivated by the actual phenomena of the workplace and marketplace. I was extraordinarily rich in the committed teachers and the dedicated fellow-students who taught me in Basic Readings I (taught by Jay Lorsch and Nitan Nohria), Basic Readings II (Howard Stevenson and Ashish Nanda), Social Behavior in Organizations (Rob Robinson), Design of Field Research in Administration (Dick Walton), and Research Design and Measurement (Al Silk). The handprints of these people are impressed on this dissertation.

Conducting field research to this extent was extraordinarily expensive, by any standard, let alone that of doctoral students. The Division of Research at Harvard Business School gave unconditional support for these activities, without which this project could not have been completed.

An essential point of this research is that learning occurs in the course of solving "production-related" problems, difficulties in doing daily work. I encountered difficulties in the course of doing my own daily work as I tried to categorize my observations and convert them into generalizations that were valid, actionable, and broadly applicable. I received much help and encouragement from Keith Turnbull and Arnoldo Cruz at Alcoa who, at the same time, were taking steps at articulating and promoting the Alcoa Business System. I hope the give-and-take among us was as valuable to them in their efforts as it was to me in mine.

I conclude by turning my attention and affection to Miriam, my wife. In the nearly four years since we first met, we have dated, gotten engaged, have wed, and are now excitedly awaiting the arrival of our first child (due on graduation day, believe it or not). Miriam is the most important discovery of my doctoral years, compared to whom all the others pale. To her, to all those mentioned, and to the very many whom were not, I am immeasurably in debt.

Steven Spear

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May 1999

PREFACE

The chapters in this dissertation play the following roles:

Chapter 1 provides a distilled overview of this dissertation. The Rules-in-Use, the primary discovery of this research, are stated with a brief explanation of the role of each in managing organizations. Definitions are given for terms that appear frequently and with specific meaning throughout the text. Chapter 1 explains the research methods used to discover the Rules. This contains two pieces, one distinguishing deductive research from the inductive approach I used. This draws heavily on distinctions Kuhn makes in The Structure of Scientific Revolutions. The second explains the similarity between the inductive methods I used and those of William Foote Whyte, a renowned ethnographer and sociologist. Chapter 1 then introduces other findings generated by this research. These include the contention that the Rules-in-Use lead to three distinctive organizational characteristics (nested modularity; frequent, fine-grained process diagnostics; and frequent, structured, problem-solving based learning). This is a theoretical explanation for how and why TPS is a greater source of value than alternatives in managing the groups engaged in collaborative production and delivery of complex goods, services, and information.

This latter portion of Chapter 1 introduces an analogy between managing the design, testing, and redesigning of a complex technical system and the design, testing (through operation), and improvement of a complex production system. This portion is especially meant for the reader unfamiliar with concepts of modularity articulated by authors such as Baldwin and Clark, Christensen, and Ulrich.

Chapter 2 goes into more depth about research methods, and it explains where and how data were collected.

Chapter 3 distills the primary findings. It presents the Rules, illustrating each with a sampling of field data. Chapter 3 references the theory that explains why and the circumstances under which the Toyota Production System is a greater source of value in the production and delivery of goods, services, and information than are other management systems.

Chapter 4 positions this dissertation within two streams of the academic literature. The Chapter reviews the research that determined that the Toyota Production System represented best practice in automobile assembly. Chapter 4 then reviews the evolution of the Operations Management literature, tracking its development from a highly techno-centric focus to one that emphasizes the development and exploitation of 'dynamic capabilities' and other micro-infrastructural factors. Chapter 4 explains that my own research builds on both of these precedents by explicitly articulating the essence of TPS and by codifying guidelines for becoming a 'dynamic manufacturer.'

Chapter 5 and 6 explore the implications of the discoveries reported herein. The Rules-in-Use reflect the multiple assumptions held by TPS managers about work-design and about the people who do work. They apparently believe that the activity, connection, and flow-path (component, interface, and system) designs people use to do work should be capable of achieving successful outcomes. The designs should also be capable of immediately signaling unsuccessful results. In other words, people should have designs that test, in use, their own reliability.

More so though, the Rules-in-Use reflect a conviction that people deserve to expect that in the course of doing their work, they will successfully provide goods, services, and information valued by paying customers. They also deserve the opportunity to recognize, fix, and improve upon their own errors. A work system of this type places demands on people at all hierarchical levels that differ considerably from those evident in more conventional managerial systems. Some of these differences are explored in Chapter 5. In addition, Chapter 5 and Chapter 6 explain the value of the Rules-in-Use as guidelines for designing, operating, and improving a complex system in light of information theory and system flexibility.

Chapter 7, because of its length, appears somewhat out of what would be a more logical order. Perhaps more appropriately positioned after Chapter 3 or 4, Chapter 7 appears as the latter five-eighths of the document so that the reader can appreciate the breath of the research as a whole before plunging specifically into its ethnographic depths. The chapter presents in great detail the field gathered data that, through inductive analysis, led to the conclusions reported in this document. It is here that the reader can gain a fuller appreciation of the research methods I used, the data I collected, and the process by which I drew conclusions from this data. In effect, responsibility for the persuasive strength of this dissertation rests heavily, though not entirely, on Chapter 7.

With quantitative research, writers often share survey or interview questions; the structured data generated by the research instrument; and the structure and results of statistical models used for analysis. In contrast, my own research generated largely qualitative data about events that did not, as a group, lend themselves to a comprehensive, numerical comparison. Rather than having easily comparable surveys or interview results, I created detailed notes about the many actions and decisions I observed others make or that I made on my own. Chapter 7 presents much of this evidence in a fashion as faithful as possible to the way in which I observed it. In this way, Chapter 7 explains why I reached the conclusions I did from this particular data. The chapter gives readers the chance both to draw their own conclusions and evaluate the methods I used to draw conclusions.

There are certain accounts in the Data and Analysis chapters that are particularly illustrative. For instance, I've tried to establish strong contrasts between behavior in TPS and non-TPS-managed situations. These include cross-sectional comparisons in 7.1 and 7.2 between the same job done in a TPS and a non-TPS plant and longitudinal contrasts between behaviors before and after the Toyota Production System was introduced as the way to manage a particular situation. In both the cross-sectional and longitudinal accounts, my own experiences as a participant are interspersed with data gathered as an observer.

In Chapter 7.2, Rule-2 is illustrated in a number of other ways. This includes a counter-example of when I mis-designed a customer-supplier connection. This also includes a detailed description of the coordinative mechanisms used in sophisticated make-to-order system.

Quality Circles, teams, and other mechanisms for collaborative problem-solving have been associated with the Toyota Production System. Detailed accounts of how these processes are employed in a number of Toyota supplier plants are contained in Chapters 7.4 and 7.5. A contrast is made between an experimental approach to improvement in which learning occurs through hypothesis-testing and a more ad hoc approach of 'kaizen blitzes.' Chapter 7.4 also contains an account of a Toyota team promoting TPS at a plant. One person exemplified the Toyota approach of using problem-solving as a teaching activity, of designing teaching as a structured, self-diagnostic supplier-activity, and of designing the student-teacher relationship as a direct, binary, self-diagnostic customer-supplier connection. This person's actions show how the Rules-in-Use are used to produce and deliver services rather than physical goods only.

The Toyota Production System has been described as 'inventory-free,' or one that operates 'just-in-time.' **Chapter-8** details the how inventory is actually used as a response to site specific problems in production and delivery. This is meant to serve as a detailed example of how the Rules are applied and how problems are resolved when the Toyota Production System is used adroitly to manage the production and delivery of goods, services, and information.

CHAPTER 1:

INTRODUCTIONS, DEFINITIONS, OVERVIEWS, AND SUMMARIES

INTRODUCTION TO THE RULES-IN-USE

The Toyota Production System ("TPS") has received much attention from academic researchers and practitioners for more than a decade. Cusumano (1985, 1988), Krafcik (1988), Womack et al (1990) and others have established that plant and company level performance differences between Toyota and its competitors are attributable to differences in the management systems within plants. Consumers have rewarded Toyota products with increasing market share in Japan and overseas. Many practitioner-oriented books and more than 2,000 academic articles have focused on tools and practices characteristic of TPS such as pull systems, kanban cards, cells, 'kaizen,' and Just-in-Time.[1] Toyota has not been shy about allowing outside investigations. Toyota's plants receive tens of thousands of visitors each year,[2] and all of the Big-Three American auto-makers had done extensive bench marking studies at Toyota plants. General Motors has operated the New United Motors Manufacturing, Inc. ("NUMMI") joint venture with Toyota in Freemont, California, and Chrysler has created and promoted the Chrysler Operating System. In other words, many people have acknowledged that the system by which Toyota and (some) Toyota-supplier plants are managed generates more value than alternative management systems, investments had been made to understand Toyota's approach, and efforts had been expended to emulate Toyota's practices.

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[1] According to an ABI Inform key word search

Despite this attention and effort, a comprehensive explanation was missing of how the individual tools and practices function as an integrated whole to produce performance advantages. This was a concern since there was growing anecdotal evidence that attempts to implement individual tools had fallen short in generating performance advantages. This implies that though there was a consensus that the management system of Toyota and Toyota-supplier plants has been a source of value, the means by which management-system generated value is actually created had not been discovered.

Through extensive field-based research, I have sought to close the gap just described. My findings constitute new insights into what TPS is and how it works. This has led to understanding the general class of managerial problems for which TPS is well suited and why TPS is difficult to propagate. Therefore, this research has revealed the means by which TPS generates value; the reasons why and the conditions under which these means generate value; and the obstacles, costs or barriers that exist in employing these means. These have stimulated numerous questions and opportunities for additional research.

FINDING ONE: CODIFYING TPS AS FIVE RULES-IN-USE

ROLE AND STATEMENT OF 5 RULES-IN-USE

My primary discovery is that the Toyota Production System operates according to five guidelines. These govern the design, operation, and

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[2] According to correspondence with the Toyota Supplier Support Center.

improvement of *activities* done by individuals and machines to transform material, energy, or information from an input into an output; *connections* between adjacent activities through which material, energy and information are transferred, and *flow-paths* -- systems of connected activities -- over which goods, services, and information take form as they are produced and delivered. These guidelines are implicit -- evident in deed but not in word. Nevertheless, they are pervasive and are applied across products, processes, functional specialties, hierarchical levels, and supply-chain stages. I have codified these guidelines and have termed them "Rules-in-Use" to reflect that they are pervasive even though they are implicit. In this regard, a Rule-in-Use is to an explicit rule as a 'theory-in-use' is to an 'espoused theory,' as described by Argyris.

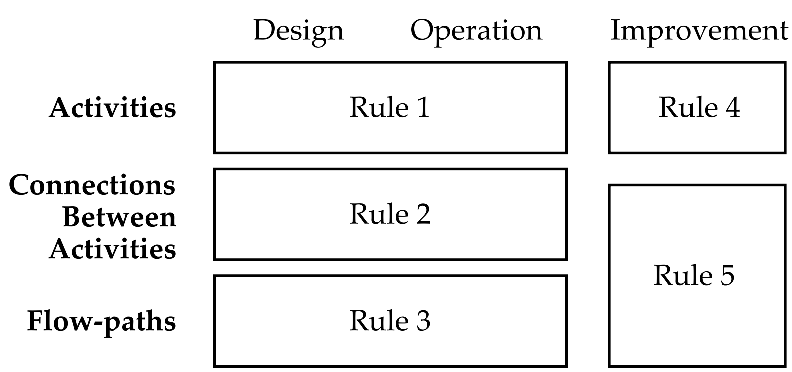


Figure 1: Role of each Rule-in-Use

Rule 1 guides the design and performance of all individual activities.

Rule-1 states: design and perform every activity so that it is *structured* and *self-diagnostic*.

Rule 2 guides the design and operation of connections between activities.

Rule-2 states: design and operate the connection between every person who or every machine that supplies a good, service, or information and the customer who receives the specific item so that the connection is *direct*, '*binary*,' and *self-diagnostic*.

Rule 3 guides the design and operation of flow-paths (systems of connected activities) over which goods, services, and information take form, within and among organizations.

Rule-3 states: Each good, service, and piece of information must have a *simple*, *pre-specified*, *self-diagnostic* flow-path over which it will travel as it takes form.

Rule 4 guides the improvement of individual value-adding activities.

Rule-4 states: Include *activity-improvement* in the work-content of each supplier. Assign a specific, capable person to teach the supplier to improve his own work by solving actual problems when and where they occur. Design and do all improvement activities so that they are experiments -- *Structured, Self-Diagnostic (Hypothesis-testing) Activities*. Continue to improve the activity until it is IDEAL.

Rule 5 guides the improvement of connections between activities and of flow-paths over which goods, services, and information take form.

Rule-5 states: Resolve *connection* and *flow-path* problems that affect a customer-supplier pair in the smallest group that includes the affected individuals. Conversely, form groups based on the expected nature and frequency of problems. Use *Structured, Self-Diagnostic Activities* to improve. Continue to improve until production and delivery is IDEAL.

DEFINITIONS

Rule 1: Structured, self-diagnostic activities

- To be *structured*, an activity must be designed and performed with a *pre-specified* sequence of steps, an *expected* time per step, and an *expected* outcome.
- To be *self-diagnostic*, an activity must be designed so a built in test immediately generates a binary (yes/no) signal if:
  (a) the activity is actually performed in a way different from its design or
  (b) the result is different than the predicted (defect-free) outcome.
  The signal must be interpretable as "a problem has occurred in the performance of a specific activity."

  A structured, self-diagnostic activity is a hypothesis-testing experiment. A problem signal refutes of one of two hypotheses: that the supplier is capable of performing the activity as it is designed, or that the activity is capable or producing a defect-free outcome if it is performed as it is designed.

Rule 2: Direct, binary, self-diagnostic connections

- For the connection to be *direct*, the customer -- the person uses a good, service, or information -- must send a request for that item to the supplier who will deliver that good, service, or information without the request going through a centralized intermediary.

Likewise, the supplier must be able to send a response to the customer without the response going through a centralized intermediary.

- For the connection to be *binary*, the request must be sent in a form that can be interpreted as DO the set of activities that will result in the delivery of a particular good, service, or information, in a pre-agreed ('defect-free') form, quantity, and response time. [No request must be interpretable as an implied DON'T DO signal]. Likewise, a response must be interpretable as a signal that the activities leading to the delivery of the good, service, or information in the defect-free form, quantity, and response time have been DONE.

- For the connection to be *self-diagnostic*, a binary (yes/no) signal must be generated immediately if a DO-request does not generate a DONE-response (i.e., generates a NOT DONE response), or if a DONE-response occurs without a DO-request.

  The signal must be interpretable as "a problem has occurred in a specific request-response connection that links a specific customer-supplier pair." Likewise, delivery in anything but the 'defect-free' form, quantity, and response time must be interpretable as "NOT DONE."

Rule-3: Pre-specified, simple, self-diagnostic flow-paths

- For flow-paths to be *pre-specified*, every good, service, or information must have one and only flow-path over which it is expected to travel as it takes form. This means each of the activities that will contribute to the production and delivery of the good, service, or information must be assigned uniquely to a single person or machine. This requires that what will be done, by which supplier, in what order, must be defined.

- To be *simple*, a flow-path must not have *loops* or *intertwined branches*.
- To be self-diagnostic, a flow-path must immediately generate a binary (yes/no) signal if a good, service, or information travels over a flow-path other than the expected one. The signal must be interpretable as "a problem has occurred in the production and delivery of a specific good, service, or information over a specific flow-path, either because a supplier expected to perform an activity did not, or a supplier not expected to perform a specific activity, actually did." (i.e., a person not assigned the responsibility for providing a specific good, service, or information, to a specific customer, actually did.)

Rule 4 and Rule 5: Hypothesis-testing improvement activities, done at the lowest possible level, moving production and delivery closer to the IDEAL.

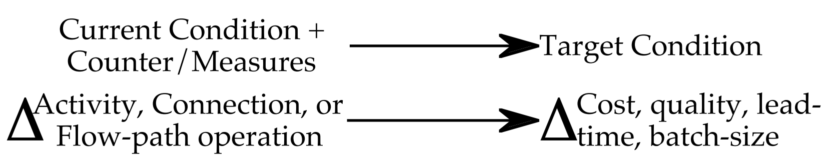
- To be a *hypothesis test*, an improvement must be designed and executed so that the expected effect of the change (in an activity, connection, or flow-path) can be compared with the actual effect of implementing the change. People whose behavior is guided by the Rules-in-Use do this by:
    - Representing the *current condition* (how an activity, or a connection or flow-path is actually operated in practice) diagrammatically, textually, and numerically.

- Identifying problems (symptoms and believed causes) in the current conditions.

- Proposing *counter-measures*: changes in the design of an activity, connection, or flow-path to remove the causes identified in the current condition.

- Articulating a *target condition*, a diagrammatic, textual, and numeric representation of how an activity should be performed or a connection or flow-path should be operated with the inclusion of the counter-measures.

The hypothesis test is:



• To be done in the smallest organizational unit, improvement must be done by the person who performs the activity or by the person who manages the smallest group that includes the connection or the flow-path.

• An activity or a system of activities is IDEAL if it always produces and delivers:

(a) defect-free responses (those that meet the customer's expectations),

(b) on-demand (only when triggered by the customer's request),

(c) in batches of one,

(d) with immediate response times,

(e) without waste, and

(f) with physical, emotional, and professional safety for the supplier. ("Safety" is defined more completely in Chapter 3.)

There is a fundamental distinction between the Rules-in-Use and the IDEAL serving as unstated guidelines for behavior, and the Rules and the IDEAL as description of consistent, universal, observable action. In the course of my research, I did not find an organization in which the design, operation, and improvement of every activity, connection, and flow-path met the criteria of the Rules-in-Use. In some instances, only some behavior was consistent with the Rules, whereas, in other cases, a large portion of work-site behavior was consistent with the Rules. Therefore, I did not find that the Rules-in-Use perfectly described observable behavior. Rather, I found that the Rules-in-Use consistently described the implied guidelines for behavior. In a similar vein, I did not observe activities or systems of activities that were IDEAL, completely on all six dimensions (I suspect that would be thermo-dynamically impossible). Rather, I observed that people designed and redesigned activities and systems of activities using the IDEAL as a guide or as a source of orientation.

EFFECT OF THE RULES ON PEOPLE IN THE ORGANIZATION

People whose work is designed according to Rule-1 can create the defect-free goods, services, and information for which they are responsible and have methods to distinguish when they have or have not done their work properly.

Rule-2 provides each person, as a customer, with a mechanism for triggering her suppliers to produce and deliver what the she needs, in the quantity needed, at the time needed. Rule-2 requires mechanisms for triggering problem-solving if a particular supplier does not respond as expected. Similarly, Rule-2 provides each person, as a supplier, with a mechanism for knowing precisely if he is working ahead or behind his customers' rates of need.

Rule-3 ensures that each person or machine has a designated supplier for each good, service, or information that is needed to complete the work so that no good, service, or information has been overlooked for any activity.

Rule-4 increases the capability of individuals to improve continuously their own work in ways consistent with the overall objectives of the organization.

Rule-5 serves to increase the capability of small groups of people to improve continuously their own work in ways consistent with the overall objectives of the organization.

COMMON THEMES OF THE RULES

Two themes underpin these Rules. These offer insight into Toyota's approach to the cognitive challenges of managing large-scale systems. One theme is learning through frequent experimentation. The second is sending binary signals to trigger action.

Learning by Hypothesis-testing (Activities, Connections, Flow-paths)

At TPS-managed sites, designs that are tested *with each use* are pervasive (for activities, connections, and flow-paths). In contrast, a similar design strategy -- of testing activities, connections, and flow-paths with each use -- was not evident at non-TPS sites. The data indicate that -- at TPS-managed sites -- activities, connections, and flow-paths are designed so that if the *expected* performance of an activity, connection, or flow-path is articulated before it is operated, then the *actual* operation confirms or refutes the hypotheses implied in the design. In turn, comparing *expected/predicted* outcomes with *actual* outcomes generates information for problem identification and knowledge creation.

Binary Signals to Trigger Activities

Binary signals to trigger action were pervasive at TPS-managed sites, but they were not evident elsewhere. This meant that a typical individual (customer) triggered the delivery of a good or a service from a representative supplier by sending a *request* in a form that meant "DO" [the activities that will deliver a particular good, service, or information in a pre-specified form, quantity, and response-time]. No request was a signal that meant "DON'T DO" the activities. The supplier's *response* was sent in a form that meant that the activities had been "DONE". The responses were not interpreted as "almost good enough" (form), "partially done" (quantity), or "nearly done" (timing). Rather, any response other than one that was correct in form, quantity, and response time was interpreted as "NOT DONE."

Just as DO/DON'T DO signals were used to trigger suppliers, Yes/No (binary) comparisons between expected and actual outcomes acted as binary DO/DON'T DO triggers for problem-solving activities. An activity had been performed was it was designed, or it was not. That it had not been could be interpreted as a binary trigger to DO problem-solving activities to find out why the activity had not performed as designed. The output of the activity was defect-free (form, quantity, timing) or it was not. The yes/no signal that it was not defect-free was a binary trigger to DO problem-solving to discover why a defect occurred. A supplier had responded to a customer request in the pre-specified form, quantity, and timing or he had not. That he had not was interpreted as a binary-trigger to DO problem-solving activities. An item had actually followed its pre-specified flow-path or it had not. That it had not was interpreted as a binary trigger to DO problem-solving activities to find out why the flow-path did not operate as expected.

DISCOVERING THE RULES-IN USE: OVERVIEW OF METHODS

EXPLAINING THE TERM "RULE-IN-USE"

Asked to explain the "essence of TPS," Toyota's most knowledgeable managers replied that TPS can't be explained, that it can only be understood by experience. The head of Toyota's Operations Management Consulting Division -- in effect a direct successor of Taiichi Ohno, one of the inventors of the Toyota Production System -- explained that Toyota didn't have any TPS experts, per se. Rather, when you go to the shop floor it is 'obvious' whether someone is using TPS well or not. (OMCD meeting, Nagoya, March 1996)

Through repeated trips to the shop floor as participant and observer with experienced members of Toyota's Operations Management Consulting Division ("OMCD") [Japan] and the Toyota Supplier Support Center ("TSSC") [North America], I discerned consistent patterns in what were considered good applications of "TPS thinking" and what were not. These patterns existed in the design, performance, and improvement of individual activities and in the design, operation, and improvement of systems of activities. The patterns were so strong, it appeared as if people were using rules to guide their decision making, even though the rules themselves were never actually articulated. Therefore, I termed these patterns "Rules-in-Use" to reflect that they were evidently used to guide behavior though they were not stated outright.

I have concluded that these Rules-in-Use are the essence of TPS:

- *At organizations in which people have learned from OMCD and TSSC teachers*, the Rules [as reflected in patterns of actual behavior] were evident across functional specialties, hierarchical levels and across a products, processes, and markets, and the Rules explain my field observations with fidelity.
- *At organizations that have not learned from OMCD and TSSC teachers*, similar patterns of behavior were evident only to a limited extent, regardless of function, product, process, or market. *Systematic* behavior that was similar to that underpinning the TPS Rules-in-Use was not evident.

This is not to say that following the Rules-in-Use is strictly a yes or no proposition, that all five are followed fully, or not at all. Even at Toyota plants, the degree varies to which individuals and groups follow each. (i.e., there are varying degrees of "TPSishness"). However, this appears to depend on managerial factors (experience, motivation, skill) and not on technical factors (product, process) or market factors (mix and volume of customer demand).

A key point is that while the Rules-in-Use are fundamental to TPS, the artifacts (kanbans, andons) and practices (quality circles, Just-In-Time) that have been widely associated with TPS are not. I based this conclusion on data collected during 176 days of first hand participation in and observation of the work done at Toyota factories, Toyota supplier plants, and non-Toyota facilities, at 33 sites in North America and Japan. Based on the evidence I gathered at the research sites managed by TPS, I concluded that these Rules are applied across a broad range of functional specialties; throughout organizational hierarchical layers; for a broad variety of technical processes; at different stages in the supply-chain; and for a variety of product-markets. In contrast, the artifacts which have received much attention in the academic and practitioner press are used with less universality within and across Toyota Production System managed sites. Therefore, one of my conclusions is that the artifacts themselves are not fundamental to TPS. They are the result of applying the Rules to specific challenges in production and delivery of goods, services, and information.

The research sites include some identified by other researchers as outstanding benchmarks. These include Toyota's Tsutsumi, Takaoka, Kyushu, Georgetown, and NUMMI assembly plants. My other research sites also include Toyota's new Indiana truck plant, a non-Toyota assembly plant, and Toyota suppliers (6 in Japan, 6 in North America). This is discussed more in the methodology section in Chapter 2.

METHODS FOR GATHERING AND ANALYZING DATA

The Rules-in-Use were developed through inductive analysis of field-gathered data. I worked or directly observed others working at 33 sites in North America and Japan, requiring 176 days in the field over a 3 1/2 year span. Supplementary data was collected from phone interviews, correspondence, and company documents. I recorded data in detailed journals of more than 1,000 pages. I analyzed data by iteratively constructing, modifying, rejecting, and reconstructing explanatory frameworks. I continued this process until the framework was validated by the data I already had, by additional trips to the field (for literal and theoretical replication as defined by Yin [1994]), and was validated by TPS experts within Toyota.

Literal replication:	predict similar results (i.e., similar behaviors in similar circumstances)
Theoretical replication:	predict contrasting results but for predictable reasons (i.e., dissimilar behaviors due to dissimilar circumstances)

Highlights of this approach include:

- 5 months as a member of the Toyota Supplier Support Center ("TSSC"), learning TPS tools and practices during the implementation of TPS at a Toyota supplier;
- 1 week working on the assembly line of a Big-3 auto maker for intimate knowledge of specific jobs so that I could compare my experiences with those of people in Toyota plants;
- three study trips, at one year intervals, to 14 Toyota-network plants in Japan, 3 of which I visited more than once allowing longitudinal comparisons;
- a longitudinal study of more than a year, involving 10 site visits, documenting a TSSC effort to teach TPS at a plant;
- study of TPS applied to diverse products such as autos, pre-fabricated homes, rebuilt starter motors, custom-made mattresses, logistics services, and post-sales service;
- study of TPS applied to diverse production processes and maintenance, training, and material conveyance; and

- presentation of the Rules-in-Use to and critique of them by Toyota plant managers, production managers, and senior members of Toyota's Operations Management Consulting Division ("OMCD").

INDUCTIVE AND DEDUCTIVE RESEARCH

I use the terms *induction* and *deduction* to distinguish between two types of mutually complementary research. In inductive research, data about specific events are gathered, and from these data, a general model is generated. In deductive research, a predictive model is used to generate testable hypotheses. Then, data is collected about specific events to confirm or refute the hypotheses generated from the model.

According to Kuhn, (The Structure of Scientific Revolutions, 1962, 1996), deductive research is associated with *normal science*, efforts to extend and refine existing paradigms. When existing paradigms cannot explain phenomena (i.e., the models do not provide predictions that are confirmed by data), inductive research is needed to collect data for the generation of new predictive models.

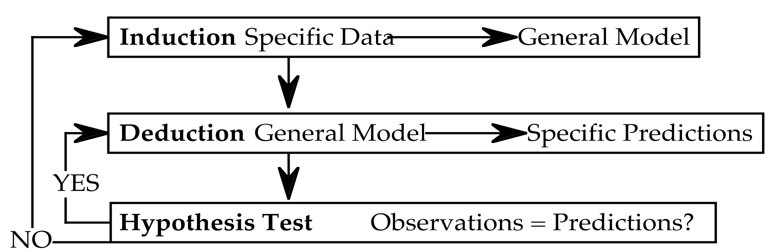


Figure 2: Cycle of inductive and deductive research

We were concerned that existing models did not explain well how the Toyota Production System generates more value than alternative management systems in the production and delivery of automobiles specifically and other goods, services, and information more generally. Doubting existing explanatory models, we had to generate alternative explanatory models through inductive methods.

A NOTE ON ETHNOGRAPHIC METHODOLOGY

Repeatedly, I refer to the experience of gathering data in manufacturing settings in the company of TPS experts from Toyota's TSSC and OMCD organizations. I pause here to remind the reader why this is important.

Like William F. Whyte who sought to decode the social and behavioral norms of Boston's North-End, Italian immigrant community (William F. Whyte, Street Corner Society, 1943, 1993), I was seeking to discover the norms that are critical elements of the Toyota Production System. Also, like Whyte, I was doing this by recording the behavior of the people (both those of the people I observed and my own behaviors) and the reaction of the community to those behaviors.

It was simpler to distinguish between behaviors consistent and inconsistent with the group's norms when accompanied by someone expert in the modes of proper behavior within the society being studied. In Whyte's case, he affiliated himself with the "Corner Boys," who helped guide him. In my case, I relied on people such as Mr. Ohba (general manager of TSSC); Lesa Nichols and Christine Parker (managers of TSSC's Research and Training group); Bryant Sanders, Olivier Lareau, Cindy Voss, Toshi Kitamura and other members of TSSC's Operations Management Consulting group; Mr. Cho, Mr. Ikebuchi, Mr.

Nakamura, Mr. Hayashi, Mr. Minura, and Mr. Tomomatsu -- all senior managers within Toyota; Mr. Takeda, Mr. Numa, and Mr. Akioka, OMCD consultants in Japan; as well as the many people who took time to educate me when I collected data in plants in North America and Japan.

FINDING TWO: ORGANIZATIONAL FEATURES PRODUCED BY THE RULES

Codifying the Toyota Production System as five Rules has led to my second research discovery. This is the general class of problems for which and the reasons why TPS is a source of value in managing the production and delivery of goods, services, and information.

All of the organizations at which I gathered data produce and deliver goods, services, and information to internal and external customers. All of these organizations have the following three characteristics:

- People are involved in both designing and performing value-adding activities.
- Information relevant to the design, coordination, and improvement of each person's activity is inextricably linked to performing the activity.
- The performance of the organization as a whole is affected by the form, timing, and quantity with which goods, services, and information are passed between adjacent activities.

  The form, quantity, and timing with which an upstream activity supplies a good, service, or information affects the efficacy of the downstream activity that receives and consumes the good, service, or information. Conversely, the needs and capabilities of the downstream activity determine the form, quantity, and timing that are most appropriate for the good, service, or information provided by the upstream activity.

The Rules-in-Use are desirable for managing organizations of this sort because the Rules generate three distinct features that I did not observe *as a set* in non-TPS settings:

- a nested, modular organizational structure,
- frequent, finely grained diagnostics of activities, activity-connections, and flow-paths,
- mutually reinforcing process improvement and learning.

There appear to be empirical and theoretical explanations for why each of these three features offer advantages in managing organizations in which people both design and perform value-adding activities, in which information relevant to activity design and improvement is tied to activity performance, and in which adjacent upstream-downstream activities interact.

- *Nested modularity* is a structure that facilitates change: modularity allows an organization to decompose and distribute responsibility for a design process while ensuring that when the sub-systems are integrated, the overall system operates effectively;
- *Frequent, fine-grained diagnostics* are triggers for change. Built-in tests confirm or refute the assumptions implied in activity, connection, or flow-path design. Problems are a signal that the assumptions are wrong.
- *Frequent, structured, directed problem-solving* is a mechanism for change in which process improvement and learning are mutually reinforcing.

The relationship between the three characteristics of the organizations I studied and the three features provided by the Rules-in-Use is discussed below.

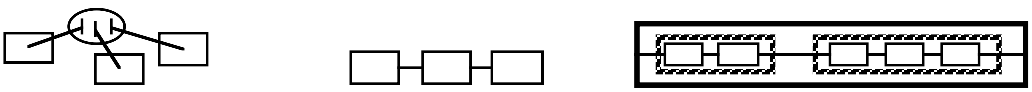
NESTED, MODULAR ORGANIZATIONAL STRUCTURE

The Rules lead to an organizational structure that is "nested, modular." Authors such as Baldwin and Clark (1999); Ward, Liker, and Sobek (1995); Christensen (1992, 1992, 1995); and Ulrich (1995) have noted the advantages offered by modularity in managing the design and prototyping/testing of technical systems by groups of people. There is compelling evidence that similar advantages result from modular strategies in designing and operating an organization (i.e., a social/technical system) in which production and delivery of goods, services, and information occurs through the collective effort of many people. Because of 'information hiding' (defined below), modularity creates the opportunity to change (experiment/redesign/ improve) the way in which one activity is performed without compromising the integrity of other activities or of the system of activities. Consequently, modularity provides a way to divide the labor and knowledge of the overall system in such a way that:

- the individual person who performs a value-adding activity has independence also to design and improve the activity locally,
- the design and improvement of individual activities contributes to and does not compromise the efficacy of other, adjacent, individual activities and of the organization's collective efforts as a whole.

TYPES OF MODULARITY

Ulrich offers a taxonomy of modularity: slot, bus, and sequential. In slot and bus architectures, components are attached to a central core. In sequential modularity, components are connected only to those other components with which they exchange information, material, or energy. I use the term "nested modularity" to mean a special form of sequential modularity in which a series of modules is grouped into a larger module. Another way to describe nested modularity is modules within modules within modules, but without connection to a central core.



Bus and slot modularity — Sequential Modularity — Nested Modularity: modules within modules within modules

Figure 3: Types of modularity

COMPARING TECHNICAL-SYSTEM AND ORGANIZATIONAL MODULARITY

In extending concepts of modularity from device design to organization design, the following analogies apply.

- An *activity* corresponds to a *component* in that both transform material, energy, or information from one form to another.

- A *connection* corresponds to an *interface* in that material, energy, or information is transferred across both.

- A *flow-path* corresponds to a *sub-system* or *system* in that both are composed of components joined across interfaces (i.e., activities joined across connections). Therefore, material, energy, or information is both transformed and transferred within a flow-path or sub-system.

FREQUENT, FINELY GRAINED DIAGNOSTICS

The Rules-in-Use do more than create a system-structure that accommodates change. The Rules create tests that diagnose the system's performance with high frequency (i.e., *tending* to every performance or operation) and fine granularity (i.e., high resolution -- *tending to* every activity, every connection, and every flow-path) during operation. Because of these frequent, finely-grained tests, every time a person performs an activity he also tests the assumptions implicit in the activity's design. This may, in turn, trigger improvement of the activity. Consequently, when the Rules-in-Use are followed strictly, information for activity-improvement is colocated with activity-performance because each activity is 'self-diagnostic.'

Likewise, when the Rules are followed strictly, each connection between sequential activities is 'self-diagnostic.' Each hand-off from an upstream to a downstream process is a *test* that the intermediate outputs are delivered properly and is a *trigger* for problem-solving if any individual hand-off is faulty. Similarly, when the Rules are followed strictly, each flow-path is self-diagnostic. As each good, service, or information takes form, the assumptions are tested that are implicit in the design of the flow-path over which the good, service, or information travels.

Authors such as Jaikumar (1997); Jaikumar and Bohn (1992); Ogata (1990); Senge (1994); Argyris (1990); von Hippel (1994); Adler (1993); MacDuffie (1997); and Shannon and Weaver (1963) have -- in various ways -- noted the advantages of locating action, monitoring, and actuation in close temporal and physical proximity. The Rules-in-Use provide guidance for bringing these advantages to the control and improvement of processes broadly and deeply in a social/technical system.

MUTUALLY REINFORCING PROCESS IMPROVEMENT AND LEARNING

Some of the authors already mentioned have noted the power of learning through problem-solving and the role of problem-solving in sustained, continuous improvement. The Rules-in-Use specify a mechanism that allows these benefits to be captured broadly and deeply in an organization. The Rules specify that the person performing an activity should be responsible and capable for improving the activity. This colocates the performance of the activity with information for experimentation and improvement of the activity. The Rules specify that attempts to improve an activity be done as structured experiments. Thus, improving an activity increases expertise for performing the activity, for again improving the activity, and for improving other activities generally.

The relationship between the characteristics of the organizations I studied and the features provided by the Rules-in-Use is summarized in the next table.

Features / **Characteristics**	**Nested Modularity** A structure conducive to change	**Frequent, finely grained diagnostics** Generates signals when change is needed	**Frequent, structured, directed problem-solving** Means of mutually reinforcing learning and improvement.
People design and	Allows the design and improvement	Performing an activity, using a	Increases the capability of the

perform activities Information for activity design and improvement is imbedded in activity performance	of the system to be decomposed into the design and improvement of individual activities, individual connections, and individual flow-paths constructed from connected activities.	connection, or using a flow-path to produce and deliver goods, services, and information tests the design of the activity, the connection, or the flow-path.	people who perform activities and who operate connections and flow-paths to design and improve activities, connections, and flow-paths.
Features / **Characteristics**	**Nested Modularity** A structure conducive to change	**Frequent, finely grained diagnostics** Generates signals when change is needed	**Frequent, structured, directed problem-solving** Mechanism for change with mutually reinforcing learning and improvement.
Upstream and downstream processes "interact"	Pre-specifies the form, quantity, and timing with which and the mechanism by which goods, services, and information are provided by upstream to downstream	Test to determine if the form, quantity, and timing with which goods, services, and information are provided and the mechanisms by which production and delivery is triggered can be	Experience gained while operating the connections and the flow-paths can be used for improvement, and experience from improvement can be used to better understand how to operate the

	activities. This is based on the upstream process's capabilities and the downstream process's needs.	improved.	connections and the flow-paths.

Figure 4: Link between org. characteristics and features provided by Rules

COMPARING COMPLEX TECHNICAL AND ORGANIZATIONAL SYSTEMS

MODULARITY IN TECHNICAL-SYSTEM DESIGN

These Rules-in-Use can be understood using concepts borrowed from the product design literature. Modularity is a strategy for designing complex technical systems that has been studied by authors in management [Baldwin and Clark (1997); Christensen (1992a, 1992b, 1994) ; Kogut and Bowman (1995); Sanchez (1995, 1996); Sobek (1997); Ward et al (1995); Ulrich (1995)] and in engineering [Hoffman (1990); Lew et al (1988); Parnas et al (1995); Rice and Seidman (1994)]. In a modular design, components are joined through standardized interfaces. That is, the components exchange information, material, or energy in a pre-specified form through a port, channel, or connection of a pre-specified design.

According to these authors, modularity offers advantages in the design of complex systems (e.g., a complex technical product such as a computer system). Experimentation and improvement of components can occur within a module, behind an interface, without compromising the efficacy of other components and without requiring a change in the system's architecture overall. Likewise, modular design allows some latitude to change the architecture without unduly compromising the efficacy of individual components. Using the language of modularity, the five Rules-in-Use can be understood as serving the following functions:

Rule-1 guides the design and operation of activities within each individual component.

Rule-2 guides the design and operation of interfaces between components.

Rule-3 guides the design of the system-architecture.

Rule-4 guides the improvement of components.

Rule-5 guides the improvement of interfaces and guides the improvement of sub-system and system architectures.

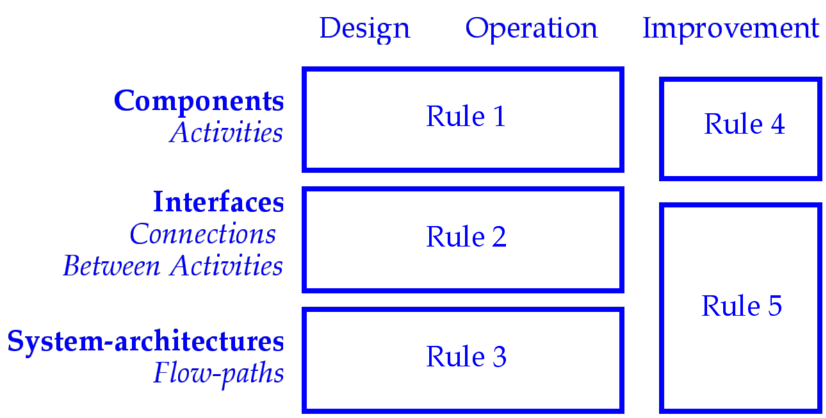


Figure 5: Role of each Rule-in-Use using product-design analogy

MODULARITY IN ORGANIZATIONAL SYSTEM DESIGN

Using concepts from the product-design management literature to discuss the design and operation of organizational systems is appropriate for at least two reasons. In both cases, there are similar managerial challenges, and in both cases, the managerial options associated with modular strategies are evident.

COMMON MANAGERIAL CHALLENGES

Managing the design and prototyping of a large, complex technical device and managing the design and operation of a large complex social/technical system present similar challenges. Both types of systems have features that make modeling, prediction, analysis, and real-time control difficult, particularly by a single person. These features include: system-scale; high-order (non-linear) interactions, the dynamics of which are not all known; interactions which are stochastic; changes in condition that are rapid; conditions about which information can be known locally only; and sensitivity to initial conditions.

Under such circumstances, responsibility for the design and testing-prototyping of the system is often divided and shared by scores, hundreds, or thousands of people. These people must design, test, and improve the individual elements for which each is responsible. Just as there must be a mechanism for dividing work and developing the individual components of the technical system, there also must be a mechanism that ensures that the individual components can be connected and function as an integrated whole.

A nearly identical challenge exists in the production/service setting. Complex goods, services, and information take their final form only after passing through the hands of many people. Just as there is challenge in product-design of both designing individual components and ensuring system integrity, so too there is a challenge in the production/service setting of both designing, performing, and improving the individual activities of functional specialists and designing, operating, and improving the entire system overall. Under such circumstances, design rules have great value if they allow responsibility for the design, operation, and improvement of activities, connections, and flow-paths to be distributed in such a way that local decisions contribute to and don't compromise collective goals.

COMMON MANAGERIAL OPTIONS

Authors who study product-design management have recognized that modularization has value specifically because it allows responsibility for component, interface, and system-architecture design, testing, and improvement to be distributed without compromising the contribution of local decisions towards collective goals. This in turn provides options for individual designers to experiment with and alter individual components without compromising the integrity of the overall system-architecture. Likewise, the options that are available when the design is modular give the project manager latitude to alter the system architecture without compromising the functionality of individual components. When modularity is not or cannot be chosen as the design strategy, component experimentation and system-architecture experimentation must be more tightly linked and have to be carefully coordinated because of interactions between modules and the system-wide effect of these interactions.

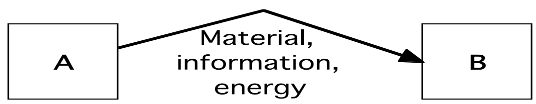
Modularization produces these opportunities, according to Baldwin and Clark (1997), because a modular design 'hides' information about a component's design and operation from adjacent components but makes information about the interface between components 'visible.' Consequently, so long as designers leave the interface design unchanged, they have latitude to alter what occurs within the component without also altering the internal functions of other components.

From observing people design, operate (test), and improve individual activities and systems of activities, it is apparent that the Rules-in-Use lead to an organizational structure in which information about an activity is 'hidden' from other activities, but information about the connection between adjacent activities is 'visible.' Baldwin and Clark have observed that the combination of hidden component information and visible interface information gives product designers behavioral latitude to *substitute* components, *augment* and *exclude* functions from systems, *port* a component from one system to another, and *invert* a function from a low level to a high level within a system. I've observed that in Rule-in-Use managed systems, people can also substitute, augment, exclude, port, and invert with relative ease, but when they are not managing with the Rules-in-Use, it is more difficult to do so.

In sum, people in organizations that produce and deliver goods, services, and information face similar cognitive and coordinative challenges to designing, testing, and improving the production system that people in product-design organizations face. It also appears that people in both settings modularize the systems whose design and operation/testing they are managing to address these challenges. In the production and delivery setting, the Rules-in-Use are guidelines for achieving a modular system design.

Hidden and Visible Information

In this usage, *hidden* does not mean 'unseeable.' Rather … Suppose two components, "A" and "B," are connected to each other. Information about how Component-A works is "hidden" from Component-B if B is not affected by *how* A does its work, but B is affected only by what information, material, or energy A sends across the interface.



• Outputs 'visible' • Methods 'hidden'

Figure 6: Distinguishing between visible and hidden information

Likewise, imagine two people, "X" and "Y" working next to each other. Person-X does the first part of a job and then gives it to Person-Y to complete. It may be that Person-Y is able to see how Person-X is doing his work. After all, they work right next to each other. However, if Person-X can change his work method and this change is not evident in the form, quantity, or timing with which the job is passed to Person-Y, then the information about Person-X's work process is 'hidden' from Person-Y. The nature of the process is not evident in the form, quantity, or timing of the outputs.

CONSEQUENCES OF THE RULES IN ADDITION TO MODULARITY

The Rules-in-Use contribute to nested modularity, a structural form that lends itself to change and that lends itself to a smooth division of design-responsibility and integration of the parts. In addition to the structural benefits, the Rules also generate dynamic benefits. The Rules create tests that diagnose the organizational analog of components, interfaces, and systems with high frequency and high resolution. Therefore, operating the system is akin to ongoing prototype-testing and hypothesis confirmation and refutation. Furthermore, the Rules-in-Use prescribe methods for improving components and systems; these improvement activities are also the mechanisms by which people learn to design, operate, and improve. In sum, the Rules-in-Use create a structure that accommodates change, test the system during operation and signal that improvements are needed, provide objectives and methods for improvement, and use improvement as a mechanism for learning.

BINARY TRIGGERS AND ALLOCATION OF COGNITIVE CAPACITY

There is an additional consequence of applying the Rules, which warrants further study. It appears that the Rules create the cognitive space for people to take advantage of nested modularity; frequent, fine-grained diagnostics; and problem-solving based learning. As mentioned previously and reinforced through the text that follows, a common theme of the Rules is that simple, binary DO/DON'T DO signals trigger action. When activity-triggers of this type are used, I have observed that people spend considerably less time trying to determine what product or service they are supposed to provide giving them more opportunity to think about how they are providing the product or service. These ideas are reflected in the following diagram.

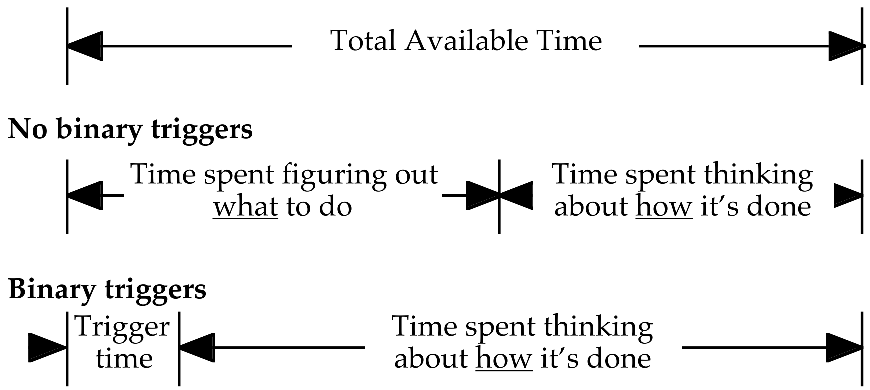


Figure 7: Using binary triggers to free 'cognitive capacity'

My experience working in a non-TPS and a TPS-managed system, and my observations watching other people work in both types of systems support this impression. As a result, it appears that with a reduced cognitive burden of figuring out *what* activities to do, people have more opportunity to observe *how* activities are actually done, both by themselves and others. This appears to have value for situations such as those I studied, in which people need the 'cognitive space' to draw information for design and improvement of activities from actually performing activities.

Ananth Raman, Associate Professor at the Harvard Business School studies the retailing industry and supply chain management. Most recently, he has focused on the costs imposed on retailers by data inaccuracy. He has found that the typical retailer has a poor idea of what is and is not on the store shelves with physical counts disagreeing with the "book inventory" (based on shipments received and recorded sales) by 30% or more. He has phrased one of the consequences this way: "in an industry dependent on creative people to discern tastes and trends, data inaccuracy inhibits creative people from being creative because they are spending time reconstructing information."

FINDING THREE: MECHANISMS FOR AND BARRIERS TO PROMOTING TPS

Recognizing that the Toyota Production System is cultivated by problem-solving based learning that is frequent, structured as experiments, and directed towards improving production and delivery leads to my third major finding: why TPS is hard to imitate. In the context of the Rules-in-Use, the ability to improve (problem solve) and learn through problem-solving -- widely practiced in a consistent fashion throughout an organization -- is a classic example of the dynamic capability concept introduced by Teece and Pisano (1994) and others.

Learning by improving and improving to learn is an inimitable resource because its development is time consuming and, in the particular case of the Rules-in-Use, context specific. The context specificity arises because there appears to be a 'network' effect to the Rules, in that they are of increasing value as the number increases of people in the organization who understand and can use the Rules to manage their processes. The logic underlying this idea will become apparent through the following pages of explanation and description.

The argument is that a single person can better design, perform, and improve her own work if she uses the Rules as guides than if she does not. However, the effect will be magnified if her immediate customers and suppliers can also use the Rules as guides to design, operate, and improve their own work and the connections and flow-paths that link their work. In the course of this research, I have not determined the 'critical mass' or 'critical density' at which this network effect begins and becomes self-promoting.

In contrast to the discovery that TPS can be codified as five Rules-in-Use, I have discovered that the artifacts that have received so much attention in the literature are actually locally idiosyncratic consequences of applying the Rules-in-Use to problems particular to specific situations. For instance, the lack of kanban cards may not signal the lack of TPS; rather, kanban cards may not be an appropriate counter-measure to problems characteristic of a site. Conversely, it is possible that a site has artifacts such as kanban cards and "kaizen blitzes," yet the site may follow the Rules-in-Use to such an insignificant extent that its management system does not resemble that of plants truly practicing TPS, except superficially.

FINDINGS: SUMMARY

Researchers such as Cusumano, Krafcik, and Womack et al have concluded that the Toyota Production System generates more value than alternative management systems when the production of similar products by similar technical products is considered. The logic of these findings is depicted in the next figure.

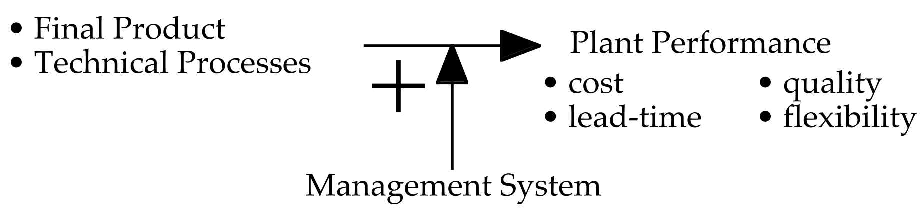


Figure 8: Management system as source of value

I propose that this management system, the Toyota Production System, can be codified as five Rules-in-Use. These Rules govern the design, operation, and improvement of individual value-adding activities, connections between adjacent activities, and flow-paths over which goods, services, and information are produced and delivered.

When followed, the Rules-in-Use generate more value than other management systems because the Rules lead to three organizational features: nested modularity; frequent, finely-grained diagnostics; and frequent problem-solving that is the source of mutually reinforcing process improvement and learning.

Based on both observation and theory, there are reasons to believe that these features offer advantages in managing organizations of the type I studied, those in which:

- people both design/improve and perform value-adding activities,
- activity design and improvement is linked to activity performance because of the amount of unencodable information imbedded in activity-performance,
- adjacent activities 'interact.' The form, quantity, and timing of upstream outputs affect downstream activity-performance, and the needs and capabilities of downstream processes determine the appropriateness of upstream output's form, quantity, and timing.

Modularity creates the opportunity for the person who performs an activity to change the design of the activity.

Frequent, finely-grained diagnostic-tests evaluate the design of activities, connections between activities, and flow-paths and trigger improvements.

Frequent problem-solving that is the source of mutually reinforcing process improvement and learning increases the capability of the people who perform activities and who operate connections and flow-paths to design and improve activities, connections, and flow-paths.

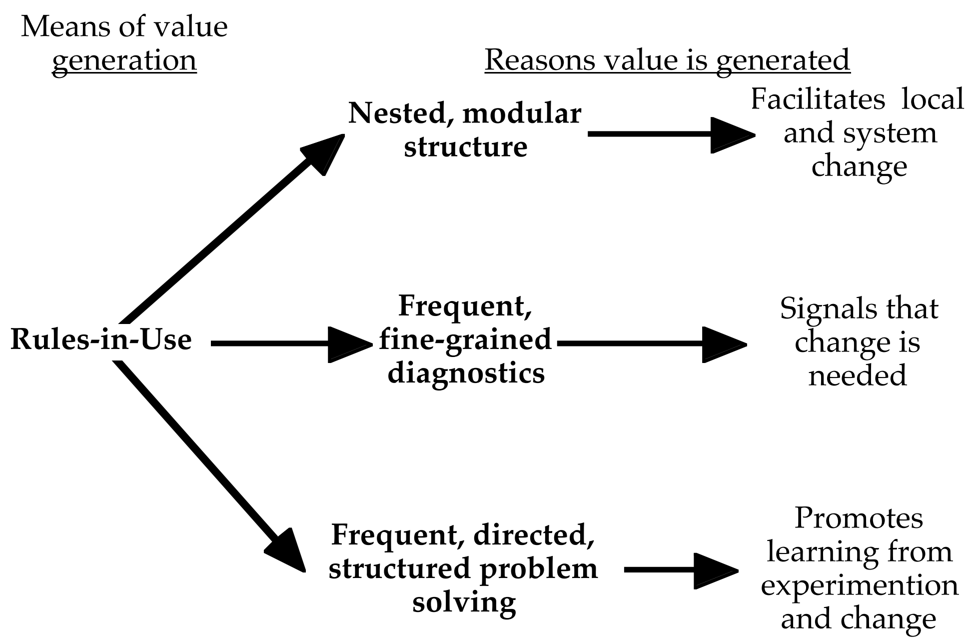


Figure 9: Rules-in-Use as a source of value

CHAPTER 2:

DETAILED DISCUSSION OF RESEARCH METHODOLOGY

OVERVIEW

The five Rules-in-Use, as an explicit codification of the Toyota Production System, were developed through inductive analysis of data gathered first hand in the field. I worked or directly observed others working at 33 sites. This required 176 days in the field over a three and one-half year span. Supplementary data was collected through phone interviews, correspondence, and review of documents. I recorded data in extensive, detailed journals.

I analyzed the data by iteratively constructing, modifying, rejecting, and reconstructing explanatory frameworks. I repeated this process until the framework was validated by the data I already had, by additional trips to the field (for hypothetical and literal replication as defined by Yin [1994]), and was validated by TPS experts within Toyota. Data collection and analysis methods are explained more fully below.

METHODOLOGICAL INSPIRATION

Street Corner Society, by William F. Whyte, was a tremendous methodological inspiration. Whyte was a junior fellow at Harvard University from 1936 to 1940, a position that entitled him to study anything, but to earn no degree.

At the time, the North End was filling up with Italian immigrants, and to Boston's Yankee and Irish establishments, the North End "slum" appeared to be a chaotic, completely unpredictable setting. Determined to discover the norms which governed life in the North End, but which could not be discerned by observation from afar, Whyte became a resident for one year, moving there in 1937 so that he could observe directly and frequently the events in North End life. From this raw data, he began to derive inductively the rules by which the society seemed to operate.

Whyte's account was very inspirational to me as I was faced with challenges similar to his. Whereas he needed to discover what was necessary to become a 'good citizen' in "Cornerville," as he termed the neighborhood in his book, I needed to discover the rules of good citizenship in "Toyotaville." Whyte drew confidence that he was discerning the unstated rules that governed Cornerville life from three sources: the increasing fidelity between his observations and his explanations, the gradual acceptance by the Corner Boys into their circle, and his ability to predict the dynamics by which social encounters would precede. Likewise, I drew confidence that I was discerning the unstated rules that governed behavior in TPS-managed plants from similar sources: the increasing fidelity with which the data and my explanatory framework agreed, the increasingly positive feedback my observations received from Toyota's own TPS experts, and my ability to predict with increasing accuracy the tools and devices I would observe in a production setting, prior to visiting the site.

The TPS experts to whom I refer were members of several organizations. These included the Toyota Supplier Support Center in North America, the

Operations Management Consulting Division in Japan, people who worked in Toyota plants, and people who worked in TPS-managed Toyota supplier plants.

The Toyota Supplier Support Center, located in Erlanger, Kentucky, was part of the Toyota Motor Manufacturing, N.A. ("TMMNA") organization. [TMMNA was a separate entity from Toyota Motor Sales ("TMS")]. The mission of TSSC has been to teach TPS tools, practices, and philosophies to Toyota supplier factories in North America. TSSC also taught TPS to companies unaffiliated with the Toyota network. In both cases, TSSC did not charge for its services. Of TSSC's consultants, some were hired directly into TSSC, some came from Toyota affiliates in North America (supplier plants and assembly plants) for 2 to 3 year periods. In addition, TSSC had a few members with more extensive experience in Japan. Of these, Mr. Ohba -- director of the Toyota Supplier Support Center ("TSSC"), located in Erlanger, Kentucky and our primary contact at Toyota -- was the most experienced, having worked for Toyota for nearly 30 years. After working on localization programs in different parts of the world, Mr. Ohba joined OMCD in 1986 and established TSSC in 1992.

OMCD, founded by Taiichi Ohno, one of the original creators of TPS, has been the parent organization to TSSC in Japan. OMCD also has been responsible for teaching TPS to Toyota suppliers. In addition, OMCD has had an active involvement in cultivating TPS within Toyota plants. OMCD has been an important training ground for Toyota managers.

PARTICIPATION - 2 SITES

Of the 33 sites at which I gathered data, I worked at two, one for a week, and another for five months.

Mr. Ohba suggested that I experience a non-TPS production environment as a prelude to studying Toyota Production System managed sites. Therefore, I spent 5 days working at various locations of the assembly line at a Big-3 plant. I installed the front right seat and performed final electronic systems tests. I also attached the roof panel in the body shop. When not working on the line, I shadowed a "zone supervisor" (the first level manager) to record his daily activities. I also visited the nearby body-panel stamping plant.

This early experience was especially useful later in my research. When I visited other assembly plants within the Toyota system I was able to make direct comparisons between my own experiences -- installing seats for instance -- and that of the people I was observing. Likewise, I was able to compare the activities of supervisors within the Toyota system with that of the zone supervisor who I came to know during my week at the Big-3 plant.

From late 1996 until mid 1997, I was a member of TSSC, and I spent approximately 60 days over a five-month span trying to implement tools and practices at a first-tier supplier of Toyota's Georgetown Kentucky plant (this supplier-plant also had two other car makers as customers). In this role, I had an "authentic" TSSC experience in that I learned TPS in much the same way as regular members of TSSC: by attempting to resolve shop floor production related problems, guided by Socratic challenges of more experienced TSSC consultants. As with the experience working on the assembly line, this immersion in the phenomenon I was studying allowed me to make detailed, concrete, informed comparisons between the tools and practices I had learned to use and those employed by people in other plants to control production, do change-overs, convey material, respond to problems, train people, allocate capacity to different products, and process customer orders, for instance.

LONGITUDINAL OBSERVATIONS - 10 SITES

Of the 33 sites where I collected data, I have visited 10 more than once. In the most intense of these efforts, I was documenting a TSSC guided transformation in a plant. This factory, not part of the Toyota network, had not had exposure to TPS prior to its interactions with TSSC. In the 13 months since TSSC's involvement began in October 1997, I visited 10 times for a total of 13 days on site. I supplemented my observations by interviewing TSSC and plant people in person, on the telephone and through e-mail correspondence.

More typically, I made periodic visits to capture changes in a site's systems. In these other cases, I have less direct knowledge of the process by which the changes occurred. Three of the plants are TSSC project sites, and one has no direct contact with Toyota. Two other plants are assembly plants.

I made three extended research trips to Japan to visit Toyota, Toyota-supplier, and unaffiliated plants, in 1996, 1997, and 1998. Of the 14 plants I visited in Japan, I went to one on all three visits, and visited two others twice.

None of these three are assembly plants (though I have also visited 3 Toyota assembly plants in Japan, one time each).

To facilitate data gathering in the Japanese plants, I always traveled with a Toyota employee who was a native speaker of Japanese and fluent in English. In addition, I spoke Japanese conversationally, having studied it through Harvard's third-year intermediate-advanced course.

SINGLE-VISIT OBSERVATIONS - 21 SITES

Of the 33 sites I visited, I went to 19 only once. Of these 19, 11 were among the 14 that I visited in Japan, and the other eight were among the 19 sites that I visited in North America. These site visits added to the variety of product and process management situations I encountered. Among these 19 sites are plants that make pre-fabricated housing, laser printers, and cell-phones. One site is a logistics facility, another is a sales organization. Four of the 19 sites I visited once are assembly plants. These visits allow cross plant comparisons with the roles I studied as a participant at the Big-3 plant and at the two other assembly plants that I had visited on more than one occasion.

CROSS SECTIONAL COMPARISON: POSSIBLE FUTURE RESEARCH

My field-work will have a confirmatory portion. In a future stage of my research, I may examine project records for the Toyota Supplier Support Center's client companies. I will do this to test whether the Rules-in-Use framework is confirmed across a broad population of sites where TPS has been taught. (In this round of analysis, I will exclude the 7 project plants where I have already gathered data that has influenced the Rules-in-Use framework.)

ADDITIONAL INTERVIEWS

By comparing what I saw occurring within the Toyota network and what the business and academic literature described as "lean manufacturing," I began to see very strong contrasts in terms of how people are trained and in how improvement activities are managed. To clarify this contrast, I interviewed two students in the Harvard MBA program. Both have worked in line management positions at companies that have tried to adopt lean manufacturing practices, and both described specific training and improvement activities in which they were personally involved. Neither of two companies where they worked are included in the 33 research sites I have been mentioning throughout.

SOURCES OF VARIATION IN THE OBSERVATIONS

The robustness of the framework I am presenting derives from the variety of settings in which I collected data and found characteristic patterns of behavior.

Products	The sites I visited manufacture products including automobiles, pre-fabricated housing, springs, metal stampings, mattresses, re-built starter motors, temperature and pressure gauges, dashboard parts, catalytic converters, laser printers, ink jet cartridges, cell phones, and piezo electric laminates with corresponding variety in product size and weight, production volumes, process rates, and degree of automation.
Processes	I studied the work associated with production processes such as: stamping, welding, quilting, injection molding, automatic

	machining, various types of heat transfer, manual assembly of large parts on conveyor lines and of small parts without conveyors, plating, and curing.
Functions	I collected data about primary manufacturing processes and also about conveyance, shipping, change-overs, machine repair and maintenance, training, and process improvement efforts.
Hierarchical Rank	I collected data by observing or interviewing shop floor workers, first level supervisors, middle level managers, plant managers, and corporate managers.
TPS vs. non-TPS Management	Of the 33 sites, 20 were managed by TPS when I visited and 4 were at various stages of learning TPS principles. 7 were final assembly plants, 1 of which was not a Toyota affiliate.
Japan and N. America	14 research sites were in Japan; 19 were in North America
Auto and non-Auto	10 of the 33 do not provide goods or services that support automobile assembly.
Service Organizations	Two sites are managed by TPS but don't produce physical goods -- of these, one is a cross-dock (logistics) facility, and one is a sales and service organization.

RECORDING DATA

I recorded data in a variety of ways. When I participated in production, I kept a daily journal noting in detail my experiences. This journal includes textual descriptions, diagrams, sketches, and numeric data, such as when I did work-motion studies. This journal exceeds 1,000 pages.

When I observed other people at work, I took detailed notes of their activities. For instance, on one trip to Japan I wanted to study the role of the team leader. I did this by shadowing a team leader and recording his activities for an hour. I then repeated this at four other plants. When I had the opportunity to observe Toyota's TPS experts at work, I recorded the questions and comments they directed at site managers. Through this, I collected several hundred more pages of notes.

To understand the material and information flows in a plant, I walked the material flow-paths both from receiving to shipping and from shipping to receiving to ensure that I captured all the steps by which final goods take form.

Once I had mapped the flow-paths over which inputs are converted into outputs, I mapped information flows. To do this I recorded mechanisms that caused activities to start and to stop (i.e., what told people what, when, and how much they were supposed to convey, maintain, produce, repair, or train); what mechanisms indicated that a problem had occurred, that assistance was needed, etc. Because I was making direct observation of individual people and processes, I was able to capture the formal mechanisms such as work instructions and production schedules. As importantly, I was able to capture the active but informal mechanisms by which people determine what they need to do such as 'hot lists,' verbal requests, and visual assessments of stores.

DATA ANALYSIS

The framework I am presenting in my dissertation, the five Rules-in-Use, emerged as the result of an iterative analysis of the data. I searched for consistent patterns in the behaviors I was learning through first hand participation and in the observable behavior of other people. Naturally, the framework did not emerge completely at a single point in time. Rather, it took form episodically.

For instance, while a member of TSSC, I tried to design the flow-paths within a portion of the plant (an experience that shaped my articulation of Rule-3); to devise a kanban pull system that linked the supplier's shipping dock to a welding station and the welding station to a stamping press (an experience that later shaped my articulation of Rule-2); to teach a stamping press team how to reduce their change-over times by an order of magnitude (an experience that later shaped my articulation of Rule-1).
[Throughout, I refer to myself as a member of the Toyota Supplier Support Center, but not as an employee. I make this distinction because I participated fully in promoting TPS while at the supplier plant in which I worked. In this regard, my role was close to that of people who join TSSC from Toyota affiliated and supplier plants for a finite period. In contrast, I was clearly not a TSSC employee as I was not paid, promoted, nor evaluated in the Toyota system.]

The realization that my specific activities were representative of general patterns in the design, performance, and improvement of activities and systems of activities was not immediate. For instance, when I was designing the pull system between adjacent processes, I gradually realized that I was constructing mechanisms to send requests and responses in such a way that they acted as a "switch" (opened with a request, closed with a response). In reflection, I realized that many of the other devices I had been constructing had the same binary, self-diagnostic, switch-like qualities. Then, as I visited other plants, I saw that individual customers and suppliers were linked consistently by similarly constructed 'switches' even though the physical form of the particular signaling tool might be different. For example, kanban cards, andon lights, music, andon boards, empty containers, full containers, empty locations, full locations, deviations from standardized work, two people talking, an idle machine, an idle person, an active person were all used -- in different circumstances -- as a binary, signaling switch. Then, in subsequent factory visits, I looked for similar binary, self-diagnostic switches in non-TPS settings, and did not find them. Through this process, I realized that such switches were a necessary, distinguishing characteristic of TPS. This insight ultimately was included within Rule-in-Use 2.

Likewise, I ultimately concluded that high-frequency, structured, directed problem-solving is the critical mechanism by which TPS is taught within and across organizations. This insight also did not occur spontaneously. Rather, during my stay at TSSC, I knew that I personally was learning the proper application of TPS tools and practices by solving shop floor, production-related problems. However, I did not recognize this as a general principle until my second trip to Japan. There, in the course of speaking with employees (team members, team leaders, group leaders, and managers) at various plants and interviewing members of Toyota's Operations Management Consulting Division, I realized that virtually everyone learned TPS through directed problem-solving and not as the result of textbook or classroom-like series of explanations.

Consequently, it took nearly a year to realize that my intense, high-frequency, directed, structured, learn-by-doing experience was a primary teaching device within TPS-managed sites but was atypical elsewhere.

The framework of five Rules-in-Use took form through repeated cycles of constructing, modifying, and rejecting frameworks. I rejected previous versions because they were over-specified -- the same idea was expressed more than once, or they were under-specified -- the framework lacked statements that were needed to capture consistent, seemingly characteristic patterns in the behavior of people in TPS-managed settings. Finally, the analogy between the design, testing, and improvement of technical systems and the design, operation and improvement of social/technical systems helped clarify characteristics of the end-point. The Rules-in-Use had to cover component, interface, and system-architecture designing, testing, and change for the analogy between devices and organizations to be complete.

In constructing this framework, I benefited from repeated challenges from other people. My advisor, Professor Kent Bowen, and I met each Friday during my five months as a member of TSSC and regularly during other phases of this research. In these sessions, he continued to challenge me on what I claimed to have learned. On several occasions, I have presented the framework to people within Toyota, to ensure that my own codification rang true with their own unexpressed mental models. For this, I have met with the managers of Toyota's NUMMI, Kentucky, Indiana, and Ontario plants. In December 1997, the head of

Toyota Motor Manufacturing North America asked Professor Bowen and me to present an early version of the framework to Toyota's North American headquarters administrative staff. Mr. Ohba had me teach this framework in an earlier and in its current form to TSSC's consultants. In Japan, in August 1998, I presented the framework, to positive feedback, to senior members of the Operations Management Consulting Division, including its general manager and to Toyota's current vice president for production.

SUMMARY OF RESEARCH METHODS

The five Rules-in-Use are the result of an extensive data collection and analysis effort. This required both close study of people at work to understand in detail how they design, perform, and improve individual activities and how they design, operate, and improve systems of activities. The data analysis required concerted efforts to find consistent patterns within the data. The data collection occurred through first hand participation in and observation of work at a broad variety of sites. The data analysis required that the explanatory framework was properly specified, internally logical, and consistent with the data in terms of logical and theoretical replication. The data analysis and explanatory framework construction process was a highly iterative process, propelled by the fidelity of explanatory frameworks to the data, and subject to challenges from my advisor and from TPS experts within Toyota.

CHAPTER 3:

MAIN FINDING: RULES-IN-USE AS CODIFICATION OF TPS

This Chapter discusses the Rules-in-Use in depth. The role, form, and effect of each Rule are presented. Connections to the academic literature are in Chapter 4. Observations from the field are referred to here, but a comprehensive analysis of the field-gathered data from which the rules are inductively derived are found in Chapter 7, primarily.

RULE-1 - ACTIVITY (COMPONENT) DESIGN AND OPERATION

Rule-1 guides the design and performance of work activities done by people and machines that transform material, energy, and information. Rule-1 plays a critical role in creating opportunities for problem-solving and learning, and it reflects the theme that each use of an activity is a chance to verify the assumptions implicit in the design of the activity. Therefore, every performance of an activity is an experiment which serves as an opportunity to learn about the process and the person doing the process. Rule-1 also reflects the theme that a signal that triggers an activity is to be sent in a binary form.

RULE STATEMENT

Design and perform each activity so that it is *structured* and *self-diagnostic*.

For an activity to be:

- *structured*, the activity's design must specify its *content* (the work elements by which the activity is accomplished), the *sequence* in which they are to be performed, the *time* each is expected to require, and the outcome each is expected to produce (the *defect-free* form, quantity, timing).

- *self-diagnostic*, there must be a two tests: *one test that immediately signals that a problem* has occurred if the activity is actually performed in a way that differs from the pre-specified work-element content, sequence, or timing, and there must be *a second test that immediately signals that a problem* has occurred if the actual outcome of performing the activity differs from the expected outcome in form, quantity, or cycle time.

IMPLIED RATIONALE FOR RULE-1

In the five months I was a member of the Toyota Supplier Support Center, I had to design many activities in this fashion. Also, while I studied the work of other people in TPS-managed plants, I observed many other activities designed and operated in this fashion. From these experiences, I came to recognize the rationale implied in designing and performing activities this way. There is of course the obvious motivation to prevent defective outputs from being passed to customers. This contributes to a modular structure. Since the customer only sees defect-free goods, services, or information, he cannot determine the process by which by which they were produced and delivered.

Additional motives are indicated by the data. One is to test the assumptions implied in the design of the activity. A second is to simplify the determination of cause and effect should a problem occur. Both of these points are taken up below.

HYPOTHESIS-TESTING

Work-elements for doing an activity, pre-specified as to content, sequence, timing, and outcome, implies two testable hypotheses.

- Hypothesis One: the person doing the activity (the supplier) is capable of performing the specified work-elements, in sequence, in the expected time.
- Hypothesis Two: if the activity is performed as it was designed, it will produce an outcome that is *defect-free*; that is, the actual outcome will match the expected outcome in terms of form, quantity, and response time.

Rule-1 requires that these two assumptions be verified with each repetition of every activity. A rejection of either can be interpreted as a simple signal to DO problem-solving activities because at least one of the hypotheses has been refuted in practice.

For example, if the supplier performs the activity as it was designed, and the outcome matches the expected outcome, the hypotheses implied in the design of the activity are confirmed. However, if the supplier does not perform the activity as it is designed, then this is a signal to trigger problem-solving activities to discover why. This test is reflected in the top portion of the chart below.

Following the same reasoning, if the actual outcome does not match the expected outcome, then this signals that the second hypothesis is flawed, that the particular activity -- contrary to expectations -- does not produce the expected result. This too is a trigger for problem-solving, both to remediate the defective output so it is defect-free and to improve the activity so that it is capable of producing defect-free results.

	Yes: Hypothesis CONFIRMED	**NO: Hypothesis REFUTED**
Test 1: Activity actually performed as designed?	Supplier IS capable of doing activity	Supplier IS NOT capable of doing activity. ⇒ Problem solve and train
Test 2: Output actually defect-free in form, quantity, and timing?	Activity IS capable of generating defect-free outputs	Activity IS NOT capable of generating defect-free outputs. ⇒ Problem solve and train

Figure 10: Implied logic of Rule-1

When Rule-1 is followed, every activity-repetition is an experiment and is an information source about the process and the person doing the process. The next diagrams depict the difference between low and high frequency process monitoring. In the latter case, fewer errors occur before detection.

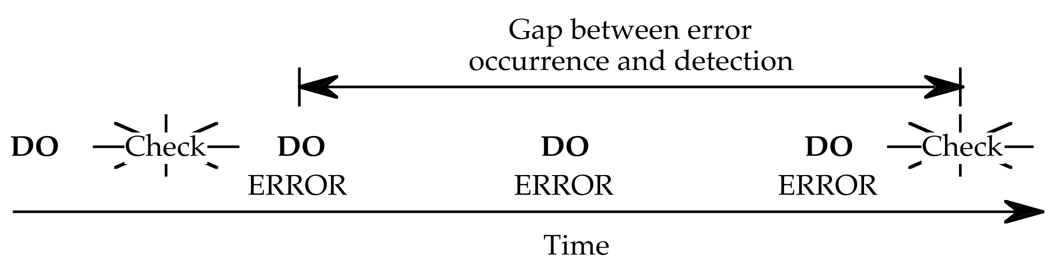


Figure 11: Low (temporal) frequency process monitoring

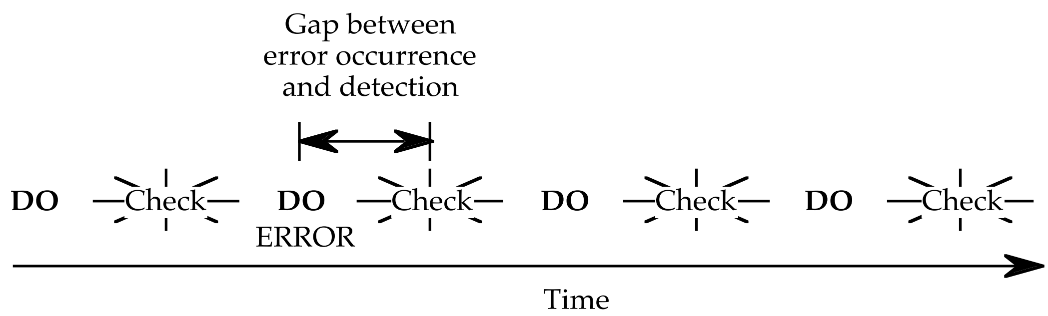


Figure 12: High (temporal) frequency process monitoring

SIMPLIFYING CAUSE AND EFFECT DETERMINATION

When activities are not designed according to Rule-in-Use 1, effects are evaluated only after of a series of actions have occurred. For instance, in the next diagram, the item being produced and delivered passes through all three steps before its actual condition (form, quantity, and timing) is compared to the expected, defect-free condition.

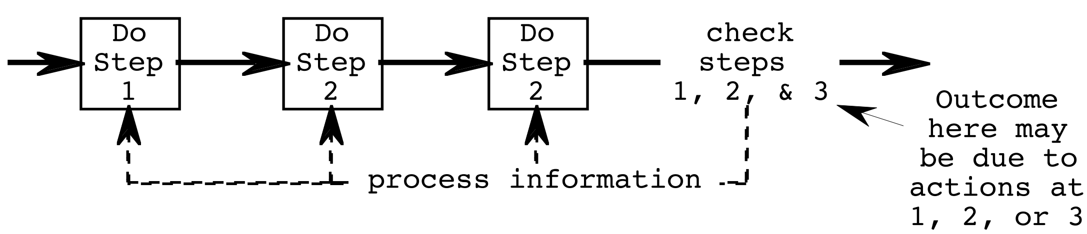


Figure 13: Low (spatial) resolution process monitoring

In this case, the process is being monitored with less resolution (coarser granularity). This may cause problems in attributing cause to effect. For instance, if a problem is detected after Step-3, the person who must diagnose the source of the problem has to consider three potential contributors, not one.

The difficulty is further compounded because of the passage of time. For instance, if a problem has been detected at the end of Step-3, the problem solver may have to investigate Step-1 as a potential source of the problem. However, the defective item may have passed through Step-1 some time earlier. Therefore, the now current conditions at Step-1 may not resemble the conditions that actually existed when the defective product was there. In other words, with the passage of time, the relevant information has *spoiled*, becoming increasingly less useful for problem diagnosis and response. (The problem of information spoilage is taken up in Chapter 5 as an opportunity for future research. This discussion has strong parallels with a theory of information that Jaikumar had been developing.)

This situation is not contrived. The plant I visited when I first began gathering data made complex electro-mechanical products, each of which had a retail value of approximately $1,000. When I visited the plant, I observed a shipping pallet of this product (approximately 20 pieces) which had been rejected for quality reasons several days earlier. According to the managers who were leading us through the plant, information that a defect had occurred and information about the source of the defect had not been conveyed back to the particular process at which the defect occurred. Consequently, the assembly worker did not receive a trigger-signal to improve the process by which the product was assembled.

A similar situation existed at the plant in which I was a member of a Toyota Supplier Support Center TPS promotion team. Containers of parts that had been rejected by the customer were stored on the production floor (some from weeks and months earlier). However, there was no mechanism to inform the production people that the defects had occurred, so they received no signal that would trigger them to change the way in which they did their work.

If Rule-1 is observed, finding cause-and-effect at the activity level is simplified when problems occur. This is true because the effect of each action is evaluated by the person who performed the action at the time when and the place where the action occurred. For instance, in the following diagram, each time an activity is performed at Step 1, 2, or 3, the output is checked before it is sent forward. Therefore, for example, should an error occur at Step-1, it should be detected before it is passed to Step-2. Therefore, when Rule-1 is followed, the system is monitored with *high frequency* (each repetition of an activity) and with *high resolution* or *fine granularity* (every activity rather than groups of activities).

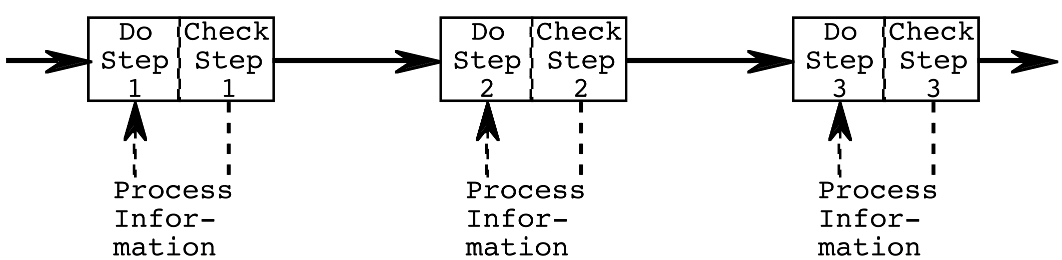


Figure 14: Activity tests when Rule-1 is followed

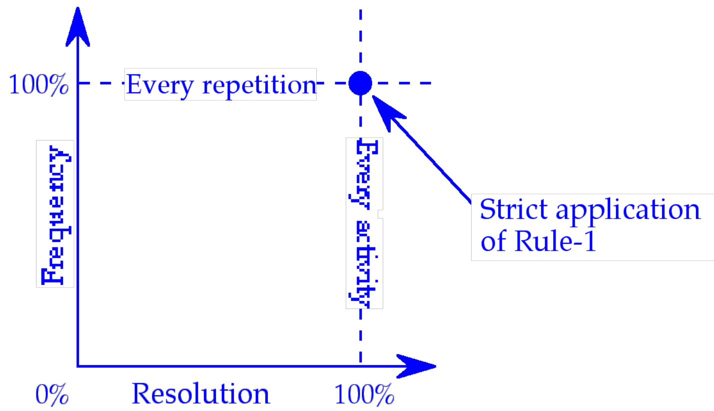


Figure 15: Frequency and resolution of Rule-1's self-diagnostic activity-tests

<u>COLOCATING ACTION AND INFORMATION</u>

Process Control

Colocating action, monitoring, and response has a number of consequences. It keeps the physical doing of an activity and the information about the activity coupled together. This is particularity important for control and improvement if knowledge about the activity is inextricably linked to the performance of the activity, as was normally true in the organizations I studied.

Modularity

Colocating action, monitoring, and response also contributes to increasing the modularity of the organization. By ensuring that all outputs sent from one activity-doer to another are defect-free (in form, quantity, and timing), information about the method used to produce the good, service, or information is not evident in the delivery of the good, service, or information. In contrast, if defects were passed along, the downstream customer would have information about the method being used by the upstream supplier, thereby decreasing the modularity of the organization's structure.

Psychological Motivation

My observations in the field suggest that there is also a psychological motive or effect for the behaviors that I have codified as Rule-in-Use 1. Colocating action, monitoring, and response provides each supplier with the means to determine if she has or has not performed her work in a way that contributes to meeting successfully the needs of the firm's external customers. I have concluded that the Toyota people consider this an important element of creating a rewarding work environment.

For example, often the more experienced members of the Operations Management Consulting Division ("OMCD") and the Toyota Supplier Support Center ("TSSC") expressed concern that a worker needs to feel a connection to meeting the needs of the external customer. Their view was that one way to do this is to give the worker immediate confirmation that the work he or she has performed has been valuable and has not been for naught. For example, managers at one Toyota managed assembly plant echoed this sentiment. A major redesign of the assembly line was planned. The managers were trying to group tasks so that a person or at least a team of people could have the "satisfaction" of completing an entire component or sub-system.[3]

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[3] Toyota assembly plant visit: August 1996

WELL KNOWN TOOLS AS EVIDENCE OF THE RULES

Several tools associated with TPS reflect the principles codified as Rule-1. Error-proofing devices are used to prevent machines from operating unless parts were loaded properly. These devices, in effect, test that the production activity is being done as designed. Go/No-Go gauges are used to ensure that an output's actual form matches the expected form. Likewise, I observed material handlers use devices and routines to ensure that they withdrew material of the correct type, in effect, testing that they had provided a defect-free service. I also observed training that is evaluated with a pass-fail test. I interpreted these pass-fail tests as the equivalent of Go/No-go tests that training had been supplied in a defect-free form.

RULE-2 - CONNECTION (INTERFACE) DESIGN & OPERATION

Rule-2 guides the design and operation of the connections through which adjacent customers and suppliers transfer material, energy, and information. These trigger the start and stop of supplier activities. Rule-2 plays a key role in creating opportunities for problem-solving and learning. Rule-2 reflects the theme that by pre-specifying expected performance, observations about actual performance can be used for problem-solving and learning.

RULE STATEMENT

Design and operate each customer-supplier connection so that it is *direct*, *binary*, and *self-diagnostic*. For a connection to be:

- *direct*, the *customer*, the person who uses a good, service, or information, must be able to send his or her *request* to the person (or machine) who will supply the good, service, or information without the request passing through a centralized intermediary. The *supplier*, the person (or machine) who produces or delivers the good, service, or information, must be able to *respond* to the customer and not through a centralized intermediary.

- *binary*, the customer's request must be interpretable as a simple signal to DO/DELIVER a good, service, or information in a pre-specified (i.e., defect-free) form, quantity, and response time. Likewise, the supplier's response must be interpretable as a signal that the delivery activity has been DONE, providing the good, service, or information in the pre-specified form, quantity, and response time.

- *self-diagnostic*, a connection must immediately generate a signal that a problem has occurred when a DO request is met by a NOT DONE response (i.e., when there is no response to a request -- interpretable as 'the supplier has fallen behind the customer's rate of demand') or when a DON'T DO (non) request is met with a DONE response (i.e., when a response is generated without being triggering by a request -- interpretable as 'the supplier has gotten ahead of the customer's rate of demand').

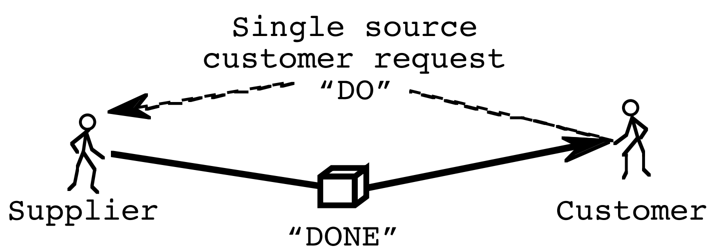

Figure 16: Single source, direct requests and responses

The logic of Rule-2's self-diagnostic tests is shown in the next diagram. If the customer says DO and the supplier replies DONE by properly fulfilling the customer's request (form, quantity, timing), the customer-supplier connection is working as it should. Likewise, if the customer (by implication) says DON'T DO and the supplier (by implication) says NOT DONE, then the customer-supplier connection is working as it should. However, should the customer say DO and the supplier does not respond in the pre-specified form, quantity and timing (by implication saying NOT DONE), this is a binary signal that the connection is not working as it was designed. In the same way, should the customer not make a request (by implication saying DON'T DO), yet the supplier provides a good, service, or information (by implication saying DONE), this is a binary signal that the connection is not working according to its design.

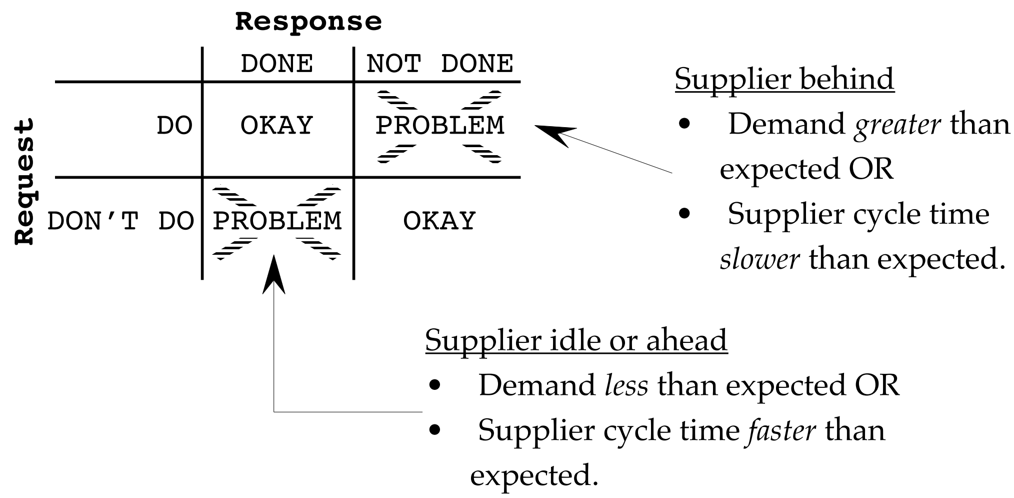

Figure 17: The implied logic of Rule-2's tests

There are preconditions for requests and responses to be viewed as a simple DO/DONE signals that carry "what" (form), "how many" (quantity), and "when" (response time) information. The customer and supplier must have:

- a *menu* of items (goods or services) that the customer can request from the supplier that is carefully defined and specific to each customer-supplier pair.
- a *definition* for a *defect-free* response for each item on the menu that specifies form, quantity, and response time and that is understood both by the supplier and by the customer.

EFFECTS OF THE RULE

Rule-2 is the guideline for designing and operating the *interface* between each customer and supplier. Designing the interface this way has implications for architectural simplification, information clarity, and problem identification. Each of these three points is discussed below.

ARCHITECTURAL SIMPLIFICATION

Rule-2 requires that requests travel directly from customers to suppliers and that responses travel directly from suppliers to customers over the same pathway. Therefore, information flows overlap the flows of goods, services, and information. As a result, the organization has a single system for carrying information flows and for carrying flows of goods, services, and information. In contrast, when flow-paths don't overlap, there are two distinct architectures, one for information and another separate one for goods, services, and information. The distinct systems have to be integrated, and changes in one have to be coordinated with changes in the other.

INFORMATION CLARITY

Connecting customers and suppliers directly, through clearly defined, over-lapping request/response channels appears to reduce the risk that the supplier receives multiple, possibly conflicting requests. For instance, in the plant in which I worked as a member of the Toyota Supplier Support Center, the production control department generated a production schedule each day at 7 AM. At 9 AM, the plant manager, the production manager, and area foremen would meet, and at 10:30 AM they would distribute a 'hot-list,' those items for which a failure to ship that day would cause the plant to miss an important delivery deadline. Perhaps at the same time, the shipping clerk, in the midst of trying to assemble one of the days shipments would discover a short-fall. Invariably, he would then try to get someone to make those parts so that the shipment would be complete. Later in the day, after doing an inspection of the existing inventory, an area foreman might give a shop floor operator another set of instructions. It was not uncommon in this plant, and it was representative of what I observed in other, non-TPS plants, for one person to receive multiple conflicting instructions as to what to produce. The inevitable result was confusion, not knowing what particular items to send, to whom, in what quantity, and in what sequence.

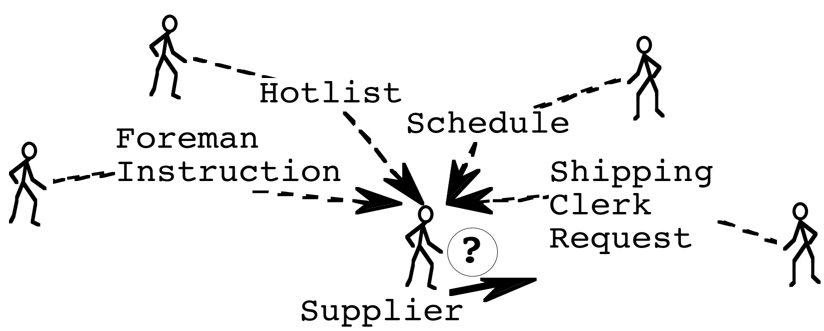

Figure 18: Multiple, conflicting signals

Though some people were bombarded with multiple, conflicting signals of what to do, at other times, people working in the same settings received too little information of what they were needed to do. This problem manifested itself in the classic symptom of a person wandering the shop floor, looking for something to which they could contribute. For example, in one case, I shadowed the material handler at the Toyota supplier plant in which I worked as a TSSC consultant. During 30 minutes, he actually moved material for only 10 minutes. I observed other people searching for the material they need to do their work, for instance a fork lift driver repeatedly spending 20 minutes looking for the steel coil that was needed for a die change, or another person searching for fasteners that would allow her to complete a device she was constructing.

The observable symptom was identical when people received too many signals or when the received too few to know exactly what was needed for them to contribute to the organizations collective effort. People spent a substantial portion of their time deciding what to do, time that was therefore not dedicated to adding value to the good, service, or information that would be delivered to the organization's external customer.

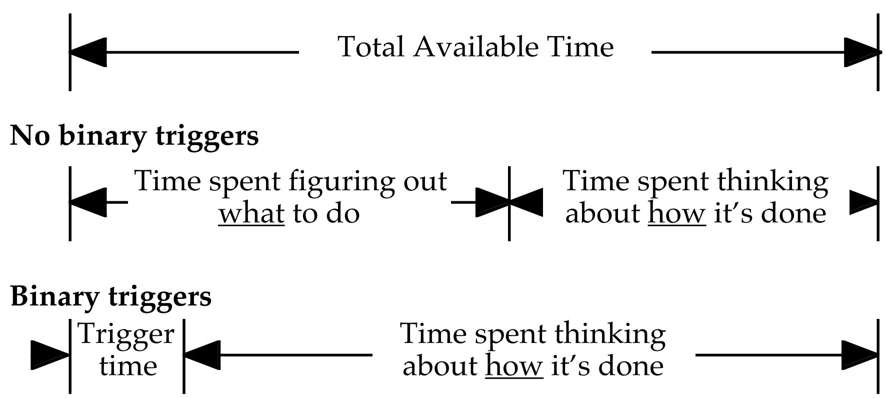

Figure 19: Using binary triggers to free 'cognitive capacity'

Furthermore, in deciding what to do, both those receiving too many signals and also those with too few made decisions based on their perception of local conditions without regard to the needs of the overall system. In other words, inadequate information led to distributed decision making that addressed local but not necessarily system concerns.

Sending requests from a single source in a form that can be interpreted as a DO signal to produce and deliver a specific item, in a specific quantity, at a specific time appears to remove the risk that the supplier will misinterpret the customer's needs (form, quantity, or timing). This reduced the risk that the supplier would inadvertently produce and deliver the wrong good, service, or information, in the wrong quantity, at the wrong time. I have also observed that this reduced the amount of time individuals spent searching for the information that would tell them what to do and when.

SYSTEM DIAGNOSIS, HYPOTHESIS-TESTING AND LEARNING

Rule-2 makes each customer-supplier connection self-diagnostic. Each request can be checked against each response or non-response. This information, generated by problem detection, can be used for problem diagnosis, remediation, improvement, and learning. This is true for the following reasons.

Assigning responsibility to only one person for supplying a pre-specified set of goods or services to a particular other person, according to Rule-2, implies two hypotheses.

Within a given period:

a: the customer will need a specific mix and volume of outputs from the supplier;

b: the supplier is capable of providing outputs in that specific mix and volume to the customer.

These hypotheses are tested with each request/response cycle. If the supplier responds properly to customer requests, then the hypotheses implied in the connection's design are confirmed. However, if the supplier does not respond with the proper form, quantity, or timing, the system has actually performed contrary to the expectations. Therefore, the hypotheses implied in the design of the connection are refuted, and this is a trigger to investigate why the *actual* performance contradicted the *expected* performance. In turn, this investigation is a source of knowledge about the supplier, about the customer, and about the process.

It also may be that the customer's needs are less demanding than expected or the supplier's capability is greater than expected. There is a test for this too. The test is that the supplier will periodically be idle, having been able to produce and deliver at a rate faster than the customer requests.

This ongoing testing of hypotheses -- with each request/response cycle serving as a potential trigger to refute hypotheses and to revise expectations -- is a means of structured experimentation. In this way, Rule-2 reflects a theme common to all the Rules, that the expectations built into the design should be tested with each operation.

RULE-3 - FLOW-PATH (SYSTEM-ARCHITECTURE) DESIGN AND OPERATION

Rule-3 guides the design and operation of the flow-paths -- constructed from connected activities -- over which final goods, services, and information are created. Rule-3 plays an important part in reducing the number of interactions in the system, thus making cause and effect more obvious, reducing cognitive burdens, and decreasing the difficulty of system operation and improvement. In reducing the number of interactions, Rule-3 contributes directly towards creating a nested, modular organizational structure.

RULE STATEMENT

Design and operate the flow-path for every good, service, and information so that it is *simple*, *pre-specified*, and *self-diagnostic*.

For a flow-path to be:

- *simple*, a flow-path must not have loops or intertwined branches

  A *loop* exists if a good, service, or information returns to an upstream process for additional work , or if a person or machine is responsible for non-sequential steps.

  An *intertwined branch* exists if a server at activity $_{n+1}$ is fed by more than one server at activity $_{n}$ AND a server at activity $_{n}$ feeds more than one server at activity $_{n+1}$.

  (As will be explained, this does not preclude flows coming together as when several slower or specialized processes supply a single faster or general purpose process, nor does it preclude flows splitting as when a high speed process feeds several slower processes.)

- *pre-specified*, every good and service must have one and only one flow-path over which it can travel as it takes form.
  i.e., if a process-flow branches, it is known ahead of time which specific branch each good, service, or information is expected to follow.

- *self-diagnostic*, a signal must be generated immediately that a problem has occurred if a good, service, or information travels a flow-path other than its pre-specified one.

PREREQUISITE STEPS FOR CREATING SIMPLE, PRE-SPECIFIED FLOWS

Several steps are required for creating a simple, pre-specified flow-path.

- Determine the steps by which the final output of a person, a group, or an organization takes form.
  Do this by starting where the good, service, or information is provided to the customer and work backwards through all supply chains to identify *all* activities that contribute to the final form. These activities include but are not limited to those that transform materials (production), move material (logistics), transform machines (maintenance and engineering), transform people (training), and transform information.

- Determine all of the physical (i.e., parts, materials, components) and non-physical (i.e., maintenance, training, real-time assistance, problem-solving) inputs that are required by each activity.

- Assign to a specific supplier the responsibility and the means for providing each particular good, service, or information that each person needs to do his or her work.

CLARIFICATION OF TERMS

This section will give several examples to clarify the terms “pre-specified,” “loops," and “intertwined branches” that are contained in Rule-3.

PRE-SPECIFIED FLOWS

Consider two products “A” and “B” both of which must go through Process-I and Process-II. At Process-II, there are two identical machines: M-1 and M-2. In one case, A and B can go to either Machine-1 or to Machine-2 at Process-II depending on which machine is available first. Consequently, sometimes A may go to Machine-1 and other times it may go to Machine-2. The flow-path for Product-A is not pre-specified as Product-A can go to either machine, depending on the particular system conditions when A is ready to advance from Process I to Process II.

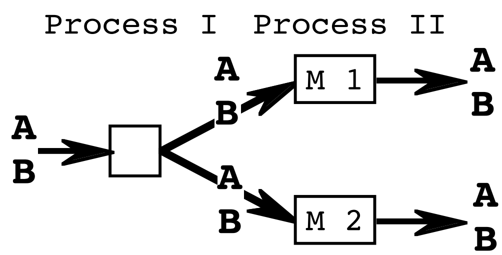

Figure 20: Flow-path for material is not pre-specified

In a similar vein, consider Worker-A and Worker-B, both of whom might need assistance in the course of performing their jobs. When they call for help, either Helper-1 or Helper-2 can respond, depending on which Helper is available first. Consequently, the flow-path -- for assistance in this case -- is not pre-specified. When Worker-A needs help, for example, it will sometimes be Helper-1 and other times it will be Helper-2 who supplies assistance.

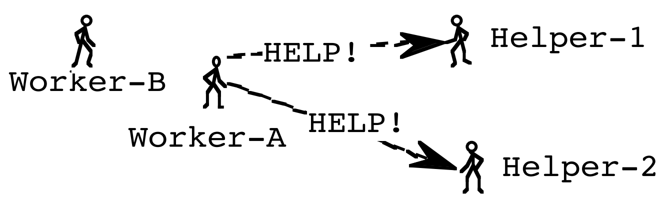

Figure 21: Flow-path for assistance (Helper) is not pre-specified

At TPS-managed sites, this approach to designing flow-paths is not taken. Rather, my finding is that each good, service, or information is assigned to one, pre-specified flow-path before it takes form. For instance, in the material flow example, Product-A's flow-path might be pre-specified as Process-I followed by Machine-1 at Process II, and Product-B's flow-path might be pre-specified as Process-I followed by Machine-2 at Process 2.

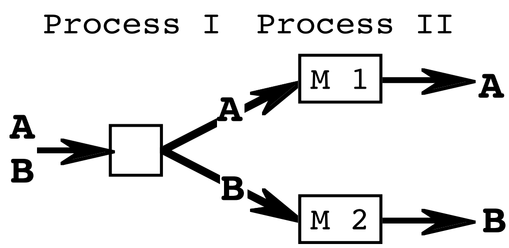

Figure 22: Flow-path for material is pre-specified

In the case of the workers who might need assistance, I observed a consistent approach of pre-specifying who will assist whom at the TPS-managed sites I studied. For instance, in the example we had, perhaps Worker-A always calls to Helper-1 for assistance, and Worker-B always calls to Helper-2.

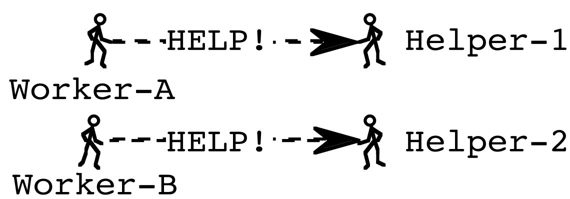

Figure 23: Helper is pre-specified

<u>1 Flow per product ≠ 1 product per flow</u>

The requirement that each good, service, or information have a single, pre-specified flow-path *does not* also imply that each flow-path have only one good, service, or information. At Toyota, single production lines each produce multiple models, often of different body types. At Aisin, described later, three specialized lines (small, medium, and large) were combined into two lines, each capable of producing small, medium, and large. Team Leaders do not only provide assistance during routine production to Team Members. They also provide assistance in learning standardized work, help in solving production-related problems, and teach problem-identification and problem-solving skills. In all these examples, multiple goods or services traverse a single flow-path.

Implied Rationale for Pre-Specified Flows

In my investigations, the apparent rationale for pre-specifying flow-paths for all good and services is that by articulating ahead of time how a flow-path is expected to perform *each time it is used*, its actual performance will confirm or refute the assumptions implied in its design *each time it is used*. For instance, suppose Product-A is meant to go to Machine-1. If Product-A actually arrives at Machine-2, there is a signal that something has gone awry, perhaps because people have been forced to compensate for an unanticipated situation.

Similarly, suppose that Helper-1 is the pre-specified supplier of assistance to Worker-A. If Helper-2 actually supplies assistance, as in the next diagram, this is a signal that something has gone amiss, causing people to make ad hoc responses to unanticipated situations. In turn, this is a (binary) trigger to investigate the system and gain a deeper understanding of how it actually responds to the demands on it.

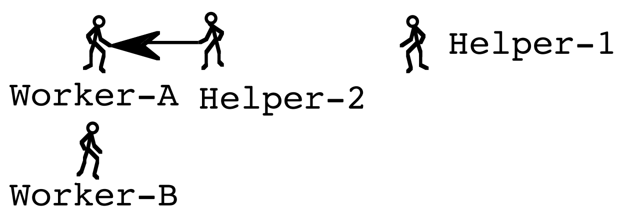

Figure 24: Worker getting assistance, but not from pre-specified Helper

REMOVING LOOPS

Rule-3 requires that 'loops' be removed from flow-paths, as illustrated in the following diagrams. In the first diagram, the product goes to Process-I, Process-II, Process-III, and Process-IV before returning to Process-II for additional work.

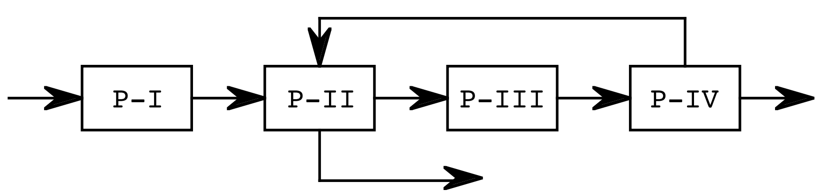

Figure 25: Looped Flow

In the next diagram, the product does not return to an upstream process. This latter example is the approach taken in sites managed according to the TPS Rules-in-Use.

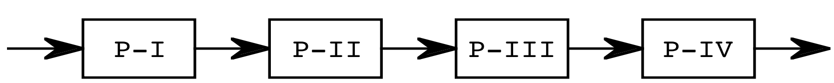

Figure 26: Simple Flow, no loops

I have observed that designing flow-paths without loops applies both to flows of material goods and to flows for intangible services. For instance, a simple-flow supply chain for training and assistance is shown in the following diagrams. In this example, one of the Team Leader's primary responsibilities is to assist the Operator, and one of the Group Leader's primary responsibilities is to assist the Team Leader.

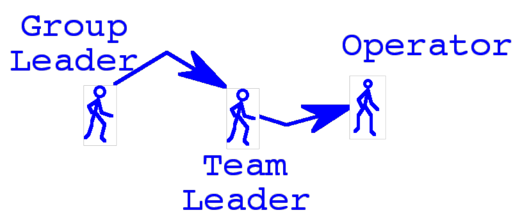

Figure 27: Simple flow for training

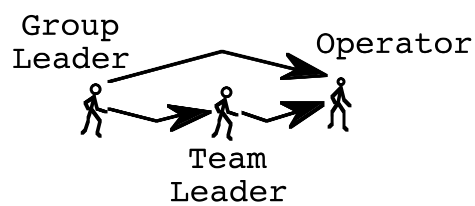

Figure 28: Looped flow for training

For example, in TPS-managed situations I have seen cases when an operator has needed help, but the Team Leader has not responded immediately. However, the Group Leader has not gone to assist the operator directly. Rather, the Group Leader's first action has been to assist the Team Leader directly and the operator only indirectly. At sites not managed by TPS, there is a less clear assignment of responsibility as to who is to help.

This does not imply that a Group Leader wouldn't leap-frog for a safety or quality issue. However, because of the pre-specified flow-path, any leap-frogging, even for something relatively minor, can be interpreted as a signal that the flow-path is performing contrary to expectations.

Implied Rationale for Flows without Loops

I have found that those well-trained in TPS remove and avoid loops while designing flow-paths for goods, services, and information. The loops make it more difficult for them to discern cause and effect relationships. This in turn diminishes their ability to discover problems, uncover the causes, and construct effective counter-measures. For instance, in the preceding "looped material flow" case, a problem discovered at Process-II may have its origins at Process-I (P-I), at P-II itself, or at P-IV whereas in the simple-flow case, the number of possible sources is reduced.

As for the training example, the implied belief in the TPS-managed setting is that if it is normal for the Group Leader to assist the Operator directly some of the time (but not all of the time), it is less clear when the Group Leader is supplying assistance over a routine channel and when the group leader is supplying assistance directly, but over a non-routine, or emergency channel. Because the routine cannot be clearly distinguished from the non-routine, there is no binary trigger to investigate assumptions about the demands on the Team Leader and on the Group Leader and about the Team Leader and the Group Leader's capacity to meet these demands.

REMOVE 'INTERTWINED BRANCHES'

Rule-3 requires that 'intertwined branches' be removed from the organization's flow-paths by reducing (to one *if possible*) the number of downstream activities an upstream process feeds (reducing the 'fan-out') and reducing (to one *if possible*) the number of upstream activities feeding a downstream activity (reducing the 'fan-in'). This is illustrated in the following diagrams. In the first case, the machines at Process-II each serve and are served by more than one other machine. Without intertwined branches, each machine serves and is served by only one other machine.

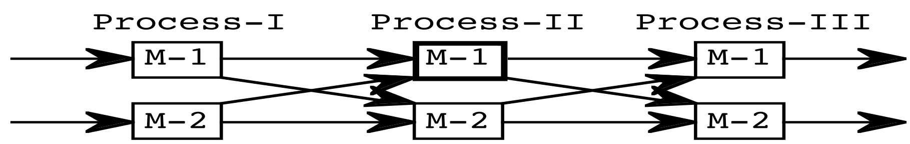

Figure 29: Intertwined Branches

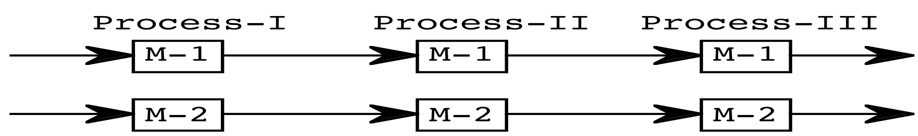

Figure 30: Simple Flows, no branches

Implied Rationale For Flows Without Branches

As in the case of Flows without Loops, the apparent concern of people in TPS-managed situations is that intertwined branches increase the complexity of the system. The branches increase the number of other activities with which each activity interacts. This makes cause and effect harder to determine and requires broader coordination for experimentation and change.

APPLICATION OF THE RULE

At first glance, it might appear that Rule-3 speaks only to the senior managers within a plant. However, these Rules, taken as a set, lead to an organizational structure that is nested, modular. Consistent with the idea of modules within modules within modules, I have observed single people who have simplified and pre-specified the flow of goods, services, and information in their own individual work space or process, and I have observed Team Leaders designing flow-paths that connect individuals within their Teams according to Rule-3. In TPS-managed sites, I've observed Group Leaders design simplified, pre-specified flow-paths that connect teams within their Groups according to Rule-3. Therefore, Rule-3 does not govern only the meta systems or structures of the organization. Rule-3, like the other Rules, is applied at all levels of aggregation, from the individual person designing a flow within her own process to the senior manager designing flow-paths within and between organizations as a whole.

RULE-4 - ACTIVITY (COMPONENT) IMPROVEMENT

Rule-4 assigns responsibility for improvement of individual activities in organizations, thereby defining in part the role of managers in TPS-managed organizations. Rule-4 provides a standard to judge the merit of improvement efforts, and it prescribes a mechanism for improvement. The mechanism for process improvement -- frequent, structured, directed problem-solving -- is also the mechanism by which people are trained. Rule-4 contributes to modularity. The consequent opportunity for distributed experimentation is consistent with system improvement -- by placing activity-improvement behind the interface that connects adjacent activities. Therefore, behaviors consistent with those that I have codified as Rule-4 play are critical in developing an organization's ability to design, operate, and improve.

From field observations, I have concluded that the improvement and learning mechanisms that I have codified as Rule-4 distinguish those organizations that truly use TPS to manage the production and delivery of goods, services, and information from those that do not. For example, the TPS experts in Toyota's Operations Management Consulting Division [Japan] and in the Toyota Supplier Support Center [North America] use these mechanisms to teach. Their evaluation of an organization's command of TPS appears to be weighted by the extent to which these mechanisms are employed.

RULE STATEMENT

- Include activity improvement as part of the work content of the person who performs an activity.
- Assign each person with a specific, capable teacher to supply training.
- Train to improve through solving problems, primarily.
- To test the assumptions implicit in the activity's new design (and in the design of the improvement activity), the improvement process should be designed and performed as an experiment with refutable hypotheses.
- A change in an activity is considered an improvement if the activity can be performed closer to the IDEAL of defect-free, one by one, on demand, immediate, waste-free, and safe production and delivery.

CLARIFICATION OF TERMS

Rule-4 has critical attributes. Rule-4:

(1) requires that improvement activities, like all activities be designed and performed as experiments. This prohibits ad hoc changes and requires that improvement be achieved by testing hypotheses, both about the underlying activity that is the object of the improvement effort, and also about the improvement activity too.

(2) provides the IDEAL as a 'True North' guide for creating tension and setting the direction for change, and

(3) states that the person who performs an activity should be involved in improving the activity and that improving activities be the primary way in which people are trained to use TPS (i.e., to learn the patterns of behavior that I have codified as Rules-in-Use).

As a result of these three attributes, Rule-in-Use 4 is the source of two features of organizations managed by the Toyota Production System. Rule-4 makes teaching a primary managerial responsibility and contributes to cascading supply chains (simple, pre-specified flow-paths) for teaching and learning. Second, Rule-4 makes frequent, directed, structured problem-solving a primary learning mechanism. These points are expanded below.

STRUCTURED, SELF-DIAGNOSTIC ACTIVITIES FOR IMPROVEMENT

The common theme of all TPS Rules-in-Use is that by pre-specifying *expectations* about an activity (content, sequence, timing, outcome), the actual performance of the activity is a chance to confirm or refute the hypotheses implicit in the activity's design. Rule-4 reflects this theme by requiring that *improvement* activities also be done in a way that hypotheses can be tested.

I concluded that people trained in TPS design and perform improvement activities as experiments with refutable hypotheses from data collected while a member of TSSC, from observing other TSSC people teaching TPS through problem-solving, and from studying other improvement efforts at TPS-managed sites. For example, when I was a member of the Toyota Supplier Support Center, I and several other people tried to implement TPS at a supplier which stamped, welded, and shipped parts to Toyota and two other automobile makers. I have summarized part of that experience because it is representative of the approach to improvement that I documented at other TPS-managed sites as well. (Accounts of other improvement activities designed as experiments are provided in Chapters 7.4 and 7.5.)

My initial activity was to "grasp the *current condition*," the current methods for production and delivery. To do this, I:

- documented the actual flow-paths for each the plant's 300 part types by identifying which parts were made by which machines.
- documented how people in production, maintenance, shipping, and quality control knew what to produce or deliver, in what quantity, and in what sequence. This involved tracking different sources of information (production forecasts, work releases, production schedules, verbal instructions) and establishing -- through direct observation -- how people responded to each type of information.
- studied how people actually performed their activities to produce and deliver parts by doing time and motion studies for each process.
- identified problems that seemed to result from the methods currently being used, such as when people could not get the parts and materials they needed to do their work or when the output of their efforts was defective.

These steps led to the construction of a *current condition*, a diagrammatic and textual depiction of how material and information flowed, how activities were triggered, and how work was actually performed in the plant.

After constructing the current condition, I then had to propose *counter-measures* to remove the problems I had identified. These included changes in flows of material, services and information through the plant, changes in how activities are triggered, and changes in how activities are performed.

For example, one suggested counter-measure was to assign several parts to the same flow-path so that they would be stamped on the same press, assembled on the same welding station, and shipped to the same customer. A second suggested counter-measure was to develop a pull system that would have shipping trigger assembly, which would in turn trigger stamping, which would in turn trigger material re-ordering. A third suggested counter-measure was to make changes in the change-over routine at the stamping press to reduce the time spent replacing the tool used to make one part with the tool used to make another.

It was not enough merely to suggest counter-measures to problems of the current condition. I also had to predict the effect of the counter-measures. Again I had to generate a diagrammatic representation, this time a target condition (the predicted results) showing how I expected material, services, and information to flow; how I expected activities to be triggered; and how I expected work to be performed once the counter-measures were in place. Finally, I had to recommend a sequence in which the counter-measures were to be implemented, an expected time for implementing each, and measures (lead time, change-over time, process cycle times, inventory, batch sizes, etc.) by which the target and the current conditions could be compared. What I had done, in effect was stated a testable (refutable) hypothesis in the form:

current condition + counter measures

--yields-->

target condition (predicted results).

I expressed this hypothesis in the format shown in the following diagram.

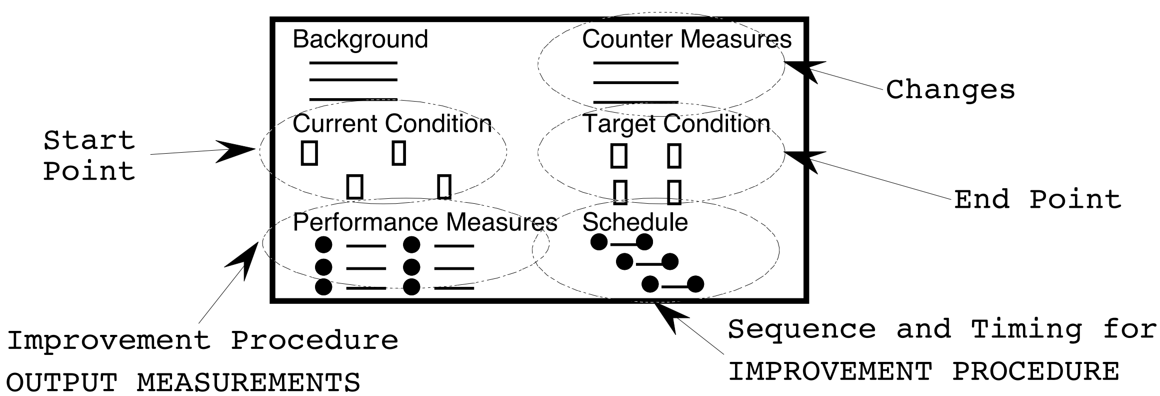

Figure 31: Designing the improvement activity as an experiment

This example is representative of the consistent approach taken at TPS-managed sites where I gathered data. When I worked with or observed the work of people who had learned TPS from OMCD and TSSC teachers, they too went through a similar process, whether the improvement was targeted at changing an individual activity, the design and operation of a small cell, or the design and operation of an entire production line. In contrast, this approach was not evident at the sites where I collected data that were not managed by TPS.

THE IDEAL

Definition of the IDEAL

At TPS-managed sites, people tried to improve individual activities and systems of activities on one of six dimensions *in the direction of* IDEAL activities, connections, and flow-paths that always produce and deliver goods, services, and information that are:

(a) Defect-free,
(b) Always produced and delivered on-demand,
(c) In batch sizes of one,
(d) With immediate response to customer requests,
(e) With no waste (at minimum cost),
(f) With no threats to the supplier's physical, emotional, or professional safety.

Defining Three Types of Safety

I concluded that TPS-trained people think of safety as a condition with three dimensions: physical, emotional, and professional.

Physical Safety: An activity is physically safe if performing it (to produce or deliver a good, service, or information) does not result in a physical injury.

Emotional Safety: Improvement of processes and promotion of TPS is rooted in problem identification and resolution. I concluded that managers in TPS-managed organizations and the TPS experts in Toyota's OMCD and TSSC groups were concerned that the work environment be 'blame free.' This meant that finding a problem and trying to solve it (even if unsuccessfully) should not result in destructive criticism or penalty.

Professional Safety: 'Continuous Improvement,' at TPS-managed sites, means moving towards IDEAL production and delivery. This may mean devising new activities, connections, or flow-paths so that fewer people are required. To assure professional safety, people cannot get fired, suffer a pay cut or otherwise be punished for making improvements. For example, when the Toyota Supplier Support Center agrees to advise a company, it first imposes a contractual requirement that productivity improvements not lead to dismissals.

The IDEAL as an Implicit Standard for Improvement

I concluded that the IDEAL serves as a 'True North' beacon that provides positive tension and direction for improvement beyond that required to meet the current needs of customers. For example, a supplier may be adequately meeting the needs of customers so that the tests of Rules 1, 2, and 3 don't indicate that there are problems that need to be solved. However, there still might be opportunities to improve the production and delivery system. In TPS-managed organizations, there is an underlying source of tension to motivate improvements beyond the tests of Rules 1, 2, and 3. In the course of my research, I repeatedly saw that people were challenged with directed questions such as: "Why is your batch-size X and not 1/2 X?," "Why are there Y people in the cell and not Y-2?"; "Why is the response time to a customer request T and not 1/5 T?."

All improvement efforts were attempts to improve towards the IDEAL on at least one of its six dimensions. For instance, at one Toyota supplier plant in Japan, a shop floor operator had an unusual device to keep track of the work she was doing. When asked why she was using this tool, she explained that previously she had been making [her particular sub-assembly] eight pieces at a time. She knew however, that she was supposed to provide the sub-assembly to the next person in line, a single piece at a time. By using this device, she was able to cut her lot size from eight to five. While still not good enough, she confessed, she knew it was a step towards one by one.[4]

More generally, when people at TPS-managed sites were asked why they were producing, maintaining, training, conveying, or improving in a particular way, the answers could be summarized in the following way:

> *Ideally*, production and delivery of **[**this particular good, service, or information**]** would be **[**defect-free, one by one, on-demand, immediate, without waste, and safe for the supplier**]**.
>
> However there was **[**some specific problem**]** which **[**caused defects; required production or delivery batches greater than one; required production and delivery in anticipation of demand; caused the customer to wait for the supplier to respond; wasted material, time, motion, or energy; or threatened the individual supplier's physical well-being, emotional safety when they found problems, or professional safety to eliminate problems**]**.

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[4] Toyota-supplier plant visit: March 1996

Therefore, we made this change [introduced this *counter-measure*] to eliminate [the particular problem] so that production and delivery would be closer to the IDEAL.

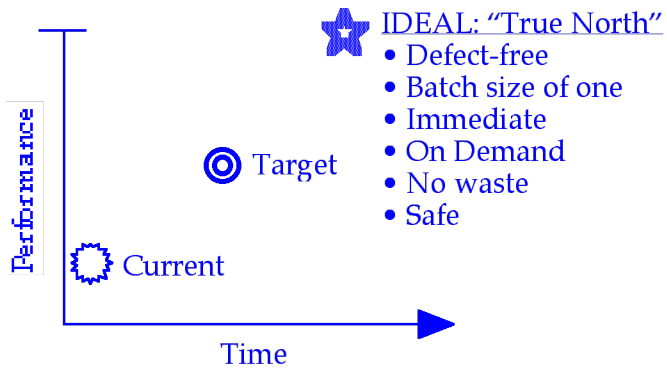

Figure 32: The IDEAL as a 'True North' beacon

SIMPLE, PRE-SPECIFIED FLOW-PATHS FOR TRAINING AND TEACHING

Rule-4 states that *activity-improvement* be included in the work content of each supplier, and states that the organization be designed so that each supplier has a specific, capable person to teach him to improve his own work by solving actual problems when and where they occur. Therefore, Rule-in-Use 4 makes it imperative that each supplier be provided with assistance and training if he cannot perform his work, recognize and resolve problems when and where they occur, or improve activities so that activities are performed closer to the IDEAL.

At TPS-managed sites in Japan and North America, I have observed Rule-4, like all the Rules, applied to individual suppliers across functional specialties and through hierarchical levels. In this regard, I have found that a part of Team Members' work content is improving their own work, a part of Team Leaders' work content is training Team Members to perform and improve, a part of the

Group Leaders' work content is training Team Leaders, a part of managers' work content is training Group Leaders, and a part of the OMCD/TSSC work content is to train higher level managers . At all stages in the training supply chain, the training occurs through directed challenges (to show that a problem exists) and directed problem-solving (to remove the problem and move production and delivery closer to the IDEAL). I observed that at all levels people learn to apply the patterns that I have codified as five Rules-in-Use by solving problems. Therefore, Rule-4's requirement that each person be assigned a specific teacher (supplier of training) makes training of immediate subordinates a primary managerial responsibility. This is illustrated in the following diagram.

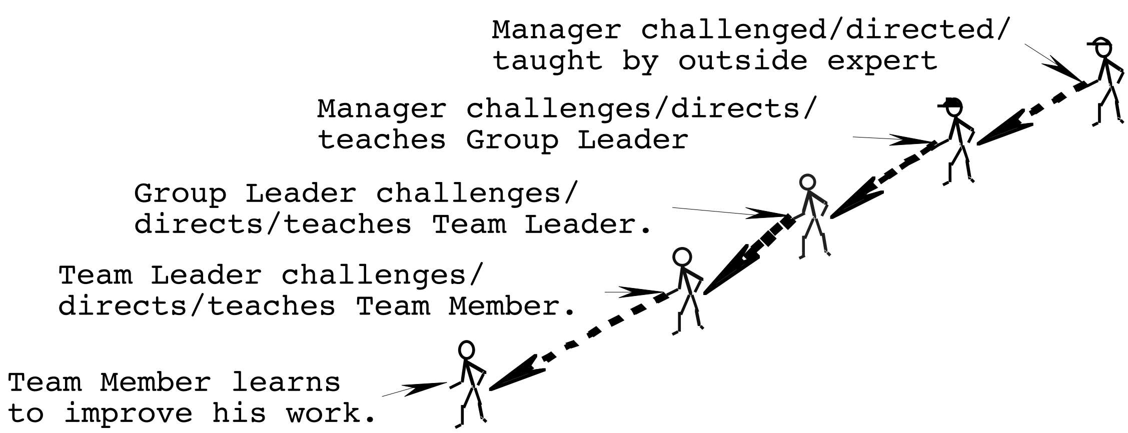

Figure 33: The supply chain for training by problem-solving

I have encountered many examples in which training occurred through a cascade (i.e., simple, pre-specified flow) of frequent, structured, directed problem-solving. In one supplier plant, cycles of problem-solving based equipment-improvement and training reduced the dependence of production workers on the maintenance department for routine up-keep of the stamping presses. Before the training, the maintenance department handled 100% of the routine maintenance. After the problem-solving based training, the production workers accepted responsibility for 80% of the equipment maintenance. According to managers, this reduced reliance on a service-supplier meant that the production department had to wait for external support in fewer instances, requiring fewer pauses in production. Also, freed from routine maintenance activities, the maintenance department had more time available for higher valued-added activities. (See account of Taiheiyo Quality Circle in Chapter 7.4.)

At another supplier, a team of assembly line workers went through a four stage development process centered around the identification and resolution of problems that affected their portion of the assembly line. The team members had to learn to work together, with the new Team Leader learning to manage a group and with the new Team Members learning to be part of the group in the first stage of the learning. In the second phase, the Team Members and Team Leaders learned to identify problems in the activities for which they were responsible. Third, they learned to develop, on paper, counter-measures to eliminate the problems. Fourth, the Team Leader and Team Members became qualified as electricians, mechanics, and machinists so that they could fabricate counter measures without being dependent on the maintenance department and other skilled-trades people. (Presentation by "Ito-Team"; Japan July 1997 -- See the Aisin, Ito Quality Circle account in Chapter 7.4.) Senior people in the plant improved the production system and deepened their TPS understanding through structured problem-solving that was directed by this company's own

TPS experts. (Plant manager presentation and interview; Japan; July 1997 -- See the Aisin System Redesign account in Chapter 7.5.)

In the team's experience, Rule-4 patterns were evident:

- The diagnosis of the production and delivery activity and the improvement of the activity increasingly became the responsibility of the people who perform the activities.
- Training was done by addressing problems that affected the specific production and delivery activity done by the people being trained.
- Training to problem solve was a key part of the supervisor's work content.

I observed or learned of other shop floor operators, mid-level supervisors and higher level managers developing skills in the same fashion.

RULE-5 - ACTIVITY & CONNECTION (INTERFACE & SYSTEM-ARCHITECTURE) IMPROVEMENT

Rule-5 guides the improvement of connections between activities on existing flow-paths and guides the improvement of flow-paths. Therefore, Rule-5 is the means by which interfaces and system-architectures are improved.

Rule-5 defines another role for people in supervisory positions, beyond that defined by Rule-4. By Rule-4, one critical role of a person in the managerial hierarchy is to teach those at the level immediately below them. By Rule-5, they are also responsible for managing the 'interfaces' between the people immediately below them in the hierarchy and for managing and improving the flow-paths over which their group produces and delivers goods, services, and information. In this way, Rule-5 has a significant impact on the structure and dynamics of TPS organizations. Rule-5 is the source of the 'nested' aspect of a TPS organization's nested, modular structure.

RULE STATEMENT

- Connections and flow-paths should be improved in the smallest group that includes the connection and the flow-path by the person responsible for managing the group.

- Individuals should be formed into small groups and small groups should be formed into larger groups based on the nature and the frequency with which problems are expected to occur.

- A change is a connection or a flow-path is an improvement if production and delivery is moved closer to the IDEAL.
- Changes for the sake of improvement should be made so that the hypotheses implicit in the connection's or the flow-path's new design (and in the design of the improvement activity) are refutable.

IMPACT OF RULE-5

Rule-in-Use 5 is used for improving the trigger mechanisms for the activities on existing flow-paths and for improving the flow-paths themselves. In this way, Rule-5 guides improvement of the interfaces between modules in an existing system-architecture and guides improvement from an existing organizational architecture to a new one.

In guiding the improvement of trigger mechanisms and flow-paths, Rule-5 assigns responsibility for:

a: resolving problems and making improvements in the design of customer-supplier interfaces for the existing architecture, and

b: changing the architecture of the business's flow-paths by making changes in who is supplying whom with what good, service, or information.

The person who has this responsibility is the person who supervises the smallest group that includes the problematic interface, the problematic flow-path, and the individual customers and suppliers who are affected. Therefore, Rule-5, like Rule-4, pushes problem-solving to the lowest level of aggregation possible.

Conversely, Rule-5 states that people should be aggregated into small groups, and small groups should be aggregated into larger groups based on the *expected* nature and frequency of problems and on the *expected* capacity of the group supervisor to address problems as they arise.

Rule-5 thus reflects the theme that is common to all the Rules. Rule-5 requires that flow-path and connection designers explicitly state the nature and frequency problems are expected and explicitly predict that the group's supervisor will be able to address the problems as they arise. Because of this, the assumptions implied in the assignment of responsibility and in the design of spans-of-responsibility within a group can be compared with the actual rate and nature of problems and with the actual capacity of the group supervisor to address the problems. Should the actual behaviors not match the predicted behaviors, a binary signal to DO problem-solving and perhaps redesign connections, redesign flow-paths, and expand or contract people's span of responsibility is triggered.

Rule-5, like Rule-4, establishes the objectives that should be pursued (the IDEAL) in making improvements, and Rule-5 establishes the methods to be used (structured, self-diagnostic, problem-solving activities). Therefore, Rule-5 also reflects the theme that improvement is an activity which can be structured so that hypotheses can be tested, validity established, knowledge can be generated, and learning can occur.

EXAMPLE: PROBLEM-SOLVING AT LOWEST LEVEL

The following diagrams illustrate the portion of Rule-5 that states that problems be resolved in the smallest possible group and that groups be formed based on the nature and frequency with which problems are expected to occur. Each team leader is responding to a problem that affects the connection between two members of the same team (with the Group Leader observing, assisting, or teaching consistent with Rule-4).

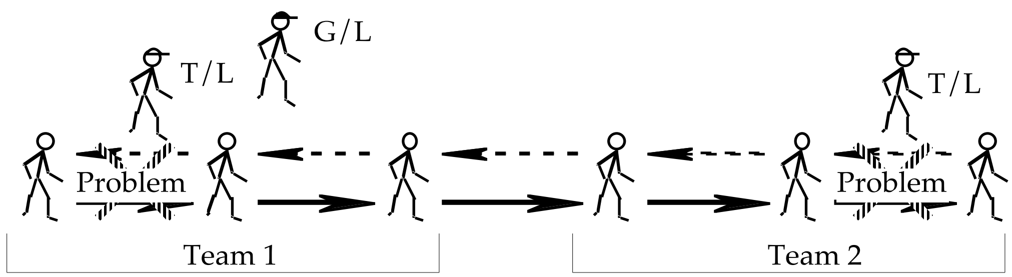

Figure 34: Group Leader supplying assistance to a Team Leader

In one plant where I gathered data, I observed that there was not a clear trigger when a downstream person needed material from an upstream person in a cell. The upstream person would therefore occasionally under-produce, causing the downstream person to wait. At other times, the upstream person would produce more than needed, thereby having to stack parts and risk losing the production sequence. As a result, it became the responsibility of the cell's team leader to help the two team members develop an interface (designed according to Rule-2) that would start and stop the upstream work based on the downstream operators needs.

The next diagram illustrates a situation in which a problem affects the interface between two teams. Because two teams are affected, neither team leader alone can improve the interface since the change would affect the team for which he is not responsible. As a result, the smallest organizational unit to which both affected parties belong is a group, it is the responsibility of the group leader to resolve this problem.

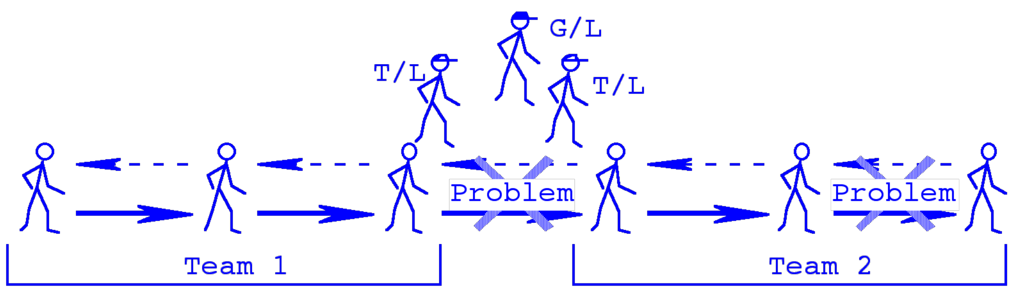

Figure 35: Group Leader managing interface problem between teams

Rule-5 requires that problems be resolved in the smallest possible group. It also requires that groups be formed based on the nature and frequency with which problems are expected to occur. This is based on the reasoning that problems are a form of customer-requests (for help) and must be addressed as they occur. In the following diagram, the Leader of Team 1 is unable to respond to problems as they occur. Unable to respond to requests to problem solve, Team Leader 1 is falling behind the rate of customer demand.

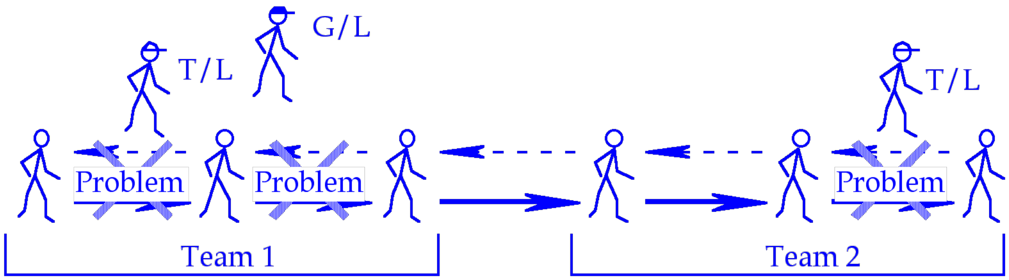

Figure 36: Team Leader unable to respond to all interface problems within team

In the situation just described, Rule-5 would require that the span of responsibility be changed so problems are addressed as they occur. This might mean that Team 1 is reduced to a size that fully loads, but does not overload, Team Leader 1. An example of a possible response is shown in the next diagram.

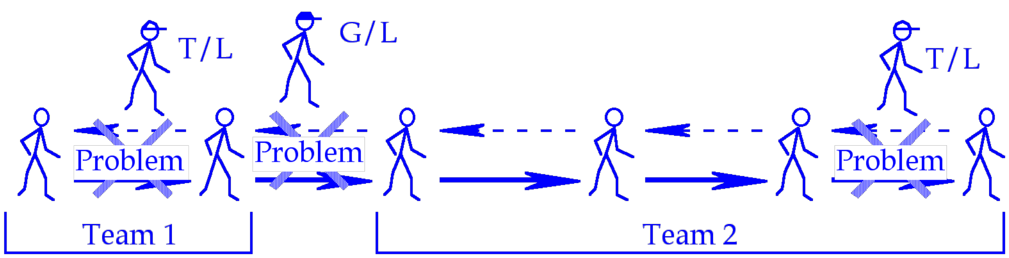

Figure 37: Nature and frequency of interface problems and spans of control

EXAMPLE: RULE-5 APPLIED TO DESIGN OF AN ORGANIZATION

Responsibility for managing interfaces and flow-paths is not assigned based on product, process, or functional specialty. Rather, responsibility is assigned based on the nature and frequency with which problems are expected.

At the Kamigo engine plant, for example, there were two Machine Divisions, each of which had four independent production shops, when I visited to gather data in the Summer of 1998. At that time, I learned that the production people were divided into four shops and that production engineers had their own group within Machine Division 2. Therefore, production and production-engineers had the division manager as a common chief. In contrast, the production-engineers were divided across the four shops in Machine Division 1. The production people and the production-engineers answered to the same shop-head as a result. This is illustrated in the next diagram.

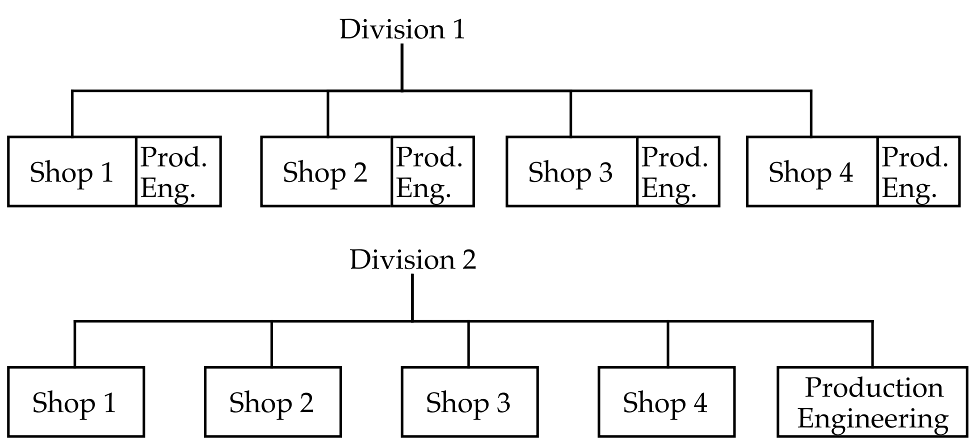

Figure 38: Organization design: Kamigo Engine Plant

According to the people I interviewed, neither structure was inherently better than the other. The problems faced by Machine Division 1 and the problems faced by Machine Division 2 were different at the time. As a result, the Division heads in each case decided to establish different customer-supplier relationships. In Machine Division 2, the Division Head, Mr. Koseki, wanted to create a situation in which his production engineers could learn from each other and in which the engineering resources could be pooled for large projects.

In contrast, the Division-1 Head, Mr. Kano, was more concerned that the production people and the engineering people cooperated on problems which were more specific to the individual shops. As explained by a former Kamigo manager, Mr. Kano's objectives were three fold:

- to achieve a better connection [between production and engineering people] with more respect for each other's work.
- to increase the technical skill of the production workers as they learned directly from the maintenance workers.
- to increase the skill of the maintenance workers to do production jobs.

I learned that in January 1999, Division 2 changed its organizational structure to match that of Division 1. According to a former manager at Kamigo, the motivation for Division-2 to emulate Division-1 was to "break the wall" between the production and engineering organizations and to get "better speed" in addressing problems.

CHAPTER SUMMARY

The primary finding of this research is that the Toyota Production System can be codified as Rules-in-Use that guide the design, operation, and improvement of activities, connections, and flow-paths. A common theme is that the Rules lead to designs that can be tested in operation, and that the tests generate 'binary' signals that confirm or refute the assumptions implicit in the designs. The Rules, the implicit hypotheses, the tests, and the response to problems signals are summarized in the next table.

Rule (*)	Hypotheses	Problem-Signal	Reaction to problem
Activity Design			
Specify the content, sequence, timing, and outcome for all activities.	The person (or machine) is able to do the activity as specified.	The work is not actually performed as designed.	Determine true capability of person or machine. Retrain person, modify machine, redesign activity.
	If the activity is done as specified, the outcome will be defect free	The outcome is defective.	Redesign activity.
Customer-Supplier Connection Design			
Directly connect each customer and supplier with specified ways to send binary requests and receive responses.	The customer will make requests in an expected mix and volume. The supplier is capable of responding in the necessary mix and volume.	The supplier's responses are not keeping pace with customer requests. The supplier is idle, waiting for customer requests.	Determine true mix and volume of customer demand and true supplier capability. Modify customer-supplier assignments.

Flow-path Design			
Specify which supplier will do what activity as the good, service, or information traverses the flow-path	Every person/ machine connected to the flow-path is necessary.	Specified supplier doesn't actually provide a good, service, or information.	Determine why person or machine was not necessary. Redesign flow-path.
	Every person not assigned to the flow-path is not necessary.	Non-specified supplier actually provides a good, service, or information.	Determine why person or machine was necessary. Redesign flow-path.
Simplify the flow-paths for all goods, services, and information by removing loops and intertwined branches.	Flow-path will be simple.	There is a loop or intertwined branches.	Redesign flow-path.
Improvement of activities, connections, and flow-paths			
Do all improvement at the lowest possible level, under the direction of a specified teacher, as an experiment, making changes that move performance towards the IDEAL.	A specific change will move an activity, connection, or flow-path closer to the IDEAL in specific amounts.	The actual result is different than the expected result.	Learn how activity was actually performed or connection or flow-path was actually operated. Determine actual effects of changes.

(*): Each Rule requires built-in tests to signal immediately a problem occurrence.

Figure 39: Summary table: Rules, experimental hypotheses, problem (hypothesis-refutation) signals, and responses to problems

CHAPTER 4:

LITERATURE CONNECTIONS

OVERVIEW

My findings build upon several streams of inquiry in the administrative theory literature. These include general studies of manufacturing organization management by researchers such as Skinner (1974); Hayes and Wheelwright (1984); Jaikumar (1986); and Hayes, Wheelwright, and Clark (1988); cross-plant/cross-company studies within the auto industry by researchers such as Cusumano (1985, 1988), Krafcik (1988), Womack et al (1990), and MacDuffie (1995, 1996, 1997a, 1997b); and detailed studies of the Toyota-General Motors NUMMI joint venture by Paul Adler and his associates (1993a, 1993b, 1996).

There are common themes in these studies. For instance, there has been a transition from a techno-centric view of the challenges faced by managers to an emphasis on problem-solving, individual learning, group learning, and continuous process improvement. The earlier perspective is articulated in Skinner's "Focused Factory" and in the early portions of Reclaiming Our Competitive Edge by Hayes and Wheelwright. The latter view is articulated in Jaikumar's Flexible Manufacturing Systems research and in Dynamic Manufacturing by Hayes, Wheelwright, and Clark. The latter perspective is succinctly expressed by Jaikumar who concludes: "Thus the new role of management in manufacturing is to create and nurture the project teams whose intellectual capabilities produce competitive advantage. What gets managed is intellectual capital, not equipment." [Jaikumar, 1986]

The automobile industry studies reach a similar conclusion. Cusumano, Krafcik, and Womack et al make persuasive arguments that there is a pronounced difference between the performance of Toyota factories and those of its competitors, and that these differences in cost, quality, efficiency, and flexibility are directly attributable to differences in management systems within the individual assembly plants. Based upon their research, in part, the Toyota Production System has become a widely recognized benchmark of outstanding manufacturing practice. Adler builds upon the findings of the earlier auto industry researchers by studying how TPS is practiced at the Toyota-General Motors joint venture, NUMMI. Whereas the advantages of TPS that accrue to the employer have been identified, Adler demonstrates that TPS offers advantages to employees in providing a work environment that is 'enabling,' 'motivating,' and conducive to the individual and organizational learning that is the root cause of continuous performance improvement.

My own findings build upon these precedents. For instance, TPS has been identified as an outstanding managerial system. I have built on this by codifying TPS as Rules-in-Use. This codification provides a systematic, actionable explanation of how TPS is practiced. This is more fundamental than explanations that have equated TPS with its characteristic tools such as pull systems and kanban cards and those that have equated TPS with intermediate outcomes such as low inventory, rapid change-overs, and employee-based process improvements.

Furthermore, earlier research provided empirical evidence that TPS is an outstanding management system for automobile assembly. I have been able to add a theoretical explanation as to the circumstances under which and the mechanisms by which TPS offers advantages in managing organizations by codifying the Toyota Production System as Rules-in-Use. For example, I have found that the Rules lead to a distinctive organizational *structure*, nested modularity. As discussed earlier, theories from the area of product design help explain why modularity is particularly useful in an organization in which knowledge and labor must be fragmented among individuals but in which the results of individual efforts must also be integrated. Also, I have found that the Rules lead to the distinctive organizational *dynamic* of frequent, fine-grained (high-resolution) diagnostics for activities (components), activity-connections (interfaces), and flow-paths (architectures). There is a body of process control and information theory (i.e., Jaikumar, Shannon and Weaver, Ogata) which explains why frequent, fine-grained diagnostics are desirable for operating complex systems.

Also, I have identified the mechanism -- frequent, structured problem-solving, directed towards the IDEAL -- by which processes are improved and people are trained in TPS-managed settings. Dynamic Manufacturing, auto industry research, and Adler's research all emphasize that high performance is rooted in individual and organizational learning that fosters improvement and adaptation. Therefore, my findings add to these precedents by articulating how learning occurs in this widely recognized, high performance system.

In sum, the past 25 years have provided valuable insights into the management of large complex organizations that produce and deliver goods, services, and information. These insights culminated in the clear message that sustainable competitive advantage can be rooted in production organizations that have well developed mechanisms for individual learning, organizational learning, and sustained improvement. This message was clearly revealed in the auto industry research. The following section reviews this previous research before showing how my own findings build upon those of my predecessors.

1974	Skinner: "Focused Factory" Focus to use technology efficiently, to foster repetition based learning, and to align efforts of functional specialists.
1984	Hayes and Wheelwright: <u>Restoring Our Competitive Edge</u> A Match product-market needs (mix, volume, quality) with process technology capabilities. B Cultivate organization wide mechanisms for learning and problem-solving.
1985	Cusumano: The history of Toyota and Nissan • Toyota productivity exceeded that of its competitors for a twenty-year period. • Productivity advantages linked to tools and practices developed over several decades.
1986	Jaikumar: Studies of Flexible Manufacturing Systems For identical machinery some firms out perform others in terms of efficiency and flexibility. The performance differences are rooted in mechanisms for learning and team-based process improvements.
1988	Hayes, Wheelwright, and Clark: *Dynamic Manufacturers* enjoy cost, quality, and flexibility advantages based on complexity reduction, distributed problem-solving, individual learning, group learning, and continuous improvement.

1988	Krafcik: Toyota is the superior auto-maker with productivity and flexibility greater than that of its competitors. Characterized by small inventories, small buffers, team designed standardized work, small rework areas.
1990	Womack, Roos, and Jones: <u>The Machine That Changed The World</u> Toyota's Takaoka plant as the exemplary "lean manufacturer."
1993	Adler: "Time and Motion Regained" Standardized work is a mechanism for problem-solving. It is not necessarily a tool for coercion. Rather, it can act to break the cycle of authoritarianism and resentment.
1993	Adler and Cole: "Designed for Learning" • Individual learning does not automatically lead to organizational learning. There must be mechanisms for both. • Standardized work is not demotivating if workers do both routine work and problem-solving.
1996	Adler, Goldoftas, and Levine: New Model Introduction at NUMMI Superior and improving efficiency and flexibility from meta level mechanisms for learning and learning to learn.
1997	MacDuffie: Shop Floor Problem-solving at Three Auto Assembly Plants • Problem-solving depends on rich data and multiple perspectives • Problem-solving benefits when problems framed as learning opportunities and not liabilities. • Standardization can be understood as the start, not end, of improvement process.

1999	Spear • Codification of TPS as five actionable Rules-in-Use for designing, operating, and improving activities, interfaces, and flow-paths. • Theoretical explanation of the circumstances under which and the reasons why TPS leads to superior performance using concepts from product design (modularity) and process control (frequent, fine-grained process diagnostics) • Codification of mechanism by which learning, learning to learn, and improvement occur (frequent, structured problem-solving, directed towards the IDEAL)

Figure 40: Timeline of research in operations management and TPS

RESEARCH PRECEDENTS

CHANGE IN FOCUS FROM TECHNICAL LEVERS TO LEARNING AND PROBLEM-SOLVING

From 1974, when Skinner published "The Focused Factory" to 1988 when Hayes, Wheelwright, and Clark published Dynamic Manufacturing, there was a pronounced change in how authors framed the challenges posed in managing organizations that produce and deliver goods, services, and information. The original perspective focused on technical levers, but the emphasis shifted to issues of individual and organizational learning, problem-solving, process improvement, and effective coordination.

Skinner (1974) stated that focusing an organization's efforts on a particular product-market is a superior manufacturing management strategy. He based this conclusion on observations that managers face three challenges. First, Skinner observed that technical equipment operates most effectively in a narrow range of product-types and batch sizes. Second, he observed that as the range of tasks for which a person is responsible increases, the frequency decreases with which each individual task is repeated. This diminishes the opportunity for repetition based learning. Third, Skinner observed that as the breadth of an organization's objectives increases, the chance that functional specialists will work at cross purposes, uncoordinated towards a common goal, also increases. Based on these observations, Skinner advocated "focus" to increase specialization of the process technology to a specific product-market, to increase people's specialization and thereby increase the chance for repetition based learning, and to increase the congruence of goals across functional specialties. As I explain below, later researchers identified means beyond product-process matching to foster cross-functional coordination, process improvement, and learning.

The early portions of Restoring Our Competitive Edge reflect Skinner's concerns. The authors, Hayes and Wheelwright, provide a strategy for achieving a "Stage 4" position in which manufacturing is "extremely supportive" of the organization's overall strategic goals. By this, the authors mean that the company pursues manufacturing-based competitive advantage in which manufacturing insights and capabilities influence the firm's strategic decisions. To achieve Stage 4 status, the first portion of the book emphasizes the importance of technology-focused managerial decisions. As reflected in the classic product-process matrix, individual machines should be chosen and flow-paths should be designed based on the particular needs of the product markets being served. For instance, at one extreme, multi-purpose machines and jumbled flows should be used to achieve high quality and flexibility for markets in which products are low volume and non-standard. At the other extreme, continuous flows should be used to achieve dependability and low cost (through long runs and scale economies) for markets in which products are high volume, standardized commodities.

In its latter portions, Restoring Our Competitive Edge changes tone. Though the intelligent matching of product and process may be necessary, the authors recognize that it is insufficient if a company is to have a manufacturing-based competitive advantage. Rather, the authors switch to emphasizing non-technical issues. In chapter 10, they write:

> "Managing technology in today's world requires the ability not only to keep abreast of an existing technology (and incremental changes in that technology) but also to mold and manage organizations that are capable of responding to gradual obsolescence of existing technologies by continually rejuvenating themselves."

This leads to their discussion of Japanese firms in which the capability to solve problems, adapt to market changes, learn, and improve extends from top managers to shop floor operators. Though the authors begin the book by emphasizing the importance and process of "…translating the business strategy into an appropriate collection of bricks and mortar…," they end by emphasizing the intellectual not the physical aspects of generating manufacturing-based competitive advantage. The authors conclude:

> "The traditional approaches that are used to improve manufacturing performance -- such as providing flexibility through excess capacity, improving delivery dependability through holding finished goods inventories, and reducing costs through labor productivity improvements -- often are reconceptualized in creative ways in Stage 4 firms. For example, flexibility may also be achieved through changes in the design of products

> and/or processes, faster delivery through shorter production cycle times, and low cost through improved product quality and reliability."

In Dynamic Manufacturing, Hayes, Wheelwright, and Clark build upon the message in the latter portions of Restoring Our Competitive Edge, and they emphasize the importance of developing mechanisms that foster individual learning, organizational learning, effective coordination, and improvement of technical processes. They deliver this message by contrasting Company A and Company B. These companies are more or less identical in terms of product and process, but they differ considerably in their management systems and in performance as measured by cost, quality, lead-time and flexibility.

Company A has sharp divisions of labor, sharp divisions of intellectual and physical tasks, and centralization of information and authority. Production scheduling is centralized so that the Materials Management Group is responsible for generating production schedules based on *expectations* of demand, inventory *estimates*, and *assumptions* of plant capacity and process rates. Likewise, other intellectual tasks are centralized, so that work within Company A is designed by industrial engineers, jobs are narrowly classified, and problems in production processes are not detected at the physical and temporal source but are detected in periodic variance reports. To overcome shortfalls due to inaccuracies in estimates and outcomes (i.e., higher than expected demand in particular parts, inventory miscounts, and process rates slower than assumed), the organization has buffers of materials to prevent blocking and starving of critical process steps.

In contrast, in Company B, system complexity and sub-system variability is reduced in a number of ways. Production modules are organized around families of parts. To simplify material and information flow, *expectations* of demand are used only for capacity allocation and rough cut scheduling. Actual production is triggered by customer demand, so that Company B makes-to-order, or, if it does make to stock, it does so by maintaining small intermediate inventories of goods to reduce waiting time between adjacent processes.

Company B's policy of make-to-order and make-to-stock with small inventories requires small batches, short cycle times, and dependable processes. These technical gains are achieved by colocating the intellectual and physical activities of routine-production and process-improvement. This way, operators closest to processes (and closest to information relevant to determining cause and effect) are able to identify, diagnose and solve problems. Employees are paid based on qualifications, not job specification, to encourage the acquisition of intellectual and technical skills. Furthermore, to preserve flexibility and to encourage learning and process improvement, employees are organized into a few broad job categories.

In Company B, managers and "technical experts" have supporting roles. The hierarchy is less for supervision and more for advice, coaching, and training. Similarly, the manufacturing systems group helps develop factory systems. However, the actual development is directed by a task force drawn from particular production units.

In sum, though Company A and Company B have a similar product-process position, they differ in terms of management systems and company performance. The message is that Company B's mechanisms for flow-simplification, make-to-order, individual learning, organizational learning, and process improvement are the source its competitive advantage. In presenting these findings the authors prompt the question: what steps are required to achieve the behaviors and performance of Company B?

AUTO INDUSTRY RESEARCH

The shift in emphasis by researchers from the physical capital of 'bricks and mortar' to the intellectual capital of learning and improvement mirrors the findings of researchers in the auto industry specifically.

Taken together, the auto industry studies argue that, through distinctive managerial practices, the Toyota Production System offers advantages both to employers -- through production that is low cost, high quality, highly flexible, and characterized by organizational learning, and also to employees -- through 'moderately high level of worker motivation' (Adler, 1993) and individual learning. As I will explain, my findings build upon these earlier conclusions by codifying how TPS is practiced and by offering a theoretical link between the codified principles and the superior performance identified in earlier studies.

Cusumano, Krafcik, Womack et al, and MacDuffie, through cross-plant and cross-company comparisons, demonstrate that lean manufacturers generally and Toyota specifically enjoy cost, quality, lead-time, and flexibility advantages over competitors in automobile final assembly. These advantages are credited to differences in plant-level management systems.

For example, Cusumano (1985, 1988) shows that Toyota's productivity surpassed that of American makers by the 1960s and the 1970s as illustrated in the following table.

Vehicle Productivity Adjusted for Vertical Integration, Capacity Utilization, and Labor Hour Differences, 1965-1983

FY	GM, Ford, Chrysler [a]	Nissan	Toyota
Relative Scale (U.S. = 1.0)			
1965	1.0	0.9	1.5
1970	1.0	1.9	2.4
1975	1.0	1.7	2.6
1979	1.0	2.0	2.7
1983 [b]	1.0	1.9	2.2
1985 [c]	1.0	1.9	2.2

Notes: [a] This column indicates average figures for GM, Ford, and Chrysler based on worldwide data.
[b] The 1983 figures for GM and Ford, but not for Chrylser, assumed the vertical integration levels of 1979.
[c] Estimate
Source: Derived from annual reports. For additional explanation of this data, see M.A. Cusumano, *The Japanese Automobile Industry: Technology and Management at Nissan and Toyota* (1985), pp. 196-200. Unless noted otherwise, annual reports for Nissan and Toyota refer to the Japanese language equivalents of the 10-K reports (*yuka shoken hokokusho*).

Figure 41: Table 1 from Cusumano (1988) page 30

Cusumano attributes this superior performance to process innovations, pioneered at Toyota and imitated by its Japanese competitors, that led to "greater flexibility in equipment and labor, lower in-process inventories, and higher overall turn over rates, more attention to process quality, and ultimately, higher levels of productivity." Some of the innovations identified by Cusumano include the pull system in the engine plant (introduced in 1948, extended in 1950); the removal of intermediate inventories in engine plant (1949); the introduction of a kanban system (1953); synchronization of body and final assembly shops (1955);

lights to indicate problems (1957); company wide small lot production (1962); increase in worker flexibility (1963); and set-up time reduction (1971).

In his account of tools and practices characteristic of the Toyota Production System, Cusumano emphasizes elements of Just in Time production and that were introduced by Taiichi Ohno, manager of the Kamigo engine plant, and one of the main inventors of the Toyota Production System. This list does not include other tools considered critical elements of TPS by Toyota people.

For example, it does not include "jidoka," an innovation of Toyota founder Sakichi Toyoda. Jidoka is the practice of designing machines so that they can run unattended by people. This requires that a machine stop when it has produced a specific number of parts. It also requires that a machine stop and call for help when it has a problem (such as a broken thread on a fabric loom, a mis-feed on a stamping press, etc.) In Toyota, jidoka is considered to be one of the two pillars of TPS. This is reflected in the following diagram that is taken from Toyota training materials and explanations of TPS.

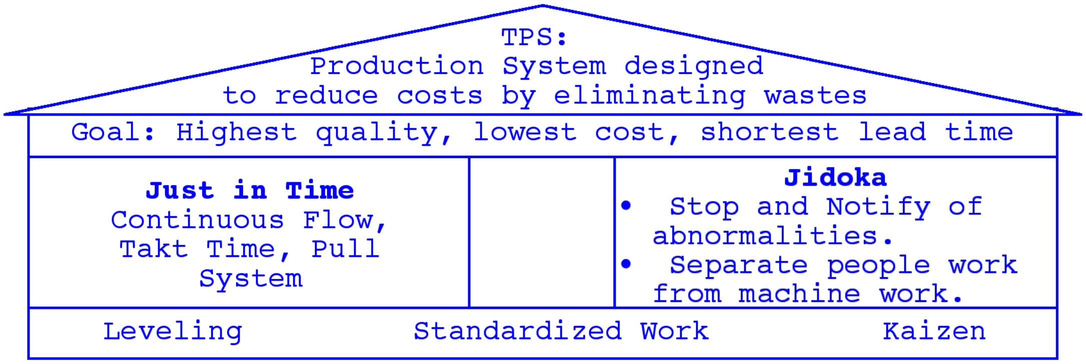

Figure 42: Just in Time and Jidoka: The twin pillars of TPS[5]

As I explain elsewhere, the nearly ubiquitous use of jidoka for machines, and the use of jidoka-like designs in the work done by people greatly influenced the form of Rules-in-Use 1 and 2. As I will also discuss elsewhere, though "jidoka" is of great importance to those trained to use TPS, and though the observations of jidoka greatly affected the form and content of the Rules-in-Use, jidoka has been virtually unnoticed by the academic literature. For instance, when I did a key word search in ABI Inform for articles with TPS or "lean manufacturing" terms, only 5 of 2,374 (0.5%) mentioned jidoka.

Separately, Krafcik writes: "Instead of finding a link between plant performance and country of location, I found links among plant performance, corporate parentage, and the management philosophies in place at each plant."[6] In identifying differences among production systems, Krafcik distinguished

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[5] Source: Toyota Supplier Support Center

[6] Krafcik, J.; "Triumph of the Lean Production System"; Sloan Management Review; page 41; Fall 1988

among Fordist plants, pre-Ford craftsmen plants, and TPS plants. He finds differences in work standardization, worker span-of-control, inventory levels, buffers, repair areas, and teamwork. These differences, summarized below, include many of the features widely associated with TPS such as small inventories and buffers, team-based problem-solving, and cross training in the form of moderate spans of control. [7]

	Production System Characteristics			
	Craftsmen	**Pure Fordism**	**Recent Fordism**	**TPS**
Work Standardization	Low	High, by managers	High, by managers	High, by teams
Span of control	Wide	Narrow	Narrow	Moderate
Inventories	Large	Moderate	Large	Small
Buffers	Large	Small	Large	Small
Repair Areas	Integral	Small	Large	Very Small
Teamwork	Moderate	Low	Low	High

Figure 43: Table 1 from Krafcik (1988) page 44

Krafcik concludes that TPS has advantages both in terms of "Level of Adaptability" and "Efficient Scale of Production" when compared with Pure Fordism (1920s), Recent Fordism (1960s-Present), and Craftsmen (1900-Present) approaches to managing production systems.

The 1990 book, <u>The Machine That Changed The World</u>, extended the findings of Cusumano and Krafcik from automobile assembly specifically to include product design, supply chain management, and customer relations. In

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[7] Note that this list includes only some of the tools and practices that Toyota describes as critical elements of the Toyota Production System.

this book, Toyota's Takaoka plant is presented as an outstanding example of the lean manufacturing model.

This auto industry research played a tremendous role in showing that differences in management practices cause superior organizational performance simultaneously on the dimensions of cost, quality, and flexibility. In turn, this research created the chance to explore for fundamental principles underlying the tools such as kanbans and pull systems and practices such as work standardization, moderate (versus small) spans of worker control, small buffers and repair areas, and high teamwork. Adler, in particular, has explored these issues, particularly those affecting the experience of workers in TPS-managed organizations.

Adler, in a series, of articles, takes a close look at how the Toyota Production System is actually practiced at the Toyota-General Motors joint venture, NUMMI. He makes the case that the productivity advantages provided by TPS to the employer are not gained at the expense of employees. Rather, the employer enjoys the advantages of low cost, high quality, and flexibility identified by the previously cited researchers while at the same time, employees gain greater motivation and satisfaction than offered in other systems. Furthermore, Adler, provides insights into the use and effect of standardized work as a critical feature of TPS.

For instance, in "Time and Motion Regained," Adler concludes: "What the NUMMI experiment shows is that hierarchy and standardization, with all their known advantages for efficiency, need not build on the logic of coercion. They can build instead on the logic of learning, a logic that motivates workers and taps their potential contribution to continuous improvement."[8] In a separate article, Adler and Cole compare TPS as practiced at NUMMI and Volvo's Uddevalla plant in which self-managed teams assembled much larger portions of the automobile than typical in mass-production or TPS-managed plants. The authors conclude that the assumptions in the Uddevalla approach are incorrect. Echoing Adler's earlier article, the authors argue against the assumption that work organization based on narrow tasks and detailed standards is dehumanizing. The authors argue that NUMMI's approach to standardized work "… is not necessarily a weapon used by management to extract maximal effort from a recalcitrant work force." Rather, "… the knowledge required to make improvements can be used … by the joint efforts of workers, managers, and engineers to fuel a continuous improvement of efficiency and quality without intensifying work beyond workers' capacities." They also argue against the assumption that organizational learning is an automatic derivative of individual learning. They write: "This is a fundamental fallacy. The Japanese

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[8] Adler, Paul; "Time and Motion Regained"; Harvard Business Review; Jan.-Feb. 1993; pg. 97

model does not take organizational learning as a given; managers consciously work to creates policies and practices that facilitate it." [9]

In a third article, Adler, Goldoftas, and Levine study two model change-overs at the NUMMI plant. The authors conclude that they have found "an auto assembly plant that appears to be far above average industry performance in both efficiency and flexibility." [10] They attribute this competitive advantage to non-technical factors just as Hayes, Wheelwright, and Clark attribute the superiority of Company B over Company A to non-technical factors. In the case of NUMMI, the authors attribute superior performance to meta routines that facilitate both learning and learning to learn; effective collaboration between sub-units responsible for non-routine tasks and those responsible for routine tasks; workers who switch easily between routine and non-routine tasks; and an enabling, not a coercive form of organization.

Taken together then, the automobile industry research reaches conclusions similar to that of the other researchers I mentioned earlier, that superior performance is rooted in management practices. These practices

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[9] Adler, Paul S. and Robert E. Cole; "Designed for Learning: A Tale of Two Auto Plants"; Sloan Management Review; Spring 1993; page 85

[10] Adler, Paul S.; Barbara Goldoftas; David I. Levine; "Flexibility versus Efficiency? A Case Study of Model Changeovers in the Toyota Production System"; working paper; May 1996.

include those that foster individual learning, organizational learning, and problem-solving based process improvement.

My own research builds upon the insights of the preceding research. The Rules-in-Use offer a comprehensive explanation of how TPS is actually practiced thereby providing actionable guidelines to generate the advantages and characteristics of Dynamic Manufacturing's Company B. The Rules-in-Use are the systematic framework that underpin TPS's distinctive tools and practices. Therefore, they make explicit what has been considered to be unstated and implicit, and the Rules allow for a theoretical link between the management system and organizational performance. Finally, the Rules add to Adler's findings by explaining the extent to which work is standardized (as structured, self-diagnostic activities of pre-specified sequences of testable work-elements) and by codifying the meta-routines and other learning mechanisms identified by Adler.

ADDITIONAL CONTRIBUTIONS TO THE LITERATURE

Codifying TPS as five Rules-in-Use; using concepts from product design and process control to generate a theoretical link between the management practices and organizational performance; and identifying the mechanism by which TPS is promoted has created several additional insights. These are discussed in the following pages.

RULE-1

Rule-1 requires that all activities be structured and self-diagnostic. While other authors have recognized that standardized work is characteristic of shop floor work in Toyota assembly plants, other authors have not necessarily had the opportunity to observe the breadth of activities that are structured and self-diagnostic in the TPS-managed setting. Because I was able to collect data across a broad range of products, processes, and functional specialties, I was able to develop or observe a broad range of structured, self-diagnostic activities including maintenance, training, assistance, and equipment upgrades at all hierarchical levels from shop floor operator to plant manager.

This complements the research of Adler. He, Goldoftas, and Levine (1996) document the new model introduction process at NUMMI (the Toyota/GM joint venture). In this extended case study, they capture many aspects of structured, self-diagnostic activities for the high level, infrequent process of system design and upgrade. Coupling their case study with my observations, we find a broad span of structured, self-diagnostic activities, from those that occur frequently to those that occur less frequently, and from those that involve a few people to those that involve many.

In addition, my research adds the idea that structuring *all* activities as pre-specified sequences of steps for each output, with a test that the activity is being performed as designed, and with a test that the actual output matches the expected output is actually a way to refute hypotheses with every repetition of a task. As a result, Rule-1, like Rule-2 and Rule-3 provides a trigger for problem identification and improvement.

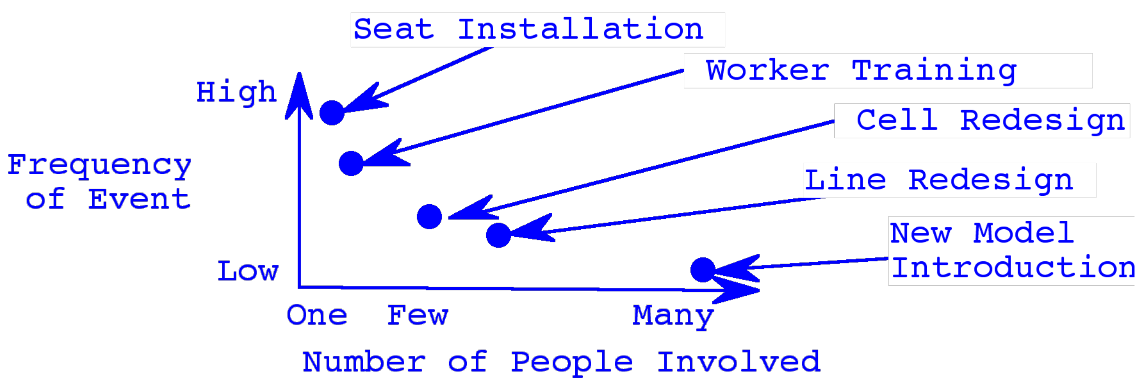

Figure 44: Examples of structured, self-diagnostic activities

The activity, connection, and system self-diagnostics of Rules 1, 2, and 3 are examples of a practice encouraged in parts of the literature. For instance, Rule-1 puts activity-*performance*, performance-*monitoring*, and *action* based on information generated by the monitoring in close spatial and temporal proximity. Therefore, information captured and processed about the activity is a more accurate representation of the state of the system than information that is captured removed in time and space. In the latter case, the true conditions of the system may change, and measurements taken after and away from the fact may reflect a world that no longer exists.

This theme runs throughout a theory of information for process control and improvement that Jaikumar was developing in some of his publications and which he explained to me in an interview (April 1997). Jaikumar's theory of information for process control and improvement is strongly influenced by his observation that the value of information decays with the passage of time. By Jaikumar's reasoning, information is characteristic of the state of the world at the time when the information was created. As time passes, the information is increasingly less characteristic of the current world-state.

Other authors have also expressed concern that information does not 'travel' well. von Hippel calls information sticky because much of the contextual knowledge of a process cannot be codified and expressed.[11] By colocating action, monitoring, and actuation, Rules 1, 2, and 3 provide a broadly applicable mechanism for overcoming the problem of information spoilage identified by Jaikumar and the problem of information stickiness identified by von Hippel. This realization provides a theoretical link between the practices encouraged by TPS and the high performance documented in other studies.

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[11] von Hippel, Eric; "Sticky Information And The Locus Of Problem-solving: Implications For Innovation"; Management Science; 4 April 1994; pg. 429

RULE-2

Rule-2 requires that connections between activities be designed so that requests go directly from the customer to the supplier of a good, service, or information and so that responses go directly from the supplier to the customer. Furthermore, Rule-2 requires that requests be sent in a way that can be interpreted as DO the activities that will deliver the good, service, or information in a *pre-specified* form, quantity, and timing. Rule-2 requires that responses be sent in a way that can be interpreted as "the activities were DONE that delivered the good, service, or information in the pre-specified form, quantity, and timing."

Rule-2 is based, in part, on the use and effect I observed of famous TPS signaling devices such as kanban cards and andon lights. They are not the essence of TPS. Rather, they are examples of <u>all</u> customer-to-supplier signaling devices in TPS-managed systems.

TPS-managed organizations have been recognized for frequent, continuous, broad-based problem identification and solving. Codifying customer-supplier signaling mechanisms in Rule-2 explains that *every* customer-supplier interface can be viewed as a binary, self-diagnostic switch. Because each customer-supplier link is designed with a switch of this sort, every request-response cycle is a chance to test that the supplier is keeping pace with customer needs and is neither ahead nor behind. Consequently, Rule-2 codifies a critical mechanism for problem-identification in TPS-managed organizations.

RULE-3

Rule-3 requires that the flow-paths for all goods, services, and information be pre-specified, simplified, and self-diagnostic. There seem to be differences between Rule-3's requirement for simple, pre-specified flows and what the literature has previously recommended. For instance, simple, pre-specified flows are not recommended ingredients of focus. Furthermore, flow simplification does not appear to be a goal that is factored into the product-process matrix which advocates jumbled and batched processes, under certain circumstances. In contrast, in the course of this research, I have observed several high variety production situations in which the managers clearly chose not to have jumbled and batched flows and instead pursued simple, *pre-specified* flow-paths for each good, service, or information.

For example, on three research trips to Japan, I visited a plant that produces make-to order mattresses. These are delivered through the retailer to customers' homes three days after the order. When I visited the factory in 1996, it seemed that it was already running well. Its inventory had been cut from 30 days worth in 1986 to 1.5 days worth in 1996. In this time, the self-reported productivity index increased from 100 to 197, the number of styles had increased from 200 to 750, and the units produced each day had grown from 160 to 530. Yet, when I had returned one year later, the plant had further increased both the mix and volume of its products, to 850 styles and 550 units produced per day. At the same time, the plant simplified its process flows by reducing the number of final assembly lines from three dedicated lines (small, medium, large) to two general purpose lines. In this particular plant then, which started at an apparently high level, volume, flexibility, and efficiency all increased, while the managers moved towards fewer, simpler flows.

This one factory is not an isolated example. While in Japan, I observed that managers were simplifying the flow-paths for other high variety, non-standard goods, services, and information. For example, in one Toyota factory I visited, custom-order pre-fabricated houses where being constructed on a moving assembly line. In another location, after-sales service and maintenance was redesigned so that it could be done along a simple, pre-specified, self-diagnostic flow-path.

Elsewhere, authors have identified simple flows as a characteristic of high performance organizations. For instance, Dynamic Manufacturing's Company B has simpler flows than its counterpart, Company A. Likewise, simple flows have been associated with "lean manufacturing." My research adds to these earlier observations by recognizing that TPS encourages the simplification and also the *pre-specification* of all flows, including those that provide services such as assistance, training, maintenance, and repair. This is a valuable realization in clarifying an apparent misunderstanding that has appeared in the literature.

For instance, some observers have suggested that when a problem occurs in the production setting, *anyone* who might be able to help can and does come to resolve the problem. This impression is not substantiated by my own observations in any of the plants I visited which are managed by TPS, and they are not substantiated by my own experience as a member of Toyota's Supplier Support Center, as illustrated earlier in the Rule-3 discussion. Rather, in the TPS-managed sites I studied, when someone has a problem, the person who is specifically responsible for helping that individual with that particular type of problem is the one is called to assist. Only when the person who comes to assist is unable to resolve the problem does another designated person get pulled into the situation. This second person is responding because that is their pre-specified responsibility. My finding is that assistance for immediate remediation of production difficulties and for longer term resolution of problems is not provided in an ad hoc fashion. Rather, assistance, like all goods, services, and information, is supplied, in a pre-specified cascade (simple, pre-specified flow-path) when the Rules-in-Use strictly guide the design, operation, and improvement of flow-paths, connections, and activities.

This is a particularly important point. As mentioned earlier in this paper, a common theme of all the Rules is that the operation of an activity, an connection, or a flow-path should test the hypotheses implicit in the design of the activity, connection, or flow-path and should trigger problem-solving when the actual performance contradicts the expected performance. Flow-path pre-specification is necessary for the design and operation of the organization's (the system's) architecture to reflect this theme.

RULE-4

While issues of improvement and learning have received a great deal of attention in the academic literature, I will touch upon only a part of that literature here, particularly that which addresses improvement in the context of Toyota Production System and lean manufacturing.

Previously, common TPS tools and practices (kanbans, andons, U-shaped cells, buffers) have not been characterized as convenient *counter-measures* that are frequently used in TPS-managed sites, but which are by no means required for a site to be “doing good TPS." Rather, the academic and practitioner literatures' inclination has been to equate the Toyota Production System with its tools: i.e., TPS is a kanban system, TPS is a system of quick die exchanges, TPS is a system of quality circles, TPS is Just in Time Production, etc.

Because of this equation of TPS with its more widely noticed tools, outside observers have often focused their studies on the characteristic tools rather than on more fundamental patterns in the design, operation, and improvement of individual activities and systems of activities. In other words, the literature has focused on the tools which have been generated in response to production and delivery problems. It has not focused on the Rules by which the tools are designed and employed.

As a result of this focus on tools rather than on the processes by which the tools are devised, the literature has articles that have argued about the practicality of inventory-less production systems and about the practicality of “Just-in-Time” production and delivery. Skepticism has been magnified, it seems, when visitors have observed that Toyota plants and Toyota supplier plants have non-zero inventories and non-zero delivery response times.

The skepticism arises, it appears, because the literature has not explained well the purpose and use of the tools and practices that have received such attention. My findings should contribute to the literature by making clear how the tools and practices that have received such notoriety are actually used in practice. For example, this dissertation should make clear that kanban cards are not essential to TPS. Rather, they, like andon lights and other less well known signaling devices, are convenient, widely used counter-measures to send DO signals directly from customers to suppliers, according to Rule-2. Likewise, inventory is neither necessary nor dogmatically shunned in TPS-managed production settings. Rather, I observed that inventory is used as a counter-measure that allows a supplier with non-zero cycle times, unstable processes, or volatile customer demand to achieve a target condition that is closer to the IDEAL by giving immediate responses to his customers. Likewise, quality circles, per se, are not essential to TPS. Rather, I observed that frequent, directed, structured problem-solving is essential for improvement and learning.

The literature has not recognized that improvement is to be directed towards the IDEAL. Nor has the literature recognized that improving towards the IDEAL increases the process control, process improvement, and learning characteristics of the organization. For example, *improving* [moving towards the IDEAL] implies, in part, reducing batch-sizes. For a given level of demand, decreases in batch-sizes leads to a proportional increase in the frequency with which requests are sent and responses are triggered. Therefore, improving towards the IDEAL increases the frequency with which local and system diagnostics are performed.

Several aspects of Rule-4 are supported by Adler and Jaikumar's research. For instance, Rule-4 colocates the physical and the intellectual elements of work. This is a factor, discussed by Adler (1993), in breaking the cycle of authoritarianism and resentment. Rule-in-Use 4 colocates problem occurrence, detection, and response in time and space. This has process control and process improvement implications such as those discussed by Jaikumar (1997). In contrast, aggregating problems breaks the connection between the occurrence of an event and information about the event. The collocation of problem occurrence, detection, and response in time, space, and person is one of several alternative approaches to problem-solving raised in MacDuffie's paper (1997) comparing problem-solving in three different assembly plants.

The obligation to supply each person with assistance and training (and, in turn to supply the supplier of assistance and training with assistance and training) leads to a cascading supply chain (simple, pre-specified flow-path) for training. This makes teaching and teaching-to-teach primary managerial responsibilities. The manager as teacher is a characterization which stands in sharp contrast to more bureaucratic views which frame management's role as a supervisory enforcer of behavioral standards.

RULE-5

Rule-5 requires that connection and flow-path problems be resolved in the smallest possible group and that groups be formed based on the expected nature and frequency of connection and flow-path problems. The literature has not discussed this aspect of TPS.

Rule-5 implies that the appropriateness of an organizational structure depends on the challenges faced by the organization. As those challenges change, the structure itself should change. In the short term, Rule-5 leads to the conclusion that the organization's existing architecture determines who will solve which problems. However, Rule-5 also leads to the conclusion that the nature of problems (both those that are expected and also those that are actually experienced but which have not been dealt with effectively) determine how the organization's architecture should change.

Finally, Rules 1, 2, and 3 provide the guidelines for developing a modular organization structure. As mentioned before, modular structures provide managerial options that allow experimentation and change within components while leaving the architecture intact. Rule-5 takes advantage of this property in guiding the improvement of customer-supplier connections and in guiding the improvement of the flow-paths that define the organization's architecture. As mentioned previously, the strongest connection with the academic literature is with those authors who have studied modularity in managing product design processes. These authors include Baldwin and Clark, Christensen, and Sobek et al. In addition, Eppinger has studied coordinative mechanisms (though not modularity directly).

The idea of forming groups based on problem frequency has some precedent. Simon (1969) suggested that "managers who frequently interact with each other should be grouped together; those who do not interact should be assigned to different groups. The role of top management is to coordinate these modules." (As described in Kogut and Bowman, pg. 251.) Rule-5 is both more specific than Simon's advice in focusing on problem-solving as the critical interaction, and it is more general since it considers the forming into groups of all people, not just "managers." As a set, the Rules seem to differ from Simon in that the role of management which he stated is coordination. According to Rule-5, managers design architecture and the interfaces for those activities, assist the people for whom they are responsible when non-routine work is required, and to teach and train people. The manager does not have a role in coordinating the "modules" for routine work. That function is satisfied by the trigger mechanisms of Rule-2.

CHAPTER 5:

IMPLICATIONS

CHAPTER OVERVIEW

This chapter briefly reviews the main findings presented in Chapter 3. Then it explores in more depth implications of these findings. The discussion progresses in a reasonably logical fashion. First, it considers assumptions about the role of people implied by the Rules-in-Use. Then, it discusses the affect that the Rules have in defining the role of managers in TPS-managed organizations.

From a general discussion of managers' roles, the chapter focuses specifically on middle managers who serve as interfaces between operating level and corporate managers. During my research trips to Japan, I learned of the role that Aisin's Operations Management Consulting Division plays in evaluating the company's plants, improving production systems, and training people. The role of Aisin's OMCD members --as an interface between those in the plant responsible for managing operations and those in the corporate office -- differs considerably from the role of middle managers described by Chandler, Bower, and others.

The administrative theory literature discusses ways in which organizations can be structured and people can be coordinated. Rules 4 and 5 hold that organizations should be designed so that activity, connection, and flow-path problems can be addressed in the smallest organizational unit. This implies that the nature and frequency with which problems are expected to occur determine the organization's structure. If so, Toyota has developed a design heuristic unlike those investigated in the literature. Therefore, this single element of Rule-5 invites further inquiry.

After this specific implication of Rules 4 and 5 is discussed, other issues of organizational form are considered. I found that the Rules-in-Use lead to an organization with a high-value structure, modularity. The contribution of the Rules in creating a modular structure and securing option value is explored. This extends the application of Baldwin and Clark's modular operators from the domain of managing product-design to the domain of managing organizations more generally. The first portion of this exploration considers all of the Rules. Then, the specific impact of flow-simplification on reducing coordinative costs and increasing modularity-generated option value is examined.

Coordination is such an important topic because activities are interdependent. There are different types of interdependence. These include sequence, form, and timing. Each of these is defined, and the consequences of each is investigated. The discussion of timing interdependency, in particular, builds on an information-based theory of process control and improvement being that Jaikumar had been developing. Using concepts borrowed from him, the discussion turns to the problem of information preservation and spoilage and the impact both have on learning.

RECAPITULATION

Cross-plant comparisons and market-response have recognized the Toyota Production System as an outstanding benchmark for automobile production and delivery. This recognition has led to many studies to unlock the essence of TPS. Despite the attention given to distinctive tools such as kanban cards, distinctive practices such as pull systems, and distinctive philosophies such as continuous improvement and just-in-time, the literature has not provided a comprehensive explanation of what TPS is and how it works, the general class of managerial problems for which and why it offers advantages, and how and why it is difficult to imitate. The lack of a comprehensive view has been exacerbated by Toyota's own inability to articulate the fundamentals of TPS. As a senior Toyota manager described it, "TPS to us is like air. We know when it is there, we know when it is not there, but we can not tell you exactly what it is."[12]

To understand TPS, I studied it, in part, as Toyota employees learn TPS: by solving production related problems. By comparing the data from my first hand experience with data collected at 32 other sites in Japan and North America, I made several research discoveries. The first of these is that TPS can be codified as five Rules-in-Use, unstated but nevertheless widely followed guidelines for:

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[12] OMCD Meeting; Nagoya, Japan; March 1996

1. *Designing and performing production and delivery activities* for all goods, services, and information. This is done using activities that are structured and self-diagnostic.
2. *Designing and operating interfaces between activities*.
   This is done using direct, binary, self-diagnostic connections within each customer-supplier pair.
3. *Designing and operating the organization's system-architecture*.
   This is done using simple, pre-specified, self-diagnostic flow-paths for all goods, services, and information.
4. *Designing and performing improvements of production and delivery activities.*
   This is done by assigning responsibility for activity-improvement to the activity-doer, by providing the activity-doer with a specific, capable teacher, by using hypothesis-testing problem-solving as the teaching mechanism, and by using the IDEAL as a source of tension to guide and evaluate problem-solving activities.
5. *Designing and performing improvements on connections and flow-paths*.
   This is done by assigning responsibility for improving connections and flow-paths to the person responsible for the smallest group that includes the connection or flow-path, by designing spans of responsibility based on the nature and frequency with which problems are expected to occur, by using hypothesis-testing problem-solving as the improvement mechanism, and by using the IDEAL as a standard to judge if a change is an improvement or not.

Two themes underpin all five Rules. First is that the hypotheses implicit in the design of an activity, connection, or flow-path should be confirmed or refuted each time it is used. Second is that signals to trigger the performance of activities should be sent in a form that can be interpreted as DO or DON'T DO and that signals generated by the performance of activities should be sent in a form that can be interpreted as DONE or NOT DONE.

My second finding is that the Rules lead to three valuable features:

- A nested, modular organizational structure.
- High frequency, finely-grained self-diagnostic tests of activities, connections, and flow-paths.
- Learning by each person through frequent, structured, directed improvement activities.

These features appear to be advantageous when:

- People both design and perform value-adding activities.
- Knowledge for activity design and improvement is inextricably tied to activity performance. This linkage may be due to an inability to codify information or due to the risk that information will spoil with time.
- There are interactions between upstream and downstream activities because the form, quantity, and timing of one activity's outputs affect the performance of other activities.

Modularity allows experimentation and change in individual activities without compromising the efficacy of other activities and of the systems architectures. High frequency, high resolution diagnostic tests place activity-performance and activity-evaluation in close spatial and temporal proximity. Learning through problem-solving makes each supplier increasingly self-sufficient in performing and improving the activities for which he is responsible.

My third finding is that TPS is promoted within Toyota, within Toyota suppliers, and within other TPS-managed organizations by frequent, structured, directed problem-solving. The need for teachers who are capable of using this mechanism, and the need for students who are willing to learn this way are obstacles to transferring TPS as a comprehensive management system from one organization to another.

In sum, researchers identified the Toyota Production System as a source of value in managing production and delivery. I have codified the characteristic behaviors of the best TPS-managed organizations as five Rules-in-Use. These govern the design, operation, and improvement of activities (that trans<u>form</u> material, energy, and information); connections between activities (over which material, energy, and information are trans<u>ferred</u>); and flow-paths (composed of connected activities) over which goods, services, and information take form. These Rules are valuable because they lead to three characteristics that generate an operations-based, sustainable competitive advantage. The Rules create organizations that are nested, modular in structure, self-diagnostic in operation, and mutually reinforcing in problem-solving, improvement, and learning.

Management by the Rules-in-Use is a source of sustained, competitive advantage because it is time-consuming to master the Rules.

Rules-in-Use and Assumptions about People in Organizations

A theme of this research is that a company must ensure that each person can add value to the final good, service, or information in a way that is high quality, low-cost, flexible, and speedy if the company is to succeed at a strategy based on operations-based competitive advantage. The organization must also have mechanisms that allow the work of individuals to be integrated so that the collective effort retains the high quality, low cost, flexibility, and responsiveness of individual contributors.

Toyota has consistently been noted as an outstanding performer and an example of best in practice in the production and delivery of automobiles. Based on a close study of Toyota over the past four years, I concluded that Toyota achieves its consistent, characteristic levels of high performance through five Rules-in-Use that guide the design, performance, and improvement of individual work and guide the design, performance, and improvement of the system in which individual work is performed.

In effect, these Rules are Toyota's effective response to a common managerial challenge of distributing responsibility and authority so that:

- people can perform closer to their innate potential than they might have otherwise, and so that
- the distributed pieces can be coordinated so that the collective whole is closer to the sum of the parts than it might have been otherwise.

These Rules-in-Use reflect assumptions of those who designed the Toyota Production System and that infuse the ethos of current Toyota managers: The work of individuals directly affects the experience of the paying customer, and the organization can and should be designed and operated to ensure that each person makes a contribution that is rewarding both as reflected in the paying customers' experiences with the organization's goods, services, and information and in each person's experience as an employee of the organization as well.

The Rules do this by ensuring that:

- each person is prepared and capable of doing work that is high quality, low cost, flexible, and responsive to the needs of the organization's customer.
- each person can trigger his or her own immediate suppliers to provide the specific goods, services, and information that are needed at the time and place that they are needed. For the end customer, this means triggering the delivery of a defect-free product, at low cost, in the quantity needed, with short lead-time. For someone within the organization, this means getting the parts and materials, assistance with equipment and problem-solving, and training necessary to contribute meaningfully to pleasing the external customer.
- each person is neither overloaded (causing the stress of being forced to fail) nor under loaded (implying that the person's efforts are not valued).

- each person has increasingly more ability and authority to improve his own work so that it is of increasingly higher quality, greater responsiveness to customer needs [batch size, on-demand], lower cost, shorter cycle time, and greater safety.

- each person will be linked to immediate suppliers and to a larger system that are improved continuously to increase quality, increase responsiveness to customer needs, reduce cost, shorten cycle times, and increase safety.

THE ROLE OF MANAGERS IN A TPS-MANAGED SETTING

The Rules-in-Use are a codification of consistent behaviors I observed in TPS-managed situations. The behavior that served as data included that of managers and supervisors. This section briefly re-expresses each Rule in terms of the role managers play in TPS-managed organizations.

Rule-1 requires that activities be designed and performed so that they are specified as to content, sequence, timing, and outcome and with built-in self-diagnostics. This implies, in turn, that managers train their immediate reports to do activities in the pre-specified fashion in which they are designed, to identify problems as they occur, and to call for assistance when it is needed. *Rule-4* requires that the person who performs an activity be responsible for improving the activity. Since each person both manages a process and is managed, this implies that each person may be both a supplier of and also a customer for:

- training to do routine production and delivery activities (including the production and delivery of services such as maintenance and training)

- assistance in the performance of routine production and delivery activities.
- training in the improvement of production and delivery activities.

Chapter 7 includes several accounts that illustrate managers in each of these roles as customer and supplier for assistance and training. In 7.1, the role of the team-leader in training team-members to do routine production work is discussed. Chapter 7.2 discusses mechanisms by which people lower in a hierarchy are connected with those higher in a hierarchy in a customer-supplier relationship for assistance. Chapter 7.4 provides accounts of specific investments made to supply team members and team leaders with training in activity improvement.

Rule-3 requires that flow-paths be designed so that each person has a specific supplier for every good, service, or information needed to complete the work for which he is responsible. *Rule-2* requires each customer be linked to each of his suppliers by a direct, binary, self-diagnostic connection. *Rule-5* requires that connections and flow-paths be improved in the smallest possible organizational unit. Therefore, in TPS-managed organizations, each manager must design, operate, and improve the interfaces that connect people in the group for which she is responsible. Chapter 7.3 provides evidence of managers performing these roles in redesigning work-sites, and Chapter 7.5 provides evidence of people exercising a systems-design view in managing the organizational unit for which they are responsible.

In sum, a manager in a TPS-managed setting does not primarily ensure that people adhere to behavioral guidelines. Rather, a manager must train people to do activities, must provide assistance in the performance of activities, and must provide assistance in the operation of connections and flow-paths. The manager must teach the skills of activity-improvement and must improve the connections and flow-paths for which the manager is responsible. Furthermore, since the manager does training, teaching, assisting, and improvement activities, the manager must improve the manager's own activities. Finally, the manager must be able to request and accept help in learning to perform and improve activities of various types.

MIDDLE MANAGERS AND CORPORATE STAFF IN TPS-MANAGED ORGANIZATIONS

Chandler, Bower, and others have described middle managers and corporate staff (referred to from here collectively as 'middle managers' for the sake of brevity) as informational interfaces between operating managers and senior corporate managers. From what I observed in TPS-managed organizations, there is an alternative role for middle managers that has not been captured in the academic literature. This alternative role is explained below for the purpose of suggesting a potential avenue for new inquiry.

The Rules-in-Use are a codification of the guidelines by which activities, connections between activities, and flow-paths are designed, operated, and improved in organizations managed by the Toyota Production System. These Rules were generated from the patterns I found in data gathered in a variety of production settings. These Rules explicitly define the role of managers. By Rule-4, for instance, managers are teachers who are to use frequent, structured problem-solving to teach their immediate reports how to design, operate, and improve activities, connections, and flow-paths. By Rule-5, managers are responsible for the interfaces between their immediate reports, helping determine the form, quantity, and timing with which requests and responses are passed between people doing adjacent activities.

Teachers/interface-managers both receive and generate information in a form, with a content and frequency, and through a delivery channel that differs from those I observed in organizations not managed by TPS and different from that discussed in the literature. For instance, in the TPS settings, information was largely denominated in operational terms (i.e., the way in which goods, services, and information are produced and delivered; the cost, quality, lead-time, batch-size, etc. of production and delivery). Communication in these operational terms extended throughout the management hierarchy. From what I concluded from data gathered at an excellent Toyota supplier, this creates a role for middle managers not discussed by Chandler and Bower or earlier by Weber and Taylor.

According to previous authors, managers at the 'shop floor' or operational level of the organization set operational parameters (i.e., work design, staffing levels, inventory levels, material and information flows), the efficacy of which they judge based on operational measurements (i.e., cycle times, lead times, run times, on-time delivery, defect rates). In all but the smallest organizations, this operational information (parameter choices, outcomes) are unusable by senior managers for decision making because of problems such as the multi-dimensionality, site-specificity, and high reporting frequency of the operational data.

Therefore, middle managers translate and compress information and provide it to senior managers in a form and at a frequency that allows an 'apples to apples' comparison across business units that may otherwise differ in terms of product, process, or market. The information that arrives at the senior management level is financially, not operationally denominated. The financially-denominated-information is used by senior managers to develop incentives, calculate rewards, establish goals, and invest in particular activities.

In turn, new goals and investment decisions are relayed through the middle management, which re-expresses the information in terms of operational outcomes. Then, the shop floor manager has to adjust operational parameters to meet the new operational objectives.

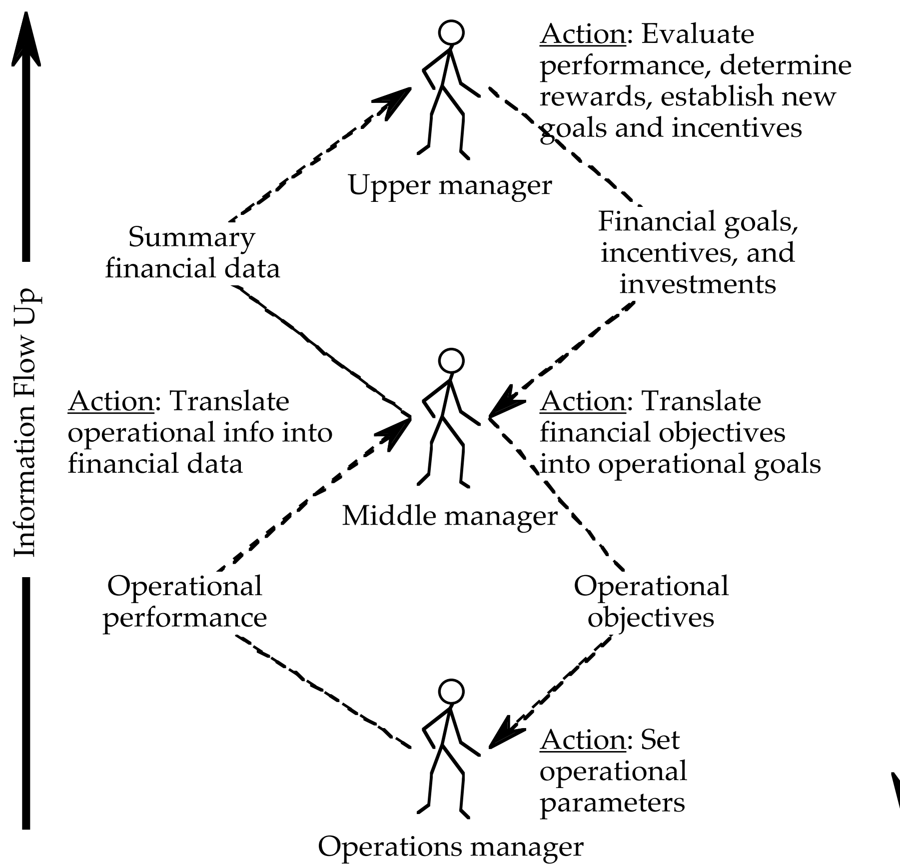

Figure 45: Hierarchical information flow: Conventional view

There is alternative role for middle managers as reflected in the information used, activities performed, and information generated. During two of the three visits I made to the Aisin mattress plant, I came to learn about Aisin's internal Operations Management Consulting Department ("OMCD"). At the time of my visit, Aisin's OMCD had 88 members. Some of these were at OMCD for 2-3 year stretches, during which they learned to manage by and teach TPS by leading problem-solving at Aisin plants. There was a group of OMCD members, age 55 and up who during their careers had became expert in a particular technical specialty, and there was a small group (3) of senior managers. [13]

According to Aisin-OMCD's general manager, Aisin had 1,300 individual production lines. Each year OMCD evaluated each line through direct observation, provided the line managers with challenges/goals for the next year's operational performance, and participated in evaluating requests for capital investment. Throughout the year, OMCD helped managers achieve the operational goals by providing assistance and training in applying TPS to the design, operation, and improvement of activities, connections, and flow-paths using the mechanism of frequent, structured problem-solving.

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[13] Aisin makes: electronic components; disc brakes, brake valves, brake cylinders; ABS and power-steering; pistons, intake manifolds, transmission cases; oil pumps, water pumps, turbo chargers; clutch covers and discs; belt moldings, door frames; seats, sunroofs; door locks, window regulators, airbag sensors; sunroofs, spoilers, roof rails, door handles; cutting machines, automatic assembly machines; beds, sewing machines; shower toilet sets. (Semicolons separate products made in different plants.)

This manufacturing occurs at 13 plants in Japan and 14 overseas (Asia, Europe, North America, South America).

If we think of Aisin OMCD as part of the middle management between the plant and the senior corporate managers, we can make the following comparison between the activities performed by, the information used by, and the information generated by the middle managers described by Chandler, Bower, and others and the activities and information associated with Aisin's OMCD members.

Information flow from shop floor to upper managers			
Who	**Information In**	**Activity**	**Information Out**
Middle Manager	Operational Results	Translate operational data into financial measures	Summary financial measures of performance.
Aisin OMCD	Operational **Parameters** and Results	Evaluate methods used in production and delivery against "IDEAL."	Identification of problematic parameters and outcomes.

Information flow from upper managers to shop floor			
Who	**Information In**	**Activity**	**Information Out**
Middle Manager	Rewards for past performance, incentives, goals, available capital	Translate financial data into operational measures	Operational goals for coming period.
Aisin OMCD	Operational goals and equipment changes	• Create challenge for plant and line managers. • Develop "hip pocket" recommendations on how to improve production system.	• Operational challenges and goals. • Advice and teaching on 'how to improve.'

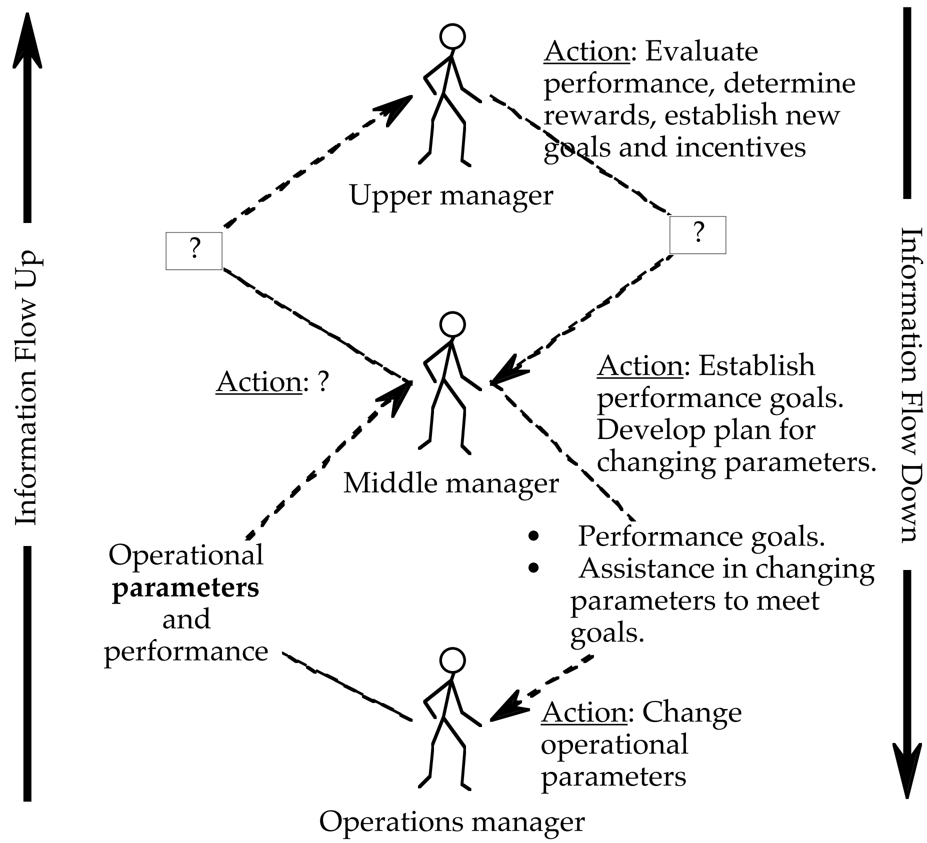


Figure 46: Hierarchical information flow at Aisin

SUMMARY

The form, content, and frequency with which information is conveyed between hierarchical levels in TPS-managed organizations differs from the form, content, and frequency with which it is conveyed in organizations not managed by TPS. It appears that operational information remains intact through more layers than in non-TPS organizations. In contrast, in the non-TPS organizations, information is translated from operational into financial terms. As a result, it would seem that managers in TPS-managed firms have more levers with which they can adjust the direction and performance of the organization they are managing. In contrast, their counterparts in non-TPS settings communicate in financial terms, so must make decisions which can be expressed in financial terms. As a result, the conventional manager is, in effect, a portfolio manager, allocating scarce capital among alternative projects. In the TPS-managed organization, it appears the manager has other tools other than capital allocation to affect the direction and efficacy of the organization's efforts.

All these propositions need investigation to be confirmed or refuted.

This comparison between Bower's middle managers and Aisin OMCDers suggests why US managers may have failed to detect the essence of TPS despite the access they had to Toyota plants in Japan and in North America. If they had been conditioned to value and hence seek out forms of information and managerial levers common to their own organization, they may have also been conditioned not to value and not to seek out other types of information and other managerial levers.

Certainly, the US-trained managers may not have learned how to look at activities, connections, and flow-paths and from these observations draw conclusions about the production system, the organization, and the organization's managers. Not knowing how to look at an organization as a system made up of components and interfaces, the US-trained managers may not have been capable of looking at the work being done to detect the Rules by which the organization and its parts were designed, operated, and improved.

STRUCTURING AN ORGANIZATION BASED ON PROBLEMS SOLVING PROBLEMS

From the observations that led to the formulation of Rule-5, I concluded that TPS-managed organizations are structured and restructured based on the nature and frequency with which problems are expected to occur. A contrast between the TPS approach and a more conventional, functional approach is shown in the next diagram.

TPS Approach	Non-TPS Approach
• A specific person is responsible for resolving problems which affect a customer-supplier pair.	• No specific person is responsible for resolving problems which affect a customer-supplier pair.
• The person who is responsible is the person who is head of the smallest group of which the supplier and the customer are both part.	• There is no rule which universally guides the assignment of responsibility.
• Groups are formed based on the expected frequency and nature of problems and not automatically by product, process, or functional specialty.	• Groups are formed based on reasons other than expected frequency and nature of problems.

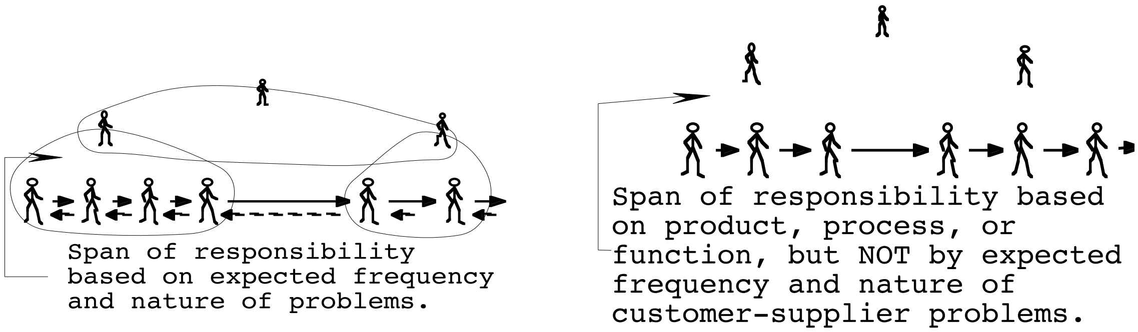


Figure 47: Interface/flow-path management: TPS and non-TPS approaches

I have several pieces of evidence that TPS-managed organizations are designed and redesigned (by adjusting the spans and 'nests' of responsibility). The Kamigo experiment, in which managers structured differently the relationship between the production and engineering groups in two divisions, suggests that the facilitation of problem-solving (and other forms of learning) is a high priority. Likewise, Chapter 7 discusses the design of the production line in Toyota's Kyushu plant. Contrary to previous plant designs in which line segments matched the span of responsibility for an assistant manager, the Kyushu plant is designed with more, shorter line segments that match the span of responsibility of the group leader. Though some observers have commented that this represents a change in attitude by Toyota, the statements given to me directly by the plant manager refute that conclusion. Rather, the plant was designed with shorter line segments because he and other people involved in the design process were concerned that the Kyushu location presented special conditions for which shorter line segments were an appropriate counter-measure. Because Kyushu is not near the cluster of plants Toyota has in the Nagoya area, most of the new employees are inexperienced, at both the team member and team leader level. Consequently, the plant-designers expected that -- given the nature and frequency with which problems occur in the course of starting up a plant, and given the anticipated capacity of inexperienced employees to resolve problems as they occur -- a greater problem-solving burden would be placed on group leaders. Therefore, the work environment had to be designed to accommodate this reality.

The importance of matching organizational architecture with the architecture of the object being designed is not novel. The idea that the effectiveness of an organization's architecture is contingent on the architecture of the product it designs and that the technical effectiveness of the product depends on the structure (and resulting dynamics) of the organization that designs it, are not new concepts. They are central to Henderson and Clark's work, and Christensen, in The Innovator's Dilemma, explains how the structure-in-use (as opposed to the formal structure or espoused structure) of a design group closely mirrors the physical structure of the product being designed.

However, there is a distinction between an organization that engages in collaborative design and testing of a physical product and an organization that engages in the collaborative design and operation of a production system. In the former case, the organization acts upon an object that is external to itself. In the latter case, the organization is both designing the production system, and the organization is the production system. As a result, the designer and the design object are one and the same, so the design-process is reflexive.

It is not clear that the literature has addressed the issue of matching object-architecture and object-design-organization architecture for reflexive design processes. Consequently, this is an opportunity for further exploration.

CONTRIBUTION OF RULES-IN-USE IN CREATING A MODULAR STRUCTURE

DEDUCTIVELY CONCLUDING THAT THE RULES CONTRIBUTE TO MODULARITY

Logical deduction and induction from observations both lead to the conclusion that the Rules-in-Use lead to an organization that is nested modular in structure. The logical deduction starts with the definition for modularity provided by Baldwin and Clark. According to them, a structure is modular if information about the internal workings of components is hidden from adjacent components, and information about interfaces only is visible.

Using that as a standard, we see that each of the Rules contributes to modularity in the following fashion.

An activity designed according to Rule-1 gives the supplier the ability to distinguish between outputs that are defective and those that are defect-free. If the supplier can prevent a defect from being received by the customer, then there is no information in supplier-generated to responses customer-generated requests that tells the customer about the supplier's methods of production and delivery. Though requests and responses are visible, both the methods by which responses are generated and the use to which the responses will be put is hidden. Therefore, Rule-1 contributes to a modular structure.

Applying Rule 2 to the design of a customer-supplier interface is, in effect, a pre-requisite for having an organization with a modular structure. Rule-2 requires that each customer-supplier connection be standardized so that only a pre-specified set of requests and responses can be exchanged between customers and suppliers in each direction. In effect, designing a customer-supplier connection guided by Rule-2 creates a visible interface between hidden modules.

Rule-3 also contributes to a modular structure. Just as reducing the number of linkages between components in a technical system would reduce its complexity, removing loops and intertwined branches simplifies the structure of an organization. This point is explored in more depth below.

Rule-4, like Rule-1, contributes to keeping component information hidden behind interfaces. By colocating activity improvement and activity performance behind a well-defined interface, Rule-4 helps keep the method by which a good, service, or information is produced and delivered hidden from the recipient who receives the good, service, or information.

Rule-5, like Rule-4, contributes to a modular structure by pushing the management of interfaces to the lowest possible level in the organization.

INDUCTIVELY CONCLUDING THAT THE RULES CONTRIBUTE TO MODULARITY

Baldwin and Clark write that if a system is modular then it can be manipulated using six 'operators.' If we extend their If-Then statement so that it is an If-and-only-If statement, we have:

IF a system is modular THEN the 6 operators can be used.

IF the 6 operators are used, THEN the system is modular.

From the data I gathered, I concluded that systems designed, operated, and improved according to the Rules-in-Use can be manipulated by Baldwin and

Clark's six operators. Therefore, we can conclude that these systems are modular in structure. If they are modular in structure, then -- again following the argument of Baldwin and Clark -- the system provides option value to its designers and operators that is not provided by systems that are not modular in design. Each of the six operators is listed and defined in the next table. After that, a simple example from the physical realm is provided with a corresponding example from the organizational realm. References linking the individual examples to other field-gathered observations are in Chapter 7.

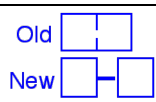
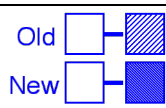
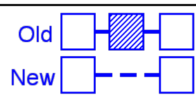
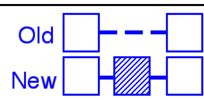
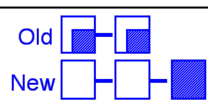
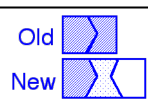
Operator	Image	Definition
Splitting		Separating systems into components that interact across defined interfaces
Substituting		Replacing one component for another that performs the same function.
Excluding		Removing a module to reduce the functions the system can perform
Augmenting		Adding a module to increase the functions of a system
Inverting		Making an imbedded function into a stand alone module
Porting		Connecting a module designed for one system (with one type of interface) to another, using a translator.

Figure 48: Baldwin and Clark's six modular operators

An example of *splitting* is to take an integrated system (i.e., the early Apple computers) and converting it into a system composed of interchangeable parts such as drives, keyboards, monitors, and printers. An organizational example of splitting is the subdivision of a large activity into smaller component pieces. As described in Chapter 7.5, Aisin did this so that it had more flexibility in adding people to and removing people from the mattress assembly line.

An example of *substituting* is replacing one type of printer with another without having to alter the equipment to which it is attached. This is possible because most printers use the same types of connector cables and exchange the same type of information with the CPU. Substituting has organizational analogs. Redesigning the work in a cell without changing the connection between the cell and its immediate customers and suppliers is one. As described in Chapter 7.4, this is what the Ito Quality Circle did by changing their work methods to improve their quality and productivity without changing their relationship with customer and supplier processes.

Augmenting means to add a function without otherwise altering the system's structure or otherwise redefining interfaces. In the technological domain, this means adding components to a system in order to increase its functionality, without otherwise changing the interfaces or the overall architecture of the device. In the organizational domain, this is akin to adding activities to create a good, service, or information without otherwise changing the patterns of work or the way in which other activities are performed. Chapter 7.2 has field-gathered examples of this, such as when a team leader adds assistance at a work station without otherwise altering the way in which goods, services, and information arrive at the location and without otherwise altering the way in which goods, services, and information depart from the location.

Excluding is the reciprocal of augmenting. It means to remove the device that performs a function without otherwise altering the system's structure or redesigning its interfaces. In the physical domain, an example of excluding is disconnecting an external disk drive or CD-ROM player. In the process domain, an analog is not performing a particular set of activities without otherwise altering surrounding activities. connections between activities, and flow-paths. Chapter 7.2 has examples of excluding, for instance when a team leader does not provide assistance because of the relatively low work content demanded at a particular location at a specific time.

Also, in Chapter 7, there is a description of a process redesign at a Toyota supplier in Japan, Araco. Three sets of production equipment were relocated in close proximity so that one operator could produce any of three products. In effect, the Araco work site was designed so that activities could be freely augmented and excluded. The lines were reconfigured so that orders for any of the three products would arrive over the same channel, and responses would depart over exactly the same channel. However, the activity performed by the operator behind the interface would change among the three alternatives without any compensating change in adjacent activities or in the interfaces connecting him to adjacent activities.

An example of *inverting* in the physical realm is removing individual, dedicated printers from individual terminals and connecting all the terminals to a single networked printer. Then a single device is accessible from all terminal locations. Chapters 7.1., 7.2, and 7.3 all contain accounts of the material handling function as performed in TPS-managed organizations. Adding a material handler is a form of inversion by which the delivery function is removed from several customer-supplier pairs and converted into a stand-alone function. Chapter 7.2 contains a particularly good example of material handling as a form of augmentation. The logic by which the cross-dock facility was designed is merely a series of augmentations of the delivery function.

An example of *porting* in the physical realm is attaching a device meant for one system to another system using a translator to complete the coupling. In the process realm, converting batched production instructions so they are usable for sending 1x1 pull signals to a TPS-managed line is an example.

FLOW-SIMPLIFICATION AS A SOURCE OF VALUE

There appear to be compelling structural and dynamic merits for designing flow-paths so that they are simple, pre-specified, and self-diagnostic. Flow-paths of this sort allow a high degree of modularity, allow learning through hypothesis-testing, and diminish the amplification of downstream disturbances through upstream processes. These points are explored below.

PRE-SPECIFICATION FOR HYPOTHESIS-TESTING

If a flow-path is pre-specified, the assumptions implicit in its design can be tested *every time* the flow-path of connected activities is used. Because flow-paths in TPS-managed settings are designed and operated so they are pre-specified and self-diagnostic -- the provision of a good, service, or information over a flow-path other than its pre-specified one is a signal that a problem is occurring and that the assumptions made in designing the flow-path are somehow faulty. If the flow-path is not pre-specified -- so that a good, service, or information can follow more than one path when the flow-path branches, assumptions implicit in the design of flow-paths can only be tested using statistical methods.

LOOP REMOVAL TO LIMIT DISTURBANCE AMPLIFICATION

Looped flows pose a special problem to dynamic systems that must complete successive cycles of sequential tasks (i.e., more than one part is made, more than one person is trained). With a simple flow, a disturbance in the form, quantity, or timing of one task's output only affects the next task. With looped flows, the downstream disturbance affects an upstream process. The disturbance in an upstream activity may then cause additional disruption in the downstream process. As a result, a single problem in a loop, rather than dissipating as it might with a simple flow, can be amplified. I collected data from a natural experiment in which exactly this phenomenon occurred. This data is presented Chapter 7.3.

FLOW SIMPLIFICATION TO REDUCE SYSTEM COMPLEXITY

Flow-path simplification reduces system complexity. Simple flow-paths have fewer structural interdependencies than do looped flow-paths or flow-paths with intertwined branches. As a result, they create fewer cognitive and coordinative burdens in design, operation, and improvement of the production system.

When goods, services, and information flow over paths that are strictly sequential, the only interdependencies are between adjacent tasks. For instance, in the diagram below, the work proceeds sequentially, and the person doing Task-3 cannot work until Task-2 is complete. It is also represented as a task-interdependence matrix -- a format borrowed from Eppinger and McCord -- below, on the right. In this matrix representation, an "x" means that the task in that row depends on the task in that column. For instance, the circled "x" indicates that Task-3 can not begin until Task-2 has been completed.

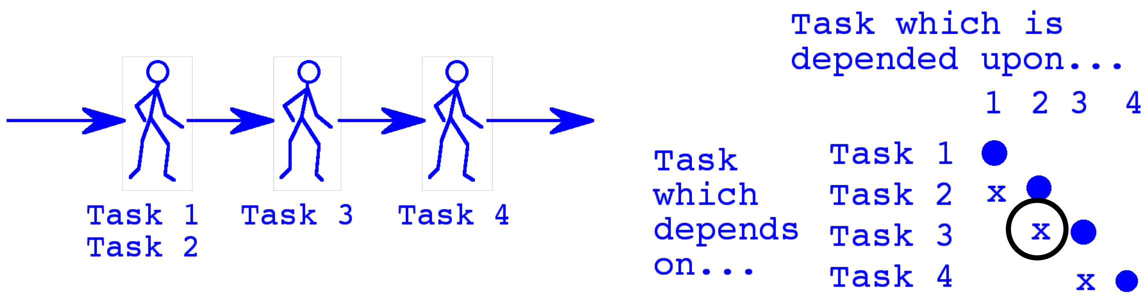


Figure 49: Simple Flow - task PERFORMANCE interdependence

Interdependence in task performance creates interdependence in task design. For example, the designer of Task-3 has to consider the form, quantity, and timing of inputs that will be received from the Task-2, and in designing Task-3 the form, quantity, and timing with which Task-3's outputs will become inputs for Task-4 must also be considered. Therefore, Task-3's designer has to worry about what Task-2 will provide, what Task-3 will do with those inputs, and what will be sent to Task-4. Therefore, while the performance of Task-3 is dependent on the performance of Task-2, the design of Task-3 is dependent on the both the design of Task-2 and on the design of Task-4. This is also illustrated in a task interdependence matrix, below.

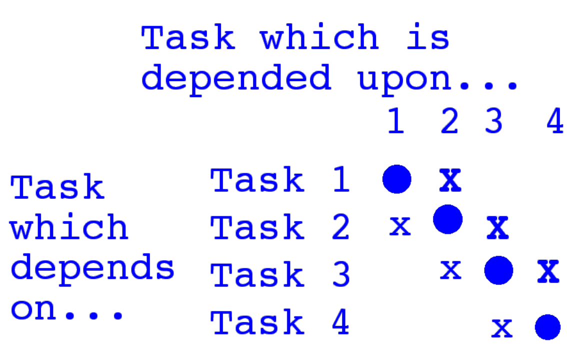


Figure 50: Simple Flow - task DESIGN interdependence

When goods, services, and information take form over flow-paths that are "looped," there are a greater number of interdependencies than if flows are simple. For instance, in the next diagram, the product is processed by the first person and then by the second person before returning to the first person for additional work.

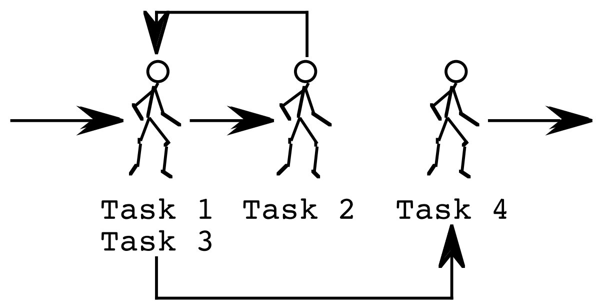


Figure 51: Looped Material Flow

Because of the loop, the performance of Task-2 affects the performance of Task-1 and Task-3, not just Task-3, as in the simple flow case. Likewise, the performance of Task-4 is directly affected by the performance of Tasks 1 and 3, not just by the performance of Task-2, as in the simple flow case.

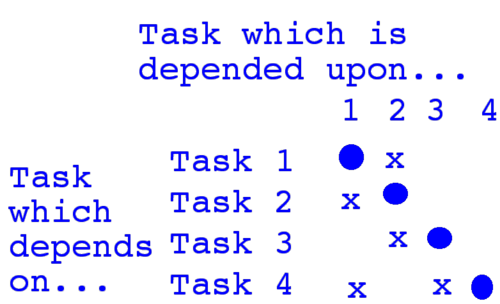


Figure 52: Looped Flow - task PERFORMANCE Interdependence

The loop increases the number of interdependencies in task performance. The loop increases even more the number of interdependencies in task-design. In the simple flow case, Task-3's design depended on the design of Task-2 and Task-4. In the looped case, Task-3's design also depends on the design of Task-1. The design of Task-4, which in the simple flow case depended on the design of Task-3, depends on design of Task-1 as well, in the looped case.

Task which depends on...	Task which is depended upon...	1	2	3	4
	Task 1	●	x		X
	Task 2	x	●	X	
	Task 3		x	●	X
	Task 4	x		x	●

Figure 53: Looped Flow - task DESIGN Interdependence

The looped flow-path has more interdependencies in task performance and even more in task-design than does the simple flow-path.

> We can assume that, all other things being equal, an interdependence must be managed because the work of interdependent people must be coordinated. If we assume that coordination has a cost, then we can conclude that systems with looped flow-paths, all other things being equal, must be more expensive to design and operate than are systems with simple flow-paths.

Just as the looped flow has more interdependencies than does the simple flow, the intertwined flow has more interdependencies than does the simple flow. This is illustrated in the next diagrams, in much the same fashion as the looped flows were diagrammed. Below, on the left, simple flows connect the people doing upstream processes (Person-A and Person-C) with the people doing downstream processes, (Person-B -- who completes Product 1 and Product 2, and Person-D -- who completes Products 3 and 4).

In the simple flow case, A sends partially completed products (1 and 2) only to B, and C sends partially completed products (3 and 4) to D only. In the intertwined case, A sends products to both B and D, and C also send products to both B and D.

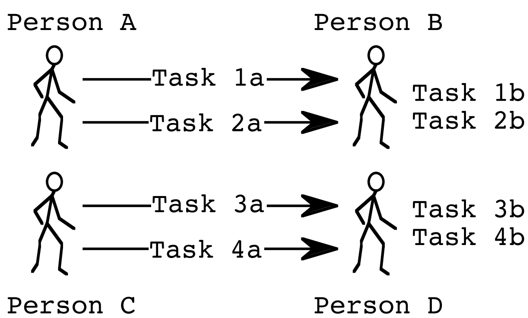


Figure 54: Simple material flow

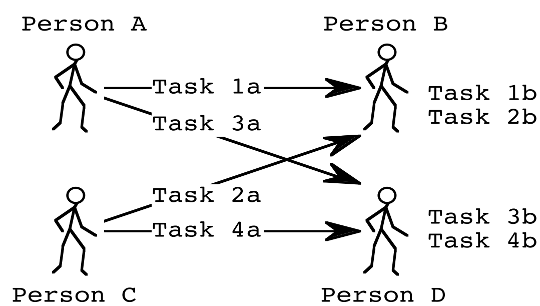


Figure 55: Intertwined branches

Even though increasing the number of intertwined branches did not affect the variety of products created by this simple system, increasing the number of branches increases the number of interdependencies. For instance, because Person-D receives inputs from both Person-A and C, Person-D's work depends both on how and when Person-A completes the preliminary work on Product 3 and on how and when Person-A completes the preliminary work on Product-1. Likewise in the intertwined-branches design, Person-B depends on both Person

A and C for inputs. Therefore, Person B's work is affected by how and when Person-A completes the preliminary work for Products 1 and 3 and by how and when Person-C completes the preliminary work for Products 2 and 4. The degree of interdependence is contrasted in the next two task-independence matrices, with the simple structure on the left and the intertwined-branch structure shown on the right.

<u>Simple Flow</u>

Person who depends on...	Person who is depended upon...	A	B	C	D
	Person A	●			
	Person B	x	●		
	Person C			●	
	Person D			x	●

<u>Intertwined Branches</u>

Person who depends on...	Person who is depended upon...	A	B	C	D
	Person A	●			
	Person B	x	●	x	
	Person C			●	
	Person D	x		x	●

Figure 56: Simple and intertwined flows: task PERFORMANCE interdependence

The increased number of interdependencies in task-performance is exacerbated in task-design. With simple flows, two interfaces have to be designed and managed, one between Persons A and B and one between Persons C and D. Furthermore, with simple flows, the work of Person-A does not impact Person C, nor does that of B affect D. With intertwined branches, everyone affects everyone else.

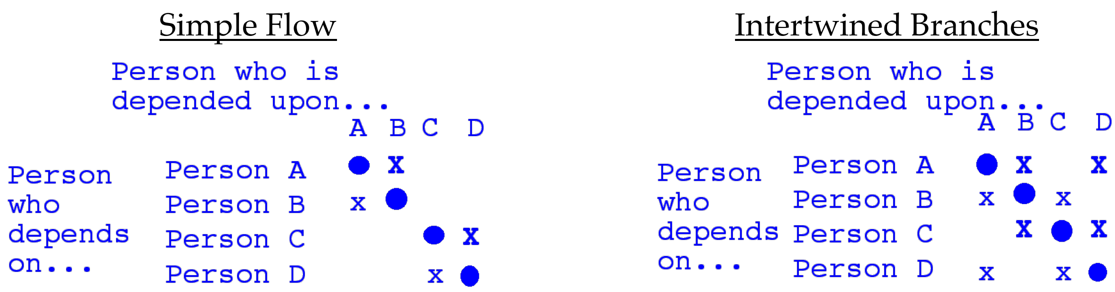


Figure 57: Simple and intertwined flows: task DESIGN interdependence

Therefore, by intertwining flows, system designers may not necessarily increase either the variety or the volume that the system is capable of producing. However, they are certain to increase the number of interdependencies in the system, raising the required investment in coordinative efforts.

We see from these simple examples that flow simplification is a source of value. System designers may not increase the variety or the volume of products that the system is capable of producing by adding loops and intertwined branches in the systems design. However, in all cases, loops and intertwined branches increase the number of interdependencies between activities. Raising the number of interdependencies raises the required investment in coordinative activities. Therefore, raising the number of interdependencies reduces the investment available for designing, performing, and improving activities that produce and deliver a good, service, or information that is valued by an external, paying customer.

Adding loops and intertwined branches destroys value in an additional fashion, and not merely through the increased overhead costs. Loops and intertwined branches increase the size of a system's basic building blocks (i.e., from single activities to groups of activities). By increasing the size of the system's building blocks, loops and intertwined branches decrease the degree to which (or the granularity with which) the system is modular. Therefore, loops and intertwined branches destroy value by destroying the option value in the system's structure.

HIGH-FREQUENCY, HIGH RESOLUTION DIAGNOSTICS

Chapter 3 emphasized the effect of the Rules-in-Use on creating activities, connections, and flow-paths that are self-diagnostic with high frequency and high-resolution. This facilitates frequent learning and capitalization on that learning. These points are summarized and explored below.

	DIAGNOSTIC TESTS	ROLE IN PROBLEM-SOLVING
1	• Is the supplier performing the activity according to its pre-specified design? • Is the activity generating a defect-free outcome?	Makes each use of a production-delivery activity a chance to test assumptions about the activity and the supplier. Makes each production-delivery cycle a chance to identify problems close in time and space to their occurrence. Colocates information about an activity with the actual doing of the activity.
2	Is the supplier behind, ahead, or keeping pace in responding to customer requests?	Makes each request-response cycle a test of the assumptions about the customer and the supplier. Provides rapid feedback as to when actions are and are not achieving their objectives. Colocates information about an activity with the actual doing of the activity.
3	Is the good, service, or information following the pre-specified flow-path?	Reduces complexity and make cause and effect more apparent. Clarifies cause and effect so experimentation is possible.

4	Is the improvement activity: • being performed as designed? • producing the expected results? • moving production and delivery close to the IDEAL?	Creates tension for problem-solving by defining non-IDEAL production and delivery as a situation to be improved. Dictates mechanism for improvement. Creates a cascading supply chain (simple, pre-specified flow-path) for teaching. Makes problem-solving the primary mechanism for learning about the underlying process.
5	Is the improvement activity: • being performed as designed? • producing the expected results? • moving production and delivery close to the IDEAL?	Creates tension for problem-solving by defining non-IDEAL production and delivery as a situation to be improved. Dictates mechanism for improvement. Makes problem-solving the primary mechanism for learning about the underlying process.

TASK INTERDEPENDENCY, INFORMATION, COORDINATION, AND LEARNING

INTRODUCTION

In conducting this research, I concluded that I was studying a general class of managerial problems: The management of an organization in which there is too much intellectual and physical work for one person, so responsibility must be given to many people, each who works on a discrete piece. Then, these pieces must be integrated if the organization is to generate effectively a coherent final good, service, or information.

This section explores issues associated with interdependence. It builds upon the concepts of modularity and dynamic process control discussed previously. Interdependence is an important issue: without it (or with interdependence but also with omniscient, omnipotent actors), coordination would be comparatively trivial. With interdependence and without omniscient, omnipotent actors, coordination is difficult.

ACTIVITIES: BASIC ELEMENTS OF PRODUCTION AND DELIVERY SYSTEMS

Production and delivery of goods, services, and information to customers occurs as material, energy, and information are transformed by activities and transferred from one activity to another. Complex goods, services, and information are generated through the combined effects of multiple activities.

INTERDEPENDENCE: BASIC CONCEPTS

THE NATURE OF ACTIVITIES

Tasks take a variety of forms. Some generate physical and others generate non-physical outputs. For example, tasks may serve to transform material; repair and alter machinery; train people; modify work methods; and process and generate information in the form of plans, designs, and instructions.

DISTRIBUTING RESPONSIBILITY AND COORDINATING EFFORTS

For complex products and services, the design of the good, service, or information to be delivered to the external customer, and the design, operation, and improvement of the production and delivery system cannot be accomplished by a single person. Rather:

- individuals can accept responsibility for only some of the many activities that must be completed by the organization as a whole.
- activities must be coordinated so that the results of each can be integrated into a coherent whole.

For coordination of distributed activities to be effective, *interdependence* of several forms must be addressed. These are: *Sequence*, *Form*, *Quantity*, and *Timing*.

SEQUENCE INTERDEPENDENCE

I have defined activities as being *sequentially interdependent* if one must be completed before the other can be started.

Definition: "$A_i(t)$" is defined as activity_i done at time_t,

Activities $A_i(t)$ and $A_{i+1}(t+\Delta t)$ are sequentially interdependent:

If $[A_i(t) = \text{complete}]$ then $[A_{i+1}(t+\Delta t) = \text{possible}]$

If $[A_i(t) = \text{incomplete}]$ then $[A_{i+1}(t+\Delta t) = \text{not possible}]$

for all Δt, $\Delta t > 0$.

Equation 1: Sequence interdependence

OUTPUT-FORM INTERDEPENDENCE

Because the output of the activity done by one person or machine becomes the input for some other activity, the needs of the customer activity define the *form* of the supplier-activity output that is *acceptable* or *not acceptable*.[14]

Because of this type of interdependency, the outputs of each person's tasks must meet specific criteria (or fall within an acceptable range). For instance, the output must be of a particular color, shape, dimension, orientation, mass, density, functional capability, etc., if it is to be used by the downstream activities.

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[14] The customer's needs are determined, in part, by the *stability flexibility* of the customer activity -- the ability (reciprocal of cost?) associated with generating a constant output in light of changing inputs. This can alternatively be expressed as the elasticity of outputs relative to inputs. For example, an inelastic process would have high stability-flexibility because relatively large changes in inputs would have relatively small effects on the

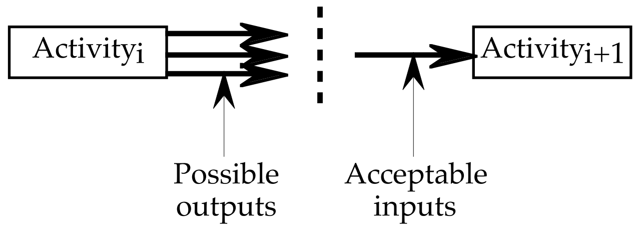

Figure 58: Form interdependency

QUANTITY INTERDEPENDENCY

Just as the downstream needs of the customer-activity define the acceptable form of the supplier-activity's output, the downstream needs of the customer-activity define the acceptable *quantity* of the supplier-activity's output. Depending on the situation, the acceptable quantity may be expressed as a minimum acceptable, a maximum that is acceptable, or a specific quantity (or volume) that is acceptable.

TIMING INTERDEPENDENCE

It is not enough for each person's activities to be performed so that they generate outputs which meet the criteria relevant to the person making use of that output. In addition, many goods, services, and information only come into being if the tasks by which they are created occur in an acceptable sequence (i.e., $Activity_i$ must proceed $Activity_{i+1}$) and separated by acceptable time intervals. For instance, if some form of *aging* is required (i.e., for curing, solidification, cooling, etc.) activities m and m+1 must be separated by at least a minimum

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form, quantity, or timing of the process's outputs. The concept of stability flexibility was introduced by Upton and is discussed in Chapter 6.

period, t_{MIN}; when *spoilage* is a risk, activities n and n+1 cannot be separated by more than some maximum period t_{MAX}.

Figure 59: Example: Time Interdependence when *Aging* is required

Figure 60: Example: Time Interdependence when *Spoilage* is a risk

Time interdependence may be expressed using the following notion.

<u>Definition</u>: Steps $A_i(t)$ and $A_{i+1}(t+\Delta t)$ are <u>sequentially and time-interdependent</u>:

If [[$A_i(t)$ = complete] AND [condition Y = True]]

then [$A_{i+1}(t+\Delta t)$ = *possible*]

If [[$A_i(t)$ = incomplete] OR (condition Y = False]]

then [$A_{i+1}(t+\Delta t)$ = *not possible*]

For spoilage (step function): condition Y = True if $\Delta t < \Delta t_{critical}$

For aging (step function): condition Y = True if $\Delta t > \Delta t_{critical}$

If condition Y is impermanent, and the probability of Y being true changes with the length of Δt:

For spoilage (decay): $P(Y = \underline{False} \text{ at } t+\Delta t \mid Y = True \text{ at } t) \propto \Delta t$

For aging (growth): $P(Y = \underline{True} \text{ at } t+\Delta t \mid Y = False \text{ at } t) \propto \Delta t$

Equation 2: Sequence and time interdependence

SUMMARY

It is necessary but insufficient for people and machines to perform their tasks adequately, but in isolation. Rather, people and machines have to act with some degree of coordination to produce and deliver the particular goods, services, and information that are needed at the time when, at the place where, and in the form that they are needed.

People and machines that contribute to the production and delivery of complex goods, services, and information are interdependent. Interdependency has qualitative (form), quantitative (number), sequencing (order), and timing (duration) aspects. Those within the organization cannot do their work until other people produce a physical good or perform a service such as maintenance, training, or logistics, in the appropriate form, in the appropriate quantity, and at the appropriate time.

TIME INTERDEPENDENCE AND SPOILAGE OF MATERIAL AND INFORMATION

In manufacturing, inventory is used as a way to "store capacity." When demand is less than capacity, extra output can be generated which can later be used for periods when demand exceeds capacity. However, the faster the spoilage rate, the lower the value of inventory. This might immediately conjure up imagines of rotting apples, and other examples of material-spoilage. However, when something is made, I have observed that it carries with it information about the process by which it was made. Even if the material doesn't spoil, the information may. The consequences of information spoilage on process control, process improvement, and learning are discussed below.

FLUCTUATIONS IN DEMAND

Production and delivery systems may be subject to fluctuations in demand-volume, and they may respond with a variety of methods.

Physical Inventory: One method of managing a fixed capacity production system facing fluctuations in demand (even if average-demand ≤ capacity) is to have intermediate buffer inventories or stores between adjacent process steps.

If $\text{Demand}_{\text{rate}} < \text{Production}_{\text{rate}}$, then Inventory accumulates

If $\text{Demand}_{\text{rate}} > \text{Production}_{\text{rate}}$, then Inventory declines

Equation 3: Accumulation and depletion of inventory

The average size of inventory and the average waiting time in inventory is positively proportional to the amplitude and negatively proportional to the frequency of demand-fluctuations.

JAIKUMAR AND INFORMATION SPOILAGE

Harvard Professor Jai Jaikumar was developing a information-based theory of process control and improvement. He generated a list of theories on the value of information for process control and improvement. These theories were prompted by his observation that in sugar refineries, processes that were actively controlled had more volatile behavior than did processes which were left to drift. From this, he began to question the interaction between information and process control. He concluded:

1. *Information's Value*: Information is only valid (valued) if it is used for process control or process improvement. Said more colloquially, information only has value if it changes behavior.

2. *Observation/Control Cycle*: You can't observe and control at the same time. Rather, you have to alternate observation and control.

3. *Perishability of Information*: You can't observe one "batch" and use that information to control the next batch.

   Definition: A new batch begins whenever a process parameter changes. (For a continuous process, imagine 'slugs' passing through a pipe. If there is a change in pressure, temperature, etc., the slug is part of a new batch. Changing a coil midway through a stamping run creates a new batch too).

Jaikumar's third conclusion holds because it is impossible to determine the 1st order impact of any control measure once the process parameters have been changed. Rather the pre vs. post comparison will reveal the effect of the <u>interaction</u> between the control action and process parameter change.

For instance, if we measure the state of the system at time_1, but act on it at time_2, the outcome that we measure is the result of the Activity on State_2, not the result of the Activity on State_1. Consequently, we don't truly know the consequence of performing the Activity on State_1 unless we know with certainty that State_1 = State_2. Furthermore, if we have not measured the system at State_2, then we cannot draw conclusions about the affect of performing the Activity on State_2 either.

This highlights the importance of temporal proximity in interdependent tasks. As tasks are time separated, there is more opportunity for the upstream process to drift or be perturbed (i.e., create a new batch) thereby allowing State_2 to become increasingly dislike State_1. For a new batch, the data collected by observing the first batch are devalued, thereby making process-control and process-improvement less effective.

INFORMATION SPOILAGE AND LEARNING THROUGH EXPERIMENTATION

Jaikumar's point is that it is not material only that spoils. Information associated with material, and information associated with the output of other processes, generally, spoils too. Information spoilage affects an organization's ability to control and improve processes and affects the ability of people and groups to improve.

LEARNING BY ASSESSING CAUSE AND EFFECT

Throughout, I have emphasized that when the Rules-in-Use are followed strictly, learning occurs, in large part, through frequent, repeated problem-solving, done as structured experiments. Learning through experimentation implies that several steps will occur:

- State Hypothesis
- Conduct Experiment
- Measure Outcomes
- Confirm or refute hypothesis

When an organization has decision making heuristics, it has, in effect, the opportunity for conducting experiments each time it takes action. For example, let **D** be a set of decision rules such that if the state of the world at time=t, $\mathbf{S}_i(t) = \mathbf{S}_j$, then do $Action_j$. For example:

If $\mathbf{S}_i(t) = S_1$ then do A_1 If $\mathbf{S}_i(t) = S_2$ then do A_2

If $\mathbf{S}_i(t) = S_3$ then do A_3 If $\mathbf{S}_i(t) = S_n$ then do A_n

If $\mathbf{S}_i(t) = S_{GOAL}$ then do $A_{NOTHING}$

Given that these are decision rules, the decision maker first has to establish the *current condition*, for instance, by determining that at time = t, $\mathbf{S}_i = \mathbf{S}_3$. Based on this belief, the decision maker would take action Action$_3$.

After taking Action$_3$, the decision maker then has to measure the new state of the world at time = t+Δt, (a state that we will call $\mathbf{S}_i(t+\Delta t)$). Is it equal to $\mathbf{S}_{Expected}$? If not, there was something incorrect in the decision maker's assumptions, since the action did not lead to the expected, intended outcome.[15] Therefore, if after taking Action$_i$ at time = t, the state of the world at time = t+Δt, $\mathbf{S}_i(t+\Delta t)$, is not equal to $\mathbf{S}_{Expected}$, then the decision-maker has to revise **D**: i.e., change Action$_i$ to Action$_i$'. In other words, by taking an action that leads to an unexpected outcome, the decision-maker has learned that his previous assumptions are incorrect. This should trigger experimentation so that the decision-maker can modify the decision rules, **D**, so that they are more effective.

THE EFFECT OF INFORMATION SPOILAGE ON LEARNING

As Jaikumar discussed, the state of the world is not constant. People, processes, materials, and environmental conditions change. With this as a given,

[15] It is also possible that the decision-maker misunderstood the initial state of the world. However, this is a problem of the same type: the action by which the decision maker sought to correctly assess the state of the world did not, in fact, lead to a correct outcome. In other words, the assumptions built into the initial *evaluative* activity were incorrect.

delays between initial measurement and action, and delays between reaction and follow-up measurement compromise the decision maker's ability to learn from experimentation. For instance, compare the next two diagrams. In the first, the gap between measurement and action is relatively short. Therefore, the decision maker is acting on a world little changed from when its condition was measured. Likewise, there is a relatively small gap between the results of the action take hold and when those results are measured. Consequently, the measurements reflect the actual results with reasonable accuracy. Therefore, the decision-maker has accurate information, with which his decision-making heuristics can be judged.

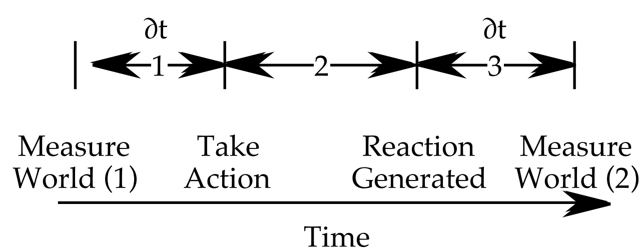

Figure 61: Action and measurement separated by short time gap

In the latter diagram, initial-measurement is separated from action by a larger time-gap than in the preceding diagram, and the reaction is also separated from the result-measurement by a larger time-gap than in the preceding diagram. Consequently, the decision-maker acts on world that has an actual condition that has had more opportunity to change from its initial condition than in the first of these two diagrams. Likewise, the decision-maker is measuring a world that has had more opportunity to change from its condition when the reaction actually took hold. Therefore, the decision-maker has introduced noise into his measurements that confound his ability to test the assumptions that motivated his actions.[16]

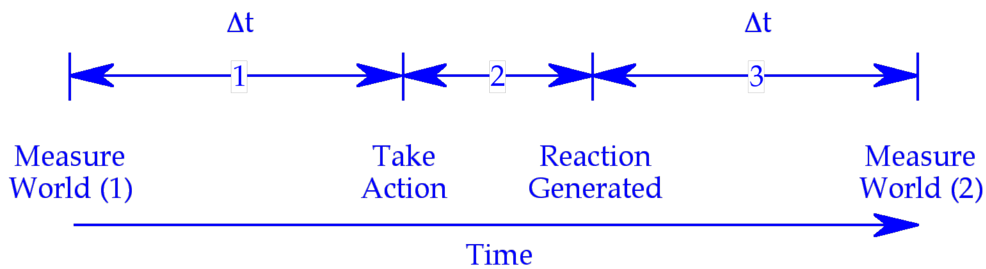

Figure 62: Action and measurement separated by large time gaps

In sum then, spoilage reduces the value of inventory, both because of material waste and because of information loss. When information spoils, the efficacy or value of downstream processes are reduced if they use information as an input. Control, improvement, experimentation, problem-solving, and learning are all processes that use information as an input. Therefore, these are adversely affected by information spoilage. As a result, the more these processes are necessary, the less valuable material inventory is as a means of addressing demand - capacity mismatches.

ALTERNATIVE RESPONSES TO DEMAND FLUCTUATION

When there is spoilage in some fashion (of outputs, information, etc.) between the time one process step is complete and the next process step is

[16] A possible exception to this statement would be when the system being measured and controlled always drifts with a predictable velocity during the measure-action and reaction-measure gaps.

started, the efficacy of intermediate stores is reduced with (1) increases in the spoilage rate, (2) increases in the amplitude of exogenous fluctuations in demand, (3) decreases in the frequency of demand fluctuations.

In the course of conducting this research, I observed multiple responses to these situations in plants managed according to the Toyota Production System. All require having some resource available other than physical inventory. The appropriateness of each response depends on the relative magnitudes and frequencies with which demand-volume and resource allocation can be adjusted.

> The common feature of these responses is that they all serve to maintain the close temporal proximity of sequential tasks. This, in turn, preserves the quality of information for process control and process improvement.

Situation	**Response**
<u>Seasonality</u>: Increase the number of people	Adjustment in vacations; temporary workers. The overall effect is to increase the number of people in the plant, decrease the tasks per person and increase the overall level of output. i.e., The capacity per hour increases.
<u>Periodicity</u>: Increase the number of hours.	Overtime without additional people. Tasks/person remains the same as does capacity/hour. The number of hours increases to increase overall output.
<u>Variation in Labor Content per vehicle</u>: Vary number of line workers.	Team Leader provides support at overloaded stations. i.e., if an operator can complete 'n' tasks within a cycle, the team leader assists when the task-bundle has n+m tasks in it.
Balance work load	Leveling of work load: Alternating high-load and low-load task-bundles; i.e., (n-m,n+m,n-m,n+m,...)

These resources are flexible, capable of performing multiple tasks. Therefore, those tasks which can be moved in time more easily can be accelerated or postponed so that the resource can be deployed immediately, and on-demand, for tasks which cannot be moved in time.

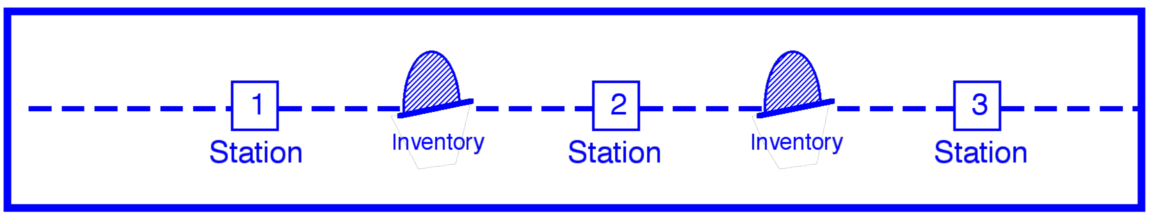

Figure 63: Inventory to respond to demand fluctuations:
Information destroying

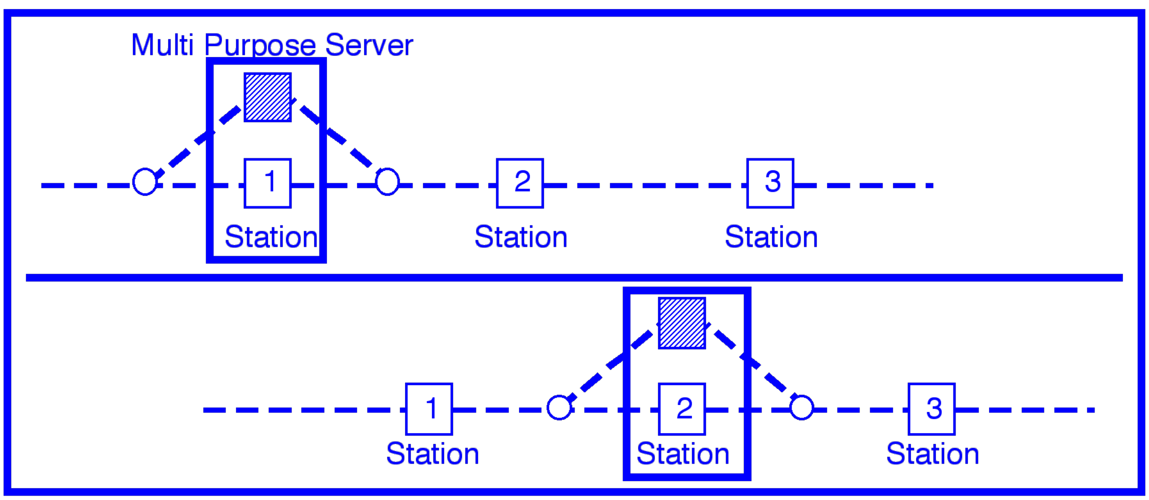

Figure 64: Flexible resource to respond to demand fluctuations:
Information preserving

Therefore, using this phrasing, the team leader can perform all the tasks on the team, filling in when someone is absent, struggling, or when demand spikes. When the team is fully staffed or demand diminishes, the team leader can teach, coach, or help problem solve. Equipment can also be used in a flexible fashion. Counter cyclical (and uncorrelated) product families can be assigned to the same equipment (and people).

Common characteristics to all these policies are:

1. Flexible resources
2. Demand on specific assets that is offsetting or uncorrelated.
3. A full workload for all assets to prevent waste in the system.

CHAPTER 6:

OTHER DISCUSSION POINTS

TPS AND FLEXIBILITY

In the course of my research, I observed that the Rules-in-Use encourage increasing amount of flexibility for people, machines, and flow-paths. Other observers too have noticed flexible people (i.e., cross trained and multi-skilled) and flexible technical systems for parts fabrication -- i.e., single minute exchange of dies, and assembly -- i.e., multiple models produced on the same assembly line. Concepts introduced by Upton (1994, 1995, 1997), and Graves and Jordan (1995) provide insight as to the type of flexibility encouraged by the Rules-in-Use and the apparent rationale for the flexibility 'strategy' I observed.

Upton has identified three types of flexibility: range, mobility, and uniformity.

Mobility Flexibility is a measure of the time and other costs involved in moving from one output to another, for a given range of potential outputs.

Range Flexibility is the extent to which output parameters can be varied (i.e., thickness, density, width, etc.) for continuous processes and to the variety of products a discrete part production system can produce.

Uniformity Flexibility is a measure of the process's robustness, the extent to which it can accept changes in inputs and still generate outputs of the same quality.

TPS-managed organizations first reduce batch sizes for existing process flows (in pursuit of the IDEAL of unit-of-one production) before pooling separate flows into single flows (in pursuit of the IDEAL of no waste). This sequence corresponds to first increasing mobility flexibility and then, second, increasing range flexibility.

There may be reasons that this sequence is preferable, at least under particular conditions. Emphasizing mobility means decreasing change-over times and reducing batch sizes. This provides proportional increases in diagnostic frequency, and proportional decreases in inventory-related costs.

More importantly perhaps, people are trained in TPS-managed settings through frequent, structured problem-solving. Increasing range mobility through reduction in change-over times can often be accomplished through relatively larger investments in studying and improving work methods and through relatively smaller investments in equipment. Furthermore, because change-over reductions can be accomplished by improving change-over procedures, they can be accomplished through the efforts of the individual supplier and that of the team. In contrast, increasing range-flexibility by combining many production flows into fewer may require more capital investment and greater coordination across more people and groups.

THE IDEAL AND PARETO EFFICIENCY ARE NOT SYNONYMOUS

The IDEAL and Pareto Efficiency are not synonymous. Pareto efficiency implies that (at least) two parties each have a finite set of assets which they can trade until they can make no more exchanges that will improve the utility of at least one person without diminishing the utility of others. However, were one to get more of any good, trade could begin again to re-establish a Pareto Efficient distribution of endowments.

In contrast, the IDEALness of a production and delivery system refers to its capability or potential to create goods, services, and information, not the endowment of the goods, services, and information themselves.

	Pareto Efficiency	**IDEAL**
Refers to...	Distribution of goods (and services ?) amongst parties.	Potential of a system to produce and deliver goods, services, and information.
Type of superiority ...	Best allocation of a specific endowment of goods (and services).	(Hypothetically) best system for generating goods, services, and information.
Achieved by...	Trading endowments among parties.	Improving activities, connections, and flow-paths.
Sign [ ] has been achieved...	No opportunity for trades which will increase utility of both parties.	No opportunity for making changes so that the system-performance improves along at least one dimension.
Degraded by...	Exogenous redistribution of endowments.	Changes in people, processes, products, market-needs.
Achievability	Theoretically possible.	Hypothetical. Not thermodynamically possible.

CHAPTER 7:

DETAILED PRESENTATION OF DATA AND ANALYSIS

Field-gathered data that led to the five Rules-in-Use follows. There is a continuing contrast between the work of a person in a non-TPS-managed environment and that of someone doing comparable work in a TPS-managed setting. For example, in explaining the codification of Rule-in-Use 1, the training and work of an assembly line worker is contrasted in both settings. This is the base upon which additional evidence is layered. The connection of the individual worker with suppliers will be contrasted in non-TPS and TPS-sites, when Rule-2's codification is explained. Other customer-supplier connections then follow. In explaining Rule-3's derivation, the evidence also starts with the individual's perspective. The discussion of Rule-4 will include characterizations of how the capabilities of individuals are developed in TPS-managed settings. Likewise, the evidence for Rule-5 will explain how systems of activities are changed to increase the collective contribution of individuals.

From this, the reader will recognize the assumptions about the needs and roles of workers and the responsibility and role of managers evident in the 'norms' characteristic of TPS-managed plants. In the TPS view, people are capable of learning to do complicated work, both in producing a good, service, or information, and in improving the process by which the good, service, or information is produced. Also, in the Toyota view, managers must teach people to design and improve activities and systems of activities if the organization is to capitalize on the full potential of its members. Finally, there is a basic assumption that people can be or should be humble enough to perceive the problems in their own work and to use problems not as threats but as opportunities.

CHAPTER 7.1:

DATA AND ANALYSIS CONTRIBUTING TO RULE-1:

ACTIVITY DESIGN AND PERFORMANCE

INTRODUCTION

RULE STATEMENT

Rule-1 guides the design and performance of individual activities by people and machines. It states:

Design and perform each activity so that it is *structured* and *self-diagnostic*.

For an activity to be:

- <u>*structured*</u>, the activity must have *work-elements that are pre-specified as to the content, sequence, and timing* by which the activity is accomplished, and there must be a *definition of the expected outcome* (form, quantity, timing) of performing the work-elements in their pre-specified sequence.

- <u>*self-diagnostic*</u>, the activity must have two tests: *one test must immediately signal that a problem* has occurred if the activity is actually performed in a way that differs from the pre-specified content, sequence, or timing
the second test must immediately signal that a problem has occurred if the actual outcome of performing the activity differs from the expected outcome in form, quantity, or cycle time.

RULE EFFECT

The principal effect of designing and performing work activities according to Rule-1 is that the activity-doer (the supplier) has clear, unambiguous (yes or no) feedback that he has successfully produced and delivered a good, service, or information with the form, quantity, and response time that meets the needs and requirements of the supplier's immediate customer. By testing the process and the output, thereby allowing only defect-free responses to customer requests, Rule-1 'hides' process information behind the customer-supplier interface. Therefore, Rule-1 contributes to modularizing a TPS organization. By contributing to the test of every repetition of every activity or work-element, Rule-1 contributes to high-frequency, finally grained self-diagnostics of TPS-managed organizations thereby making each use of an activity an experiment that tests the hypotheses implicit in the activity's design. By colocating action and outcome information in time and space, Rule-1 contributes to frequent experimentation as a learning mechanism. Therefore, Rule-1 contributes, in part, to addressing the general managerial challenge of distributing responsibility for designing and performing small pieces of the organization's total activity-set and ensuring that each piece is done correctly, so that each piece contributes and does not impede the organization's collective efforts.

DERIVATION OF RULE-1

I derived Rule-1 inductively from consistent patterns found in the design and performance of individual activities in Toyota Production System managed situations. The patterns I codified as Rule-1 became evident in several ways:

- The patterns of behavior in the design and performance of activities were consistently observable in TPS-managed settings. They were absent elsewhere.

- When Toyota's TPS experts promoted TPS within a plant, they invariably tried to design the work of the plant's workers (and to teach managers to design the work) so that it was structured and self-diagnostic.
  This was, in part, what I did as a participant-observer during my five-month membership with the Toyota Supplier Support Center.

- When I collected data in the company of Toyota's Supplier Support Center (North America) or Operations Management Consulting Division (Japan) members, they were consistently critical of activities that were not structured and self-diagnostic.

This section presents the data that led to the development of a Rule-in-Use that governs the design and performance of activities. First, it describes the data I collected at a Big-Three assembly plant attaching roofs to car bodies (body shop), installing seats in cars (final assembly), and conducting final electronics tests (final assembly). This data is then contrasted with the way in which similar jobs are designed and performed at Toyota assembly plants (NUMMI, Toyota Motor Manufacturing, Kentucky ("TMMK"), Toyota Motor Manufacturing, Indiana ("TMMI"), and Kyushu). From these specific examples in auto assembly, I will expand the data set to describe the broad range of activities that I observed and that were structured and self-diagnostic in TPS-managed organizations but that were not elsewhere. This includes activities performed with high-frequency during routine production and others performed with less frequency but with no less structure and self-diagnostic testability in maintenance, service, training, conveyance, and process redesign.

FREQUENT, ROUTINE ASSEMBLY ACTIVITIES: NON-TPS SITE

SEAT INSTALLATION AT THE BIG-THREE PLANT

Purpose: I gathered data by working and observing the work done at a Big-Three assembly plant for one week in June 1996. This was done to have first-hand data which would provide comparisons with observations the I would make elsewhere.

Choosing the plant: This particular plant was selected by a senior executive as an example of a 'well-run plant operated in a traditional fashion' [in contrast to plants in which the company's self-described effort to emulate TPS was being implemented].

Nature of the data collection: During the week, I had several experiences typical of a worker in this plant. On my first day, Monday, I attended the human resources, union, and safety orientations with people who had just been hired as part-time employees, those who would be called in as fill in for absent workers (primarily on Friday, Saturday, and Monday). Then, a zone supervisor (the first level supervisor for a portion of the final assembly area) placed me at different locations within the plant so that I could experience doing production work. The orientation and on-the-job experiences are reported below and are compared with the work of people whom I observed elsewhere.

Activity	Role
Monday	
• Orientation	• Participate
• Seat Installation	• Do work

Tuesday	
• Seat Installation	• Do work
• Electronics Testing	• Do work
Wednesday	
• Electronics Testing	• Do work
• Tire/Rim Wheel Sub-Assembly	• Observe
• Rolls Test	• Observe
Thursday	
• Stamping Plant	• General overview • Stamping Plant Learning Line (observe)
• Zone 9 and Area Manager Trouble Shooting	• Observe
• Engine Sub-Assembly	• Observe
Friday	
• Body Shop	• Do work
• Paint Shop	• Observe/Tour

Figure 65: Summary of research activities at the Big-Three plant

[As I characterize the role of managers in TPS-managed environments in contrast with those in non-TPS settings, I will return to the Big-Three experience and discuss the activities of the zone supervisor, who I shadowed for extended stretches.]

ORIENTATION

I arrived at the plant on Monday morning, June 10th. After being introduced to some of the managers, I went to a four-hour orientation for part-time employees. First, we received a lecture from a manager about on-the-job safety and quality procedures. The descriptions I recorded were:

- Vehicle, Safety and Emissions tests for items such as brakes and other automobile safety related items.
- FMVSS: Federal Motor Vehicle Safety Standards (Safety and Emissions)
- Manufacturing Assurance Standard, Safety and Emissions
- "Purge": The error remediation process. Periodically, cars are checked that production standards have been met (i.e., torque on bolts, etc.)

The "purge" process was explained as periodic checks done by a "Torque Route Person" that were entered into the daily audit system. For instance, in the figure below, no problems are revealed at checks 1 and 2. Therefore, the assumption is that there are no problems with the cars that were produced between the two checked cars. However, a problem is detected by check number 3. Consequently, all the cars that that had not been checked between check 2 and 3 must be "purged" from the system for inspection and possible rework.

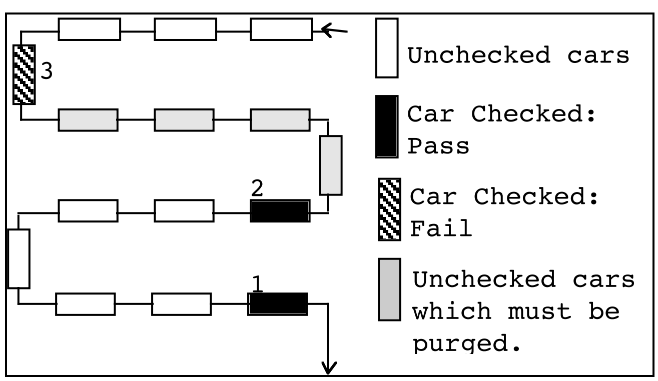

Figure 66: Quality Checks and Purges

While we were told that 10 to 12 purges occurred per day in the system, we did not learn the frequency with which these tests were done or the number of cars which were purged daily.

Several of the new part-time employees asked questions. These included:

Question: Does a car have a number so if you have a problem you can tell someone?

Answer: Cars are built in sequence with a sequence number

Q: Who is supposed to find problems?

A: It is the job of the operator [i.e., assembly line worker] to tell if something is or is not right in your area.

Q: What do you do if you have a problem?

A: The line does not stop so you notify your supervisor and your ATC (Area Team Captain).

In addition, we were told that the plant had been retooled a few years prior at a cost of $350 million, that the plant has 278 robots with 256 in the body assembly area, that part stacking was less than 54 inches for visibility, and that parts boxes were reusable. There was also mention of something that was called “Lock-In Sequencing” and a “Performance Feedback System." Unfortunately, my notes from the orientation meeting do not provide nor can I recall more details about these systems.

After the lecture, we watched a video that explained that suppliers received a 10-day advance notice of the production schedule, that suppliers delivered parts sequentially, and that the plant used "scientific material management" methods. We also learned that 98% of stamped parts came from the nearby stamping plant and that there had been a product quality improvement team consisting of people from Stamping and Assembly.

After the video, a member of the Local Joint Health and Safety Committee provided Safety Instruction. From him, we learned that the plant had 3,300 employees in the plant, that safe operation of machine and equipment was important and that we should always watch out for hi-los (fork-lifts) when moving about the aisles. The presenter also added that safety glasses were required in all areas, and that hearing protection was necessary in some places. Once on the line, we would be responsible for good housekeeping in our work areas and that if we were injured on the job and needed a medical pass, we should ask our supervisor. We were also told that there would be job-specific hazard communication and personal protective equipment. We next learned that part-time employees cannot become full-time workers and that wages would be $12.59 per hour; 50% higher on Saturdays and double on Sundays.

Then, the managers left the room, and we had a meeting with three Union Stewards. One advised us to look at this job as a temporary stepping stone to something better, but not something to rely on (he had spent 1980 with only 4 hours of part-time work per week due to production cut-backs). Another felt that this was a job which could lead to financial security and that with diligent work, a “keep your nose clean” attitude, punctuality, and hustle, an auto assembly job would be a reliable source of employment and income. A third Steward warned us never to get comfortable “because a comfortable man is dangerous to himself.” [I recall thinking that the three must have had markedly different experiences working at this plant.]

With this portion of the meeting concluded, the part-time workers were told the phone number they would call each Thursday to learn if they were needed to fill in from Friday through Monday. After hearing a separate presentation and receiving a handout about repetitive motion injury risks, they were dismissed for the day. I however, got my first taste of assembly line work.

ON THE JOB TRAINING

Before the end of the shift, the zone supervisor (first level manager) who was my host brought me to the portion of the assembly line where seats were installed. I was introduced to James (who was responsible for attaching the front, left, driver’s seat) and to Willie (who was responsible for attaching the front, right, passenger’s seat). They were told to show me how to do the jobs they were doing. With this, the zone supervisor drove off in the golf cart he routinely used to get around the plant during the day, as he responded to walkie-talkie calls for help.

Walkie-talkies as an example of customer-supplier connections

Rule-2 guides the design and operation of connections between customers and suppliers. Walkie-talkies and paging systems are ways to connect customers (typically operators) with suppliers (managers called upon to offer assistance). Therefore, I will return to the example of this zone supervisor to set a contrast between customer-supplier (i.e., worker-supervisor) connections in non-TPS and TPS-managed situations.

Seats came to the assembly line at the preceding work station, where another worker took them off the seat conveyor and placed them in the car. Willie and James attached the seat by driving four bolts with an air powered torque wrench (similar to the familiar, high-pitched devices used by pit crews to replace the tires on racing cars).

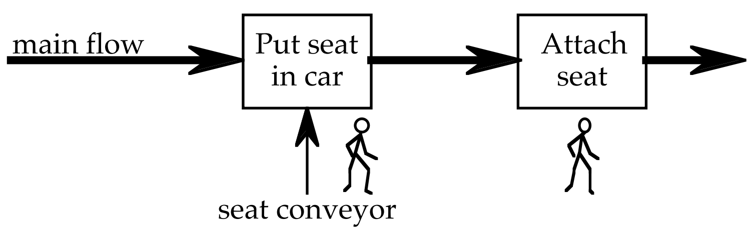

Figure 67: Work flow at seat installation

Willie showed me how he did the job. First, he took four bolts out of a card board carton that was on a work bench a few feet from the line. He then walked to his left, placed two bolts in the rear foot well, and began by driving the front two bolts, through the carpet, into the frame.[17] Then, he slid the seat

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[17] Though my notes don't indicate, I believe the carpet had pre-cut holes for the front two holes, but not for the back two.

forward, to give himself room to maneuver the air gun while driving the rear bolts. With the four bolts attached, Willie then placed the air gun back on the work bench, punched a code into the computer indicating whether or not a problem had occurred with this particular car at his station, and waited for the next car to arrive before starting the cycle again.

PERFORMING THE JOB

After watching Willie perform this sequence several times, I tried to do the same but immediately discovered that what Willie performed effortlessly was extremely difficult for me. I fumbled while grabbing the correct number of bolts, had problems getting the bolts seated straight, and had trouble aligning the torque wrench so that the bolt would thread properly into the frame. On this first try, Willie had to complete the sequence. On my second try, I had difficulty again, and Willie completed the seat's installation. After many tries, I gradually began to feel a bit more fluid. However, concentrating on getting the bolts in the right holes within the cycle time, I continually forgot to enter that the job had been done in the computer console.

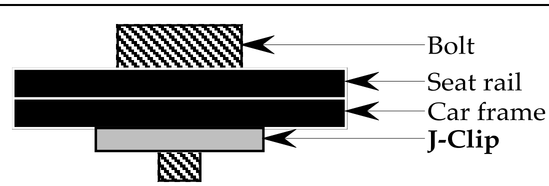

Figure 68: Correct: Bolt through J-Clip

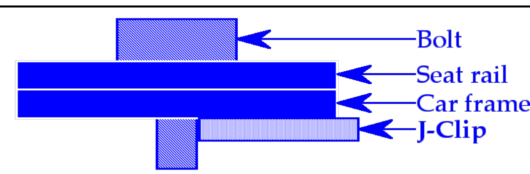

Figure 69: Incorrect: Bolt missing J-Clip

Even with practice, the job never was easy, and after several hours, I was still rarely able to do a complete sequence. In order for the seat to be fastened correctly, the front-two bolts had go through a slot in the frame, and pick up the threads of a "J-Clip" nut on the other side. The problem was, occasionally the J-Clip would be slightly out of line. Then, the bolt would not find the center of the Clip, but would push it aside. Not having threaded itself into the J-Clip, the bolt would spin freely, the seat not attached to the frame. When this happened, Willie would remove the bolt manually, take an awl from his work bench (or retrieve the awl from James who also needed it occasionally), use the awl to align the J-Clip, and re-drive the bolt. He showed me how to do the same thing when problems like that occurred. This was almost always effective, though many times I had to ask Willie to complete the sequence for me. Once, neither of us were able to get the bolt aligned in the J-clip, so Willie punched a problem code into the computer console.

According to Willie, we had more problems in the early portion of our shift, because the cars we were working on then had been assembled the previous night by the second shift workers. As the day went on, and the cars we worked on were made that same morning, Willie felt the J-clip problem was less severe.

Though every car did not have this problem of out-of-line J-Clips, the problem occurred often enough that I took to carrying the awl in my back pocket, so that I wouldn't have to find it each time I actually needed it. Instead, I gradually found it easier to use the awl for each car, as insurance before driving the bolts. I had to add this precaution to each car because I was too slow to risk mis-firing with a bolt and then having to pull it out.

Responding to supplier unreliability

Checking the J-Clip's position on every car is a specific example of a more general situation: I, as a customer, adopted a practice as a response to a problem introduced by a supplier. I did this even though my response negatively affected the cost, quality, lead-time, batch-size, or safety of my own work.

This strategy was not without some hiccups though. One time, I managed okay with the awl, but when I finished, I forgot to take it from the car. I then had to run down the assembly line and find the car where I had forgotten the tool in the foot well.

After doing this for the morning portion of the shift, I was better able to get all four bolts installed (even when a J-Clip problem occurred) and enter the computer console code, all within the cycle before the next car arrived. While I was more or less able to do what was required, I certainly wasn't skillful, as I was drenched in sweat from my exertions.

SIMILARITY OF SEAT INSTALLATION TO OTHER ACTIVITIES

My experience trying to learn to install seats was typical of my experiences doing other assembly line jobs, even when they required less physical exertion. Furthermore, my experience doing assembly work was similar to that of other novice people more generally, as will be illustrated in the following accounts.

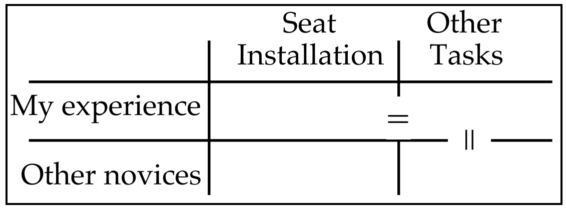

Figure 70: Comparability of production experiences

Electronics Test

Installing seats was not simple for me. Try as I might, I couldn't master the process with anything near the fluidity of Willie. The zone supervisor compassionately assigned me to a far less strenuous job, one I was able to do while sitting down.

The Electronics Test is done at the very end of the assembly process. When the car arrives on the conveyor belt, it is physically complete. All of the parts have been attached, gasoline and other fluids have been added, and the very next thing to do is start the engine and make sure the various systems are running properly.

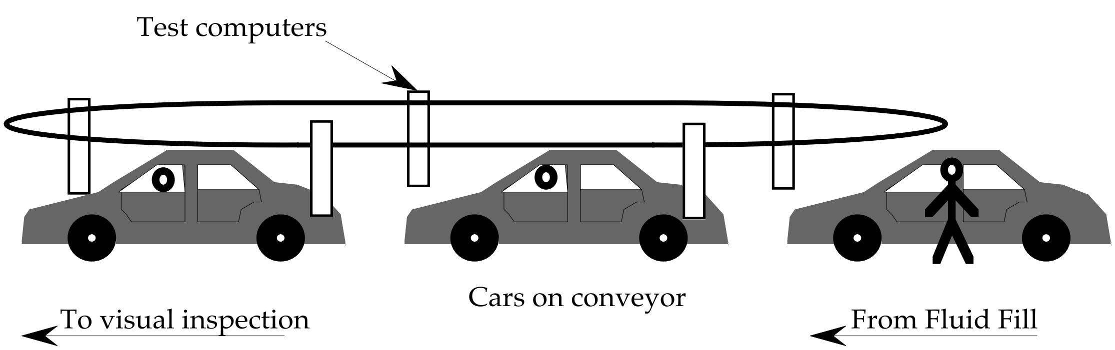

Figure 71: Electronics tests

As with seat installation, I was introduced to one of the people, Theresa, who ordinarily did the work, and like in seat installation, I learned how to do this activity, first by watching her perform the entire routine and then trying to do the whole routine myself with her coaching.

The test steps were: Along with the other people who did the test, we waited on a picnic bench for the next car to arrive. We took a video cassette and the license plate frame from containers on the picnic table where we sat, put them in the glove compartment, and then, as the car continued to move on the conveyor, attached the car to the test computer, which -- riding on its own conveyor -- moved in synch with the car. Once inside the car, we started the engine and went through a series of steps such as honking the horn, using the wipers and the headlights, turning on the radio and checking the pre-set buttons.

This activity was far less strenuous than installing seats, but it had its own share of challenges. Not the least of these was remembering the sequence of test steps. The seat installation activity provided a number of clues as to whether I had done my work correctly or not (i.e., I had used all of the bolts I had started with, and each bolt had tightened when hit with the torque wrench). The Electronics test offered fewer visual and tactile clues yet was more sensitive to sequence because the computer was programmed to test particular components and systems in a particular sequence. For instance, on the first of the two days that I did the Electronics Test, Theresa, who rode in the passenger's seat, continually needed to correct me, telling me that I had missed a step or had gotten the steps out of order.

One of the benefits of doing the Electronics test was that we were able to listen to the radio inside the factory. Specifically for the purposes of testing the radio, there was a small broadcast antennae in the area. The only draw-back was that we could only listen for 45-50 seconds before having to leave the car, so it was normally not possible to hear an entire song.

BODY SHOP

During the first part of the week, I did work in the final assembly area. Later in the week, I also worked for ninety minutes in the body shop, attaching rear-quarter and roof panels to cars as they passed between welding stations.

WORK STATION INTRODUCTION

In this job, I attached metal panels temporarily so that they would hold in place long enough for the welding robots to fasten the parts permanently. The process flow and the work area layout are in the next diagrams.

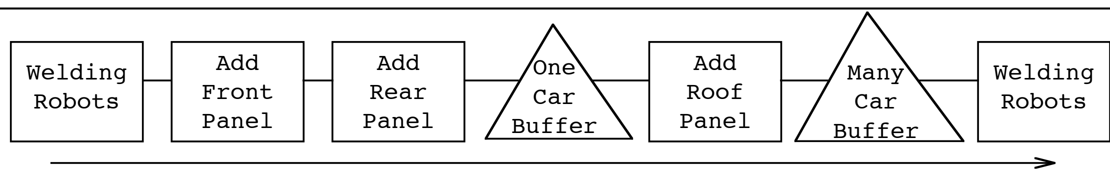

Figure 72: Schematic view of work station

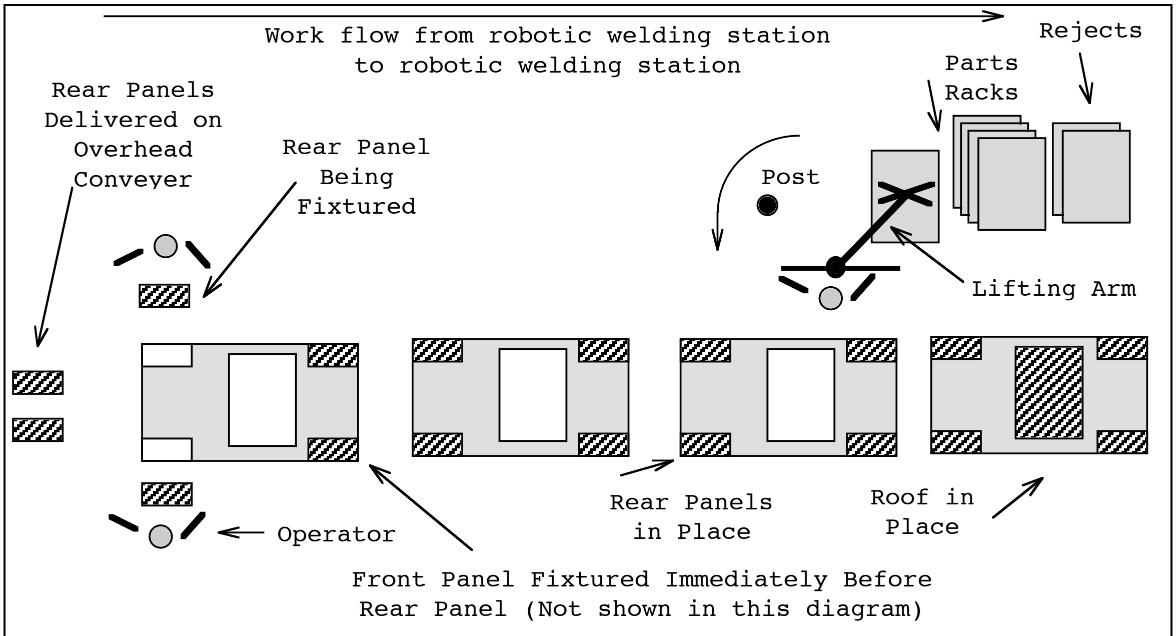

Figure 73: Body shop part attachment station

On The Job Training

Training for this assignment was entirely on the job. The person who normally worked in that job showed me the entire sequence for several cycles, coached me through the entire sequence for the next several cycles, and then left me on my own until the break (about an hour).

This training appeared to be typical for a novice worker, even one not in the plant under the special circumstances characteristic of my situation. For instance, while I was working in this station putting on the roof panels, a new part-time worker with whom I went through the Human Resources introduction the previous Monday, was performing the same job on the adjacent assembly line. He too was working alone, without a direct supervisor, and separated from adjacent work areas by work in progress.

Rear panel placement

Just as seats were brought to the main line by a conveyor, rear panels also came to the workstation via an overhead conveyer. As the operator at that station, I did the following steps:

1. Raised a small hydraulic parts carrier up to the part (at a height of approximately 12 feet),
2. Pressed buttons to "grab" the work piece with suction cups and a clamp,
3. Lowered the piece to waist height,
4. Used an air gun to apply a bead of sealant,
5. Released the clamp so that the panel was held only by suction cups,
6. Pushed the panel onto the waiting car,
7. Held the panel in place with the left hand, and released the suction cups with the right hand by pressing a button,
8. Pushed the conveyor away and made sure the panel was well seated,
9. Bent two metal flanges by hand to hold the panel to the car,
10. Walked five steps to a parts bin to get a 3 foot horizontal cross piece,
11. Attached this piece to the rear panel and the car body with a thumb-push plastic "rivet,"
12. Placed a bead of sealant where the roof panel was to be placed,
13. Took the next panel from the overhead conveyer,
14. Pressed an "all-clear" button that released the car to the next station.

Roof Placement

The steps to attach the roof panel were:

1. Using a mechanical parts carrier with suction cup attachments, lifted the roof from a parts bin,
2. Turned to the left (counter-clockwise) to face the car body and align the roof (this required clearing the light post shown in the diagram.),
3. Lowered the roof panel onto the car body,
4. Pressed a button to release the part from the carrier,
5. Bent a metal flange to hold the panel in place,
6. Turned clockwise to take the next piece from the parts bin.

Periodically, when the parts bin was empty, I had to push a button to automatically remove the empty bin and replace it with a full bin. There was a separate bin in which I could place roof panels I judged to be defective.

There were some differences between attaching the roof and attaching the rear panel. First, the roof panel came out of a carrier and did not have to be lowered from a moving conveyor. Second, I had fewer, less time-consuming steps to do. Therefore, even when the line was running without pause, I had a fair amount of waiting time. In contrast, while I was able to work at a comfortable rhythm when attaching the rear panel, it took nearly the full cycle to complete the work.

Problems in Roof Placement

While the roof placement job was one of the least rushed ones I performed, it did have its frustrations. As shown in the preceding diagrams, moving the roof from the parts rack to the car body meant clearing a light post. Judging by the banged and cracked lens on this light, it was obvious that the work piece often hit the light, thereby risking damage to the product and damage to the equipment.

The problem was, as a fill-in, I had no way of removing the obstacle. I had no idea even whom to tell about the difficulty. Judging by the degree to which the obstacle post was marred, the regular worker also lacked either the authority or the responsibility to make changes in the work area. Therefore, every car required that the operator use extra care and make extra effort not to damage either the equipment or the product.

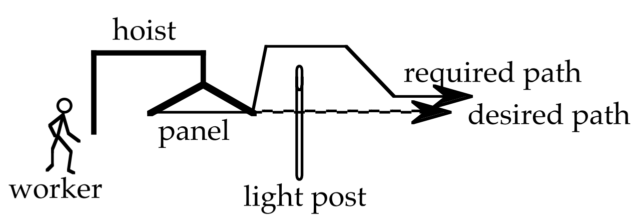

Figure 74: Avoiding the light post obstacle

There was another problem I recognized only in hindsight. I had a place to put defective roof panels. It was not empty when I began working at that station, so presumably, the panels occasionally were defective. However, I didn't know how to determine if a panel was or was not defective. Were I to find a defective panel, it is not clear how putting the panel in the defective-panel rack would have generated information useful for process improvement.

Paradox: When an easy job is really a very hard job

Putting on the rear-quarter panel occupied me for most of the 100 seconds available in each cycle. In contrast, putting on the roof panel occupied only 40 seconds, so I was idle for more than half of the operating cycle. However, due to the layout (with cars filling spaces between work stations), it was not clear how to balance work better so that one worker might be less rushed and the other could be more productive.

Writing this section reminds me of a comment made by Mr. Ohba when we first met. We were touring a non-Toyota plant in June 1995. After watching a worker perform assembly work -- he commented that the employee had a particularly difficult job. That comment struck many of us as odd since this particular worker was hardly rushed. Actually, of the minute or so per cycle, she had nothing to do for nearly 30 seconds. In fact, her job seemed relatively easy, not difficult by any means.

I later came to understand Mr. Ohba's perspective (developed, presumably, during his employment with Toyota). Because the assembly worker was not busy, her job was boring. For thirty seconds of every minute, she had to occupy herself mentally.

It was more than boredom that was the problem. Because her employer was not keeping her busy throughout the work cycle (in effect, she spent half of the shift doing nothing), her employer was implying that her time and she herself were not valuable, according to Mr. Ohba.

If that is not intuitively obvious, consider the signs of someone being valued in the professional world: pagers, cell phones, faxes, e-mail, call waiting, day planners and Palm Pilots -- all devices which remind us that we are indispensable. It is not only beneficial for the employer if everyone is fully occupied creating goods, services, and information valued by customers, it is beneficial to the employee as well.

Problems in Rear-Quarter Panel Placement

Banging the roof panel against the obstructing light post was but one of the problems I experienced while working in the body shop. More significantly from the perspective of worker safety and product quality, the equipment I used to lower the quarter-panel off the overhead conveyer failed, and it twice released the metal piece from a height of about 10 feet, so that it fell past my face before crashing on the floor. Both times, the person working next to me and I were able to pick up the piece, visually confirm that it was not damaged, and then put it on the car body within the cycle time of 100 seconds. After the second failure, the Area Team Captain came over and fiddled with the equipment, explaining that the problem was a recurring one with this piece of equipment.

Upon reflection, it seemed that the adjustment he made solved the immediate problem, but the underlying problem was not solved. My concern was that the next time the equipment again goes “out of tune," it would again drop the material until the same temporary solution is used, thereby posing an ongoing risk to the integrity of the part and the safety of the employee.

Also, upon reflection, I realized something else. I wasn’t the person who called the Area Team Captain for help. Either someone else called him, or he observed the difficulty I was having and came to my assistance after the *second* failure. To be precise though, I was not doing, nor was I able to do, the job I had been assigned during orientation. During the orientation, we had been told that when problems occur, we were supposed to notify the ATC or the area supervisor. However, I neither knew who these people were nor did I know how to reach them.

Again, I must add the caveat that I was doing this job under special circumstances, so it may be presumptuous to draw far reaching conclusions from this event. However, I was working across the line from a part-time worker who had gone through the same orientation and who had received the same instructions. Also, this condition was not strictly characteristic of this portion of the Big-Three line. In the other non-TPS plants in which I gathered data, the operators (i.e., the people doing the activities for which the customer is paying) were not able to distinguish good from bad, did not know who to call if they could tell good from bad (i.e., that a problem had occurred), or did not have a reliable mechanism of calling for help when a problem occurred, even if they knew who to call.

SUMMARY: ROUTINE PRODUCTION WORK AT THE BIG-THREE PLANT

Before discussing the design and performance of other activities done in other work settings, I'll pause to highlight the salient characteristics of the activities I did and observed in this particular plant.

Orientation	As the reader will recall, we were told about various quality and safety systems during the orientation. However, no one with whom I worked referred to these systems when teaching me what

	to do. Therefore, at least part of the orientation was not relevant to doing the actual work. Likewise, during the orientation, we were told that we as workers were responsible for detecting problems and alerting the Team Captains and supervisors. However, in reality, problems were not well-defined nor was it simple to send the message that a problem had occurred. Consequently, at least part of the orientation was not actionable.
Off-line training	None of the off-line training was specific to the particular job I was to do (or that part time workers were to do).
On-the-job training	Informal, the points that were emphasized depended on the style of individual operator.
Work design	Work design was highly personal. There was no standard sequence of work-elements to which I had to adhere. Rather I copied and modified what I learned from Willie, Theresa, and others.
Problem detection	Based on individual heuristics.
Problem notification	Data entered into the computer; unclear who to tell when a problem occurred despite responsibility assigned during orientation.
Problem remediation	Done after the fact, and not by the person doing the work.

The next portion will compare the design and performance of activities in TPS-managed plants with the description just given. Before this transition, I want to make something clear.

The comparisons that follow will, to some readers, imply an advocacy for the Rules-in-Use as guidelines for designing, operating, and improving activities, activity-connections, and flow-paths. Though I tried to write these descriptions without a judgmental tone, a bias may nevertheless be evident. However, please do not mistake partiality for a system characterized by a particular set of heuristics with disrespect for the people who work in other systems.

For instance, though the work at the Big-Three plant may have contained difficulties and challenges that were not evident in TPS-managed situations, the people whom I met at the Big-Three plant were universally excellent. Both line workers and supervisors worked exceptionally hard to provide the customer with an outstanding product. The zone supervisor who was responsible for me that week treated his employees and his colleagues with respect and compassion. His response when someone erred was to show them how to do better. He did not respond in a stereotypical characterization of intimidating rage. Likewise, Willie, Theresa, and the others who helped me do their work, were trying to "get it right" each time.

The attitude of the workers and managers in the plant was positive and infectious, as reflected in the following journal entry.

> 16 June --, Michigan (my birthday today!)
>
> Wow. What a week. Six days of six o'clock shifts, seat installations (one bolt every twelve seconds), and an articulating arm in the body shop that

occasionally dropped the sheet metal panel I was supposed to attach in the welding line.

I'll tell you what though, leaving the motel parking lot on my way to the airport, I pulled up alongside a trailer load of brand new, shiny cars, right off the line, and there was no small sense of satisfaction that with my own hands I might have contributed in some small way to creating that product.

A nice way to end the week.

This clearly is not the "Dear Diary" notation of someone who emerged from a unpleasant experience with unpleasant people. Rather, as I make comparisons between work done at the Big-Three plant and Toyota specifically, and between work done in non-TPS settings and TPS-managed sites more generally, I'm not being critical of the people in either setting. As I will try to illustrate, the non-TPS *systems* limit the ability of people, even those with the best of intentions, from doing an outstanding and a continually more outstanding and satisfying job.

For instance, I described that in the body shop, I was active only 40 of the 100 seconds that each car spent at my work-station. However, it was not clear that there was anything I could have done to add more value to the product that customers would pay for. Likewise, Willie may have had to devote time during each cycle and during each shift adjusting the J-Clip in cars as they came by.

However, he could not change the way they were inserted in the first place to eliminate this little bit of rework each time. In other words, even a talented, motivated person was bounded in making local changes that would have positive system repercussions. Therefore, as I begin to compare observations across sites and functions, please remember that I am comparing management *systems*, and I am not judging the people in the system.

PRODUCTION WORK AT TOYOTA ASSEMBLY PLANTS

The preceding portion described my experience as a novice worker in a conventionally managed Big-Three plant. These experiences included the initial orientation, on-the-job training and hands-on work in three activities: body panel installation in the body shop, seat installation in final assembly, and one of the final quality checks. This next portion describes several sets of observations I made in Toyota assembly plants. These observations include:

- new-hire training given to assembly workers at the Tsutsumi plant in Japan and at the Toyota truck plant in Indiana.[18]
- on the job training at Toyota's Georgetown plant.[19]
- seat installation at Toyota assembly plants where I collected data: including Kyushu, NUMMI, and Kentucky.[20]

Observations from these plants allowed me to construct a composite of the experience a worker has from the time they are hired at a Toyota plant through several years on the job.

From this composite, we can compare the design and performance of training activities, production activities, and assistance activities at the Big-Three

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[18] As explained and demonstrated by HR managers at each of these two plants, in Spring '96 and Fall '98, respectively.

[19] As explained to me by a final assembly team member, Fall 1998.

[20] The Indiana plant was not yet in operation when I visited.

and the Toyota plants. Later, other evidence will be introduced to show that the specific observations made at the Big-Three plant are representative of activity design and performance generally at plants not managed by TPS, and that the specific observations made at the Toyota assembly plants are representative of activity design and performance generally in TPS-managed situations.

STRUCTURED, TESTABLE PRODUCTION ACTIVITIES

The way in which work was performed in the Toyota plants differed considerably from the way in which I performed or observed similar tasks performed at the non-TPS-managed sites where I gathered data.

SEAT INSTALLATION - TMMK (TOYOTA - KENTUCKY)

At the Big-Three plant, Willie had his own method for putting the right, front seat into the car. While he showed this to me so that I could do the work, I don't believe he expected that I would follow his approach exactly, nor, would I consistently use exactly the same approach. This impression is borne out by the fact that Willie provided further guidance only when I was unable to complete the whole task. In other words, he intervened when the outcome was flawed but not when the method was flawed.

Likewise, in the body shop and in the electronics test, there was not the expectation that each worker would do the same job the same way as other workers, or repeatedly use the same method without variation. Therefore, there was variation between the method used by me and that used by Willie and there was variation in the method I used each time I tried to attach the seat in the car.

This was not the case at Toyota's Kentucky plant, at the Toyota/GM joint venture, NUMMI, or at the Toyota Kyushu plant where I also observed people installing the front seat. At Toyota-Kentucky, for example, installing the right front seat had 7 distinct, pre-specified steps. Each step was designed (expected) to take a specific amount of time, and there were intermediate tests to ensure that the work was actually performed as it is designed to be performed and that the actual outcome matched the expected outcome. In other words, seat installation at Toyota's Kentucky plant was structured and self-diagnostic with:

- work-elements pre-specified as to content, sequence, and timing
- a pre-defined, expected outcome
- a test that the actual work is being done as designed
- a test that the actual outcome is equal to the expected outcome

The seven, pre-specified installation steps are summarized in the following table. They required 46 seconds of work and 5 seconds of walking, thereby occupying 51 seconds of the 55 second cycle. [I observed this sequence of work-elements directly on a visit to the Kentucky plant in November 1998. The time-per-element are from the standardized work sheet. The quality checks were described to me while I observed the work and were included in the standardized work sheet.]

Step	**Description**	**Time (work/walk)**		**Quality Check**	**Safety**
1.	Check manifest	2			
2.	Set hoist to seat	3			
3.	Set seat to door area Place rear bolt covers on rear floor and return hoist	6 4	2	Gun torques out (to pre-specified torque) to confirm tightening. Blot head flat to seat rail.	T/M must be trained to use equipment for safe ergonomics
4.	Install 2 front seat bolts	14			
5.	Adjust seat forward	4	3		
6.	Install rear seat bolts	11		Gun torques out (to pre-specified torque) to confirm tightening. Blot head flat to seat rail.	Use left hand to shoot outside rear bolt to reduce strain on right hand and elbow
7.	Install bolt covers	7			
	Total	46	5		

Figure 75: Standardized work: Right front seat installation - TMMK

In addition to this pre-specified sequence of steps, there are multiple tests to ensure that the steps are performed properly and that the actual result equals the expected result. For instance, in the next diagram, I have duplicated the standardized work chart that was developed and initialed by the team members and team leaders who do this particular job. On it, the *expected* starting and finishing location for each work-element is marked on the chart. Because each team member and team leader is supposed to know where each work-element is supposed to (expected to) begin and to end in the course of the cycle, both the team member and the team leader can compare the workers' actual location with the expected location. A difference between the actual and the expected acts as a signal that the worker is not keeping pace and is falling behind.

For instance, in the standardized work chart, Step-4 is supposed to (expected to) begin before the car has been in the work zone 15 seconds. If, however, the worker actually starts Step-4 when the car has advanced to the 18-second location (marked by an A in the diagram), the worker has fallen behind by 3 seconds. Consequently, this test sends an immediate signal to both the team member and the team leader that the worker has fallen behind the expected pace of production.

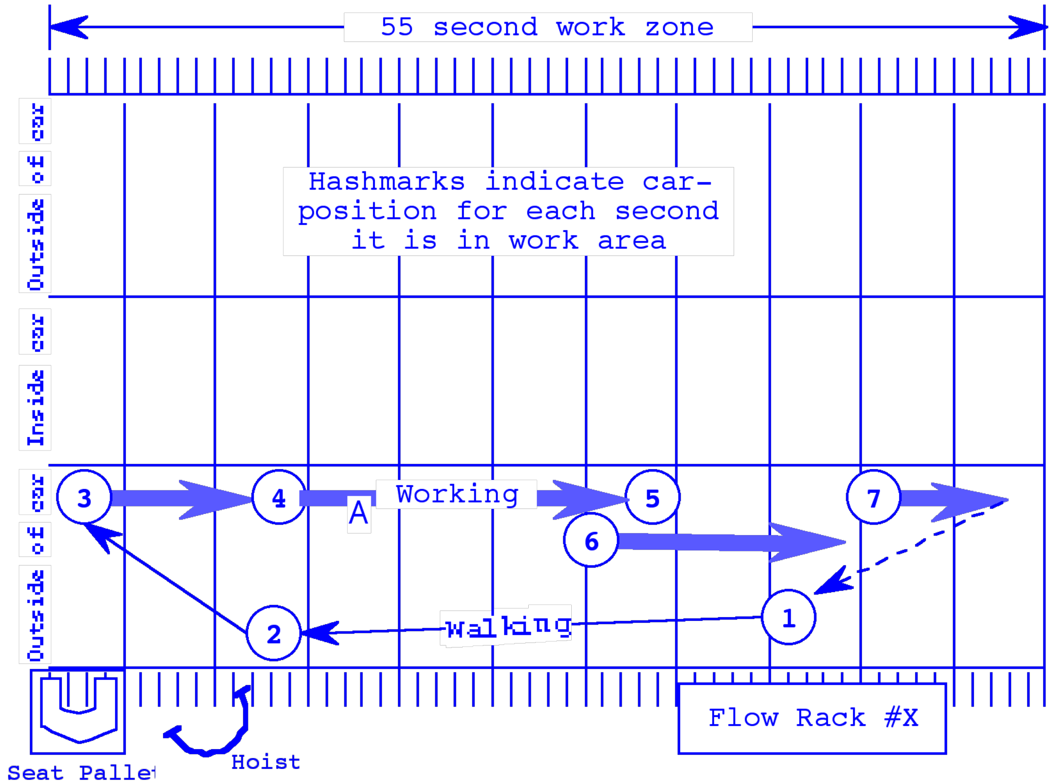

Figure 76: Standardized work chart - Seat installation, Toyota Kentucky

At the Toyota assembly plants where I collected data, the assembly line floor was marked with painted lines so that both team member and team leader can compare the portion actually done with the portion of work that should have been done. At Kentucky and Kyushu, for instance, demarcations were every 1/10th of the work cycle. This is illustrated in the following diagram.

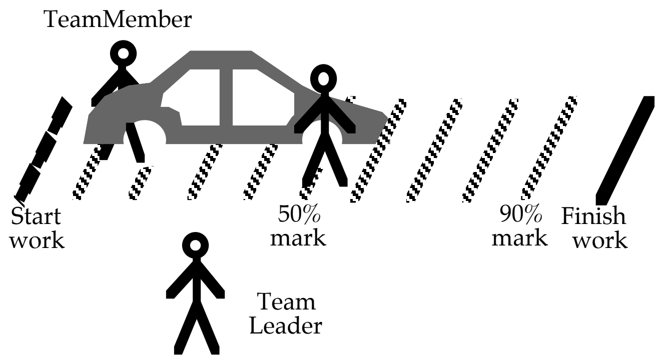

Figure 77: Self-diagnostic activity: example - Car at 50% done mark

The hash-marks on the work area floor are one test that the pre-specified work elements are being performed as they were designed to be performed. In addition, at both Step-3 and Step-6 of the seat installation standardized work, there are two tests that check that the actual outcome is equal to the desired outcome. There is both a visual test (that the bolt head is flat to the seat rail) and there also a physical test that the torque wrench has 'torqued-out' to the pre-specified level.

In sum, though all the assembly plants I visited install front, right seats, the way this installation was done differed between the Big-Three plant in which I worked and the Toyota plants in which I observed. At the Toyota plants, the activity had:

- work-elements pre-specified as to content, sequence, and timing.
- a pre-defined, expected outcome from doing the work-elements as designed.
- tests that the pre-specified content, sequence, and timing were being followed (signaling a problem when they were not).
- tests that the actual outcome met the desired (expected) outcome (signaling a problem when it did not).

Therefore, comparing my experience installing seats at the Big-Three plant with what I observed at Toyota contributed to (but was not the sole basis for) the conclusion that an essential element of TPS is that activities be designed and performed as *structured, self-diagnostic activities*.

Final Assembly: Toyota (Pre-fabricated) Homes

I observed a similar approach to making a production activity structured and self-diagnostic at a plant in which Toyota makes pre-fabricated homes. There, assembly of housing modules done by standardized work (i.e., work elements pre-specified as to content, sequence, timing, and outcome). Unlike auto assembly with cycle times less than a minute, a house-module spent 5 minutes at each station. Consequently, managers explained that the end of cycle was too late to determine if the supplier (assembly worker) was ahead or behind.

In response to this perceived problem, a signal board was created that indicated the passage of each minute so that the operators and team leaders would have more frequent diagnostic opportunities than if they checked only at end of cycle.

Comparison between micro and macro data

The reader may have noticed that each Toyota worker does the same work as two workers at the Big-Three plant to which I have been referring. There, one person took the seat from the hoist, and the other (Willie) bolted it to the frame, both working within the 57 seconds that each car was at each work-station. At the Toyota plant, one person performed both activities in 55 seconds or less. Not only were two people required to do the same job that one person could do in Toyota's Kentucky plant (as well as at NUMMI), double the floor space was required, since each person had their own work zone.

Elsewhere, I discuss Cusumano's observation that Toyota was twice as productive as its North American competitors through the 1970s and the 1980s. Therefore, my observations made at the micro-level and his based on aggregated data are consistent with each other.

TRAINING

Other observations also contributed to the articulation of Rule-1 specifically in the context of production work. I will share these data later in this chapter. For the moment though, I will continue to discuss observations related to the seat installation activity. Now though, I will step back from the actual performance of this specific production activity and focus on the training activities used to prepare a new hire for assembly line work.

In gathering data, I discovered that training (i.e., a specific example of a service activity) was both structured and self-diagnostic in TPS-managed situations. Therefore, training-related observations contributed to my conclusion that -- where TPS applied most rigorously -- *all* activities would be designed and performed in a structured and self-diagnostic fashion.

The training-activities done at Toyota differed from those done at the Big-Three plant. Recall that at the Big-Three plant, the new part-time workers and I had a four-hour orientation that provided information that was out of context with the jobs we might actually be doing. Our next training occurred on the job as we tried to master a particular assembly task while the line was operating at full speed. As I described above, the operators trained me in an informal way, introducing various tricks of the trade, such as using an awl to align the J-Clip, as problems arose. The training lasted less than a shift, and I personally was not well equipped to identify problems as they occurred, to resolve the problems on my own, or to call for help. This starkly contrasts with the experience of new workers in Toyota assembly plants.

OFF-LINE TRAINING AT TSUTSUMI [21]

At the time of my visit to the Tsutsumi assembly plant, new hires had an off-line training session. Before a new person was assigned a line job, they had to demonstrate that they had mastered certain skills. Mastery was demonstrated by means of a pass/fail test. For example, to demonstrate flexibility, the person had to be able to flex their wrist back (knuckles towards the forearm) so that the

21 Based on a single day plant visit in Spring, 1996.

interior angle was less than 80˚. This was to ensure that the person was flexible enough to avoid repetitive motion injuries. To show dexterity, the person had to lift steel marbles with chop-sticks. This was to show that the person was able to pick and manipulate small parts on the line. Also, to show manual dexterity, the person had to reach into a bag and withdraw the exact number of bolts requested by the instructor. All these tests were designed to ensure that when a new hire joined a team on the line, they were fully capable of learning the specific tasks required at that particular work-station.

OFF-LINE TRAINING AT TMMI (INDIANA)[22]

At Toyota's new truck plant in Indiana, I learned that new hires were also to receive extensive off-line training so that when they joined a production team, they would be capable of learning the skills specific to their new assignment. To accomplish this, the off-line trainer, a member of the Human Resources department, was going to teach the new-hires how to work on a scale model assembly line. This model line was approximately 15 feet long by 4 feet deep, accommodated 4 workers, and was used to build mini-trucks from Lego blocks. On this line, the new-hires were to learn basic concepts and tools which were to be widely used in the production setting. These concepts and tools included:

- standardized work
- takt time production

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22 Based on a single day plant visit in Summer, 1998.

- reading manifests to know what work must be done on each unit
- error detection
- kanban cards to request replacement parts and materials
- andon cords for calling assistance

The instructor was to apply a pass/fail test to ensure that the new-hire had learned the relevant skill or tool. If the new-hire passed all of the tests, they would be eligible for assignment to an actual assembly line job. If they had not passed, they were to be trained until they were able to pass. As several managers indicated during a discussion, there would be no pre-specified length of time for this training. People would be trained until they had learned the skills that they were being taught.

From this data, I concluded that training activities about which I learned were designed and performed in much the same way that production activities were designed and performed in the Toyota Production System managed situations that I had studied. Just as with a production activity, training was defined as an activity that converts an input (an untrained person) into an output (a trained person). In both cases, there were work-elements, pre-specified as to content, sequence, timing, and outcome, that were designed to produce the defect-free output. Likewise, in both the production and the training settings, the activity was testable. Defective outcomes such as mis-aligned bolts and workers who had not mastered skills could be distinguished from defect-free outcomes such as properly aligned and tightened bolts and workers who had mastered the skills that they had been taught.

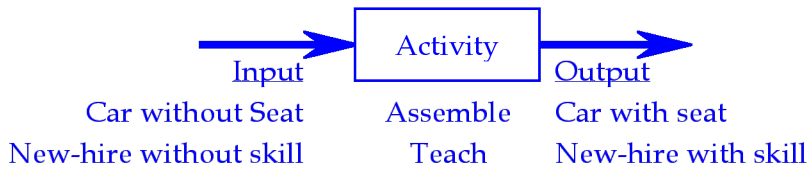

Figure 78: Assembly, teaching: activities with yes/no inputs and outputs

ON THE JOB TRAINING - TMMK (KENTUCKY)

At Toyota's Kentucky plant, I learned that new workers were assigned to a particular location on the assembly line. There, they learned specific work-elements in a way different than what I experienced at the Big-Three plant. Comparing the training I experienced on the job at the Big-Three plant, the training I observed workers receiving in other non-TPS settings, and the on-the-job training I documented at TPS-managed sites (through direct observation and interview) contributed to the articulation of Rule-1 so that it applies broadly to *all* activities and not only those that transform material from one form to another.

I had observed that workers installed seats at Toyota's Kentucky plant by following work elements pre-specified as to content, sequence, timing, and outcome. In addition, both the actual work and the actual outcome were tested to ensure that the work was performed as designed and to ensure that outcome was defect-free. I observed the same approach towards seat installation at

Toyota's Kyushu plant and at the TPS-managed NUMMI plant in Fremont, California. The same held true for on-the-job training to install the seat.[23]

At the Kentucky plant, I learned that a new-hire -- a person who had passed the flexibility, dexterity, and other skill-tests administered during off-line training -- joined a team and learned production jobs from a more skilled worker, normally a team leader. In this regard, this sounded similar to how I learned seat installation from Willie or electronics tests from Theresa.

Despite this surface appearance, the differences were substantial. Remember, neither Willie nor Theresa had work-elements of a pre-specified, self-diagnostic content, sequence, timing, and outcome to guide their work. Rather, they each had an individualized approach to their work. Furthermore, when they taught their work to me, they showed me their entire work routine and then let me try the entire work routine. I was not able, even after many hours, to correctly install a right, front passenger seat without Willie intervening in some fashion. Sometimes he made sure that the code was entered into the computer monitor, sometimes he completed bolts when I fell behind, or sometimes he retorquing a bolt that had missed the J-Clip.

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23 The following account and comparison is based on interviews with a team member, team leader, and manager at the Toyota Georgetown plant in the November, 1998. Similarity between the training they described to me and that performed in other TPS-managed settings will be described below.

In contrast, the training work was done differently at Toyota's Kentucky plant. Just as the assembly work was done as work-elements with a pre-specified content, sequence, timing, and outcome and with pass/fail tests throughout, the training work also followed a pre-specified sequence with pass/fail tests. According to the line-workers and managers with whom I spoke, new workers were shown each of the work-elements and were then allowed to perform the first work element, with the experienced worker completing the sequence. This continued until the new person was always able to perform that first work-element in the time indicated in the standardized work. Only once the new-hire had passed this test did they move onto practicing the second work-element, with the teacher completing the remaining five. This process continued until the new person has mastered the entire sequence.

Again, the differences between how I was trained at the Big-Three plant by Willie and Theresa, and how the team member and team leader who provided this description were trained are subtle but important.

Both Willie and Theresa showed me the entire work routine, allowed me to try the entire work routine, and intervened as I had difficulty. Where I had difficulty varied from cycle to cycle, sometimes in early steps, other times in later steps. In other words, my problems were stochastic, unpredictably occurring anywhere within the 57-second work cycle.

A new worker at Toyota, Kentucky was also bound to have trouble. However, consider the implication of teaching in a step by step fashion, not advancing to a new step until the preceding step has been mastered. Whereas my problems as a trainee at the Big-Three plant were spread out over a 57-second interval, the problems of a trainee at Toyota Kentucky would have been confined to the time segment of one step. Because the training/learning process was designed, was being performed, and was being controlled with greater resolution (finer granularity) the response to problems could be done with finer resolution and finer control. When teaching me, Willie had to be able to detect and respond to problems at any point in the work cycle. Had he been training me in the step by step fashion, he would have been able to concentrate his attention and his efforts more precisely.

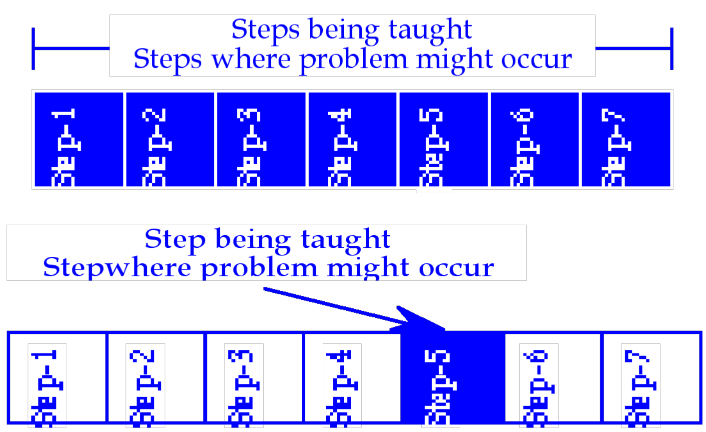

Figure 79: Step by step teaching to isolate location of problems

According to the team member who described on the job training in seat installation, learning to use the seat hoist typically requires 2 hours. In contrast, learning to install the seat requires two weeks. The relative difficulty associated with each task is consistent with my own experience at the Big-Three plant.

Taking the seat from the hoist is akin to moving body panels as I did in the body shop, a task which I found to be relatively stress free in contrast to bolting in the seat which left me exhausted.

EASE OF WORK - NUMMI AND KENTUCKY

Earlier, I emphasized that in making comparisons between TPS and non-TPS-managed work environments, I am not making judgmental comparisons between those who work in TPS-managed situations and those who do not. Seat installation provides an example of this distinction between judging the management system and the people being managed.

The assembly line worker who I observed installing the right front passenger seat in Toyota's Kentucky plant did the work of two people in the Big-Three plant. By this comparison, I am not suggesting that the Willie, in Michigan, was any less motivated or possessed any less inherent skill than his counterpart in Georgetown, Kentucky. Rather, Willie's counterpart was working with certain advantages that Willie, individually, cannot duplicate or off-set.

First, as explained before, Willie's counterpart had the benefit of a structured, self-diagnostic activity with its work elements pre-specified as to content, sequence, timing, and outcome, and with built-in, 'real-time' tests that the work was being done properly and that the output was defect-free. Second, Willie's counterpart had a work area specifically designed to facilitate greater productivity by the individual worker without extra effort, stress, or exertion. For example, Willie did a lot of walking in his job. He walked to get bolts from the line side table, he walked to get the torque wrench, and he walked if he needed the awl to straighten the J-Clip. In contrast, Willie's counterparts at NUMMI, Kyushu, and Georgetown had carts that carried the air gun and that carried the bolts for the worker. Therefore, the worker did not have to repeatedly leave the line for parts and equipment. Rather, the cart joined the car at the start of the work-station and traveled with the car for the entire 55 second cycle. Consequently, the worker had what he needed, when he needed it, where he needed it. In contrast, Willie had to spend time getting what he needed, bringing it to where he needed it, when he needed it. As a result, the work area itself at the Toyota sites was designed so that the worker could spend more time adding value by installing seats. In contrast, the work area was designed so that Willie and James had to spend relatively more of their time retrieving the material and machinery they needed to create value for the plant's customers.

COMPARISON OF NON-TPS AND TPS SEAT INSTALLATION-SUMMARY

The following chart summarizes the differences between the design and performance of seat installation and seat-installation training activities that I experienced at the Big-Three plant and about which I gathered evidence at Toyota assembly plants.

	TPS-managed	**non-TPS**
Off-line Pre-training	• Work-elements with a pre-specified, testable content, sequence, timing, and outcome	None
On-line training	• Work-elements with a pre-specified, testable content, sequence, timing, and outcome	Informal, Not-testable
Activity	• Work-elements with a pre-specified, testable content, sequence, timing, and outcome	Not standardized
Activity Test	• Hash-marks on floor to check work element timing • Standardized work known by team members and team leader.	None
Output test	• Torque wrench • Bolt counting • Visual check of bolt position	Heuristics of individual operator

ADDITIONAL DATA CONTRIBUTING TO ARTICULATION OF RULE-1

NHK TOYOTA: FULLY LOADED JIGS

Auto assembly was not the only work that I observed to be done as structured, self-diagnostic activities. For instance, at the NHK (Nippon Spring) Toyoda plant, wire was cut, bent, and the pieces were welded together to form a seat frame. To create a defect-free product, the production worker had to insert approximately a dozen wires into fixture that a robot then welded together. The problem was that each work-station had as many as four different jigs, so it as difficult for a worker to remember the correct loading sequence and to know which sequence was required when. Therefore, it was possible for the operator to forget to insert a wire before starting the robot. In response to this problem, sensors were installed on the jigs, so that the welding robot could not begin until all the slots in the jig are filled. For this activity, this was a self-diagnosing test to ensure that no parts were missing and to increase the likelihood that the output would be defect-free.

ACME: WORK DESIGN

While promoting TPS at the company that rebuilds starter motors and alternators, the Toyota people helped developed structured, self-diagnostic activities for assembly work. This included the development of standardized work in final assembly; arranging parts so the operator picks left to right (thereby increasing the structure of the work and increasing the clarity that it is being done correctly or not (yes/no), and demarcating start-work and end-work lines to ensure test that work gets done in expected space and that one worker doesn't feel the need to drift into another's space.

LONGITUDINAL COMPARISON: DIE CHANGEOVERS

The preceding examples made cross-sectional comparisons between the design and performance of activities used to make similar products using similar processes. I will again compare activities that were similar in terms of product and process. However, rather than a cross-sectional comparison between sites, I will make a longitudinal comparison at the same site. Specifically, I was a member of a team that spent five months trying to promote TPS at a first-tier supplier of Toyota's Kentucky assembly plant. While promoting TPS, we tried to teach the workers and managers how to reduce the time required to change the dies in the plant's stamping presses. Our objective was to reduce changeover time so that the plant could produce parts for a greater portion of each shift, thereby allowing it to reduce the sizes of its batches, decrease the length of its lead times, and decrease the frequency of missed shipments. We tried to convert an activity from a form in which it was neither structured nor self-diagnostic to a form in which it was structured and self-diagnostic. We did this by working with the people responsible for a 400-ton press including the operators, a die setter, a fork-lift driver, a tool and die maintenance person, and the team leader.

The experience of training this team also provided data which led to the formulation of Rule-1, the guide to designing and performing activities so that they are structured and self-diagnostic with a pre-specified, testable content, sequence, timing, and outcome. Studying the die-change process at other plants also contributed to the formulation of Rule-1. Therefore, a discussion of these other observations will follow.

Press-Shop Roles

In the press shop, the operator was the relatively less skilled worker, the die setter the relatively more skilled worker. Operators tended the machines while they ran, collecting parts in containers and replacing full containers with empty containers. Die setters were active when a die had to be removed and a new die had to be placed in the press in order to make a different part. Because the die had to be precisely located in order to make a good part, die-setting was considered a skilled trade in that it required more expertise with the tools and equipment.

Initial Condition

The supplier plant in which our Toyota team worked stamped metal parts using presses ranging in size from 60 tons to 400 tons. A bolt or pin was welded to some of the parts after they were stamped while others received no additional processing. In addition to Toyota, the plant had two other auto companies as customers (both transplants), with Toyota representing approximately 50% of the plant's production volume and one-third in terms of part numbers.

Our team found that the downtime on the presses was substantial because several hours could elapse from when the last piece of one batch was finished to when the first piece of the next batch was produced. With such long changeover times, the stamping equipment was frequently idle, thereby necessitating long runs (i.e., large batches and large inventories) and often causing short falls in the welding/assembly process and in shipping.

For example, to get a sense of the overall downtime in the plant (as running times and downtimes were not recorded by plant personnel), I made spot checks of the equipment each day for several days. I would go to each machine, record the part it was making and the rate (strokes per minute; "spm") at which it was running. For instance, Press 4 is one of the two 400-ton, high-speed automatic transfer presses in the plant. In the seven spot checks I made, it was running only twice. Four times, it was in the middle of a changeover, and once a tool and die maker was grinding a tool while it was in the machine.

#	Jan 29	Jan 30	Feb 3	Feb 4 am	Feb 4 pm	Feb 5	Feb 6	Running
4	30 spm	C/O	46 spm	C/O	Die Rpr	C/O	C/O	**2/7**

Likewise, the other 400-ton press, Number 5 was running only three times during the spot checks. Twice, dies were being changed. Once, a die was being repaired, and once, there was no operator to run the press.

#	Jan 29	Jan 30	Feb 3	Feb 4 am	Feb 4 pm	Feb 5	Feb 6	Running
5	IDLE	C/O	RUN	Die Rpr	C/O	RUN	RUN	**3/7**

As the reader can see in the following table, the situation was not much better for the other automatic transfer presses.

#	Jan 29	Jan 30	Feb 3	Feb 4 am	Feb 4 pm	Feb 5	Feb 6	Running
6	38 SPM	36 spm	C/O	IDLE	35 spm	32 spm	IDLE	**4/7**
7	IDLE	27 spm	30 spm	34 spm	C/O	46 spm	38 spm	**5/7**
8	22 spm	22 spm	46 spm	38 spm	IDLE	C/O	40 spm	**5/7**
9	43 spm	C/O	IDLE	45 spm	44 spm	45 spm	IDLE	**3/7**
11	IDLE	72 spm	IDLE	C/O	72 SPM	80 spm	75 spm	**4/7**
12	MAIN	70 spm	72 spm	IDLE	C/O	60 spm	IDLE	**3/7**

To reduce the die changeover time, we worked with the operators and team leader to develop and activity pre-specified as to content, sequence, timing, and outcome and tests to help them accomplish each step correctly.

CREATING A SELF-DIAGNOSTIC PRE-STAGING PROCESS

One of the most time consuming aspects of changing dies was searching for the new die and the new material after the press had stopped running. Therefore, one of the first changes was to create a staging area where the next die and the next steel coil could be placed before the current batch was completed. To create a signal that those work elements were accomplished, a single box was marked off for the next die and a single box was marked off for the next coil. This created a simple but clear diagnostic signal. If the box was full, the material and tool were available for the next job. If they were not, the team was not ready to do a changeover.

Die-Change Time Reduction: Evidence for Rule-2

Reducing the changeover time depended on developing a 'pre-staging' process for the tools and materials so that the press would not be idle while workers searched for supplies. The effectiveness of pre-staging depended on building effective connections between a customer (the press operator) and suppliers of tools, dies, and steel coils). Designing and operating the connections used to facilitate effective pre-staging informed Rule-2, so this evidence will be revisited in the next data and analysis section.

BINARY TEST FOR DIE-SETTER

Other aspects of the changeover were converted to work-elements pre-specified and testable as to content, sequence, timing, and outcome. One particularly difficult job was placing the multi-ton die on the bed of the stamping press and aligning it correctly left to right and side to side. This was critical to part quality. Correct alignment was difficult because the forklift driver had his vision obstructed by the die he was trying to place correctly.

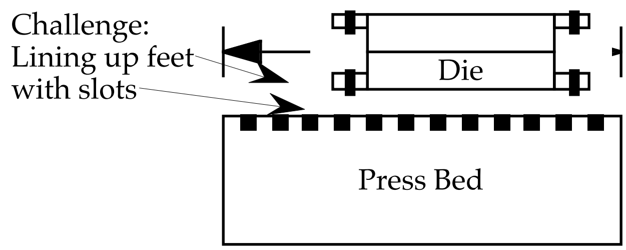

Figure 80: Trouble centering die on press bed

One of the operators developed a simple technique to make matters simpler for the forklift driver. The die itself had four feet. These feet were connected by pins to slots in the press bed. Ed, one of the operators, stuck a green card in the foot of the die and a matching card in the press bed slot to which the foot was going to be attached. For the fork lift driver, this change converted an ambiguous situation into one in which correct could be distinguished from incorrect in a yes/no, binary fashion. The die was correctly centered left to right if the one card lined up with the other. The die was not correctly centered left to right if the cards were not lined up.

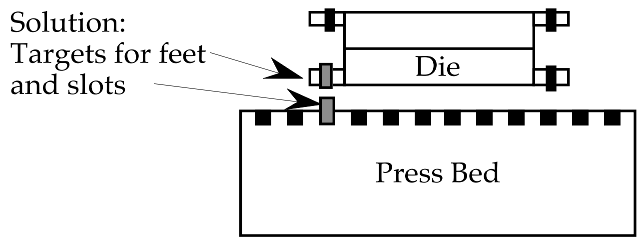

Figure 81: Die centering using the target cards

This simple device reduced the time required to position properly the die in the press. For example, on March 25, 1997, the team was placing the die for part 77139-06020 into the die at 8:30 AM. I observed that Ed had not placed the target card in the foot of the die. On this try, it took the fork lift driver, Luis, 112 seconds from when he approached the press with the die to when he had the die centered on the press-bed and he could back away. Likewise, on April 1st, when the die for part 61665/666 was being placed in the die, it took 73 seconds because there was no target. However, on April 2nd when the target was used, this particular work element required 25 seconds.

BINARY TEST: COLOR CODED SCRAP CHUTES

The team developed yes/no tests that the work-elements for pre-staging the die, pre-staging the steel coil, and centering the die were completed correctly. They developed another yes/no work-element test as well.

In the stamping process, tiny pieces of scrap metal were created as the die punched holes in the sheet metal. These pieces of scrap were carried away from the die in scrap chutes. A single die might have required several chutes of different sizes. If, during the changeover, the operator tried to attach a chute that was too big, the chute might have fallen off. If the operator tried to attach a chute that was too small, the scrap might have fall onto the bed of the press, requiring non-value-added cleaning during a subsequent die change. The problem for the operator during the die change was that it was often difficult to distinguish between chutes of similar, but not identical widths, and it was difficult to determine the specific size chute required on each die.

Brooks, team leader for Press-5 during the night shift developed a simple way to create a yes/no test for the chute selection work element. First he color-coded each of the chutes (i.e., 5″ = green; 6″ = red; 7″ = red; 10″ = brown). Then, every time a die was placed in the press and the correct chutes were matched to the scrap ports, he spray-painted and color-coded that location on the die. As a result, when the die next went into the press, Ed, Randy, Moon, and the other operators could determine quickly which chutes were required and could compare quickly the color of the chute with the color of the paint on the die. Therefore, they could determine easily that they had completed the chute-selection and attachment work elements correctly.

OUTCOME TEST: JIGS AT PRESS SIDE

After the new die had been set, the first pieces had to be checked mechanically that they were dimensionally correct. This was to protect against the case of the die not being set properly, or even if it was set properly, there being some flaw in the tool that might cause defective-parts. The problem with these mechanical checks was that the engineering department did them, and the engineers were elsewhere in the plant. Hence, once the die was set, the operator would then generate a few pieces, carry them to the engineering office, and find someone to check the pieces using the jigs and fixtures in the office. If the pieces were approved, the operator came back to the press to resume full operation.

There were problems with this arrangement. The round-trip from the side of the press to the engineering office could require five minutes or more, depending on whether someone was in the office at the time the operator arrived. Consequently, during the operator's absence and without the approval of the mechanical check of dimensional correctness, the press sat idle. This idle time necessitated longer runs (more inventory) and additional overtime.

As a response to this problem, we (the Toyota team members) worked with the engineering department people to move the test jigs to the press side and to train the press operator and team leader to test the parts. This simple step converted the operator's work from non-value-added (running to, waiting in, and returning from the engineering office) to value-added (running the press and changing dies). This simple step eliminated a low-value-added work-element from the engineering team members' responsibilities (using the test jigs) so that more time was available for more difficult, technically challenging tasks.

DIE CHANGEOVER PROCESS: SUMMARY

A key finding of my research is that a fundamental aspect of the Toyota Production System is the guideline to design and perform individual activities so that they are structured and self-diagnostic. As discussed above, I observed this fundamental guideline reflected in work-elements that were pre-specified and testable as to content, sequence, timing, and outcome in seat installation, seat-installation training, and off-line training of new hires. The same fundamental approach guided us in redesigning the die change process at a Toyota supplier in order to reduce the length of a die change from several hours to less than 20 minutes. We developed a structured, testable activity for pre-staging the tools and materials, we developed a structured, testable activity for setting the die (i.e., the target card), we developed a structured, testable activity for attaching the scrap chutes, and we provided a final outcome test by moving the test jigs from the engineering department to the side of the press.

While each of these changes may individually seem small and incremental, cumulatively they contributed to a large impact on the productivity of the Press-5 team as indicated in the following table. Changeover times were cut from several hours to 18 minutes, overtime on the press was eliminated, and lot sizes (as measured in days of customer demand) were reduced from more than three weeks to less than one. While not calculated, these direct effects reduced costs and improved safety since far less material had to be crowded and stacked in storage areas.

		Week of:			
	Original	**4-1-96**	**4-8-96**	**4-15-96**	**4-21-96**
Parts made	Not known	15,080	19,500	23,140	23,140
Avg. C/O time (min)	2-4 hours	21.3	20.6	19.1	18.2
Overtime (hrs)	30 +	26	16	10	0
Lot size (days of demand)	3 + weeks	15	9	5	4.7

Figure 82: Press-5 productivity improvements

OTHER DIE CHANGE EXAMPLES

We developed a structured, testable activity for die-changes at this supplier (from Dec. 95 to April 96). I observed structured, testable activities for changing dies at other TPS-managed sites as well.

Several of the Toyota suppliers that I studied made injection-molded parts from thermo-plastic resins. Though this technical process was different than stamping in terms of type of energy transfer and material transformation, the injection molders faced a challenge similar to that just described. The injection molding presses were large, relatively high speed, general-purpose equipment that required time-consuming tool-changes to switch from one part to another. I observed that at Toyoda Boshuko -- a Toyota supplier that produced various types of filters -- the tool change activity that was done by production workers was pre-specified and testable as to work-element, content, sequence, timing, and outcome. Therefore, data gathered at this plant also contributed to the formulation of Rule-1. [Data gathered in Spring 1996 and Summer 1997].

In injection molding, liquefied thermo-plastic resin is forced into the cavities of a large, multi-ton steel tool. The quality of the part is affected by the temperature and pressure with which the plastic is injected into the mold, the temperature gradient experienced by the plastic inside the mold's cavities, and the hold-pressure gradient experienced by the plastic inside the cavities. Each injection-molding tool has heating elements and cooling lines that are used to achieve the target injection temperature and pressures and to achieve the target hold-temperature and hold-pressure gradients. These heating elements and cooling lines must all be connected correctly to external sources of energy and fluid if defect-free parts are to be produced. For the time between the last piece of one run and the first piece of the next run is to be short, the previous tool must be removed quickly, the new tool inserted quickly and the connections must be made quickly.

TOOL POSITIONING

At one plant that supplied injection-molded parts to a Toyota and other assembly plants, I measured the last-piece to first-piece tool-change time as approximately 12 minutes. Aligning the new tools was one of the most time-consuming aspects of the changeover. The tool was carried from the storage area on an overhead lift and then had to be placed precisely into the molding machine. The lift operator had to move the tool back and forth several times before getting the correct front to back and side to side location.

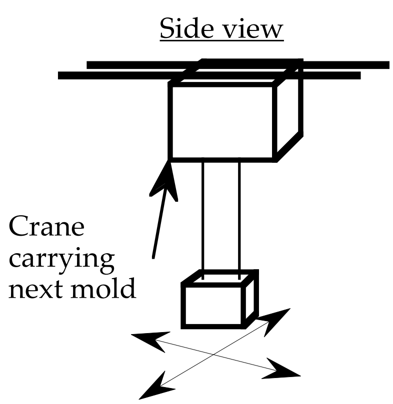

Figure 83: Difficulty positioning injection molding tool

Elsewhere, I observed a solution to this problem that converted this work element into one that provided the activity-doer with clear yes/no, correct/incorrect feedback. The problem was much the same, getting precise front to back and side to side positioning for a multi-ton (stamping, not molding) tool. However, in the latter case, the lift projected a light beam onto the floor. When the beam was centered on a target that was painted on the floor, the tool was correctly positioned. By using the locator beam, the operator avoided much of the back and forth 'jiggling' required to get a precise alignment in the previous instance.

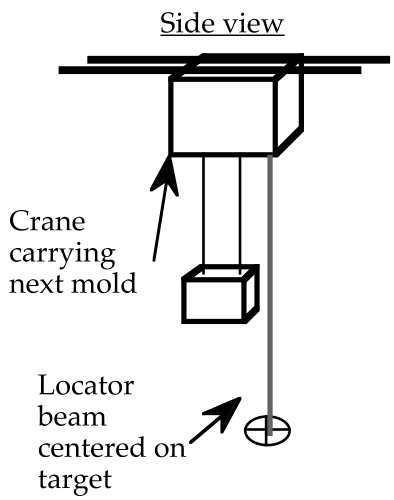

Figure 84: Yes/No feedback on tool-positioning activity

In the Toyoda Boshuko plant I observed that tools were not loaded directly into the injection molding press during a changeover. Rather, they were pre-staged on a roller rack. To replace tools, the operator merely shoved one out of the press and shoved the new one into place in a matter of seconds. The physical geometry of the roller rack ensured that the tool was correctly aligned.

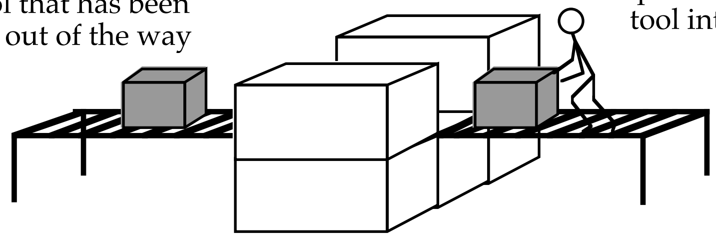

Figure 85: Roller racks to allow pre-staging and certain tool placement

CONNECTING THE TOOL

At a Toyoda Boshuko plant in the Summer of 1996, I observed that the press operator's work was made easier using a color coding scheme similar to the one we developed for attaching scrap chutes on the stamping-press tool. Each of the ports on the tool was painted a color that corresponded to the hose or power line that matched it. Therefore, the tool-change operator had simple yes or no confirmation that each hose or cable was attached to the correct port.[24]

In comparing these two suppliers, we found that they were similar in terms of product and production process in that both make injection molded parts using similar equipment. At both, the time required to change tools directly affected batch sizes and inventory levels. In the former case, the tool

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[24] This is an important example in terms of data analysis and interpretation. Two groups of people -- one at the metal stamping plant in which I work and the other at an injection molding plant in Japan were each trying to use TPS to manage a production situation. Both developed similar responses to similar challenges, even though they were otherwise working in different situations: one in North America, the other in Japan, one in a stamping plant, the other in an injection molding shop.

change was accomplished in 12 minutes. In the latter case -- because the tool change activity was designed with work-elements pre-specified and testable as to content, sequence, timing, and outcome -- I observed that the tool change activity could be performed in 5 minutes. Then, in 1998, I observed that the changeover had been reduced to 3 minutes due to additional modifications. [The time had been reduced because several hoses and cables had been combined into a single coupling that could be attached in one motion not several.][25]

In discussing seat installation in Toyota final assembly plants, I commented that because the content, sequence, and timing of activity work elements was pre-specified, the activity-doer and an activity-observer could determine if an activity was being performed correctly or not. This was evident in observing the die change too. The work was designed to last 3 minutes exactly, yet, on one cycle, it required three minutes and 20 seconds. The manager who was conducting the tour noticed this discrepancy and was able to uncover its cause. The operator, rather than making all of the connections on one side of the tool before making all of the connections on the other, did only some on one side, did the connections on the second side, and had to return to the first to complete the activity. [Afterwards, the manager commented that the worker was suffering from 'stage fright' since he was being watched by 5 or 6 people, one of whom was this senior manager.]

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25 The changeover process contributed to the articulation of Rule-1. The reduction in

TESTS OF OUTPUT

Rule-1 requires that the person who performs an activity should be able to determine if the final output is defect-free or not. Several observations, in addition to those already reported, contributed to this aspect of Rule-1.

PASS/FAIL TESTS: YES/NO GAUGES

In one plant (United Electric plant visit, summer 1995), I learned that, in machining parts, visual inspection was inadequate for distinguishing between defect-free and defective results. Therefore, go/no-go gauges were developed so that each part could be evaluated before being passed to the next process. I later grouped these gauges within the general category of yes/no, pass/fail activity-output tests.

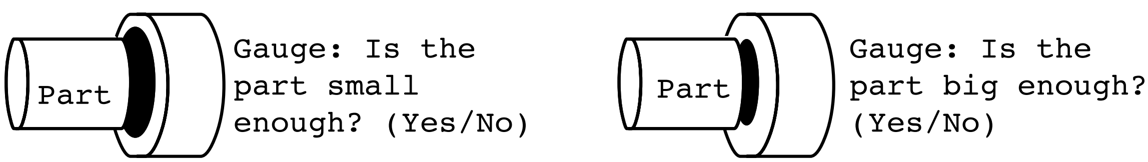

Figure 86: Process diagnostics: Tests of Output-Quality

PASS/FAIL TESTS: DETAILED EXAMPLE

A Toyota employee provided the following description of pass/fail testing fixtures used at Toyota's Sango Plant in Toyota City Japan.[26]

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the time required for the changeover process contributed to Rule-4's development.

[26] Description, diagram, and written summary provided by Bryant Sanders; Toyota Supplier Support Center member based on his plant visit in Japan; November 1998

Processes: Stamping, welding, painting, assembly

Products: brake pedals, clutch pedals, under body cross members, exhaust pipes

Example: Stamping process for brake pedal arm

Step 1: Customer provides part specifications to Sango plant.

Sango creates a checking fixture to be used at process to check first and last pieces of a production run.

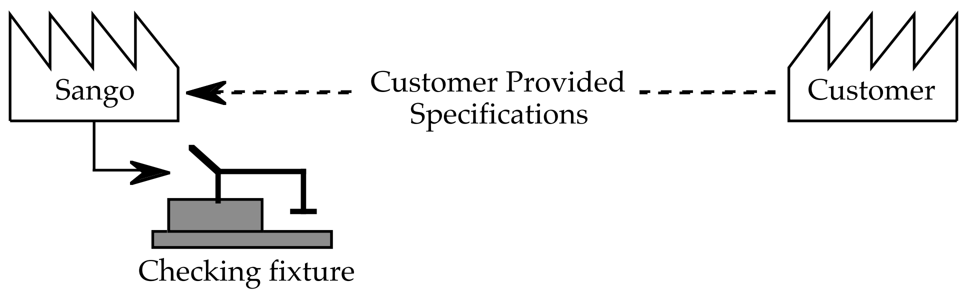

Figure 87: TSSC provided diagram: Kyushu Quality Test - Step 1

Step 2: Group leader has primary responsibility for developing standardized work (i.e., work elements pre-specified and testable as to content, sequence, timing, and outcome) on how to use checking fixture.

Step 3: Group leader provides training to Team Leader and Team Member on use of Standardized Work instructions and checking fixture.

Step 4: Training is continued by Group Leader for 1 to 2 weeks.

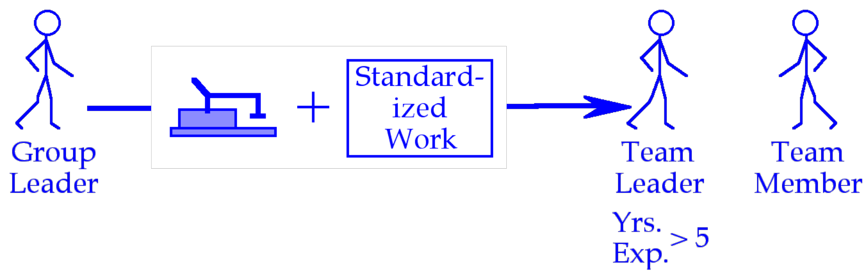

Figure 88: TSSC provided diagram: Kyushu Quality Test - Steps 2-4

Step 5: Team member checks first piece and last pieces according to Standardized sampling plan: Results posted and checked by group leader each day.[27]

- If defect, machine stopped.
- Team Leader notified
- WIP Checked --> limited quantity in process
- Team Leader, Team Member identify cause --> G/L notified

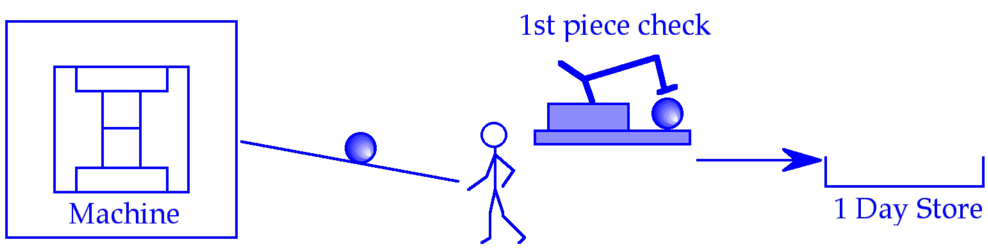

Figure 89: TSSC provided diagram: Kyushu Quality Test - Step 5[28]

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27 I didn't learn the length of the run (number of pieces, number of hours, hours of customer demand), or what errors are actually recorded on the chart.

28 The "1 Day Store" is a day's worth of customer need, not supplier output.

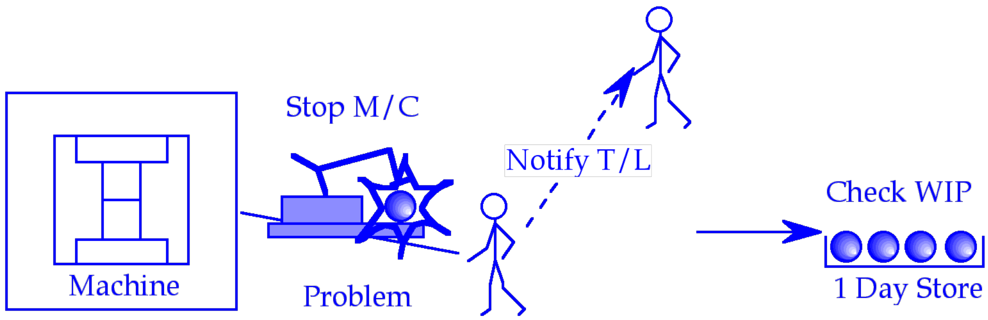

Figure 90: TSSC provided diagram: Kyushu Quality Test - When defect is found

OUTPUT TESTS: KYUSHU TRANSFER PRESSES

Observations such as the one just reported contributed to the conclusion that when activities are designed and performed in a "good TPS" way, the output of the activity receives a yes/no quality check. I was further convinced that yes/no tests of output quality are inherent in the design and performance of individual activities when I observed a situation in which it is not possible to construct simple test fixtures and jigs.

At the Kyushu assembly plant (August 1998), I observed the stamping shop generating large body panels such as those for the hood (bonnet) and truck lid. Because the panels were to be painted and because their final finish would be so visible to the customer, a defect-free finish was essential for overall customer satisfaction. I noticed something odd: as the panels came off the transfer press, the press operators were inspecting the parts visually and manually by running their hands over the part to check for a smooth finish. This type of inspection surprised me as it did not seem consistent with the idea of simple yes/no tests to determine the quality of an activity's output.

When asked why inspection was being done this way, Kiyotoshi Kato, the plant's senior managing director, responded that they had been unable to develop a mechanical device that was sensitive and robust enough to check the finish quality of the panels. Therefore, the plant employed "Quality Group" team members to do the final inspection of surface quality in Stamping. I used a follow-up inquiry to gather more information about the stamping quality checks and about the investment made at the Toyota Kyushu plant to incorporate a pass/fail output test in the activity.

According to Mr. Kato, quality group members were responsible for the final inspection of surface quality. The experience and capability required for the job was equivalent to that of a team leader (approximately 10 years).

For a 7 year old plant to have workers with ten years of experience, "... experienced people came from TMC headquarters (plants). One portion of them came from volunteers who wanted to return to their 'home country' and met the experience criteria." (According to a response from the Kyushu plant forwarded through TSSC, e-mail from TSSC: Apr. 26, 1999)

In gathering data, I had also visited the stamping plant near the Big-Three assembly plant in which I worked for one week in 1996. I noticed a difference between the design of work there and at the Kyushu plant. In both situations, two human operators working together removed the stamped body panels from the end of the press. In the Big-Three plant, the two people had to use both hands to lift the panel, carry it from the end of the machine and place it in a parts rack. In the Toyota Kyushu plant, a machine did the lifting. Having seen this job done by hand at the Big-Three plant, I asked why it was done by machine at Toyota. The plant manager -- who had been involved in the design of the plant prior to its construction -- responded that Toyota had been unable to develop an automated test that the panel was defect-free. Therefore, his plant employed these mechanical lifters so that the hands, eyes, and attention of the human operators could be devoted exclusively to examining the panel. He explained that if the operators had to lift, then their hands would not be available for making tactile tests, their muscles would fatigue, and what they inspected would be determined -- not by the highest priority items -- but by the angle at which they physically moved the part from the press to the rack.

OUTPUT TESTS: WORK REDESIGN AT NUMMI

During a Spring 1996 visit to the NUMMI assembly plant, managers explained plans to relocate assembly activities on the line. They explained that an objective of the redesign was to increase the number of locations in which an individual person or a team completed an entire module within their work area rather than completing part of one sub-assembly unit and part of another. Their motive for this, they explained, was twofold. The psychological aspect was to give the person the satisfaction of entirely completing something rather than denying that satisfaction to the worker by having him assemble only a bit or a piece of something. They explained that the second motivation involved in the line redesign was to simplify the activities of the workers so they more easily could determine if their work was DONE or NOT DONE.

MATERIAL HANDLING: STRUCTURED, SELF-DIAGNOSTIC ACTIVITIES

Rule-1 was grounded on data about many different sorts of activities. In TPS-managed settings, material-handling activities were also structured and self-diagnostic with work-elements pre-specified and testable as to content, sequence, timing, and outcome. Two examples follow: material handling at Aisin's Shinkawa plant and at an Araco plant.

AISIN: SHINKAWA

At Aisin's Shinkawa plant, I saw that the material handler cycled through the factory on a pre-specified path, collecting parts containers from the finished goods stores at various production cells. He conveyed these containers to downstream processes and staging areas in shipping, as warranted. The material handler's challenge was that the plant produced hundreds of parts, many of which were similar in appearance and which were conveyed in similar or identical containers. Therefore, there was a genuine risk that the material handler (or off-line operator as he was described by Toyota people) would accidentally withdraw and deliver the wrong container of parts. Because of this risk, the material handler carried a bar code scanner that compared the bar code on the withdrawal card with the bar code on the card attached to the container being taken. If the cards matched, he was able to proceed. If the parts didn't match, the scanner immediately generated a signal that a problem had occurred, thereby triggering the off-line operator to withdraw the correct container.

ARACO: MATERIAL HANDLING

I watched a material handler at Araco also cycle through the factory on a pre-specified path, collecting parts containers from finished goods stores. He too had to ensure that he had withdrawn the correct material when hundreds of different part-types were moved in identical containers. In response to this risk, Araco used the back of the kanban card for internal use. It was greatly simplified in comparison to the front of the card, with larger letters, color-coding, and information that was not relevant to the task removed from the card. These features were meant to reduce the possible sources of confusion for the off-line operator and make simple visual comparisons easier and more reliable.

COMPARING AISIN AND ARACO ACTIVITY TESTS

Material handlers at both Aisin and Araco faced a similar challenge: withdrawing and delivering the single, correct container of parts when the plant produced hundreds of similar looking containers of parts. Both plants addressed this problem by creating tests that the material handling activity was performed correctly. However, the TSSC and OMCD members who had visited these plants with me favored the Araco approach. In their view, the Araco method of testing was transparent to the person doing the work whereas with the Aisin approach, the method was opaque to the activity doer. In the Araco case, they felt, the off-line operator could contribute to activity-improvement. In contrast, the Aisin off-line operator (i.e., someone relatively junior and technologically unsophisticated) would be precluded from contributing to activity-improvement because of the computerized test equipment.

> *This contrast between a tool that was technologically 'opaque' to its user and one that was 'transparent' contributed to Rule-4. In criticizing a tool because its user could not modify it, and in praising another tool -- that served precisely the same purpose -- because its functioning was evident to the user, the TPS experts with whom I was visiting the plant were indicating the value they placed on the activity-doer also being the activity-improver. Hence, these observations about material handling contributed both to Rule-1's 'requirement' for built-in tests and also to Rule-4's requirement that the person who is responsible for an activity also be responsible for improving that activity.*

MOVEMENT OF EQUIPMENT

I discovered many activities designed with work-elements that were pre-specified and testable as to content, sequence, timing, and outcome. These include activities done frequently by single people such as seat installation, activities done with somewhat less frequency by groups of people such as die changes in stamping shops, and activities done with relative infrequency by larger groups of people such as the relocation of equipment from one part of the plant to another.

For example, at one Toyota supplier in Japan, equipment was moved in response to changes in demand for certain products. Three sets of specialized machinery, each of which previously had enough customer demand to occupy a single operator, were being located close to each other so that one operator could attend all three (due to a decline in demand for these particular product lines). Moving the machinery was broken into 14 separate events. Each event was designed as a series of work-elements, each assigned to a specific person who was to do each work-element in the pre-specified sequence. [29]

Making the movement of equipment a series of structured, self-diagnostic activities is an example of an activity performed infrequently by many people, in contrast to seat installation, for example, which is performed with great frequency by one person. The observation that infrequent activities done by

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[29] Information provided by managers during my visit to the plant in Summer 1998.

many people are also designed and performed with work-elements that are pre-specified and testable as to content, sequence, timing, and outcome is borne out by Paul Adler also.

EXAMPLE: REFERENCE TO PAUL ADLER ARTICLE

Adler, Levine, and Goldofstas have reconstructed the process by which two models were introduced at NUMMI through interviews, plant visits, and document reviews. They have then sought to highlight differences between one model introduction process and the next and to understand the meta process by which the model introduction process was improved.

The authors show that NUMMI was able to develop a series of structured problem-solving exercises to develop and de-bug the new production system. These structured problem-solving exercises occurred at several levels. First, NUMMI began with the 'recipe' used by its sister plant, Takaoka, where similar models had been introduced one year earlier. NUMMI personnel learned the Takaoka recipes by going to Takaoka and participating in production work on the new model. Then, NUMMI personnel brought the recipe book home to their own kitchen/plant, where they made a series of modifications to adapt to local conditions such as the work force's training and experience, plant layout, available production equipment, supplier capabilities, logistics challenges, and product mix and volume.

Repeated, structured experiments were used to convert the Takaoka recipe for design and production processes into a recipe better suited to

NUMMI's particular conditions. At the level of the line worker, standardized work designs (the recipe for assembly) were tried, critiqued, and redeveloped.

At the assistant manager level, the assignment of responsibilities to team leaders and groups leaders -- such as span of responsibility for training, assisting with high-labor content cars, coaching, and problem-solving -- was similarly tried, critiqued, and redeveloped in response to the particular challenges of the NUMMI production environment.

At the manager and general manager level, a similar process of design, doing, evaluation, and redesign occurred. The senior personnel tried, critiqued, and redesigned system level processes such as ways to collect, process, and distribute information and ways to pass work from one area to another (such as from welding to painting or from painting to assembly, and from one zone to another within final assembly).

The senior personnel not only designed, critiqued, and redesigned the production system, they also designed, critiqued, and redesigned the process by which the production system was designed.

The authors describe a common behavioral pattern -- a series of repeated experimental cycles of standardization, evaluation, and redesign for all processes done at all levels of aggregation and seniority in the plant:

- redesigning standardized work,
- redesigning the team and group leader processes,
- redesigning the production system
- redesigning the process of designing the production system.

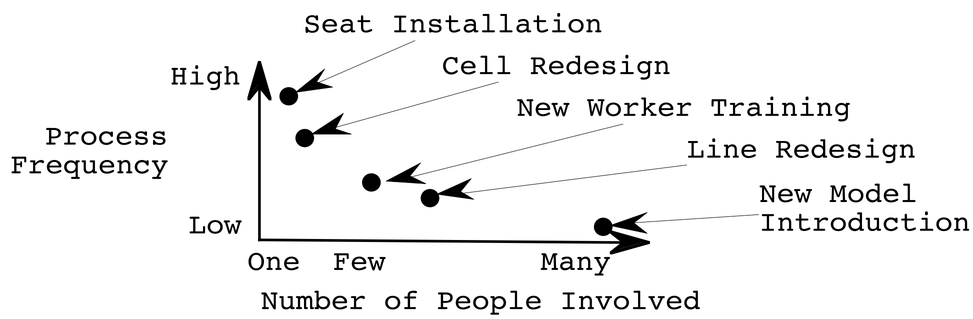

Figure 91: Summary of structured, self-diagnostic activities

What we see then are activities -- that are constructed from work-elements that are pre-specified and testable as to content, sequence, timing, and outcome. Some are done with high frequency, and some are done infrequently; some of these activities are done by individuals, and some are done by groups. In all cases, the structure and self diagnostics help distinguish defect-free outcomes from defective ones and provide mechanisms for problem identification, hypothesis testing, and improvement.

DISCUSSION

Standardization -- of simple tasks done by one person, such as installing a bolt, and of complex activities done by groups, such as redesigning a production line -- is a key theme of Rule-1. It transforms each performance of a task or a task-set into an experimental test of the hypotheses implicit in the task's design:

Hypothesis 1: The person doing the activity is capable of doing the activity.

Hypothesis 2: If the activity is done as designed, the actual outcome will equal the predicted outcome.

Standardization may be misunderstood from being associated with excesses of Taylorism. In fact, standardization is a tool for learning since it allows for repeated tests of hypotheses. Therefore, it is not a tool for achieving rigidity. Rather, it is a tool for facilitating experimentation, thereby increasing the potential for learning to be flexible.

	Mis-perception of Standardization	**When standardization is used for structured experimentation**
Meaning	Adhering to a process regardless of conditions or outcome.	Doing an activity as it was designed and comparing the actual performance and outcome to the expected performance and outcome.
Effect	Task-doer locked into inappropriate actions.	Task doer can effectively compare effected and actual conditions.
Meaning	'doing it one way only.'	The same problem can be approached using alternative standardized approaches.
Effect	Precludes comparing alternative approaches.	Creates chance to do comparative experiments among alternative designs.

Figure 92: Summary: Standardized work as a series of repeating experiments

CHAPTER 7.2:

DATA AND ANALYSIS CONTRIBUTING TO RULE-2:

CONNECTION DESIGN AND OPERATION

INTRODUCTION

RULE STATEMENT

Rule-2 guides the design and operation of connections between individual customers and suppliers over which requests and responses are transmitted. It states: **Design and operate each customer-supplier connection so that it is *direct*, *binary*, and *self-diagnostic*.** For a connection to be:

- *direct*, the *customer*, the person who uses a good, service, or information, must be able to send *requests* directly to the person (or machine) who will supply the good, service, or information, and not through a centralized intermediary, and the *supplier* the person (or machine) who produces or delivers the good, service, or information, must be able to *respond* directly to the customer and not through a centralized intermediary.

- *binary*, the customer's request must be interpretable as a simple signal to DO an activity with a pre-specified output (form, quantity, and response time). Likewise, the supplier's response must be interpretable as a simple signal that the activity has been DONE, generating the good, service, or information in the pre-specified form, quantity, and response time.

- *self-diagnostic*, a connection must immediately generate a signal that a problem has occurred when a DO request is met by a NOT DONE response (i.e., does not generate a DONE response) or when a DON'T DO request is met with a DONE response (i.e., when a response is generated without a triggering request).

EFFECTS OF RULE-2

When a connection is designed according to Rule-2:

- The customer has a clear, unambiguous (DO/DON'T DO) way to send requests to each supplier of each good, service, or information.
- The supplier has clear, unambiguous (DO/DON'T DO) instructions on what activity to do (form, quantity, sequence/timing).
- The supplier has a clear, unambiguous feedback (DONE/NOT DONE) if he has gotten ahead or fallen behind in successfully providing a good, service, or information with the form, quantity, and response time that meets the customer's needs and requirements.

Therefore, Rule-2 contributes, in part, to addressing the challenge of:

(a) distributing responsibility for designing and performing part of the organization's total activity-set and

(b) ensuring that distributed parts are integrated effectively.

It does this by contributing to structural modularity and fine-grained, frequent diagnostics. Modularity is enhanced by having well-defined interfaces connecting each customer pair. Testing every connection with every use enhances system diagnostics.

DERIVATION OF RULE-2

I derived Rule-1 inductively from consistent patterns I found in the design and operation of individual connections among activities in Toyota Production System managed situations. The patterns I codified as Rule-2 became evident in several ways.

- The patterns of behavior in the design and operation of connections were consistently observable in TPS-managed settings. Elsewhere, they were absent.

- When Toyota's experts promoted TPS as the management system within a plant, they designed connections between people and machines (and taught managers to do the same) so that the connections would be direct, binary, and self-diagnostic.

- When I collected data in the company of Toyota's Supplier Support Center (North America) or Operations Management Consulting Division (Japan) members, they were critical of connections that were not direct, binary, and self-diagnostic. Their concern was reflected in their questions about shop floor behavior. For instance, they would frequently ask: how do people know what to do and when; how does the people know if they are ahead or behind?

This section presents the observations and experiences that led to the development of Rule-in-Use 2. As with the data presentation for Rule-1, the experience of a worker in the Big-Three production setting is compared with that of those in the Toyota production settings. From these specific examples, I broaden the data set by explaining my own experiences creating direct, binary, self-diagnostic connections during the five months I was a member of the TSSC team that promoted TPS at a first tier supplier. Then, data from additional observations will be shared.

This section will conclude with an example of 'literal replication.' Yin defines literal replication as an instance when a model generated from data gathered in one setting can be used to construct accurate predictions of behavior in other settings. The data that contributed to the articulation of Rule-2 was gathered primarily while I was participating in the promotion of TPS at the Toyota-supplier stamping plant in Kentucky. After Rule-2 was articulated, I had the opportunity to visit and gather data at a 'cross-dock' logistics facility. Prior to the visit, I used Rule-2 to predict how customers and supplier connections would be constructed between supplier plants in the industrial mid-west and Toyota's assembly plants (the customers) in Kentucky, West Virginia, Indiana, and California. The predictions and observations were entirely consistent, thereby bolstering my confidence that Rule-2 captured an essential aspect of the Toyota Production System.

OVERVIEW

Chapter 7.1 presented Rule-1 as a 'norm' that governs the design and performance of work in TPS-managed settings. Designing and performing individual activities is necessary if each individual is to do outstanding work, but it is insufficient. No person is self-sufficient, able to perform without the support of other people who supply material, equipment-maintenance, assistance, training, etc. [This is true in factories, and also in other organizations in which many people each generate only a part of the final good, service, or information.] Therefore, individual ability alone is insufficient for outstanding group performance. Rather, people must procure necessary goods, services, and information. The best situation is one in which each person receives these in the quantity, at the time, and in the place they are needed.

As the following accounts demonstrate, the way in which work was triggered in the non-TPS settings that I studied differed considerably from how work was triggered in the TPS-managed setting that I studied. Beyond being different, the Toyota Production System approach appeared to be better. The TPS approach of direct, binary, self-diagnostic links was more likely than were alternative approaches to ensure that each person received the goods, services, and information needed, in the quantity needed, at the time needed. Consequently, the behaviors that I codified as Rule-2 seem to ensure that the whole of the collective effort is closer to the sum of its parts than it would be if immediate customers and suppliers were connected in other fashions.

CONNECTING WORKERS TO SUPPLIERS OF MATERIAL AND SERVICES

The next accounts contrast how Willie and his colleagues at the Big-Three plant were connected to their suppliers and how Willie's counterparts at Toyota plants were connected to suppliers of material, assistance, and equipment maintenance.

CUSTOMER-SUPPLIER CONNECTIONS AT THE NON-TPS SITE

Willie received his main piece of material, the car that needed a seat attached, as it traveled through his work zone for 55 seconds. At the end of 55 seconds, the car left Willie's work area whether or not he had completed the necessary work, and a new car arrived. [Remember, that I was often unable to complete the full installation of a seat, yet the car left the work area. Also, recall from the Rule-1 data section that during the orientation for part-time workers, the manager explained that the line would continue to move even if we encountered problems.] Therefore, the system was not designed so that Willie had control over the rate at which his suppliers provided him with material.

Second, consider how assistance was called for when an equipment maintenance problem occurs. When I was working in the body shop, twice a sheet metal body panel fell from the hoist and crashed to the floor. Only on the second occurrence did the Area Team Captain come and fiddle with the equipment. As I explained, I did not call for his help. He either saw or heard what was going on and came to assist on the second equipment failure. The way the system was designed, I did not have control over the timing of when I received assistance.

Third, consider how assistance was called for when work could not be accomplished in the required cycle time. Willie and I had to enter a code into a computer console to indicate if we had or had not achieved the desired outcome in seat installation. Entering that code did not bring a response to our work area. Rather, the response may have occurred elsewhere, as the production sequence was compared to the sequence of reported complaints. Therefore, we did not control when we received help with problem resolution. Furthermore, the information content of the code was relatively low. While it said that something had gone wrong, it did not say what had gone wrong, how it had gone wrong, or what unusual circumstances existed when it had gone wrong.

Another example follows of how assistance was requested when work could not be accomplished in the required cycle time.

During its final assembly, vehicles arrived at the wheel installation station hanging from a fixture. The cars left this station standing on their new wheels, bearing their own weight for the first time. If the cars left the station unable to support themselves, they might have toppled, stopping the line and perhaps causing damage to themselves, the equipment, and the workers. Therefore, there were cost, quality, and safety imperatives to ensure that the wheels are attached successfully and within the time the cars were at the work-station.

While I was with a zone supervisor, he was called on the walkie-talkie that his help was needed urgently at the wheel installation area. A problem had occurred that might have caused the line to stop or cause damage to a vehicle.

A car entered this portion of the line, but the workers were unable to put the wheel onto the axle. (The brake had not been fixtured properly at an earlier station, was hanging loose, and prevented the wheel from being attached.) Several workers and two zone supervisors (both beckoned by a walkie-talkie call) responded with haste (the car would be in the wheel installation station for only a few minutes). While both supervisors watched, the workers braced the right front axle in the absence of a wheel.

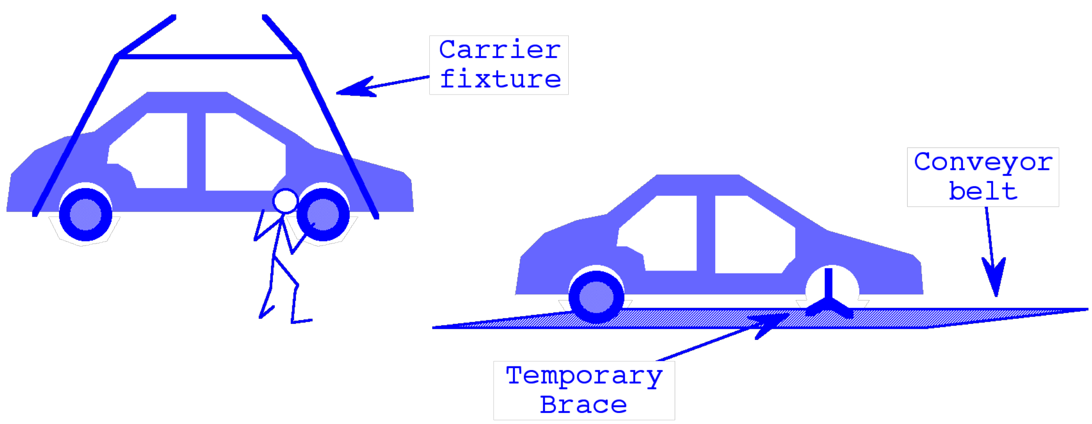

Figure 93: Temporary Brace

The brace supported the car as it automatically transferred from the conveyor fixture to the conveyor belt. Then, as the car went through the remaining stations (fluid fill and electronics test), other workers stayed with the car trying to attach a wheel so that the car could roll off the end of the assembly line 10 minutes later.

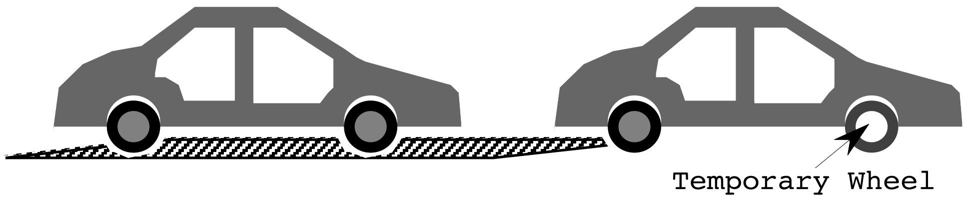

Figure 94: Temporary Wheel

In this case, help was called in an ad hoc fashion, with the zone supervisor responding to a verbal signal broadcast over a walkie-talkie. In addition, the situation was remediated only through a temporary, impromptu response.

In addition to the haphazard way in which a multitude of people was drawn into addressing the immediate problem, there was something else characteristic of this response. There was no information flow back to the person who supplied the car with a defectively attached brake component. The line never stopped, and messages were not conveyed to the work-station where the brake had originally been attached.

I feel confident in this assessment. I spent hours that day with several of the zone supervisors, yet I did not become aware of deliberate attempts to change the work methods, train the workers, adapt the equipment at brake installation, or otherwise change the activity to prevent this problem from recurring. Consequently, I concluded that if there was feedback, in the form of a change in practice to avoid the problem again, it was an ad hoc and not a systematic response.

In summary, for the time I collected data as a worker and observer in a conventionally-managed plant, I had little confirmation that the work I was doing had been done correctly or not. This was explained in Rule-1's data section. In addition, workers had little control over the behavior of suppliers. Material was pushed; workers did not control the rate of its arrival. They could not trigger assistance reliably in work completion or problem resolution, and they could not trigger reliably changes in upstream processes that might positively affect the quality, safety, and cost of the work they did.

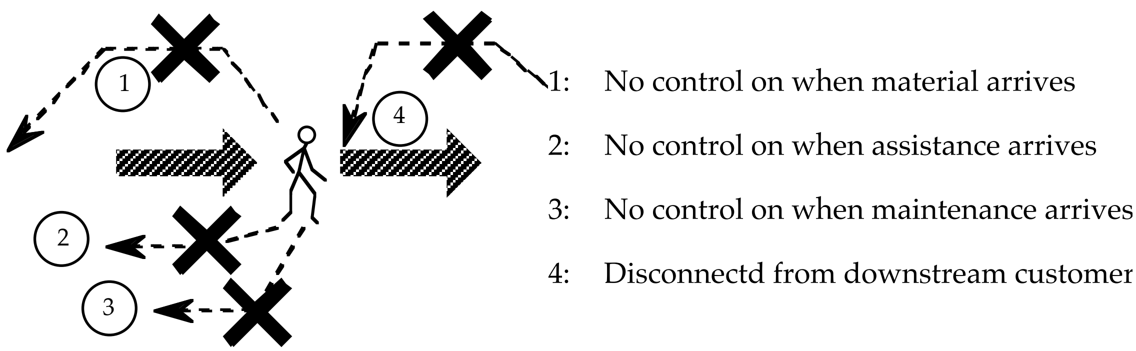

Figure 95: Inability of non-TPS worker to control suppliers

CUSTOMER-SUPPLIER CONNECTIONS AT NUMMI, GEORGETOWN, AND KYUSHU

The work environment of Willie's counterparts at Toyota is a contrast. I observed that people in the TPS-managed work systems at Kyushu, NUMMI, Kentucky, and elsewhere had mechanisms to send yes/no signals that triggered the production and the delivery of goods, services, and information when, where, and in the quantity needed. As explained below, individual workers could control the re-supply of small parts and even the flow of the auto bodies. They could send a direct, binary (yes/no) signal that says "DO the activities that will deliver assistance, when it is needed, in the quantity it is needed." Finally, as will be explained, if first level mechanisms failed to generate the expected response, the failure itself was a yes/no signal to someone else to provide assistance. Because of differences in the design and operation of customer-supplier connections in TPS-managed plants, the experience of people appeared to be considerably different due to more control by the customer over the supplier.

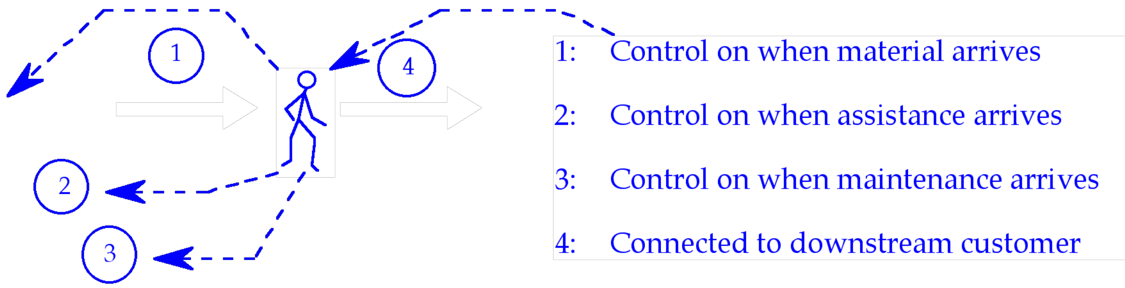

Figure 96: TPS worker's control of supplier-behavior

REQUESTING PARTS AND MATERIALS: KANBAN CARD

The kanban card and the pull system are well-known artifacts associated with the Toyota Production System. In the case of the seat installer, when he needed a new container of plastic bolt-covers, he gave a *request* card to the material handler. The card indicated what the *defect-free response* should be: the correct part (form), in the correct quantity (the specific number that is supposed to be in one container), and the expected response time (i.e., the next material handling cycle). Said differently, the card provided a yes/no signal that the customer (the seat installer) was making a request to a supplier (the material handler) for something in a pre-specified form, in a pre-specified quantity, with a pre-specified (expected) response time.

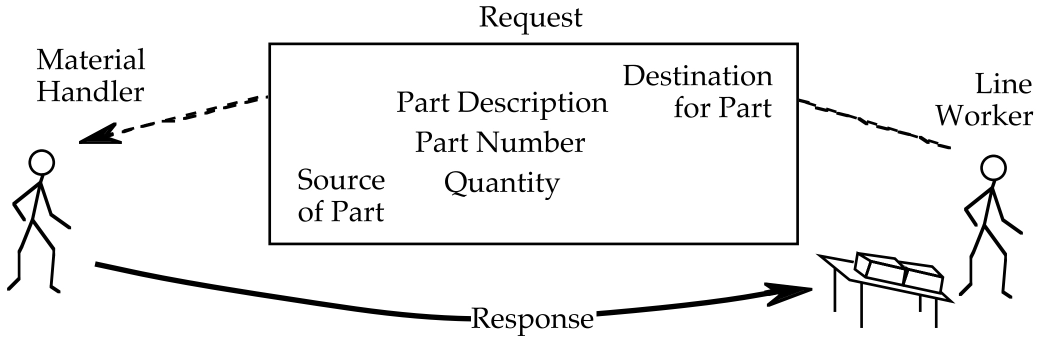

Figure 97: Direct, binary, self-diagnostic request for material

This method of sending requests was used in a nearly identical fashion at Toyota's Georgetown, Kyushu, and NUMMI plants as well as in other TPS-managed plants in which I saw frequent transfers of small parts and other, frequently used materials.

REQUESTING MATERIAL: ADVANCING AND STOPPING THE LINE

The line workers who I observed in TPS-managed situations had control over the arrival of more than minor parts and materials such as plastic bolt covers. In the TPS-managed situation, the line worker controled the flow of major components, even the car being produced. For example, if the person installing a right, front seat completed his work within the cycle time, he released his car to the next station. That his station is empty was a signal that permitted his upstream supplier to DO the activities that sent/delivered the next car. However, if the work was not complete, the current car remained in his work-station. This signal denied permission to the supplier at the preceding process and meant DON'T DO the activities to send/deliver the next car.

ACTIVE REQUESTS FOR ASSISTANCE: ANDON CORDS

I also observed that people requested non-physical services from a specific supplier using a simple signal that could be interpreted as DO (something) in the pre-specified form, quantity, and timing. For example, the andon cord is a tool that is commonly found in Toyota plants and that has been described as characteristic of TPS-managed factories. Most have noted that it allows a line worker to call for help when a problem occurs during routine production. When I studied the use of andon cords in Toyota plants, I learned realized that they are designed in a very particular way.

- The operator was supposed to pull the cord for help at the *first sign* of a problem.
- The cord-pull caused a bulb to light or a signal to sound. This was a message that was directed to a specific person who had been given the responsibility of providing assistance to the specific person who called for help.
- The signal was in a DO/DON'T DO form: either help was requested (the bulb was lit) or it was not (the bulb was not lit).
- The expectation was that when the signal was sent, the person who was responsible for providing assistance would respond *immediately*.

The sequences of responses at Toyota's Georgetown plant to a line-side problem illustrate these principles. A team member and a team leader explained to me that if the torque wrench lost power, this would generate an automatic andon call from the team member to the team leader. The team leader, upon investigation, would call for support from the maintenance department, expecting a response time in less than 30 seconds. In the meantime, the team member would use a back-up tool while waiting for the maintenance person to arrive to repair the torque wrench.

PASSIVE REQUESTS FOR ASSISTANCE: WORK STATION HASH-MARKS

I observed other DO/DON'T DO connections that didn't require the customer to call actively. Rather, the request-signal was generated passively. For example, the Rule-1 explanation discussed the use of painted hash-marks as a process test. The hash-marks in the assembly work-area tested that the actual rate at which the production worker is doing the work-elements equaled the rate at which the sequence was designed or expected to be performed. If the worker's actual rate was not equal to the expected rate, this was a yes/no signal to the team leader to DO assistance activities. In turn, if the team member had sent a request for help (by the gap between the actual and the intended rate of work) and the team leader had not responded, this became a yes/no self-diagnostic test that there is a problem in that connection.

Supplier/Team Leader

Customer/Team Member	DONE	NOT DONE
DO	Worker asks for help Worker gets help	~~Worker asks for help~~ ~~Worker DOESN'T get help~~
DON'T DO	Worker doesn't ask for help. Worker gets help	Worker doesn't ask for help. Work not provided.

Means DO assistance activities

Figure 98: Self-diagnostic team-member/team-leader connection

CALLING FOR ASSISTANCE: ANDON BOARDS

Just as the team members whom I observed had active and passive mechanisms to trigger the team leader to DO assistance activities, the team leaders that I observed also had both passive and active ways in which they could send a direct, binary, self-diagnostic DO request to group leaders.

For example, in the Toyota assembly plants in which I gathered data, each assembly line Group Leader had a distinct andon board specifically corresponding to the teams for which he was responsible. Each work location had its own square on the board. If the square was yellow (gray in the following diagram), a team member had sent a signal to a team leader. If the square had turned red (black in the diagram), the team leader had not been able to resolve the problem and needed help from the group leader. In other words, the red box was an *active* direct, yes/no signal from the team leader to the group leader to deliver assistance to a specific person at a specific location.

The team leader could also send a passive signal. If the group leader had observed that a team leader had been called by two team members, this was a signal that the team leader was unable to meet the needs of his customers since one had to wait for help while the other received assistance. Therefore, two lit lights on the same team was a *passive* direct, binary signal from the team leader to the group leader that help was needed.

For instance, in the diagram, two team members have requested assistance, illuminating location-b and location-d for Team-1 on Andon Board-1.

These two, simultaneous requests serve as a passive request to his Group Leader to provide assistance. In turn, the assistant manager in the diagram is observing the andon boards of the two groups for which he is responsible. He notes that on Andon Board-2, there is only one request to the Leader of Group-2. Therefore, that Group Leader is sending a signal to the Assistant Manager that means DON'T DO assistance activities.

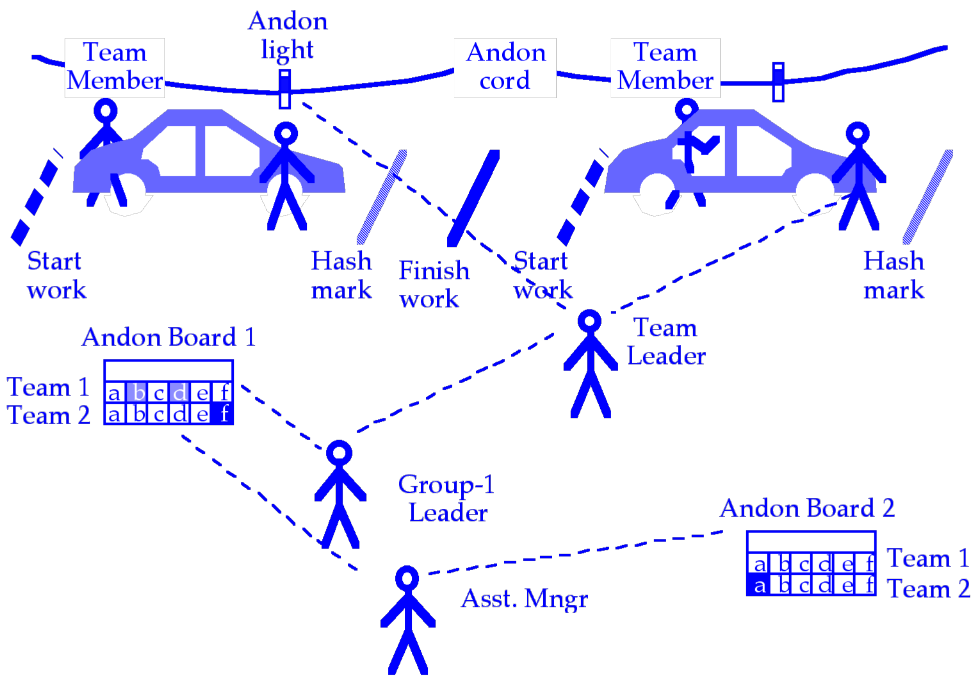

Figure 99: Information rich shop floor: Binary signals to DO assistance

In contrast, there are two requests on the Leader of Group-1, one from Team-1 (the two simultaneous yellows, meaning he has to help the leader of Team-1) and one from Team-2 (the red light, an active call from assistance from the leader of Team-2). He can interpret this as a binary signal from the Group Leader to DO assistance activities. The next table summarizes these direct, binary, self-diagnostic connections.

Tool	From Who	To Whom	Meaning	Quantity	Timing
Kanban	Assembly worker	Material Handler	DO activities to deliver parts	1 kanban's worth	Next delivery cycle
Hash-marks	Assembly worker	Team Leader	I'm behind in my work. DELIVER assistance.	1 assist	Now
Andon Light	Assembly worker	Team Leader	DELIVER assistance.	1 assist	Now
Andon Board	Team Leader	Group Leader	I need help, helping team members. DELIVER assistance.	1 assist	Now
Andon Boards	Group Leader	Assistant Manager	I need help, helping team leaders. DELIVER assistance.	1 assist	Now

Figure 100: Summary of shop floor tools for sending direct, binary requests

PRELUDE TO DISCUSSION OF IMPROVEMENT

The preceding example illustrates that when a person who does work that is valued by the paying customer has a problem, a cascade of assistance is generated, from the team leader, the group leader, and the assistant manager. For more severe problems, this cascade might start at higher levels in the organization. What would happen if the same problem recurred? The field data led to a basic discovery of this research.

The Toyota Production System Rules-in-Use lead to work that, when performed, tests the assumptions implicit in its design. For example, the assumptions in an activity's design are:

(a) the person doing the activity is capable of doing as specified, and

(b) if the work is performed as specified, the result will be a defect-free good, service, or information.

The assumptions in a customer-supplier connection design are

(a) customer demand will be in a particular mix and volume and

(b) the supplier will be able to meet those demands.

In the preceding example, a team member could not complete his work, so he demanded assistance by the team leader. In turn, the team leader could not meet the needs of the team member so made demands on the group leader. The group leader was also unable to fulfill his obligations as a supplier, so requested help from the next level supplier, the assistant manager.

Events of this sort would call into question the assumptions implied in the design of each person's work and in the assignment of customers to suppliers. What was it about the team member's skill level or the design of the assembly work that forced him to ask for help? What was it about the nature and volume of team-member problems or what was it about the team leader's skill that forced the team leader to ask for help? These questions are continuously generated so long as people are unable to do the activities for which they are responsible. This way, the organization is continuously doing automatic self-diagnostic tests as it performs routine work. As these tests indicate that problems have occurred, the organization identifies opportunities to solve problems, deepen its expertise in its core work, and deepen its skill at problem solving more generally.

BUILDING CUSTOMER-SUPPLIER CONNECTIONS AT A TOYOTA SUPPLIER

Creating a 'model line' at a Toyota supplier helped me recognize that connections between customers and suppliers must be direct, binary, and self-diagnostic. A longitudinal comparison between how people were linked before and after we created a model line follows. The text explains:

- the way in which material and information flows connected people originally,
- the role of the material handler, Doris, in connecting the shipping dock with the welding station that assembled the part,
- the binary, self-diagnostic tests for each connection,
- problems that arose when I mis-designed a connection.

INITIAL MATERIAL AND INFORMATION FLOWS

When I began my work as a member of a Toyota Supplier Support Center team, information flows that triggered and that were triggered by production related activities were processed centrally. Customers sent orders to the plant, these orders were received by Production Control which in turn instructed each department what to do: how many parts of which type that should be stamped in the press shop, how many parts of what type should be assembled in the welding shop, and how many parts of what type should be trucked from the shipping dock. Within each department, the foremen (Ron in stamping, John in Welding, Hoppy in Shipping) had to disaggregate these departmental- level instructions into individual assignments for the people who worked in each area. At the end of the day, the foremen then reported what had been produced or delivered so that production control make the production and shipping schedule for the following day. The flows of information are shown as dashed lines in the following diagram. Movement of parts into intermediate inventories are shown as broad, striped arrows.

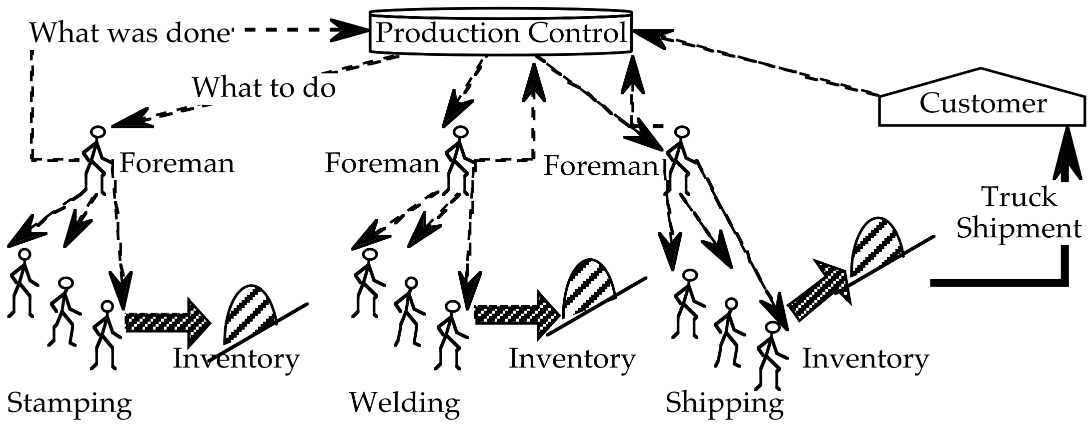

Figure 101: Original Material and Information Flow

<u>PROBLEMS OF CENTRALIZED INFORMATION PROCESSING</u>

The centralized processing of production related information caused several problems. Someone would look for the parts that were needed to complete an assignment only to find that the parts were not available (either they did not exist or they could not be found in the various piles of inventory). Even worse from the perspective of the person trying to accomplish his or her assigned work, the previous process had not scheduled the parts to run. Therefore, people had to adjust their own activities because they did not have the parts they needed, in the quantity, and at the time that they were needed. This was a particularly pronounced problem when Hoppy, Doris, and Kathy in the shipping area were assembling one of the two daily shipments to Toyota and one of the weekly shipments to other customers. Hoppy would urge Ron and John to adjust their plans to get him the parts he needed. Changing their own plans was problematic, particularly for Ron since this would mean interrupting the parts being run on a press in order to insert a different tool to create a different part.

Because of the competing priorities of the various departments, differences were addressed in a daily production meeting that involved the foremen, the plant manager, the production manager, the materials manager, and often one or two other managers for an hour or more. Consequently, the actual flow of information is better represented in the following diagram, in which John, foreman for the welding area, received instructions and requests from the daily production schedule, from the schedule-updates generated in the production meeting, and from Hoppy, the foreman in the shipping area.

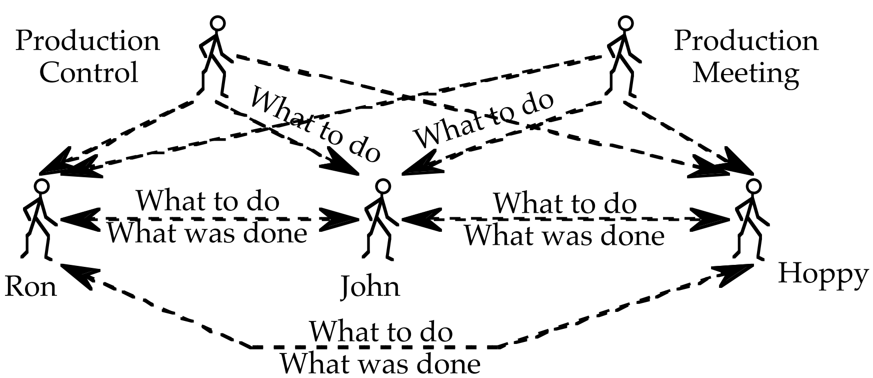

Figure 102: Multiple, conflicting messages to John, the welding area foreman

This was an expensive response to the coordination problem, though. I first arrived at this plant and was trying to understand its operation, I attended the production control meetings. In all that I attended, the managers devoted their time to nothing but recreating information (trying to learn what parts were needed by whom and what parts were available) and modifying instructions to people on what parts to make, in what quantities, and in what sequence. In my field notes, I calculated that since 5 to 8 managers were in this meeting each day, and it lasted for from 60 to 90 minutes on average, the plant was spending between $50,000 and $100,000 per year in manager's salaries just to figure out what to make, in what quantity, when.

INVENTORY AS A SYMPTOM AND AS A SOURCE OF COORDINATION PROBLEMS

There were additional problems with this approach to managing the flow of information. Because each department's efforts were not well-coordinated with that of other departments, the plant had containers of partially finished and fully finished parts stacked on shelves to the plant's ceiling. Consequently, fork-lift drivers such as Earl and Stanley spent their time raising and lowering the parts from the racks. Material handlers such as 5′ 1″ tall Doris had to lift 30-pound containers of parts from overhead shelves by hand. Consequently, the lack of coordination led to extra inventory, the extra people to move the inventory, the handling of which posed ergonomic and safety risks.

Finally, the mis-coordination affected productivity at the level of the individual worker. Because material was stored in large quantities, it was kept in large metal tubs with thousands of pieces each. When parts were processed, they were removed, counted, put into another tub, and recounted on the next use. As a result, operators did considerable double handling.

Costs and Causes of Inventory: Summary

As explained in the preceding paragraphs, centralized processing of production-related information was less than fully effective. People in adjacent departments did not coordinate their activities well. Consequently, large inventories and meetings were necessary to buffer the system from the mis-information being fed into and generated by the production control calculations. Large inventories produced additional, costly reverberations. The multiple handling of material posed risks to safety, timeliness, and worker productivity.

In effect, inventory was a symptom. People's actions were not coordinated well because each person lacked clear information about the form, quantity, and timing of their immediate customers' needs. Inventory was held so activities could operate disconnected from the production vagaries of upstream suppliers and need vagaries of downstream customers. Yet, inventory was not only a symptom of the coordination problem, it was a cause too.

COSTS OF RECONSTRUCTING INFORMATION

With large inventory stores, there was little clarity on what parts were available, in what quantity, and in what location. Therefore, managers, foreman, and material handlers spent considerable time reconstructing information. In the case of managers, they spent 90 minutes per day establishing production priorities. Material handlers spent a great deal of time searching for material, rather than actually providing material to the people who needed it. There were other, indirect costs of reconstructing information as an ad hoc response to faulty coordinative mechanisms. For example, at my request, the production manager recorded his activities one morning to illustrate how his time was allocated. For emphasis, I've bolded those items that are primarily information gathering.

1. **5:30 AM - walk through shop; check on housekeeping and tidiness**
2. **Check on missed shipments from previous nights midnight truck**
3. **Check on WIP**
4. Check on People. Who is on overtime?
5. **What products were running at end of 2nd shift last night?**
6. **Check on quarantine area**
7. Stacked up paper on desk to be reviewed later.
8. Got with . . . . on assembly fixture that is causing a quality problem.
9. Check on another assembly process which is causing quality problems.
10. **Went back to tool room to see if mold was repaired for part which missed previous night's shipment.**
11. Work on parts rack for injection molding press.
12. Work on ejector pin for mold.
13. **Walk through shop for 7 AM start up of molding area.**
14. **Walk through shop for 7 AM start up of assembly area.**
15. **Check with Human resources to find out who is absent.**
16. **Check with shipping to see what won't make 7 AM truck.**
17. **Make sure new people (temps) are properly assigned to assembly area.**
18. **Check on safety problem report in assembly cell.**
19. Set up temps to sort material due to quality problem on one press.
20. **Check on another quality issue with quality assurance department.**
21. **Check in receiving area for material and to evaluate safety of unloading**
22. Review Engineering Change Order
23. Started working on Assembly Cell upgrade.
24. **Spent 15 minutes forwarding production reports.**
25. Dealt with employee issue in molding.
26. Another quality problem in an assembly cell.
27. Added new employee in assembly area.
28. **Check back on other temp workers who were added before.**
29. **Went to 9:30 Production meeting.**

Little of this person's time was spent changing a process, teaching a person, or making a decision about capacity allocation (i.e., assigning a worker). Rather, the bulk of this person's time was spent gathering information (i.e., on the status of missed shipments or the condition of dies for the stamping press).

The production manager had agreed to record his morning activities after confessing the night before in the break room:

> "Man, this is one tiring job. I just cannot be effective here. There is just so much going on, that I write up my daily schedule at 12:30 every night, and by seven oh five the next day it is already all shot to hell. This is so frustrating. I don't mind taking crap if I don't do a good job, but I don't even get the chance to do a good job because I'm pulled in so many directions. "[30]

Frustrated by the current condition of his job, the production manager was open to our suggestion that he document his morning activities so that he could compare his actual responsibilities with his *expected* responsibilities and begin constructing 'counter-measures' with his boss, the plant manager.

The experience and sentiment of the production manager were shared at other levels within the plant. For example, on February 19th, I recorded a conversation with Anita, one of the team leaders in the press shop: "I spend 85%

[30] "Same-day" journal entry based on conversation in break room, March 1997.

of my time looking for people and things." Ora Lee, another of the 1st shift team leaders seconded the idea, accounting how she had spent the better part of the day looking back in the WIP area and back in the press area for the materials she needed to keep her operators occupied so that they could meet the production targets established in the day's schedule.

Comment on methods

In this section, I make qualitative statements about the proportion of time spent on various activities at the plant in which I tried to promote TPS. From these observations, I learned to identify those behaviors that were most important to measure. As a result, later in my data gathering, I knew to follow off-line people, recording their precise activities (and time per activity) as I did when doing time-motion studies for die changes and welding. For instance, I did this when visiting Toyota suppliers in Japan, where I deliberately shadowed team leaders and group leaders. I also knew to take more precise qualitative measures while documenting the promotion of TPS by TSSC at Acme or when observing a natural experiment.

MODEL LINE MATERIAL AND INFORMATION FLOWS

The objective in designing the model line was to ensure that each customer in the supply chain could trigger the timely delivery of the parts and the services needed. The goal was to eliminate the conditions that caused the team leaders, Anita and Ora-Lee, and the production manager, Greg, to spend such a large portion of their time trying to figure out what to do so they could spend more time in a value-adding capacity.

One basic design-principle for the model line was to ensure that the person who needed something sent that request directly to the person who would supply the response rather than to a centralized intermediary. This design principle is shown in a generalized fashion in the following diagram. In it, the external customer sends requests directly to shipping, shipping sends requests directly to welding -- and welding sends requests directly to stamping.

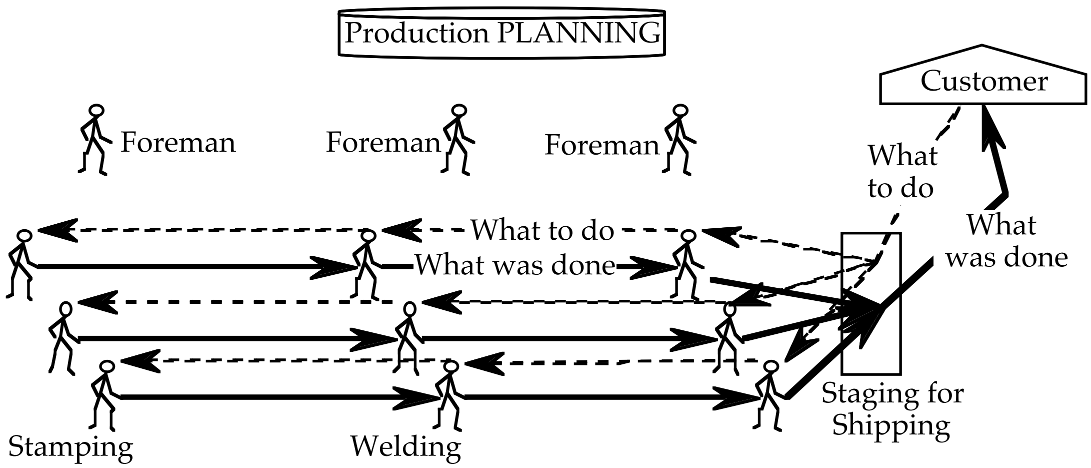

Figure 103: Model line material and information flow

Before getting into the specifics, several changes are worth noting. In the original situation, someone -- for instance in welding, would receive a production instruction, generate a physical output that went into inventory, and, separately, welding would report the results of their efforts to the Production Control department. Discrepancy between what was done, what was reported, and what could actually be located when needed was a source of confusion.

In contrast, the material and information flows were different for the model line. Each customer in the supply chain sent a message directly to the supplier saying what to do (what part, quantity, sequence/timing). The message did not go through a centralized intermediary. Second, the response, in the form of the product that had been requested, contained the information of what had been done (what part, quantity, sequence/timing). Therefore, in the original condition, the physical good and information about the physical good traveled over separate flow-paths. Also, the information was often incomplete, lacking the sequence or timing dimension. In the model-line situation, the physical good and information about it traveled together, over the same flow-path.

Another change is worth noting. Several people were disintermediated from the information flow. Customer requests no longer had to pass through production control and through the foreman. As a result, model-line people in shipping and in welding didn't need managers to play a coordinating role, freeing the managers for other activities.

CONNECTING SHIPPING AND WELDING: DORIS

So that everyone, as customers, had the ability to trigger their immediate suppliers to produce and deliver, we had to create mechanisms that would convert a customer's need into an instruction for the supplier.

Following this basic logic, the first connection was between the receiving dock at Toyota and the shipping dock at the supplier plant. Twice a day, a truck arrived from the Toyota plant. It arrived with empty parts containers from a previous shipment, and it arrived with a stack of cards, each one representing a request (an order) for exactly one container of a specific part in a specific quantity. The customer expectation was that the parts would be shipped on the truck departing exactly one day later.

Toyota's orders (in the form of a stack of kanban cards) came directly to the shipping dock. Doris would parse out the cards into 8 stacks, corresponding to the batches she would collect at 8 AM, 9:15 AM, 10:15 AM, 11:15 AM, 12:45 PM, 1:45 PM, 2:45 PM, and 3:30. Therefore, since Toyota asked for approximately 1,500 parts each day, and the parts were transported in containers of 50 parts each, each day the supplier received approximately 30 kanban request cards for this part, or approximately 4 per pick-up cycle by Doris. To make sorting the cards simpler, we constructed a small box, out of cardboard, in which she could place the cards.

Figure 104: Card sorting box for model line

At each pick-up, Doris went from this sorting box near the shipping staging area to welding where this part was produced. There, Doris would take one container of parts for every card she carried and carry the part-containers back to staging.

The need for parts by the customer at the Toyota assembly plant was the trigger that caused Doris to collect parts and stage them for shipping the following day. In turn, Doris's need for parts triggered Ora-Lee, the person operating the welding station, to make more parts. Ora-Lee produced containers of parts, and had a roller rack that could hold four containers. For each container taken by Doris, Ora Lee was supposed to make a replacement container. Then, for every container of parts that Ora-Lee used, she gave a card to Stanley *requesting* that he provide a replacement container of parts. The various, direct, binary links between customers and suppliers are shown in the following diagram.

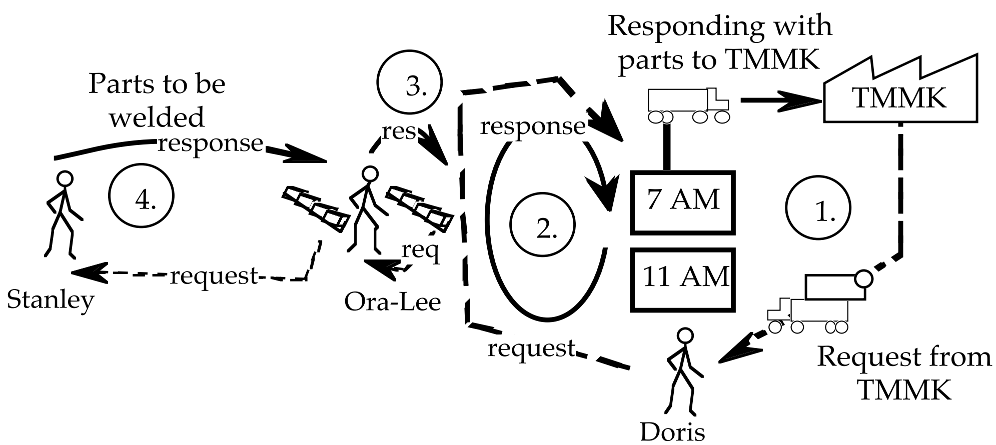

Figure 105: Model Line: Material and Information Flow

Link-1 is between the receiving dock at Toyota and its supplier, Doris.

Link-2 is between Doris and Ora-Lee's store of finished parts.

Link-3 is between Ora-Lee's store of finished parts and Ora-Lee.

Link-4 is between Ora-Lee and her supplier, Stanley.

BINARY, SELF-DIAGNOSTIC TESTS FOR EACH CONNECTION

It was not only the *patterns* of material and information flows that were reconfigured (from centralized to direct); the frequency and information content of the signals that flowed between customers and suppliers were changed as well. For most of the plant, Production Control sent instructions early in the day and received confirmation late in the day that the instructions had been followed. However, these confirmations were often inaccurate, compromised by miscommunication among operators, foremen, and managers. As a result, the system checked itself infrequently, and inaccurately.

In contrast, the model line diagnosed itself frequently and accurately. Because of the simple sorting system for Doris, it was clear how many containers she needed to collect on each of her 8 material handling cycles. For example, Doris was supposed to collect parts from Ora Lee at 8 AM, 9:15 AM, 10:15 AM, 11:15 AM, 12:45 PM, 1:45 PM, 2:45 PM, and 3:30. Therefore, to find out if Doris was keeping pace with the needs of her customer, it was only necessary to check the sorting box. For instance, anytime between 1:45 and 2:44, 6 of the 8 boxes should have been emptied of cards. If only five boxes have been emptied, then it was apparent that Doris had fallen behind the pace of delivery of her customer.

Figure 106: Doris at required pace

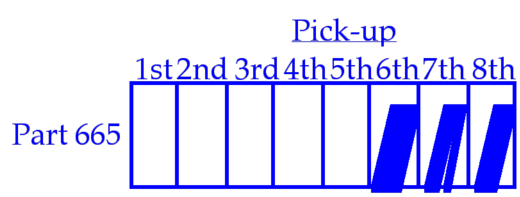

Figure 107: Doris behind required pace

Designing the sorting box this way made the link between the customer and Doris direct, binary, and self-diagnostic. Likewise, the connection between Doris and her supplier in welding, Ora-Lee, was also direct and binary, as explained previously, and self-diagnostic. Each time Doris went to collect material, it was available or it was not. If it was available, then the customer-supplier connection was working well. If material was not available, Doris placed the kanban card for which she couldn't take a container of parts (i.e., the request for which there was no response) in a clear plastic envelope at Ora-Lee's work-station. This yes/no signal -- which required no ambiguous verbal communication -- told both Ora-Lee and other members of the model line that Ora-Lee had been unable to produce at the rate demanded by Doris.

COMPARING PROCESS DIAGNOSTICS

We designed the model line with direct, binary, self-diagnostic connections linking each customer-supplier pair. This tested each person who served as a link in model line supply chain every hour. In contrast, elsewhere in the plant, performance was tested only when a shipment was missed. Consequently, the production system, as it existed elsewhere in the plant, was self-diagnostic with less frequency and with less granularity (resolution).

Other plants, more experienced at TPS, had self-diagnostic tests that occurred with great frequency and granularity because of frequent conveyance of material in small lots. For example, at Summit Polymers, I saw that material handlers circulated on an 8 minute cycle, not 60 as for the model line I helped construct. At Acme, [the company that rebuilt starter motors and alternators] a material handling route was developed that operates on a ten-minute cycle.

Conveying smaller lots with greater frequency increases the frequency with which each connection is tested. In addition, I observed other design details that increased the resolution or granularity with which the system is tested. For example, on the model-line we created, we routinely put 3 or 4 request-cards (i.e., kanbans) in each slot of the sorting box. In contrast, I observed that, at other plants, the box was designed so that it had one slot for each expected card. For instance, had we done the same, we would have 30 slots for Part-665, not the 8 we actually used.

The difference between the way I designed the card sorting box and the way it was designed at plants with a deeper TPS expertise is subtle, but it reflects a distinctly different approach. In my own case, I had inadvertently reduced the diagnostic capabilities of the sorting box. By putting several cards per slot, it was not readily apparent whether Toyota had made requests at a normal level or at an abnormal level (low or high). In contrast, when these sorting boxes are built with one slot per expected request, the very act of loading the box was itself a test that the customer's demands are equal or not equal to expectations.

This point is illustrated in the following diagram. In it the 'readability' of a single-slot-per pick-up design is compared with the readability of a single-slot per request design.

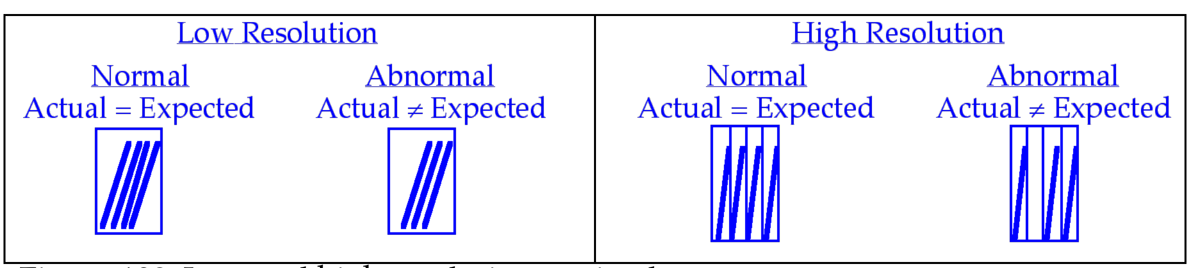

Figure 108: Low and high resolution sorting boxes

Signal to the press room

Creating frequent, fine-grained diagnostics had measurable benefits. As I recorded in my notes on January 24, 1997, frequent request-response cycles saved the plant from missing a shipment. I wrote:

> "When we starting kaizening the process at Spot Welder 8, the anticipation was for an easier work load on [one of the welding station operators] and a consequent improvement in production rate. There was another unexpected consequence. Because the shipping folks were pulling in response to customer demand, and because the material handlers were supplying the welding station in response to production levels, they discovered during the day that the supply of stamped parts in WIP was about 50% to 100% of the of the daily requirement. Furthermore, when the material handler alerted Monty [who was responsible at the time for setting the production schedule], they learned that these parts were not due for the press-room for several days. Consequently, the more visible display of information and the more frequent generation [of information] averted the problem of a part being needed when none was available leading to a panicked response of expediting something through the press room with the schedule disruption and potential need for overtime work. With this advance warning, the part was be inserted into the schedule in a more thoughtful manner."

PROBLEMS CAUSED BY MIS-DESIGNING A CONNECTION

That connections between customers and suppliers should be direct, binary, and self-diagnostic was a key insight from working as a member of the Toyota Supplier Support Center. I learned this, not only by correctly designing customer-supplier connections, but also by designing connections incorrectly. The next account illustrates how a poorly designed connection compromised the diagnostic capabilities of a connection, and, simultaneously, threatened workers.

At first, we developed a model-line that applied to only 2 of the plants 300 parts and connected one person in shipping, Doris, to one person in welding, Ora-Lee. Because Ora-Lee was able to produce the daily requirement of approximately 1,500 pieces of part numbers 665 and 666 in less than a single shift, it was rare that Doris was unable to collect a container of parts at each of her hourly withdrawals.

Buoyed by the success we were having with one family of parts, we sought to expand the model-line to include another family of parts. However, there was a fundamental difference between the first set of parts and the second set of parts produced by the model-line workers. These differences caused problems. The parts made by Ora-Lee each had a single bolt. Therefore, each part required only one weld. In contrast, in the second set, produced by Sadie, one part required two welds and the other three. Therefore, whereas Ora-Lee could make all her parts within a single shift, Sadie could not produce all the parts demanded by Toyota during the first shift alone.

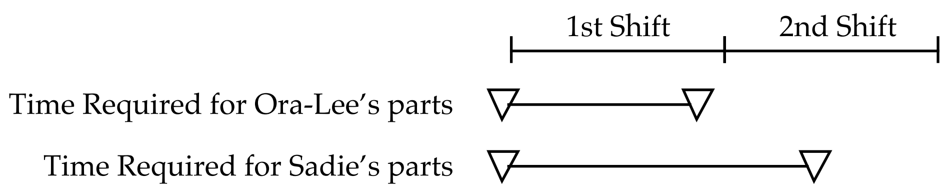

Figure 109: Difference in time required by Ora-Lee and Sadie to make their parts

In designing a withdrawal system for Sadie's parts similar to the one already being used to pace the withdrawal of material from Ora-Lee, I did not divide or level the cards over a longer work period. Therefore, though it was rare for Doris to leave a card in the "Not Done" envelope for Ora Lee, she almost *always* left a card at Sadie's work station. Consequently, Sadie fell behind early in the day and continued to fall further behind, no matter how hard she tried to catch up.

The stress on Sadie was only increased by her situation. She was part of the model-line, so people were inclined to investigate how things were progressing. Also, by using the simple devices of the sorting box, the flow racks, and the "Not Done" envelopes, we had made information very visible. As a result of my poor design, Sadie was more prominent, more visible, and failing. After a few days, there was a chill in the air; Sadie stopped saying hello in the morning and good bye in the evening.

Finally, through Ora-Lee, Doris, and Kathy (another of the material handlers) I learned of the problem. We had taken a normal situation (Sadie working at a reasonable rate) and had unintentionally translated it into an abnormal situation (Sadie working slower than demanded). As a result, my design ruined the diagnostics of the connection and simultaneously degraded the comfort of the work environment for someone.

We corrected the situation by modifying the card sorting box so that it extended into the second shift. Therefore, each hour Doris came to collect/request a reasonable amount of material, not an impossible number of containers. Within a week, the "Not Done" envelope served its purpose of serving as an alert that something had gone amiss, and Sadie was again wishing me well at the start and the end of the shift and talking to me at the snack truck during breaks.

CONFUSING NORMAL AND ABNORMAL

In other production settings it was also difficult to distinguish between abnormal and normal conditions because of customer-supplier connection designs. In one case, a material handler circulated through the plant. When he arrived at a production cell and there were no containers of the particular part he needed, he placed the unsatisfied kanban card in a slotted rack, much like that used to hold time cards.

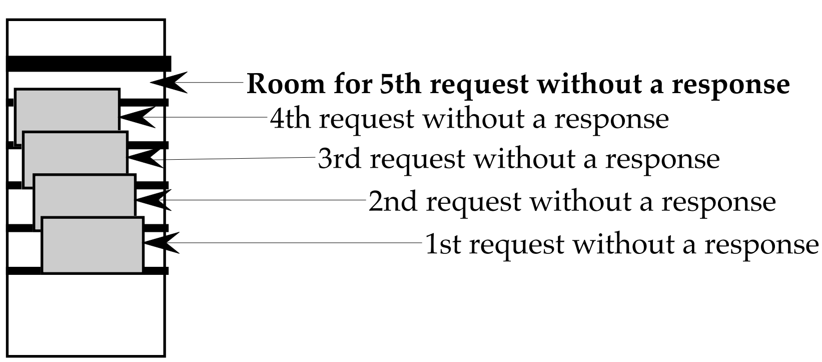

Figure 110: Back-log card rack at production cell

Because an observer could not visually distinguish and find meaning between three and four cards in the rack, in this arrangement, an observer could not distinguish easily between a normal situation (the cell producing at a rate somewhat less than the rate of demand, but close enough that it could catch up) and an abnormal situation (the cell producing at a rate much slower than the rate of demand, and too slow to catch up). Furthermore, in this arrangement, the material handler was forced to call for help only when he ran out of slots in the rack. Therefore, the managers of this cell had allowed the rack manufacturer – who had decided how many slots to put in the rack – to define what was and was not recognized as a problem condition. As a result, this compromised the ability of the material handler to send a direct, binary, signal that the cell had failed to respond to his requests. In turn, this compromised the ability of the cell to send a direct, binary signal to a team leader or another designated manager that a problem had occurred and that assistance was needed. Said differently, the generation of a problem-signal was not built into the work. Signaling that a problem had occurred required additional effort.

This particular plant had other situations in which customer-supplier pairs were not connected with direct, binary, self-diagnostic links. For instance, in one cell, parts were processed sequentially by three people, as shown below.

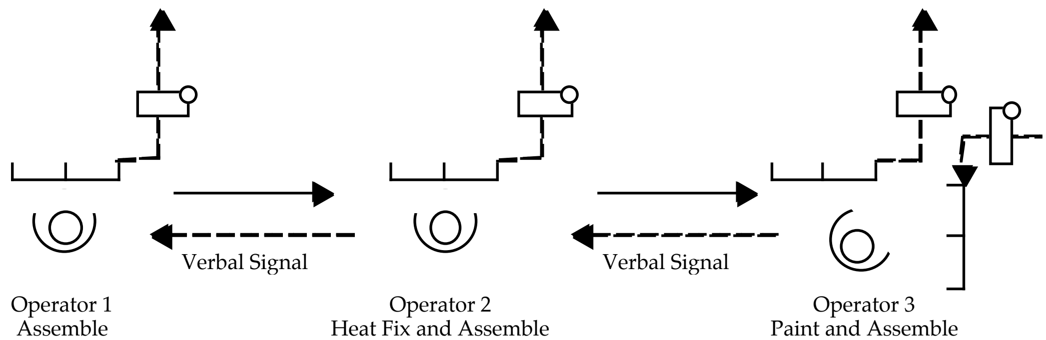

Figure 111: Production cell without clean customer-supplier connections

More than one member of the Toyota Supplier Support Center confirmed that communication within the cell was problematic on two accounts. First, when it came time to change from one color to another, the third operator *told* the first two to make a change. This created the chance that the signal was not heard, or that it was misinterpreted (either by what color is next needed or by when precisely the switch should be made). Second, there was no clear signal from one person to the other to send material forward. Therefore, sometimes a worker waited with nothing to do and, other times, work piled up arbitrarily between two people. In both cases normal (expected or planned) could not be distinguished from what was abnormal, not expected, or unplanned.

In contrast, at a Toyota supplier in Japan, the space between two workers was marked with a single square. If a part was in the square, then the supplier could not forward another. An empty square was a 'request' by the customer for the supplier to forward another part.

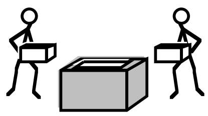
Supplier Customer

Figure 112: Normal condition

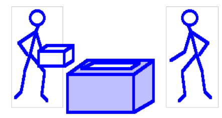
Supplier Customer

Figure 113: Supplier behind

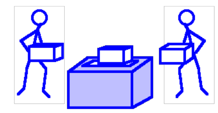
Supplier Customer

Figure 114: Supplier ahead

This simple, 'deviceless' approach to sending a request prevented the supplier from delivering at a rate faster than that needed by the customer. Furthermore, anytime the customer was not working, and the taped off square was empty, it was a clear, yes/no signal that the supplier's responses had fallen behind the customer's requests.

OTHER EXAMPLES OF RULE-2 CONNECTIONS IN COMPLEX SYSTEMS

This section concludes with other observations that contributed to Rule-2 as the guideline for designing and operating direct, binary, self-diagnostic customer-supplier connections. The first explains how material-handling activities were triggered at Toyota's Tsutsumi assembly plant. The second explains how Rule-2 connections coordinated multiple, parallel feeder lines in the production and delivery of a high variety, custom order product. The third explains how Rule-2 was used to 'design' a TPS-managed system. In this last case, I used Rule-2 to predict how material and information would be processed before I visited a logistics facility. The close match between predicted and actual behavior is an example of literal replication, as defined by Yin.

TSUTSUMI: MATERIAL HANDLING

In March of 1996, I observed and learned about the work of the off-line operator (a.ka. material handler) at Toyota's Tsutsumi plant. The design and performance of the material-handling activity illustrates both Rule-in-Use 1 and 2. For example, the work was designed as an activity with work-elements pre-specified and testable as to content, sequence, timing, and outcome. Each cycle, the off-line operator followed a defined flow-path, on a defined interval, providing material in response to defined request-signals. These were interpreted as "DO the activities that will deliver a specific part, in a specific quantity, in the expected response time to a specific location." This is illustrated and explained below.

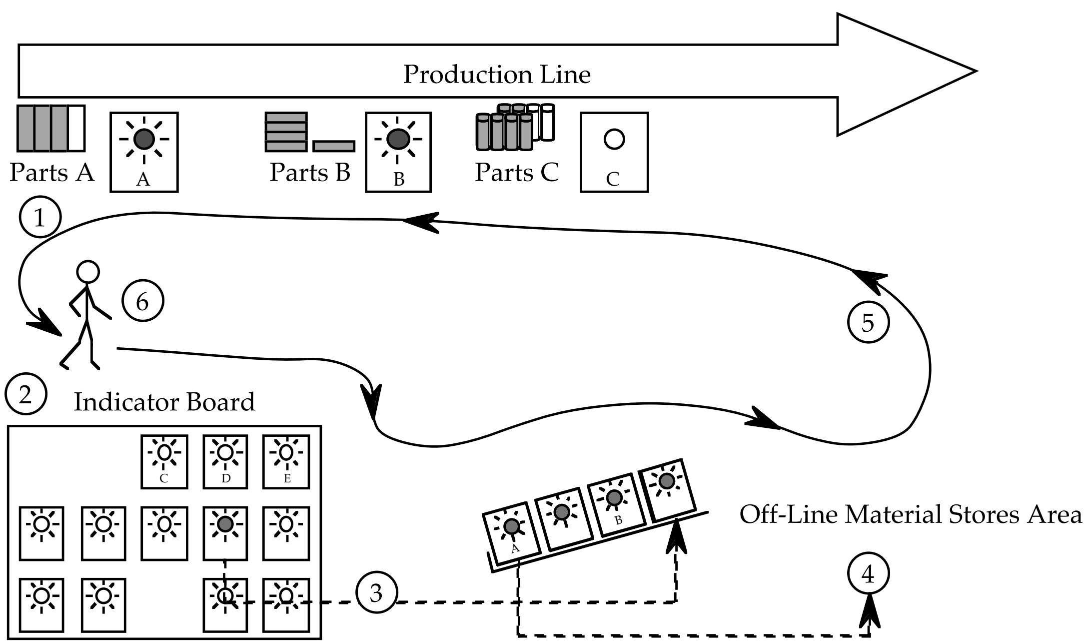

Figure 115: Tsutsumi Material-Handler's Route

Each production line worker had a small store of the parts. Taking the first part from a container both generated a line-side signal that a replacement container was needed (1 in the diagram) and also generated a signal on an indicator board (2 in the diagram). This board had one spot for each line-side location for which the material-handler was the designated supplier. When the indicator light for a particular part was illuminated, the corresponding card was removed from the board, and inserted in an order-rack that maintained the sequence in which orders had arrived (3 in the diagram). The material handler took a pre-specified number of cards from the order-rack and used that as a 'shopping list' at the off-line material stores area (4 in the diagram). After gathering the pre-specified number of items, the material handler delivered the parts to the line (5 in the diagram) before returning to the route's start at the indicator board (6 in the diagram).

There were many direct, binary, self-diagnostic connections in this.

- The light on the indicator board was a yes/no sign that a particular on-line-operator needed a specific item, in a specific quantity. If a light on the board was lit, but its card has not been moved to the order-rack, this was a signal that the customer-supplier connection somehow has been broken. A broken connection was a yes/no signal to a pre-specified person to assist the material handler by discovering the nature of and developing a response for the problem that had occurred.

- The order-rack provided a yes/no signal that material was needed line-side. If the material handler took the pre-specified number of cards from the order-rack for each cycle, and there were still cards left in the rack, then this was a yes/no signal that orders were arriving from the line faster than expected or that the material handler was slower than expected. This was a yes/no signal that a problem needed investigation.

- The line-side light indicated which locations had requested parts. Going past an illuminated, line-side light without making a delivery was a signal that the material handler had had a problem.

<u>COORDINATING HIGH VOLUME & VARIETY, MAKE-TO-ORDER PRODUCTION</u>

I visited Aisin's mattress factory on three occasions: Spring 1996 (1 day), Summer 1997 (2 days), and Summer 1998 (1 day). Because of Aisin's high level of TPS, because I spent several days on site, and because I made longitudinal comparisons, Aisin was a rich source of data, contributing to the codification of all five Rules. Here, observations that contributed to Rule-2 are shared.

Aisin produced make-to-order mattresses. While the product itself was technically less sophisticated than an automobile, and the processes by which it was produced were technically less sophisticated than those in an auto plant, the production of a mattress -- on a make-to-order basis as was done by Aisin -- posed coordination challenges affecting other organizations. Consequently, understanding Aisin's production system provided insights for understanding the adroit application of TPS more generally.

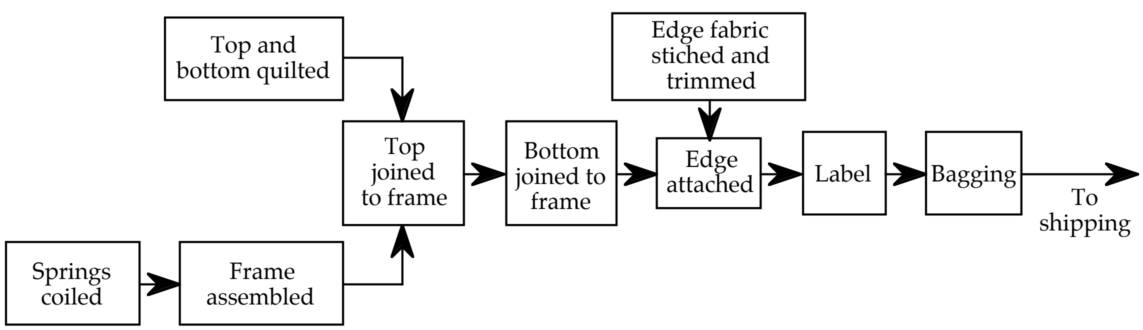

Figure 116: Simplified process flow for mattress production

I learned that a mattress was created in several distinct steps. The spring frame was created. Separately, a liner layer was quilted to an outer layer, and, separately, the material that covers the circumference of the mattress was stitched together. These three main 'sub-assemblies' were joined, before the complete mattress was labeled, bagged, and moved to the shipping area.

The relative simplicity of the material flow, as shown in the preceding diagram belies the difficulty of creating information flows that effectively coordinated the line-segments. One approach could to disconnect the line segments so that Framing, Quilting, Edging, and Final Assembly can operate independently of each other. In fact, this was precisely the strategy used when the plant offered fewer models in low volume. As shown in the following diagram, the material and information flows were similar to those in the supplier plant in which I tried to promote TPS. Customer orders were converted into production instructions sent to each work center.

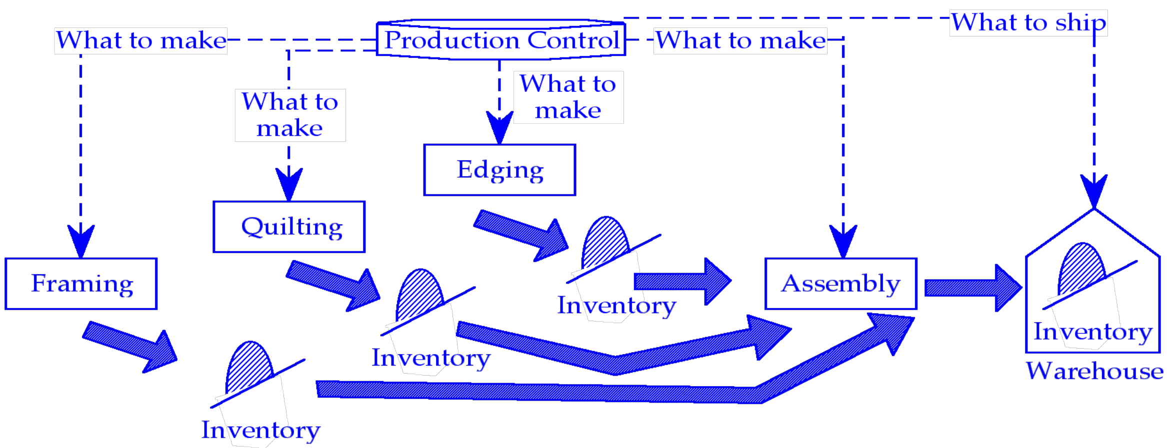

Figure 117: Aisin mattress material and information flow: circa 1986

With this approach, there were problems of large inventories, low flexibility, and expensive overhead devoted to coordination. (Information source: interviews with managers in 1996 and 1997; company documents) For instance, in 1986, Aisin offered 200 alternatives and produced 160 units per day, maintaining 30 days worth of finished goods inventory.

By my third visit to the plant, changes in coordinative mechanisms allowed Aisin to compete with a higher overall production volume with a higher product-mix variety, yet with considerably fewer symptoms of poor coordination, such as large buffering inventories. Aisin's simultaneous improvement in terms of variety (styles), volume (units per day), productivity, and inventory (days of finished goods) is shown in the following chart.

	1986	**1988**	**1992**	**1996**	**1997**
Styles	200	325	670	750	850
Units per day	160	230	360	530	550
Units per person	8	11	13	20	26
Finished goods (days)	30	2. 5	1.8	1.5	1.5
Productivity Index	100	138	175	197	208

Figure 118: Aisin mattress production: Historical mix, volume, and inventory

SENDING REQUESTS WHEN VARIETY IS HIGH AND LEAD-TIME IS LONG

To understand the customer-supplier connections used to control the production and delivery of goods, services, and information on Aisin's shop floor, it is worth first explaining a method I saw used commonly in TPS-managed production environments.

LOW VARIETY, SHORT-LEAD TIME PROCESSES

The data I've presented prior to and excluding this Aisin example concern customer-supplier pairs that are similar in several ways. The good, service, or information being transferred across the customer-supplier link is used in high volume, the variety of goods or services that are passed within each pair is relatively low, and the lead-time is relatively short. Therefore, each customer can send a direct request to the immediate supplier that implies the 'what' that is needed, the quantity that is needed, and the timing of the desired response. The customer can expect a rapid response. This situation is generalized in the next diagram.

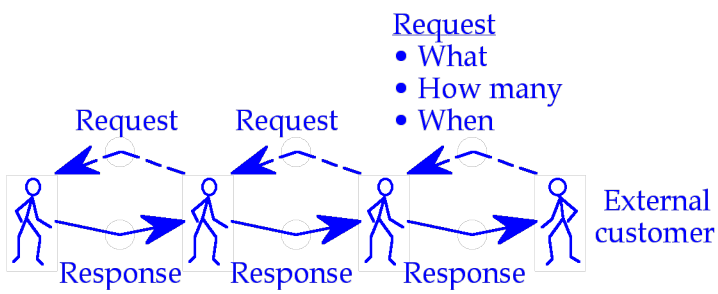

Figure 119: Simple "Rule-2" Customer-Supplier links

<u>LOW-VARIETY, LONGER CYCLE TIME, CHEAP HOLDING COST</u>

It happens though, that the supplier's manufacturing lead-time might be too great to meet the needs of the adjacent customer. Therefore, the supplier might keep a small store of goods on hand so that when a request is received, the response can be in the form of an immediate *delivery*, even if the production itself is not immediate. This was precisely the condition that required Sadie and Ora-Lee to have containers of parts available for Doris on each of her hourly collections. The same condition necessitated the off-line operator moving parts from the off-line storage to line-side racks in the Tsutsumi plant.

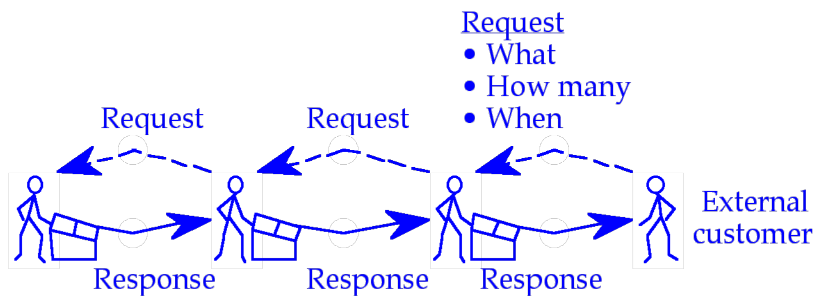

Figure 120: Simple "Rule-2" Customer-Supplier links with small stores

<u>HIGH VARIETY, LONG CYCLE TIME, HIGH HOLDING COST</u>

I observed many situations in which keeping stores was not feasible, however. The products might have been large in size or otherwise expensive to hold; the product might have spoiled with age, preventing production in advance of consumption; or the product might have been produced in such variety, that holding stores was quantitatively prohibitive. All three conditions affect the automobile industry, and in the same way if not to the same extent, all three conditions affected Aisin as a manufacturer of make-to-order mattresses.

In both instances, the final product is relatively large and space consuming to store. In both instances, the final product ages -- if not rotting like fruit or an uncured thermo-setting resin -- spoiling in the sense of going out of fashion, like apparel and other style-driven products. Finally, both cars and Aisin-mattresses are produced with great variety with several thousand possible combinations when picking a car's features, and nearly a thousand from which to choose for an Aisin make-to-order mattress. In such cases, the customer-supplier connection is still direct, binary, and self-diagnostic, but with a slight, but universally consistent modification in TPS-managed settings.

In the case of a product that cannot be stored and that has long lead-times at each stage, a customer might request the final product from the last person in the supply chain. The best that the supplier can do is promise a delayed response while sending a request for the product in its final (minus one-step) form to the next person in the supply chain. The person who is the next link also can do no better than promise a delayed response while sending the request one more step upstream, asking for the final product in its final (minus two-steps) form. As a result, the request would have to leap frog its way to the start of the supply chain before returning in the form of a response.

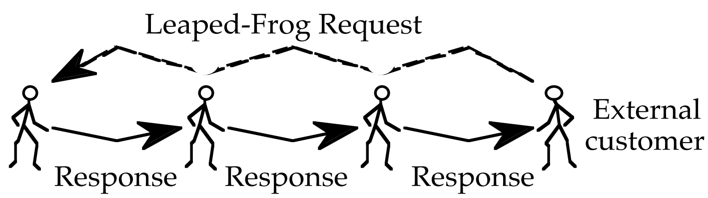

Figure 121: When stores are not feasible and responses are not immediate

Rather than burden each person in the supply chain with the additional responsibility of forwarding the customers request, Toyota has developed a simple mechanism for designing and operating customer-supplier links when the product that is being transferred cannot be kept in an intermediate store and when the manufacturing lead-time is greater. I observed that in such cases, the customer's request was split into two components: information necessary for establishing a production sequence -- what was needed, in what quantity, in what order -- was sent directly to the start of the supply chain. This reduced the burden on each link to relay the information upstream. However, each customer still controlled the *rate* at which the supplier provided goods, services, and information. Therefore, each customer told the immediate supplier when to DO the activities that would result in the next product coming forward. Such material and information flows are shown below. A concrete example follows.

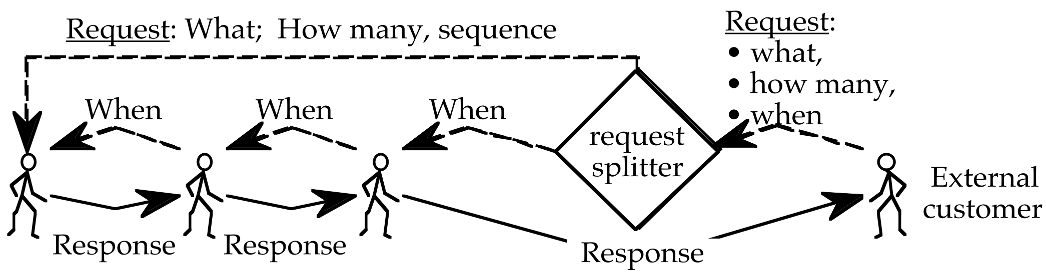

Figure 122: "Rule-2" Customer-Supplier links when stores are not viable

For example, earlier I explained that in the TPS-managed production setting, the seat installer exercised more control over his suppliers than did Willie in the Big-Three plant. The difference was not only in the ability to trigger the production and delivery of goods, services, and information that were used in high volume but in low variety. The difference also existed due to the ability of the Toyota person to prevent his supplier from delivering the next car and the inability of the Big-Three worker to exercise similar control over the rate at which his supplier.

To summarize: I observed two general classes of direct, binary, self-diagnostic customer-supplier connections. Those in which:

A: the single request signal carried information about the *form*, the *quantity*, and the *sequence/timing* of the customer's demand, and

B: the request signal was split into two pieces. One piece carried information for setting the production content (mix, volume) and sequence. This was automatically 'leaped-frog' to the start of the supply chain. The second piece carried information for setting the rate or timing of production and delivery. This second piece was passed -- one individual person at a time -- upstream.

This distinction makes it simpler to understand how Aisin operated direct, binary, self-diagnostic customer-supplier links to coordinate several feeder lines while producing large-variety, make-to-order products, in high volume, with short lead-time (3 days) and small inventories (1.5 days of finished goods).

MATERIAL AND INFORMATION FLOW AT AISIN MATTRESS FACTORY

The following diagram illustrates (in a somewhat simplified version) some of the system-level material and information flows that I documented on a plant visit in the summer of 1997. In placing orders, customers set the mix (what), volume (quantity), and timing with which mattresses must be produced and delivered for Aisin to maintain its promised three-day turn around from order to home delivery. This first step ("1" in the diagram) occurred at a furniture dealer such as the Yasui furniture store or at a department store, both of which I visited in 1998 to understand the ordering process.

At the retail outlet, customers could view and test several model beds, examine fabric samples, and investigate catalogs, using the store visit to determine the size (small, medium, large), outer fabric, lining material, quilting pattern, mattress firmness, and trim material that will be used in constructing their own mattress. During the visit, they could also select a bed-frame that would be delivered with the mattress from one of many alternatives.

Weekly cyclicality affected production scheduling when the order arrived at the Aisin factory. Though the plant operated the same number of hours each day, its orders peaked on the weekends when couples had an opportunity to shop on their day off. Likewise, customer orders had to be sequenced so that the mattress was produced when the customer wanted it delivered and not ahead of time. Therefore, the production sequence did not exactly match the order sequence. Some days, it run an abundance of orders for individual customers and other days it runs an abundance of orders for institutional buyers such as hotels and hospitals that don't need immediate turn around.

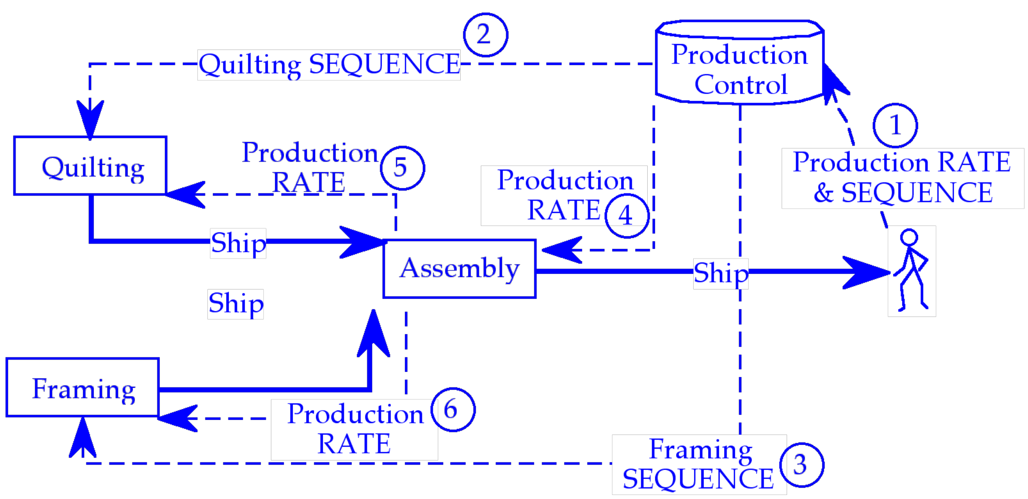

Figure 123: Aisin: Simplified material and information flow

Changeovers were a major consideration in determining the production sequence within a single day. It was at the quilting machine where the cover fabric, the liner fabric, the quilting pattern, and the color of the quilting thread are combined. However, there were non-zero changeover times required for each of these features. Therefore, Aisin divided the production day into two-hour segments. Within each segment, production was lumped to minimize changeovers so that equipment could be more fully utilized. [However, there was no lumping across these two hours segments nor across days due to changeover considerations]. Every two hours then, each of the five quilting machines received a sequence of items that it was supposed to make, and every two hours, each of the two framing lines received the sequence of springs it was supposed coil and assemble. These two sets of instructions are shown as information flows "2" and "3" in the preceding diagram.

Every two hours, the rate at which production must occur was also determined. This determined the rate at which units were to be removed from the end of the production line and transported to the staging area for shipping. Since each of the assembly lines had room for only one finished, labeled, bagged mattress, the rate at which mattresses were taken from assembly to shipping determined the rate at which mattresses could be assembled. Because the start of the assembly line had room for only one incoming frame and only one incoming quilt, the rate at which assembly occurred determined the rate at which framing and quilting occurred. In turn, because both framing and quilting requested new materials only at the rate at which those feeder lines were consuming materials, the rate at which quilting and framing worked determined the rate at which material was delivered from off line stores. Finally, the rate at which material was provided from off-line stores determined the rate at which replacement materials were ordered from and delivered by outside vendors.

Therefore, literally and figuratively, the order of each single person at the Yasui furniture store was converted into a request that triggered someone in Aisin's shipping department. This individual -- using a DO/DON'T DO signal -- triggered the workers in assembly, who triggered the workers in quilting in framing, who triggered specific off-line operators, who triggered production and delivery of external suppliers. In other words, these simple, Rule-2, direct, binary, self-diagnostic links served to coordinate the production and deliver of goods, services, and information through at least three tiers of the supply chain (e.g., the retail store, the Aisin plant, Aisin's suppliers) in order to meet the demands of one individual customer at a time.

SELF-DIAGNOSTICS OF THE DIRECT, BINARY LINKS

The preceding exposition emphasized the direct and binary qualities of customer-supplier links in the Aisin plant. I also made observations that contributed to my finding that customer-supplier links are self-diagnostic too.

For example, for all the customer-supplier links to be direct, binary, and self-diagnostic, the supplier must have a way to control the pace of production and delivery by the supplier. A clever device allowed the final assembly line to set the production pace for the quilting machine.

After the quilting machine operator completed a set of covers, she attached one of five poker-chip like, wooden tablets to the 'sub-assembly.' When the quilted layers were taken by the final assembly line, the tablets were returned to a rack. The quilting machine operator was only allowed to make the next quilted cover-set if she had a tablet as authorization. Therefore, because the assembly line's actual rate of production determined when the tablets were returned to the quilting operator, the assembly line was determining the rate at which the quilting operator produced and delivered.

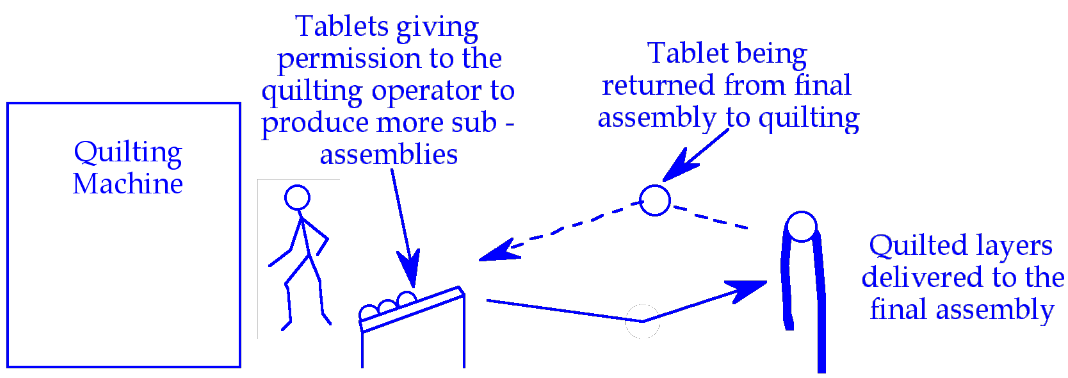

Figure 124: Connecting assembly to quilting

This connection between the assembly line as customer and the quilting process as supplier was both self-regulating and self-diagnostic, generating a call for help when actual system performance did not match expected system performance. The expectation was that the assembly line would need quilted sets at approximately the rate at which the quilting machines could provide them (that there are five tablets allowed for some variation in the production rate of each). However, were the production line not to return any tablets to the tablet-rack, this would have been a sign that the rate of demand or consumption had fallen and remained below the rate of production. Therefore, the rack was designed that when it was empty of tablets, a limit switch was flipped which in turn told the group leader to determine what had caused the two segments to get out of balance.

Similarly, were the production line to return all of the tablets to a tablet-rack, this would be a sign that the rate of demand/consumption by assembly had risen and remained above the rate of production in quilting. In anticipation of this possibility, the tablet-rack had a second limit switch that was flipped when the tablet-rack was one tablet short of full. This generated a signal that the quilting line had fallen behind and was on the verge of starving the assembly line. The signal was directed to a particular group leader who interpreted it as DO the activities that will resolve the problems that have caused the assembly line to fall behind (i.e., DELIVER assistance now.)

Another particularly interesting connection was between the workers on the final assembly lines and their group leader. There was a large digital display above each of the final assembly lines that indicated the precise number of completed mattresses the line was ahead or behind compared to the target number for that point in the day. For instance, suppose the target production rate was 1 mattress every 3 minutes. At the end of 3 hours of production, the line was expected to have produced 60 units. However, if the line had actually produced 57 units, the display would have read: – 3. Likewise, if the line had actually produced 61 units, the display would have read +1.

This display was used not merely to let people working on the line know how far ahead or behind they are. Rather, this display was used to create a direct, binary, self-diagnostic connection between the line workers and the group leader. According to the group leader whom I shadowed for an hour, his standard work included watching that display. If it read –1, –2, or -3, he was not to do anything. However, if it read –4, he was to add a person to the line. Then, he was to keep that extra person on the line until the display read + 1. During the time that the line was recovering, his pre-specified responsibility was to observe the work being done by each person and make inquiries that would help him understand what caused the line to produce at an actual pace less than the pace it was expected to be capable of operating.

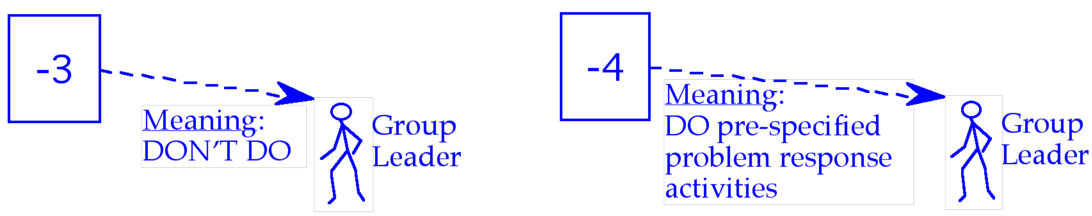

Figure 125: Interpreting final-assembly display board

SUMMARY OF AISIN DATA

The preceding accounts presented some of the observations that led to the formulation of Rule-2 as the guideline for designing and operating connections between customers and suppliers. Direct, binary, self-diagnostic connections linked and coordinated feeder lines with the main assembly line. Likewise, connections of this sort provided customers with the means to start and stop the production and delivery activities of direct suppliers. As the examples illustrated, the final assembly line had a mechanism (the wooden tablets) to control its upstream supplier, the quilting process. This mechanism was self-diagnostic, generating a problem signal when the quilting line had gotten unexpectedly ahead or unexpectedly behind its customer. This problem signal acted as a direct, binary request to a supplier of assistance and problem-solving expertise. Likewise, the display above each production line sent a direct, binary signal that triggered a pre-defined, defect-free response.

Though I will not go into as such great detail here, similar or identical mechanisms were evident in other TPS-managed production settings but were not evident in non-TPS settings. For instance, at the Toyota managed NUMMI plant, a nearly identical system to Aisin's display board connects the wheel sub-assembly process with the final line. I saw that when the queue of wheels rose to a pre-specified amount, the wheel sub-assembly process had to shut down. When the queue fell to a pre-specified level (10 sets, a quantity determined by the travel time from the feeder line to the main line), this generated a problem signal, which in turn were to trigger problem-solving activities.

In contrast to the system used at NUMMI, the wheel feeder-line at the Big-Three plant in which I worked for a week was not linked to the main line with a self-diagnostic connection. Tires and rims were joined according to a computer-generated manifest, and I observed that assembled wheels were then placed on a conveyor that took the wheels to the line. When the conveyor was full, the wheel feeder line was forced to stop working by the physical constraint. However, stopping did not act as a signal to investigate a problem. Furthermore, from what I gathered, there was no formal trigger for problem-response activities by a particular person should the queue shrink to a pre-defined level.

In sum, I observed a consistent approach in TPS-managed settings of designing and operating connections so they would be direct, binary, and self-diagnostic. I did not detect this approach in non-TPS-managed settings. This distinction was true even if the TPS and non-TPS settings were similar in terms of product and process. Therefore, I concluded that the mechanisms and practices reflected something fundamental to TPS and not fundamental to the industry or technology. Upon close examination and by comparing a variety of communication devices, I concluded that Rule-2 captures an essential norm of good TPS behavior.

"DESIGNING" A CROSS-DOCK FACILITY

By and large, I derived the Rules in Use through an inductive process. I gathered data in specific situations and from this data developed a general model. For instance, by comparing the design and performance of the seat installation activity at the Big-Three plant and Toyota plants, I developed a model of how activities in TPS-managed settings are designed and performed more generally. However, on occasion, I was able to gather data and reach conclusions in a deductive fashion, using a general model to predict the behaviors I would observe in a specific setting. If the actual observations matched the predicated observations, this would confirm (or, more precisely, not refute) the model I had developed. An example follows.

In June 1997, I visited a logistics facility run by a Toyota supplier and managed according to TPS principles. Based on a prior description of the activities conducted at the work-site, I made predictions about how material and information flows would be processed. Then, when I visited the site, I was delighted to learn that the predications matched the actual practice nearly exactly (for confirmation, I compared my predications and observations with the summary notes made by another visitor, Brent Johnson, an employee of Alcoa, and a student in MIT's Leaders For Manufacturing Program).[31]

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[31] Johnson, Brent; The Soft Side of the Toyota Production System is the Hard Side; Master's thesis, MIT Department of Civil and Environmental Engineering; June 1998

BACKGROUND

At the time of my visit, Toyota faced a logistics challenge in North America unlike any faced in Japan. In Toyota's home market, Toyota's plants and those of its suppliers had been located nearby, and those that were farther away were located along the main highways that run the length of what has been a relatively narrow industrial corridor. In North America, in contrast, Toyota had plants that are geographically dispersed, and its suppliers too were geographically dispersed. Therefore, direct, point to point daily shipments from each supplier plant to each customer plant was not feasible. The logistics facility had been created specifically as a cross-dock, transfer point for material traveling from suppliers in the industrial Midwest to Toyota plants in Kentucky, Indiana, and West Virginia. Prior to my visit, I tried to 'design' such a facility from what I thought to be true about TPS-managed customer-supplier connections.

I started with the basic idea that the best supplier is one who gives the customer exactly what is needed, on-demand, in batch sizes of one, immediately, and without waste. We observed nearly IDEAL customer-supplier links between two people working at adjacent locations in some production cells, for instance.

However, it may be uneconomic to transport and deliver piece by piece if the customer and the supplier must be physically separated. Consequently, a typical response that I observed was to produce one by one but deliver container by container, for instance between locations in the same plant. Likewise, while it may have been feasible to deliver container by container within a plant, it was unfeasible to deliver in such small batches with such great frequency between plants. For example, at some plants that supply Toyota's Georgetown factory, production was piece by piece, and internal conveyance was container by container on a few minute material handling cycle. However, shipment to Toyota occurred truck-load by truck-load a few times a day.

Nevertheless, whether the customer requests and supplier responses were denominated in pieces, containers, or shipments, the connections were still direct, binary, and self-diagnostic.

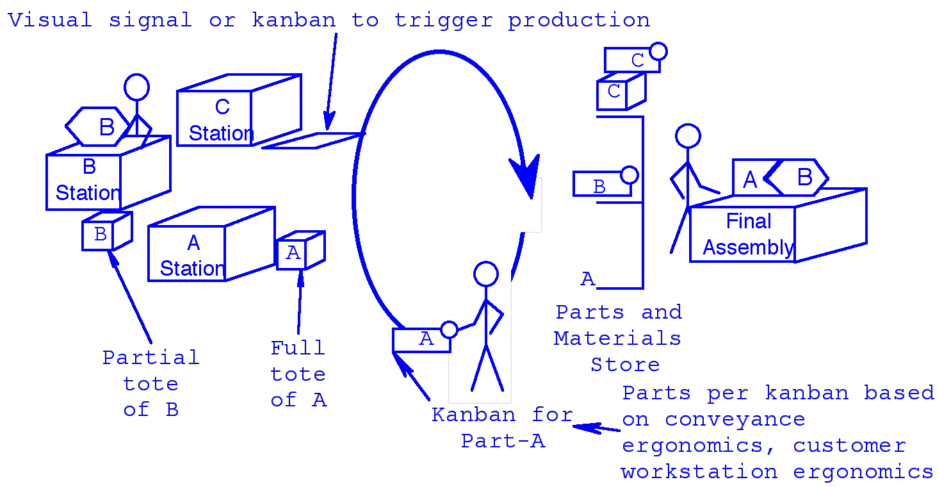

Figure 126: Moving material within a plant

Direct, binary, self-diagnostic connections existed, even for a single 'milk-run' truck that collected material from more than one supplier plant, as in the diagram below.

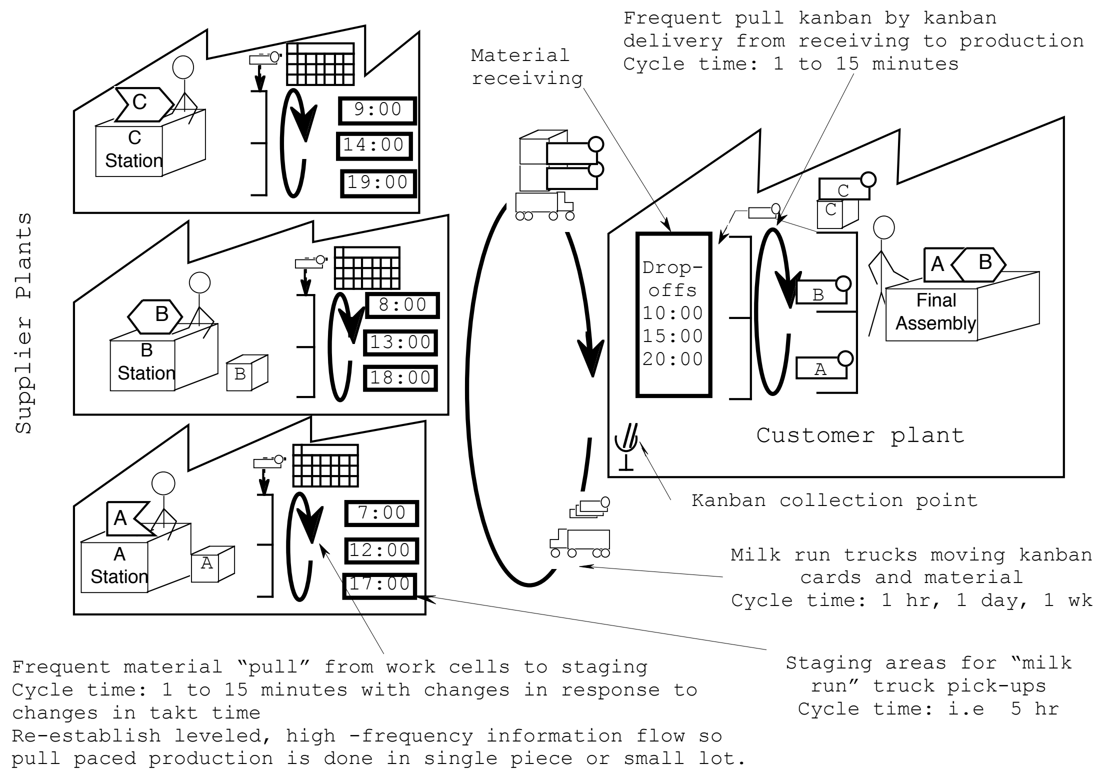

Figure 127: Moving material between cells (at *different* supplier plants)

In the plant in which I worked in Kentucky, orders came in the form of the physical kanban cards sent from the customer plant. However, in constructing my deductive 'prediction' of the cross-dock facility, it was easy to imagine that if trucks had to travel great distances, then from the time they departed from the customer's plant until they arrived at the supplier plant, a great deal of time might elapse, compromising the immediacy with which the supplier learned the needs of the customer. It was easy to imagine that the customer could send requests electronically, not as physical kanban cards requests) instead. This was anticipated in the following sketch.

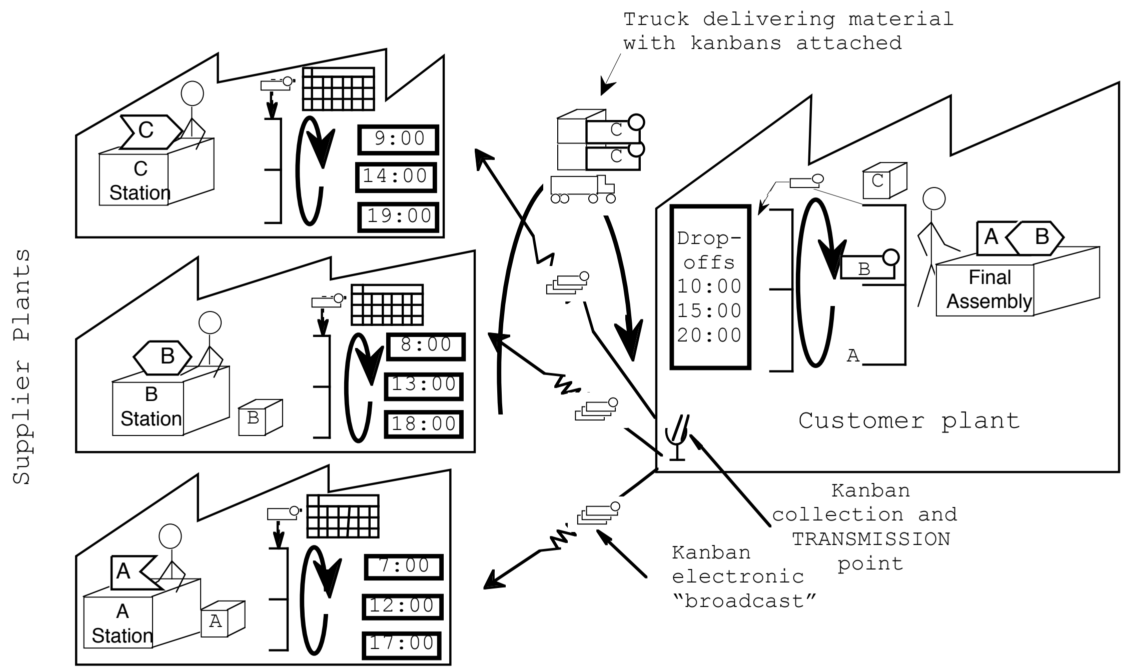

Figure 128: Moving material between cells (at different *distant* supplier plants)

Likewise, if several customers had to communicate with several suppliers, then each might send requests electronically, but *directly and in a binary form* to each supplier. However, if each supplier had more than one customer, and both the suppliers and the customers were geographically distributed, it might not be economic to have trucks run point to point routes or to have trucks follow 'milk run' routes that visited all the plants. This might require extra driving and reduce the frequency with which pick-ups are received and deliveries are made.

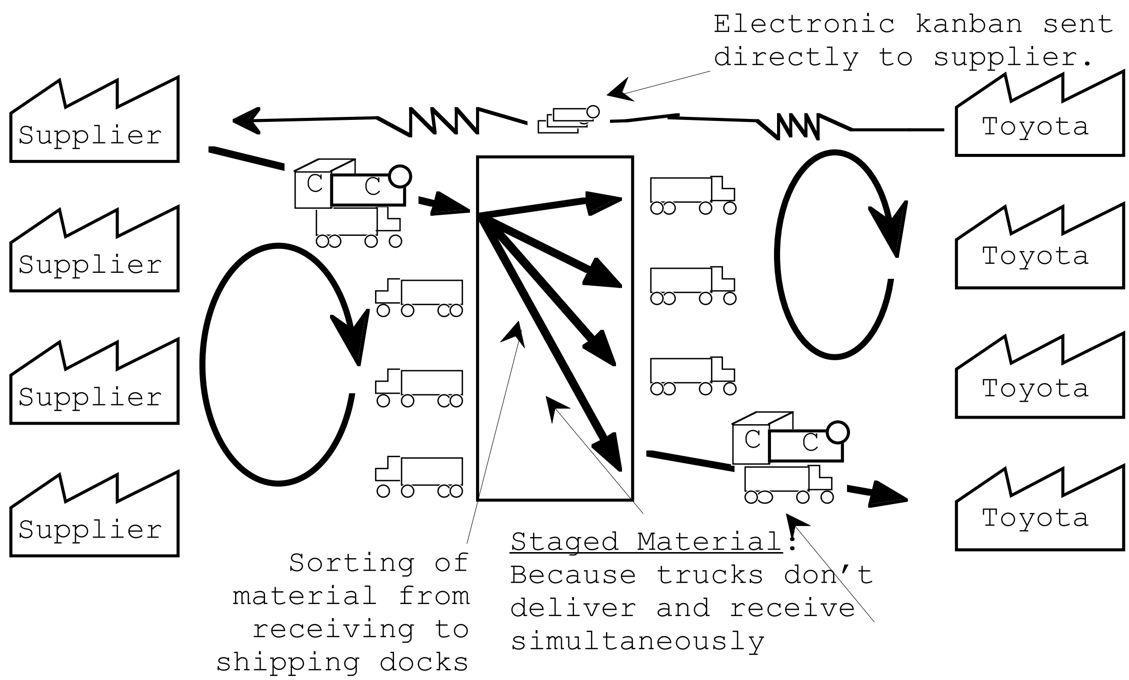

Figure 129: Basic *predicted* design of the cross-dock facility.

The cross-dock facility, as I designed it deductively, following the principles of Rule-2, addressed each of these concerns. Because of great travel distances, I predicted that orders would be sent electronically, but still in form of signals that could be interpreted as DO a pre-defined set of activities that will result in the delivery of a pre-defined good. Likewise, because of the relatively low volume with which some suppliers served some customers, I predicted the use of milk-run routes so that each supplier delivered smaller response-batches more frequently rather than larger response-batches less frequently. Because the customers were spread out, I predicted that there must be some location in which material could be taken from the milk-run trucks that visited several suppliers and placed on trucks that carried a mixed load of material to each customer plant. Because, the trucks coming from the suppliers and the trucks departing for the customers would arrive at the transfer location, then the location itself must have some mechanisms for taking the material coming in and allocating it correctly in staging areas.

The last diagram, above, turned out to be an accurate prediction of how material and information flowed between customers and suppliers, through the cross-dock facility. The gratifying part was that it was possible to generate an accurate prediction by relying on fundamental principles and not by relying on interpolations or extrapolations from a vast library of analogous situations. Rather, maintaining a commitment to direct, binary, self-diagnostic connections plus the steady application of counter-measures as each problem was presented led to a prediction or design that accurately matched the actual design created by Toyota's own TPS and logistics experts. This, in turn, was an exciting confirmation that I was making progress towards codifying the implicit models by which TPS-guided managers designed, operated, and improved organizations.

CHAPTER 7.3:

DATA AND ANALYSIS CONTRIBUTING TO RULE-3:

FLOW-PATH DESIGN AND OPERATION

INTRODUCTION

RULE STATEMENT

Rule-3 guides the design and operation of flow-paths (systems constructed from connected activities) over which goods, services, and information take form.

It states: **Design and operate the flow-path for every good, service, and information so that it is *simple*, *pre-specified*, and *self-diagnostic*.**

For a flow-path to be:

- *simple*, a flow-path must not have *loops* or *intertwined branches* A *loop* exists if a good, service, or information returns to an upstream process for processing, or if a person or machine is responsible for non-sequential steps.

  An *intertwined* *branch* exists if a server at activity $_{n+1}$ is fed by more than one server at activity $_{n}$ AND a server at activity $_{n}$ feeds more than one server at activity $_{n+1}$. (As will be explained this does not preclude flows coming together as when several slower or specialized processes supply a single faster or general purpose process, nor does it preclude flows splitting as when a high speed process feeds several slower processes.)

- *pre-specified*, every good and service must have one and only one flow-path over which it can travel as it takes form.

  i.e., if a process-flow branches, it is known ahead of time which specific branch each good, service, or information is expected to follow.

  This requires that responsibility for each activity that will contribute to a good, service, or information taking form be uniquely pre-assigned to a single person or machine.

- *self-diagnostic*, a problem-signal must be generated immediately if a good, service, or information travels a flow-path other than its pre-specified one. Alternatively, this means that a problem signal must be generated immediately if a person or machine who was not assigned responsibility for doing an activity actually performs that particular work or if a person who was expected to do an activity actually does not.

RULE EFFECT

There are at least three consequences of designing flow-paths so that they are pre-specified, simple, and self-diagnostic. Each is discussed in this chapter.

- *Pre-specification* creates the opportunity for hypothesis-testing.
- *Simplification* reduces the structural complexity of the system by reducing the size of the smallest modular building block. Following the reasoning of Baldwin and Clark, this increases the option value in the system's structure.
- *Loop-removal*, as a specific form of simplification, increases system stability by preventing disturbances in a down stream process from being re-injected into the system at an upstream process.

DERIVATION

I concluded that TPS-managed flow-paths are simple, pre-specified and self-diagnostic from a variety of data. Some of these data are cross-sectional. In TPS-managed plants, I could start at shipping (the point closest to the customer), and trace each product and all its contributing sub-assemblies and supporting services back along single flow-paths to their origins. I could not do this in non-TPS plants. Other data were longitudinal. Toyota and Toyota-trained people redesigned flow-paths so that they would be pre-specified, simple, and self-diagnostic.

This chapter concludes with data from a natural experiment comparing looped and un-looped systems.

SIMPLE, PRE-SPECIFIED FLOWS

The following evidence supports my conclusion that pre-specification and simplification are both essential and distinguishing characteristics of flow-path design and operation in TPS-managed systems.

TOURING A TPS-MANAGED PLANT

I gathered data at 33 sites. Of those, 5 were TPS-managed Toyota suppliers in North America, 6 were TPS-managed Toyota suppliers in Japan, 2 were TPS-managed plants in Japan, but not in the auto industry. At *all* of these 13 plants, I was shown the facility in exactly the same fashion, backwards. Rather than starting at receiving and following the process flows to shipping, as was the typical approach taken by hosts in non-TPS settings, we *always* started at shipping and traveled upstream. At *every* stage from shipping back to receiving, there was a clear indication of the specific location in the plant from which materials and services would be provided.

For example, on a 1996 research trip in Japan, I visited a Toyoda Bushoku plant that makes air and oil filters. We started in the shipping area. There, shipping lanes were clearly marked, and above each shipping lane, there was a schedule showing the arrival time for a truck, the departure time for a truck, and the destination. In effect, each truck was a specific customer receiving a pre-defined product -- a complete shipment. These customer trucks each had a pre-specified supplier -- a specific staging area where parts and material were gradually accumulated from the time one truck departed to the time the next truck arrived. In turn, each of these staging areas was a customer that received specific parts and materials from designated locations in the plant. In turn, each of these designated locations was replenished by a single, designated cell or line. Each of these cells was a customer for a supply of parts and materials that came from another designated location. In turn, each of these locations was replenished by a single, designated, injection-molding machine.

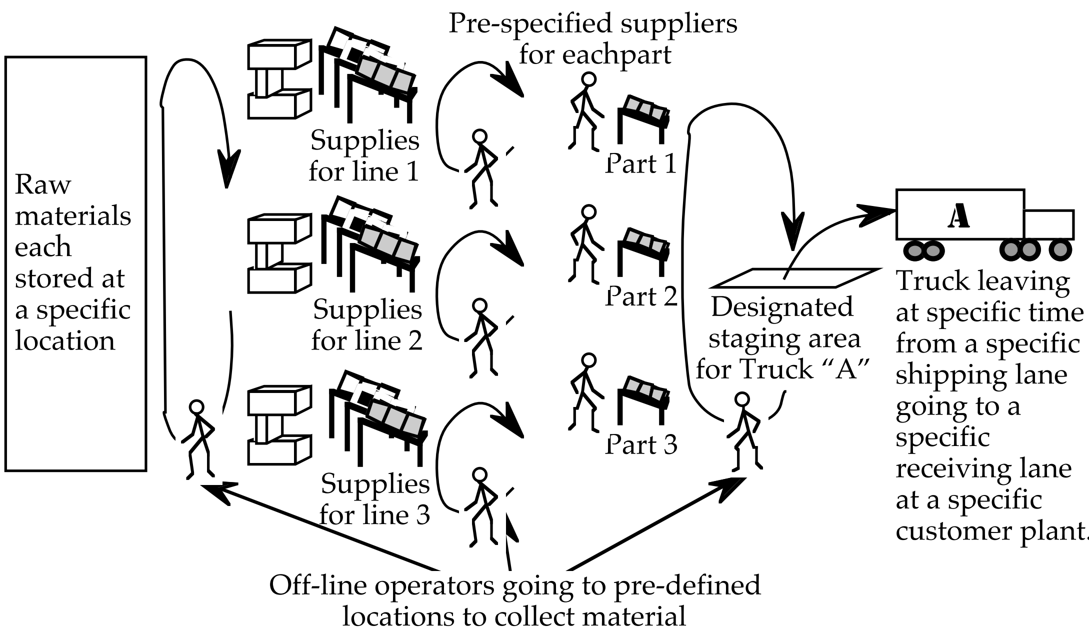

Figure 130: Pre-specified flow-paths at TPS-managed sites

It was not just flow-paths for materials that were pre-specified. Flow-paths for services were pre-specified and simple too. For example, there was one and only one operator who was directly responsible for changing dies and loading material for each machine (this does not imply that a single supplier has only one customer, only that each customer has a single supplier for specific good, service, or information). In turn, this single supplier of die changes and material loads had a single supplier for assistance. In this we saw that the supply chains for services too were simple and pre-specified (a point made when Chapter-7.2 discussed direct, binary, self-diagnostic connections between team members, team leaders, group leaders, and assistant managers).

TOURING A NON-TPS-MANAGED PLANT

Every TPS-managed supplier plant in which I gathered data had pre-specified, simple flow-paths for goods, services, and information. In all of them, it was possible to start at the shipping dock, pick up a part destined for a specific customer, and track back the path over which that specific part had actually taken shape. At the non-TPS-managed sites in which I collected data, it was not possible to start at shipping and -- with absolute certainty -- trace the specific paths over which goods, services, and information contributed to the development of every part.

For example, when I was part of the TSSC team promoting TPS at the stamping plant supplier, Doris, in shipping, had to search in the final goods inventory to locate each of the parts she needed. None of the parts were kept in a designated location. In turn, when she found the parts, there was no certainty that they had come from a specific welding station. Rather, the parts would have been run on a station based on the moment to moment discretion of John, the welding shop foreman. Likewise, when people in the welding shop such as Sadie or Ora-Lee needed material to make parts, there was no designated location from which they could be supplied. Therefore, Earl or Stanley -- the fork lift drivers -- would search the plant looking for the parts that were needed. In turn, once they found the parts, there was no way to determine on which press they had been run.

Consider a simple example: Part 665 could have run on either Press-4 or Press-5. After stamping, it could have been stored in one of 20 locations. It could be welded on one of 10 machines, and in turn, the finished part could have been stored in one of 10 other locations. In other words, when Part 665 finally made it onto a truck bound for the customer, it might have followed one of 4,000 flow-paths through the plant.

Even if Part 665 always went to a specific storage location between stamping and welding and then went to a specific location between welding and shipping, a single part might have traversed one of 20 flow-paths from stamping until it was loaded on the customer's truck. This was similarly true for each of the plant's 300 parts.

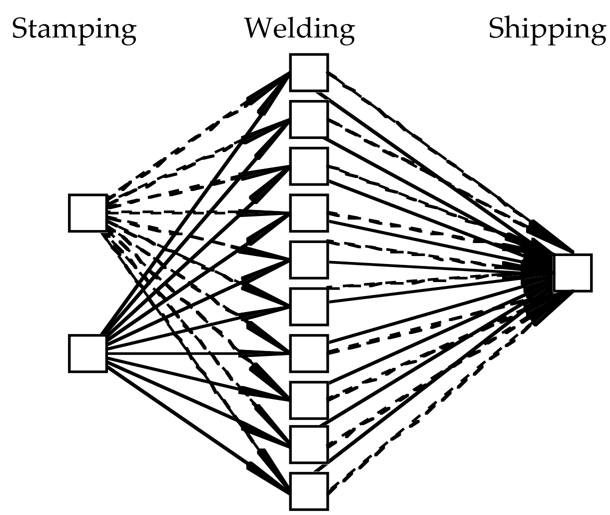

Figure 131: Possible flow-paths for Part 665

This plant was not alone in having flow-paths that were not pre-specified. For example, I have made several visits to a company that makes products from thermal setting resins. The basic process flow is shown below.

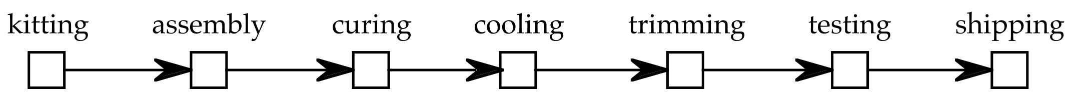

Figure 132: Basic Process Flow - XYZ Corp.

However, the actual process flows were not so simple. The production cell had 2 assembly stations, 3 curing stations, 2 cooling stations, 3 trimming machines, and 3 test stands. Therefore, before a product reached shipping, it might have traversed 1 of 108 possible pathways. Since this cell produced 7 distinct products, the actual number of product flow-paths was as high as 756.

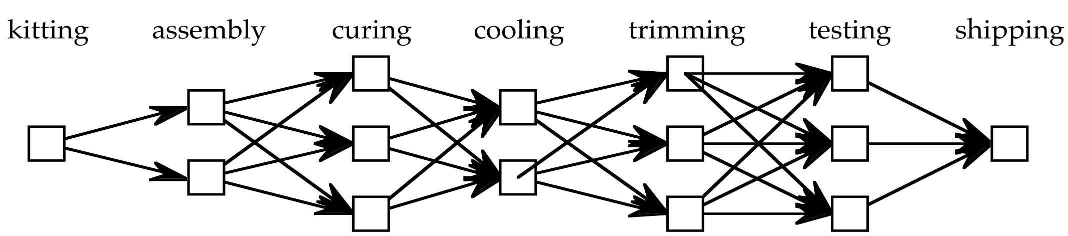

Figure 133: Possible product flow-paths - XYZ Corp.

LONGITUDINAL COMPARISONS

This chapter started with the explanation that in *all* the TPS-managed facilities in which I collected data, flow-paths were pre-specified. It was literally possible to pick up a part as it was loaded onto a truck and trace the material and service flow-paths over which it was created. Likewise, of the facilities not managed by TPS in which I collected data, *none* created their products over pre-specified flow-paths, and *none* provided services such as maintenance, assistance, and training over pre-specified flow-paths. Finally, in every case, when a site was learning TPS, flow-paths were converted from non-specified to pre-specified. The data and analysis chapter for Rule-2 alluded to this in describing the creation of a model-line at a Toyota supplier. A nearly identical change was promoted at Connecticut Spring and Stamping, United Electric, Acme, and Summit Polymers, all client companies of the Toyota Supplier Support Center about which I made first hand, longitudinal observations.

Similarly, in Japan, TPS-managed companies attempted to pre-specify and simplify the flow-paths over which goods, services, and information are provided. At Toyota Homes, the modules for pre-fabricated houses were assembled on a single moving assembly line. In other words, the module moved from customer to customer to customer as it took form rather than having parts, materials, and services come to it in a haphazard flow. Likewise, Toyota Motor Sales was experimenting with TPS in the after-sales service and maintenance process. On a visit to a TMS office, we learned of efforts to redesign service areas so the car would move on a mini-conveyor from work station to work station, rather than having the car on an immobile platform to which materials, people, and services come in a haphazard fashion.

SUMMARY

In the TPS-managed systems in which I collected data, simple flow-paths were pre-specified for all goods, services, and information. In non-TPS-managed systems, the flow-paths were not pre-specified. Rather, as a good, service, or information took form, it might follow a branch based on the moment-to-moment discretion of a local decision maker. John, the welding foreman, put parts on machines based on his own local concerns and information (i.e., what machines are available at this moment) just as Earl and Stanley stored parts based on local concerns and information (i.e., what storage space is available at this moment).

The next section contains my observations of TPS-managed sites trying to compress multiple lines into single lines. This is followed by the data and analysis that looped flows are antithetical to "good TPS." This precedes an account of a natural experiment comparing a looped and un-looped system.

SIMPLIFYING FLOWS BY REMOVING INTERTWINED BRANCHES

In gathering data, I observed that at TPS-managed settings, efforts were made to compress multiple, specialized lines into single, flexible lines. Three examples follow. One for material flow, one for services flow, and one counter-example.

AISIN - SHOP FLOOR REDESIGN

I visited the Aisin factory that produced make-to-order mattress. In the Spring of 1996, three specialized final assembly lines fed the shipping area. When I returned a year later, I found that the three specialized lines had been compressed to two general purpose lines.

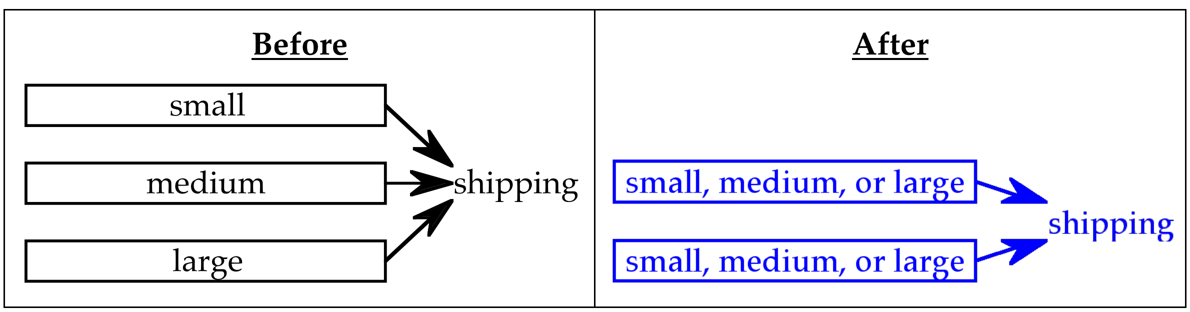

Figure 134: Aisin Shop Floor Redesign

Despite this reduction in 'capacity' and increase in flexibility, the plant actually increased the mix, volume, and productivity with which it produced.

	1996	**1997**
Styles	750	850
Units per day	530	550
Units/person	20	26
Productivity Index	197	208

TAIHEIYO - COMBINING ROUTINE PRODUCTION AND ROUTINE MAINTENANCE

In 1997, I visited a Toyota supplier, Taiheiyo. Managers explained a training effort meant to increase the ability of production workers to maintain machines. Previously, 100% percent of maintenance responsibility had been done by production engineering. After the training, 80% was done by the production workers.

I interpreted this as evidence of a desire on the part of TPS trained people to design flow-paths so that several branches are compressed into single, more flexible flows. For example, in the original case, one person was specialized in supplying the services necessary for routine production (changeovers, material conveyance, etc.) and another person was specialized in supplying services necessary for maintenance. After the training, the same person was more flexible, supplying both routine production services and maintenance services.

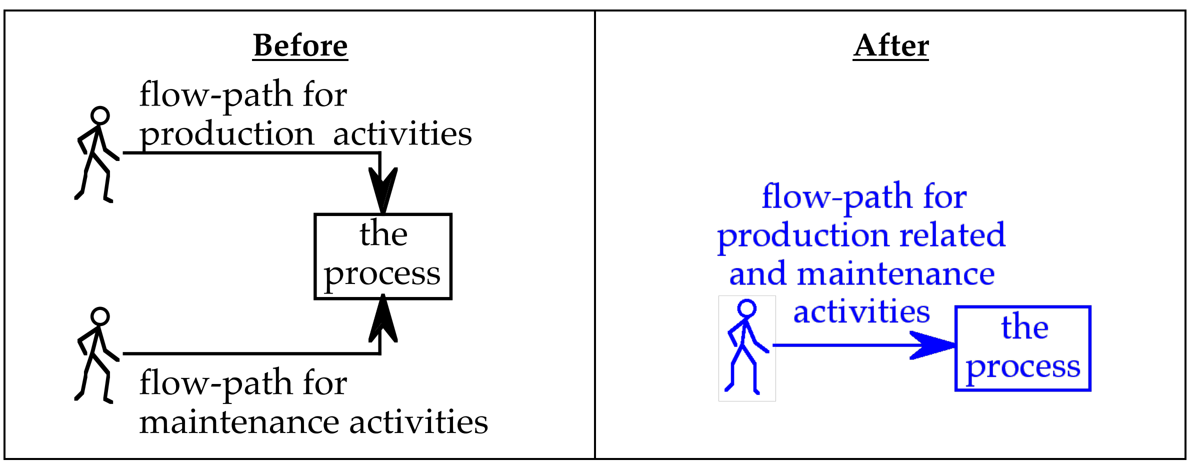

Figure 135: Flow-paths before and after training effort

ARACO - COLOCATING THREE SPECIALIZED LINES

Between my visits in 1996 and 1998, three production lines were moved from separate locations in the plant so that they were colocated and could be tended by a single operator. (The managers explained that the machinery was too specialized to be consolidated into a single cell.) Here too, multiple flows were consolidated to one.[32]

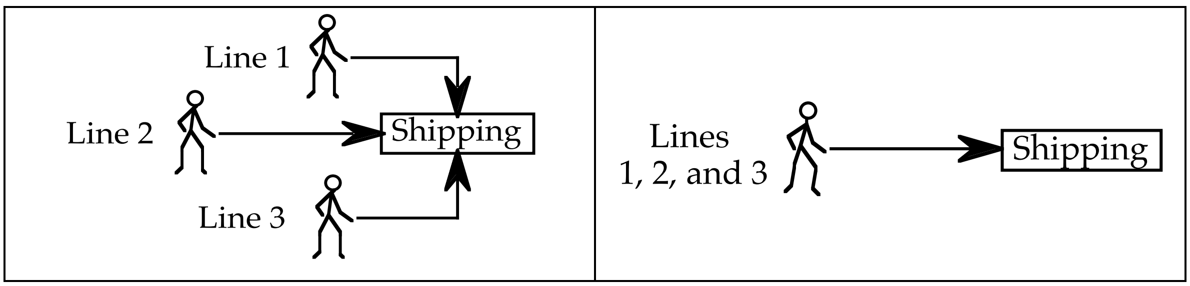

Figure 136: Araco - Before and after equipment relocation

[32] The design of this relocation activity was discussed in Chapter 7.1. It was part of the data that led to that conclusion that activities are designed with work-elements that are pre-specified and testable as to content, sequence, timing, and outcome. As mentioned earlier, the purpose of pre-specification and built-in testing is so that the hypotheses implicit in each activity's design are tested each time the activity is performed. In the case of moving this equipment, the entire endeavor was sub-divided in many, smaller steps. Each step served as an experiment in which hypotheses about the equipment-moving activity-design and the equipment-moving activity-doers could be challenged and so that improved understanding of the activity just done could be incorporated into the activity about to be performed.

SIMPLIFYING FLOWS BY REMOVING LOOPS

CRITIQUE BY A TPS TEACHER

During a plant visit to a non-Toyota plant, Mr. Ohba -- general manager of the Toyota Supplier Support Center and one of TSSC's operations consultants, observed that the product looped back to an upstream operator during assembly (the diagram below is duplicated from the one in my field notes). They were both critical of this practice, enough so that during the post-tour discussion, Mr. Ohba highlighted five key points with which he took issue. This loop was one of them.

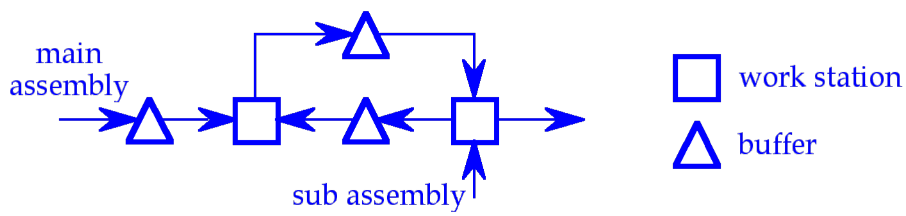

Figure 137: Actual material flow at one research site

PROCESS REDESIGN AT TOYOTA SUPPLIER SUPPORT CENTER CLIENT

I have documented a shop floor transformation in which Toyota people removed loops from process flows. The practice had been to remove products from the line when rework was necessary and reinsert them at the same point from which they had been taken, as shown in the next diagram. [Because this plant rebuilds starter motors and alternators, its raw materials arrive in various states of *disrepair*, so rework is a relatively normal occurrence.]

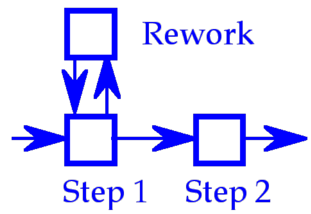

Figure 138: Material looping back into the flow from a rework process

During one training session, people from the Toyota Supplier Support Center taught TPS to members of the plant's work force through problem-solving and process redesign. One of the problems they addressed was this loop of products back to their point of origin. Together with the plant people, they redesigned the flow (and to a certain extent the work done at the activities that were part of the loop), so that the material could continue to the next step without returning to an upstream process.

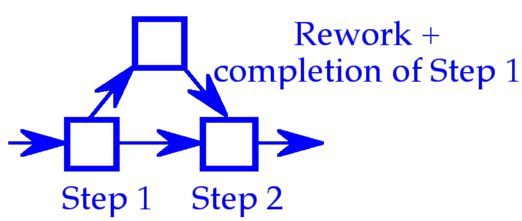

Figure 139: Loop removed from material flow-path

KEEPING LOOPS OUT OF FLOWS FOR ASSISTANCE AND TRAINING

I observed that TPS trained workers and managers were diligent in removing loops from the flow of assistance and training from people more senior in the hierarchy to those less senior. For example, in the Georgetown, Kyushu, and NUMMI plants, each of the team members whom I observed were connected directly to a specific team leader for assistance in production tasks. Each of these team leaders were connected to a specific group leader. The group leaders were connected to assistant managers.

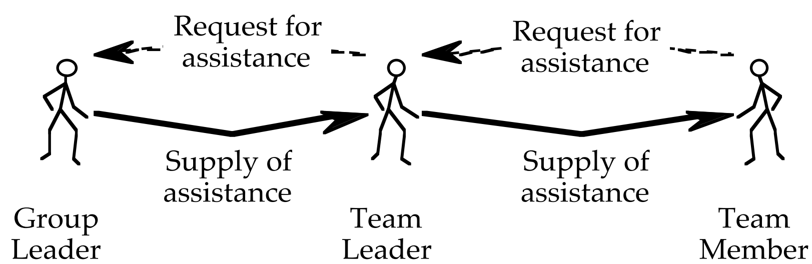

Figure 140: Simple flow-path for assistance in production work

Had flow-paths had loops in them, I might have seen group leaders connected directly to team members. Though I did not do an exhaustive analysis of every customer-supplier connection, of those I did study, none were designed with a loop, with the team member returning to an upstream supplier for assistance and training.

NHK TOYOTA

I had other evidence that assistance is provided over a flow-path without loops in a TPS-managed system. While gathering data in the Toyota supplier plant that makes seat-frames, I shadowed a team leader for an hour and then interviewed his group leader, Mr. Seto.[33] While shadowing the team leader I noticed that there were obvious opportunities to improve the work of the people on his team, but, apparently, the team leader had not yet shown them how to improve the work nor had he improved the work himself. For instance, the team

[33] Plant visit: Summer 1997

members could not do fixture changes. I then asked Mr. Seto why obvious improvement opportunities remained. His response was that this was a new team leader, and that he, as group leader, was still training him to do routine tasks such as changing fixtures in the welding machines and conveying material to the team members. According to Mr. Seto, if he solved production problems directly, he would remove opportunities to teach the new team leader, and through him, to teach team members. I interpreted Mr. Seto's comments (and those of two other group leaders who concurred with this approach) in the following fashion.

- In the best case, the team member should improve the work.
- If the team member cannot improve the work, then the team leader should supply the team member with training.
- If the team leader cannot train the team member, then the group leader must supply the team leader with training.
- Training should occur through solving production-related problems.
- If Mr. Seto solved the problems, he would leap-frog the team leader and deny him the chance to learn through problem-solving.

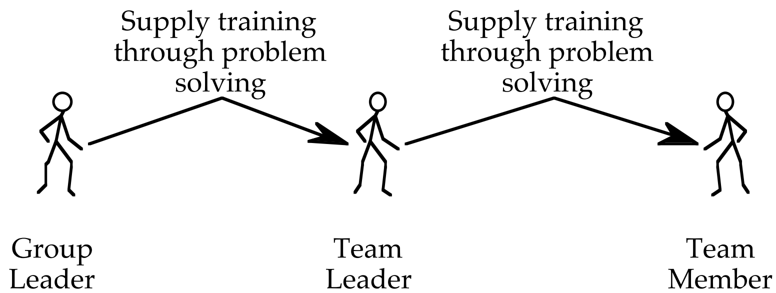

Figure 141: Mr. Seto's view of correct flow-path for training

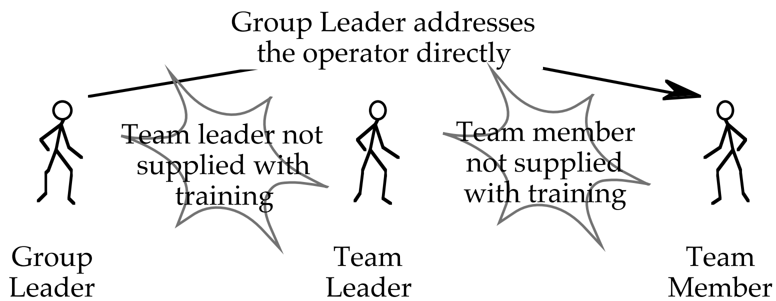

Figure 142: Mr. Seto's view of broken flow-path for training

I shared this interpretation with the Toyota-Japan and Toyota-North America people who were my hosts and guides. They agreed with this interpretation.

BRYANT AND OLIVIERS'S TRAINING

I interviewed two members of the Toyota Supplier Support Center who participated in a problem-solving based training session at Toyota plants in Japan, Bryant Sanders and Olivier LaReau. They were members of problem-solving teams, each of which was composed of 7-10 team members, one team leader, and an advisor. During an interview, I asked them who spoke to whom during the training. The replied that as team members, they mostly received direction from their team leader, and that their conversations with the advisor were mostly limited to him acting as a translator. However, the advisor had other conversations directly with the team leader. In contrast, when Bryant took the role of team leader for a few days, a more experienced team leader spoke most with Bryant, giving Bryant the opportunity to speak directly with the team members. In turn, the group's advisor directed most of his comments to the experienced team leader. This reinforced my conclusion that training and assistance are delivered over simple, un-looped flow-paths.

COUNTER-EXAMPLE: MANAGER DISTRACTIONS DURING CHANGEOVERS

In Chapter 7.2, I described designing and operating customer-supplier connections for a model-line and the negative consequences of designing a connection improperly. While working with managers in the same plant, I observed what occurred when the flow-path for assistance became looped. One of primary activities was to help a stamping shop team learn to reduce the time required to change a die in a press. The reader will recall accounts of this training activity in the Rule-1 Data and Analysis chapter (Chapter 7.1). During the time that we were teaching the team leader, Anita, and team members such as Moon, Randy, and Lewis, we encouraged the plant managers to observe and participate in the training. On occasion, they issued instructions directly to Moon, Randy, and Lewis during the changeover, in effect leap-frogging Anita, and creating a loop in the flow-path connecting managers to first line workers. Though their interference was apparently well-intentioned, the effect was negative. The team members did not know to whom to turn for assistance. The managers had less opportunity to observe and evaluate the design of the process, and Anita could not practice managing the process as it was designed to operate.

NATURAL EXPERIMENT IN THE CONSEQUENCES OF LOOPED FLOWS

In addition to data gathered in the field, I also had an opportunity to gather data from a natural experiment. This contributed to my conclusion that looped flows have deleterious effects on dynamic systems.

First year MBA students at the Harvard Business School were assigned to teams. Each team was given an identical assignment: Design a production system for simple circuit boards of a defined design, using a kit of parts identical to those provided to all other teams. The students had some days to design and test their system -- in which each took on a role such as material handler, assembler, quality checker, etc. -- before the factory's design was tested in a 20 minute competition.

On the day of the competition, all of the teams were given an identical challenge. Every 30 seconds, the customer would generate an order for one of three possible models. The team had to provide products in response to these orders. There are penalties for defects, being out of sequence, and consuming too much material.

There were a variety of ways in which the students organized themselves in doing the work. However, there was one design decision that provided only two alternatives. The team was responsible for collecting the order from the customer every 30 seconds (and collecting material to produce the order), and the team was responsible for delivering the order to the customer when it is complete. Some teams chose to assign each of these tasks to separate people, and some teams chose to assign both material handling tasks to a single person. In effect, the students had a choice between creating a simple and a looped flow in their system. If they separated responsibility for picking-up orders and delivering products, this was, in effect, a simple process flow. However, if the same person was responsible both for picking up the orders and delivering the products, the students had -- perhaps inadvertently -- joined the doing of the first step with the doing of the last step. As a result, they had inadvertently added a loop to their process. This is illustrated in the following two diagrams.

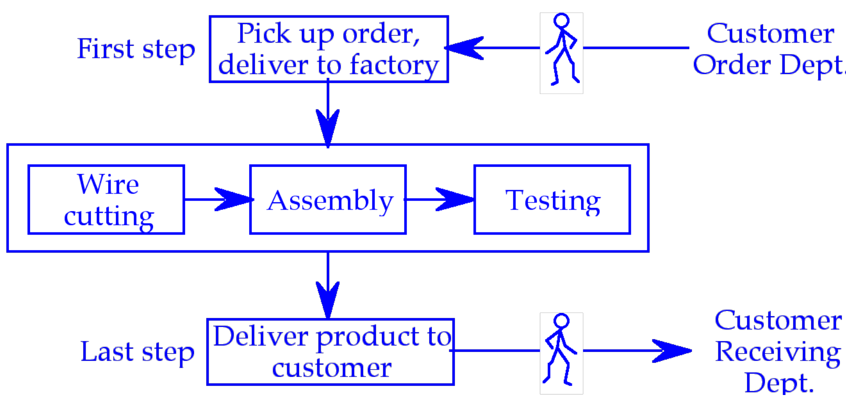

Figure 143: Simple flow-path, order pick-up and delivery separated

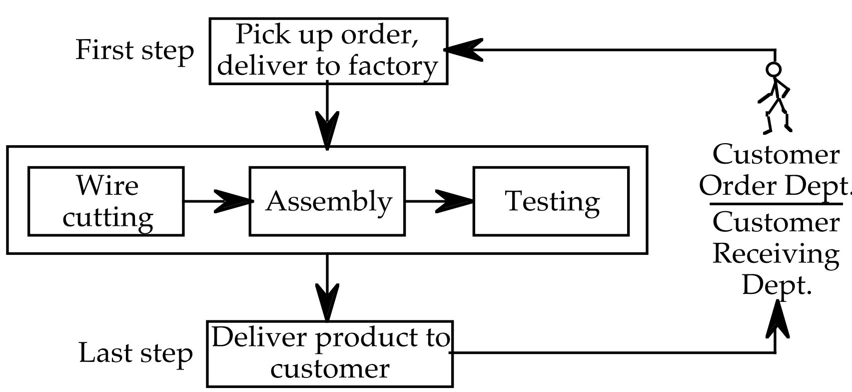

Figure 144: Looped flow-path, order pick-up and delivery combined

I observed that with these looped designs, problems in the last step of the process were injected into the first step of the process. Down stream disturbances were broadcast back into the system upstream, and amplified.

More specifically, a new order for a single circuit board was generated every 30 seconds. There was essentially no variance in this. However, there was significant variation in the time required to provide a circuit board for shipping (the board to board gap was between 20 seconds and several minutes). When the two activities were assigned to the same person, delays in shipping caused the material handler to be late in collecting the next round of orders and in delivering raw materials to the line. Therefore, people in the earlier processes lacked the information (what to make) and the material that they needed. This caused them to suffer performance fluctuations with negative effects on the downstream processes. Thus, the downstream disturbances injected volatility back into the upstream processes. The closed loop led to a gradual amplification of the volatility.

In contrast, it appeared that teams that separated the order pick-up and the finished goods delivery tasks prevented downstream disturbances from being injected back into the upstream processes. Consequently, the material handler who collected orders and provided input-materials was able to maintain a steadier pace.

The stark implications of this design decision are shown in the following graphs. An assistant and I timed the inter-arrival time of the material handlers for three teams (i.e., the time between pick-up p and p+1 and the time between delivery d and d+1) For two of the teams, one person picked up orders, and another made deliveries. For the third team, a single person did both tasks.

Notice that in the first graph, immediately below, the order pick-up and delivery roles were split. The person doing the order pick-up could complete that task, returning consistently every 20 to 40 seconds, even though the volatility of the team's delivery was higher. Likewise, the other team with a design of two material handlers, one to pick up orders and one to deliver products, also experienced relatively low volatility in the first step despite a production process volatility. In both cases, the order-takers spent little time getting orders, and the bulk of each 30-second cycle making products.

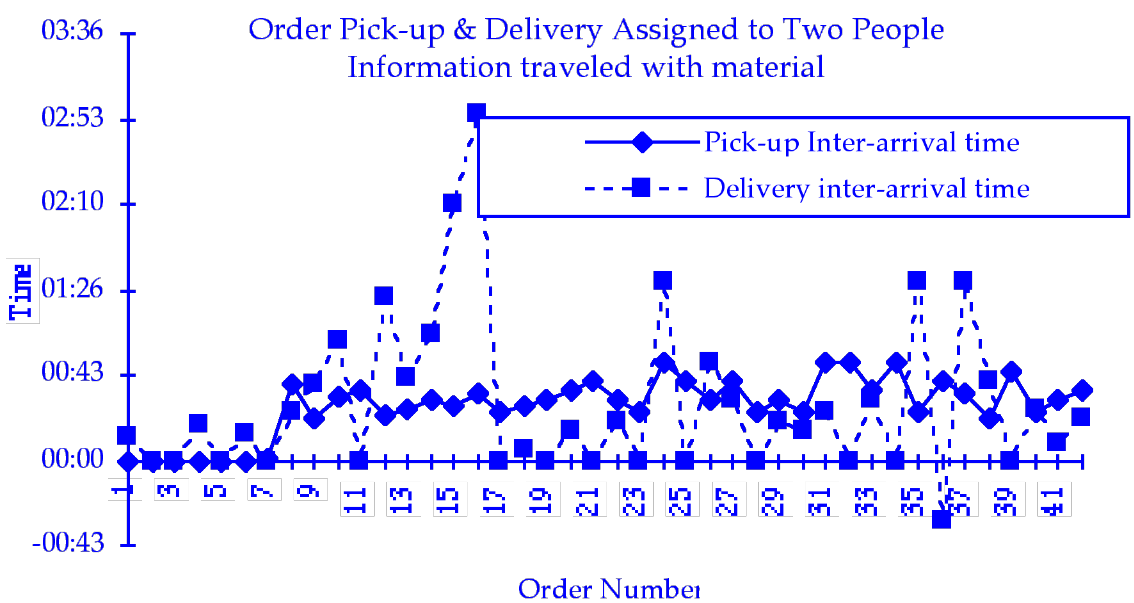

Figure 145: Pick-up and delivery done by two people (case 1)

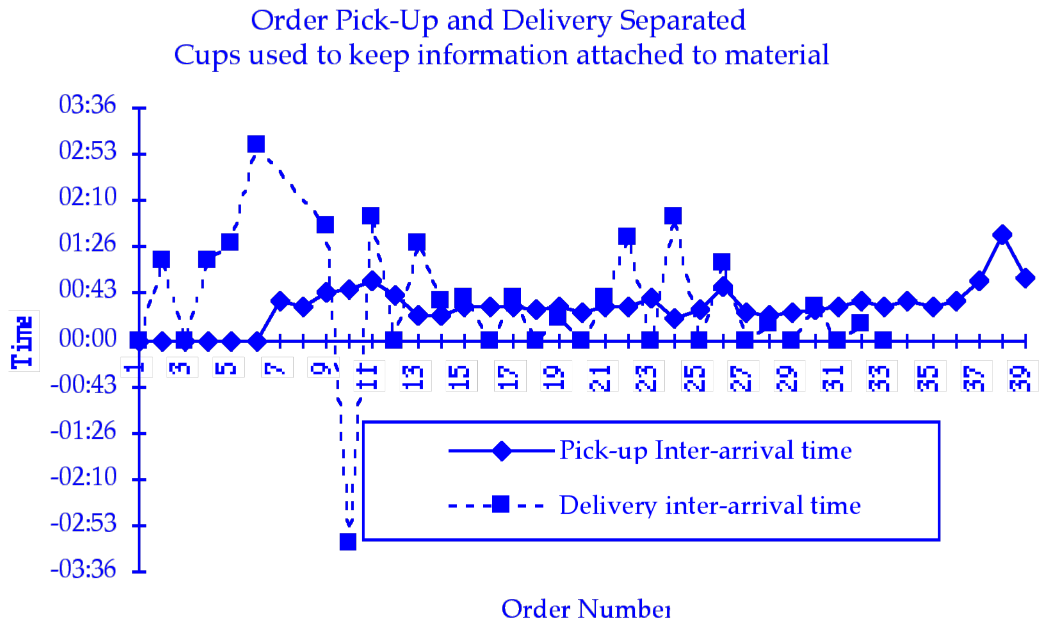

Figure 146: Pick-up and delivery done by two people (case 2)

For the team that gave both tasks to one person, the customer generated orders every 30 seconds also, but the orders were picked up irregularly. Orders were collected in batches, and minutes would pass before the next was gathered.

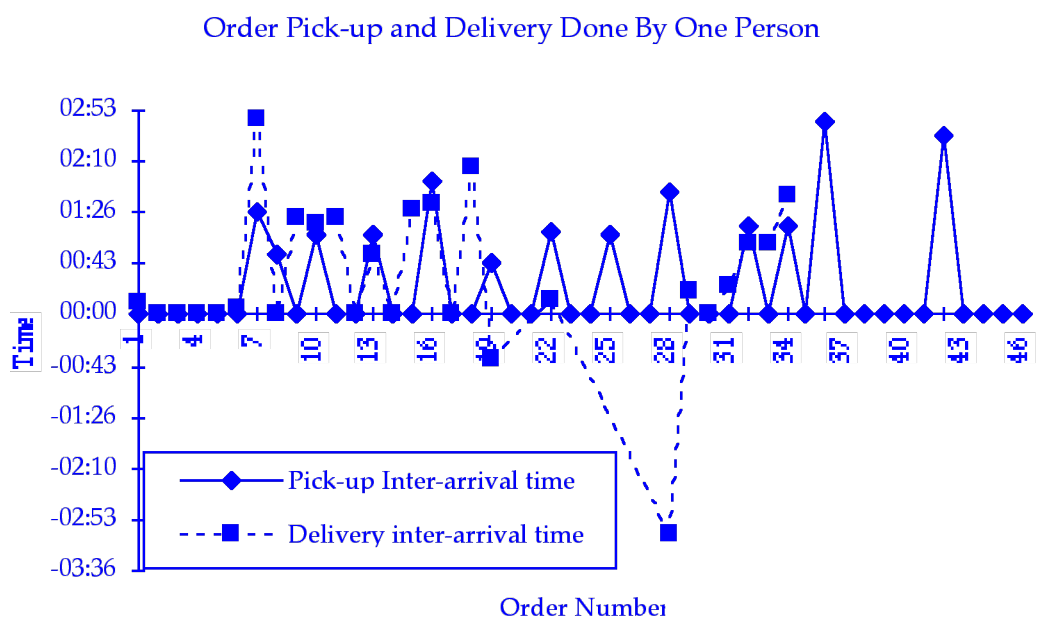

Figure 147: Order pick and product-delivery done by one person

<u>RULES FOR DESIGN AND OPERATION: SUMMARY</u>

Rule-3 completes the set of Toyota Production System guidelines for designing and operating an organization. Rule-1 guides the design and performance of activities, the equivalent of components in devices. Rule-2 guides the design of connections between activity-doers/output-creators and activity-output-users. These supplier-customer links are the analog to interfaces in devices. Rule-3 guides the design of flow-paths that are constructed from connected activities. These flow-paths are the organizational parallel to sub-systems and systems.

According to Rule-3, flow-paths must be designed so that before they are operated; who is expected to supply what to whom should be explicitly specified. When a flow-path is designed according to Rule-3, its operation tests the assumptions imbedded in its design: (a) which specific people and machines are required to create a good, service, or information and (b) which people and machines are specifically not required to create the good, service, or information.

These assumptions are tested in the following fashion. Should a person assigned to the flow-path remain idle, then the assumption that he is necessary to that flow-path has been refuted. This is a signal that triggers problem solving and flow-path re-design and improvement. Conversely, if a person who had not been assigned to the flow-path actually contributes to the production and delivery of the flow-path's goods, services, and information, then the imbedded assumptions are also challenged. It had been believed that the person was not going to be necessary, but, in fact, he was. This too is a signal that triggers problem solving and flow-path redesign.

Because of these tests that are repeated every time the flow-path is used, flow-path design and operation, just like connection design and operation and activity design and performance, is experimental. Hypotheses that have been built into designs are tested in use. Through this experimentation that is repeated each time an activity, connection, or flow-path is used, TPS-managed organizations are repeatedly conducting self-diagnostic tests that facilitate problem-identification, learning, and continuous improvement.

Rule-3 requires that flow-paths be pre-specified. It also requires that they be simplified. Pre-specification is necessary for experimentation. Simplification of flow-paths through the removal of loops and intertwined branches make experimentation easier. Simplification increases the clarity of who is actually performing what activities to provide intermediate goods, services, and information on behalf of which other activity-doers.

Loop removal specifically has another beneficial consequence. By preventing goods, services, and information from returning to upstream activities from downstream activities, problems can be isolated and addressed locally. When loops are kept in flow-paths, downstream problems can be re-injected into upstream steps, getting amplified as disturbances. This effect was illustrated in the natural experiment of student teams designing and operating mini 'factories' do produce circuit boards.

CHAPTER 7.4:

DATA AND ANALYSIS CONTRIBUTING TO RULE-4:

ACTIVITY IMPROVEMENT

INTRODUCTION

RULE STATEMENT

Rule-4 is the guideline for redesigning and improving activities.

Rule-4 states:

- Include activity-improvement as part of the work content of the person who performs an activity.
- Assign each person a specific, capable teacher who supplies training.
- Train to improve through solving problems, primarily.
- The improvement process should be designed and performed as an experiment with refutable hypotheses to test the assumptions implicit in the activity's new design and in the design of the improvement-activity.
- A change in an activity is considered an improvement if the activity can be performed closer to the IDEAL of defect-free, one by one, on demand, immediate, waste-free, and safe production and delivery.

RULE EFFECT

Designing and performing improvement-activities according to Rule-4 has a number of implications.

- Just as Rule-4 requires that activity improvement be a part of the work content of each person, it also requires, by implication, that teaching be the work content of every person in a supervisory, managerial, or hierarchically superior role. In effect, this requires that every organization be designed with teaching cascading from the organization's head to front line workers.

- Assigning responsibility for activity improvement to the activity-performer contributes to the nested, modular structure of TPS-managed organizations.

- Rule-4 provides the IDEAL as a universal standard for the 'best-possible' production and delivery system both from the perspective of the customer and the supplier. A universal standard increases the likelihood that people will more quickly agree that a problem exists (and on what dimensions it exists), thereby freeing more time for problem resolution.

- It appears that designing improvement activities as experiments increases the chance that changing an activity will increase knowledge about the activity. I suspect that behavior that is not experimentally testable is less likely to increase fundamental knowledge and is more likely to increase the importance of mythology and personality (and mythic personality).[34]

DERIVATION OF RULE-4

Rule-4 was inductively derived. For example, I concluded that part of the TPS ethos is that the activity-performer should be the activity-improver in the following way. My advisor and I had asked the Toyota people to show us plants that were, in their eyes, doing TPS well, and they chose plants that they felt represented TPS at its best. In these plants, there was a noticeable investment in developing the problem-solving capacity of people whom I observed, regardless

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34 The relationships among hypothesis testing; frequent, fine-grained process monitoring; and learning are discussed at some length in Chapter 5.

of their hierarchical levels. From this, I concluded that people adhering to the norms of TPS consider the development of problem-solving and improvement skills in activity-doers to be critical in managing. This chapter presents data collected at several plants illustrating the Toyota approach of training people to solve problems by having them solve problems of increasing challenge with increasing frequency. I also concluded that a primary managerial function is to teach through directed problem-solving. This is clear in the data too.

Common metrics were used for the improvement efforts that I observed or in which I participated. Therefore, I concluded that these common metrics act as a universal standard, in TPS-managed organizations for judging the efficacy of an attempted improvement. Evidence is presented to justify each of these six.

Finally, I concluded that according to TPS, activities should not be re-designed or improved in an ad hoc fashion. Rather, there was a strong emphasis on conducting improvement activities as structured experiments in which hypotheses could be tested. Illustrations of this approach are presented. To test if this approach to improvement is particular to the Toyota Production System, I interviewed two students in Harvard's MBA program who have worked for companies that have made publicly visible investments in 'lean manufacturing.' Both provided personal accounts, documentation, and other 'artifacts' from improvement exercises in which they participated. Their experiences are offered as a counter-example to demonstrate that the method by which activities are improved at TPS-managed sites is characteristic of TPS improvement and not representative of improvement efforts more generally.

WHO MAKES IMPROVEMENTS

Rule-4 requires that the person who performs an activity should be the person who improves the activity, that to learn to improve an activity, a person must have a supplier of training, and that learning to solve production and delivery-related problems should occur through solving production and delivery-related problems. This section of Chapter 7.4 includes accounts that contributed to this conclusion. They were provided during several plant visits in 1997 (Aisin, NHK Toyota, and Taiheiyo). In addition, I include evidence from the longitudinal study I have been doing of an effort by the Toyota Supplier Support Center to teach TPS in a plant that rebuilds starter motors and alternators. I found this latter evidence convincing as it includes examples and counter-examples, both of behavior (as an explanatory variable) and outcomes.

AISIN QUALITY CIRCLE

Several times, this dissertation discusses Aisin's make-to-order mattress production system. Details of this system design are provided as evidence in Chapter 7.2, justifying the conclusions about connection design and operation. Details about its system are presented in Chapter 7.3 to support the conclusion about flow-path design and operation. Evidence collected at Aisin also supports the conclusion about the design and performance of improvement-activities.

On my second of three annual visits to Aisin's Anjo plant, in July 1997, members of the Ito Quality Circle made a presentation, recounting their experience in the final assembly portion of the production line.

In the first phase of their employment, before joining the Quality Circle, they were responsible only for doing the standardized work for which they were responsible and for calling for assistance when they were unable to do the standardized work and generate a defect-free outcome. Initially, as members of the quality circle, they learned to distinguish between conditions that were and were not problematic in the work environment. During this period, the group leader challenged the team leader and team members to become more critical of the way in which their work was performed. After many months of learning to identify problems, the team gradually learned to suggest counter-measures to the problems that they perceived. Having learned to identify problems and suggest responses, the team learned ways in which they could actually design and test counter-measures to problems. In the last phase of their training, some members of the team learned skilled trades so that they would be able to fabricate counter-measures to problems. Concurrently, other members of the team passed the qualifying test for assembly jobs that required higher technical skill. In other words, the team's capability increased on two dimensions. The sophistication increased of the production activities for which it could be responsible. Simultaneously, its ability to improve those activities increased too. Details of the Ito-Team's experience follow.

According to Ito, in 1993, the volume in the plant was growing, as were the number of workers. As a new team leader, his attitude was that he was going to solve problems and "be a hero in the boss's eyes." Though there was some accomplishment after 3 months, it did not meet the targets, and the group's sentiment was that he was "leading alone," enough so that some people wanted to quit the team.

For example, each of the three production lines had the goal of reducing rejects to 250 (in a six-month period). While Lines 2 and 3 met this target with an actual reject level of 204, and 232 respectively, Line-1 suffered 258 rejects in the same period (October 1993 through March 1994). For 1994, then, the goal was to contribute to the reduction of rejects on Line-1; increase productivity by reducing idle time; and "produce a work-force in which new techniques can be learned and applied."

These objectives for the Line were quantified as: reduce the number of defects from 258 for the six months ending in March '94 to 170 for the six months ending in September (a 34% decrease), and to 140 for the six months ending in March of 1995 (for a total decrease of 55%). At the same time, the Line was challenged to reduce the production time from 26.3 minutes per unit to 22.8 minutes in September (a 13% decrease), and to 18.4 minutes in March of 1995 (for a total reduction of 30%). Part of this improvement was to be accomplished by factory level improvements, part within the department, and part by Ito's Quality Circle.

According to Ito, one of the first things he did was create a suggestion box to increase the buy-in for the team's goals. After one day though, the box remained empty, so he wrote his own suggestion letter. Nevertheless, no one paid attention, so, by himself, he worked on the problem he had deposited in the suggestion box. Midway through this project though, Ito was hospitalized with appendicitis, the discomfort of the illness magnifying and magnified by his frustrations as team leader. Ito was depressed enough that he wanted to give up. Unbeknownst to Ito, the team -- perhaps motivated by sympathy -- had regrouped, and after three days, the assistant team leader, Tetsuo, delivered the suggestion box to Ito, filled with letters.

Of the line's 258 rejects from Oct. '93 to March '94, 49 occurred in March. Of these 49, the most frequent problem -- with 25 occurrences -- was that the edging tape that bound the edge of the uppers and lowers to the border would come off.

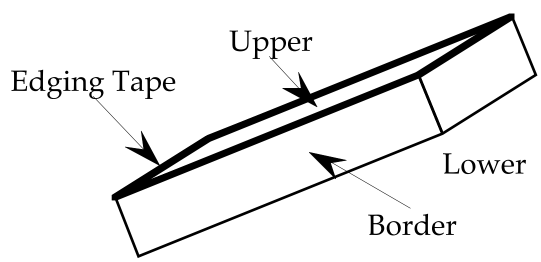

Figure 148: Parts of a mattress

This production problem served as an opportunity to train the team in root cause analysis. For instance, the team summarized their diagnosis in the following diagram.

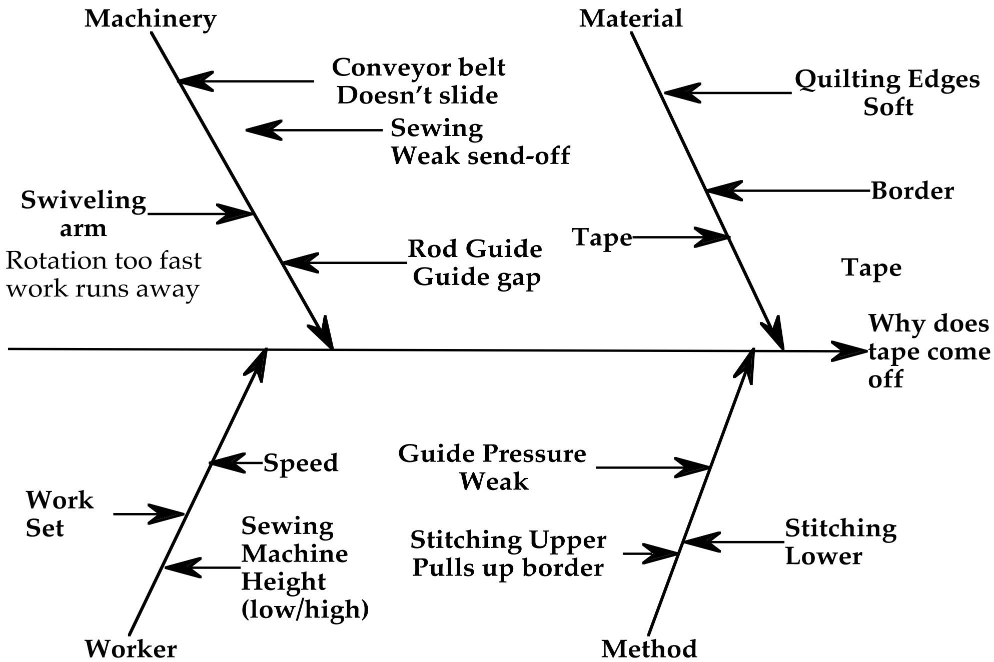

Figure 149: Simplified version of Ito-Team's fish-bone diagram

This analysis contributed to the redesign of the work method and the machinery used by the worker to attach the tape. This led to a reduction in tape-related problems from 25 in the April to 9 in June. (It was through another set of changes, in conjunction with the group leader, that the team was able to reduce the defects from this cause to zero in September). The approach of improving the process by teaching first level workers to improve the process was practiced at other TPS-managed suppliers.

TAIHEIYO QUALITY CIRCLE

At the time I gathered data at a Taiheiyo plant, it was a first tier supplier for Toyota's Tsutumi, Takaoka, Motomachi, and Tahara assembly plants. The primary processes were stamping, welding, and plating. On July 22nd 1997, during a research trip to Japan, a team member -- Mr. Ohashi -- explained a two-year problem-solving exercise of which he was part.

As he described it, the Quality Circle was organized both to develop the kaizen (improvement) skills of the operators and create a cleaner work site in the welding department. The team addressed the problem that the CO_2 welding robots generated spatter and smoke. The hot spatter increased the risk of a fire, the smoke forced the operators to wear uncomfortable masks and left a residue that was difficult to clean, and the combination made the work site dark, smoky, and otherwise unpleasant.

The 10 members of the Quality Circle met after work in one-hour weekly meetings. According to Mr. Ohashi, who was a participating Team Member, and Mr. Koiwa, an Assistant Manager responsible for two Groups of 20 people each, a group leader facilitated the meetings. The group leader's job was to ask questions that would develop the thinking of the team members, provide summaries as they proceeded, clarify roles as necessary, determine who was best suited for tasks, and who needed development in different skill areas. In other words, a part of the group leader's work content was to teach by guiding the people in his group in problem-solving efforts.

Over the course of two years, the team engaged in a series of experiments that culminated in generating a resolution to a problem (affecting 28 of the arc welding robots) and that resulted in a Ministry of Science and Technology ecology award.

The first experiments were aimed at reducing the scattering of the spatter. The first trial, a dome like cover for the torch, proved ineffective because the spatter accumulated inside the cover. In a second trial, an umbrella like cover for the welding torch was successful in preventing the spatter from scattering above, but it increased the spatter to the sides. The third trial, of a bronze shutter that shielded the torch, proved most effective.

Having addressed one problem, containing the scattering spattering, the team faced a second problem: the amount of spatter that accumulated on the base of the machine had increased. Therefore, they tested a variety of base covers with the following results.

	Material	Melting temp. (°C)	Heat Capacity (cal/°C)	Analysis	Conclusion
1	0.3 mm bronze plate	1,083	0.024	Made holes, spatter stuck	Rejected
2	1.3 mm bronze/zinc	1,083	0.102	Made holes	Rejected
3	3.0 mm tile	450	0.154	Dirty, rough, not formable	Rejected
4	1.2 mm stainless steel	1,450	0.103	Made holes, difficult to form	Rejected
5	1.8 mm aluminum	685	0.103	Dirty, Made holes	Rejected
6	5.5 ceramic plate	400	0.102	Dirty, made holes, not formable	Rejected
7	4.0 mm bronze plate	1,083	0.32	Good	**Accepted**

In conducting these experiments, the team concluded that the material must be able to withstand 1,000˚, that it must have a heat capacity above 0.3 cal/˚C, and that the material must be formable. Of course, in conducting these experiments, the team learned the general concepts of material properties and heat transfer too.

Having dealt with spatter, the team next developed alternatives for capturing the fumes generated in the welding process. Here, again they conducted experiments on three types of intake mechanisms, and changed the shape and location of the cover to maximize the amount of fumes drawn in while minimizing the amount of spatter that dirtied the hood. Developing an effective ventilation system caused another problem. The vacuum used to draw in the fumes also drew in some of the spatter, risking damage to the vacuum fan and threatening to ignite a fire in the device. Therefore, the team tried to build a spatter filter in the ventilation mechanism. Here too, they encountered problems that they resolved through experimentation.

The main issue was that a filter capable of stopping the spatter might seriously reduce the draw of the ventilating fan. The team began to test a variety of filtration materials. Drawing the fumes through a container of pebbles proved ineffective. Replacing the pebbles with golf balls was only partially successful. The golf balls accumulated residue and needed to be replaced because they could not be cleaned. At ¥100 per ball, this was prohibitively costly. Pachinko balls were too densely packed to be effective. However, glass marbles, like those used to seal certain soft drink bottles, worked effectively. At ¥2 per ball -- each of which could be cleaned and reused -- the price was right. [35]

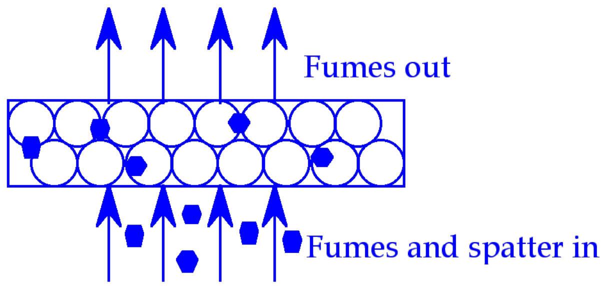

Figure 150: Taiheiyo fume filter

The team encountered other issues before arriving at their final design: how many layers of marbles, 1, 2, or 3 and how to remove other contaminants from the fumes once the spatter was gone. They finally arrived at a design that included the 'marble-ator' to clean the spatter and a static electricity dust collector to clean the fumes. As proof that the air coming out of the device was clean, they put the exhaust tube into a fish tank, which -- according to Mr. Ohashi and Mr. Koiwa -- was perfectly fine for the fish.

Clearly, this particular supplier invested heavily in the problem-solving capability of team members and other activity-doers. However, there were multiple, benefits. The problem-solving skills of the team were increased. The

[35] Christensen has written that innovations in one domain often are sourced from other domains. This air filter is such an example. According to Mr. Ohashi, the inspiration for marbles as filters came from one team member. He recalled seeing glass marbles used to keep cigarette butts, gum wrappers, and other refuse from clogging bathroom drains.

cost of equipment maintenance was reduced. The environmental quality, safety, and comfort of the work site was improved, and the more technically skilled members of the maintenance department were unburdened of routine maintenance responsibilities and were freed to address more technically challenging situations. Whereas, the maintenance-engineering department had done 100% of the maintenance, the production workers were now able to do 80% of the routine maintenance work.

NHK TOYOTA

The improvement effort by the Ito Quality Circle at Aisin and the improvement effort by Mr. Ohashi's Quality Circle at Taiheiyo shared common characteristics. In both, process improvement was used as a mechanism to develop the capabilities of line workers. In both cases, improvement activities were designed and performed as experiments with structured tests of design alternatives. I learned that another Toyota supplier, NHK (Nippon Hatsujo Kabushiki kaisha -- Japan Spring Corporation) used a nearly identical mechanism to improve processes and train workers. During a July 1997 visit to NHK's plant in Toyota City, workers made a presentation that explained the efforts of a Quality Circle to improve the quality and lower the cost of producing arm rests, in the cold molding area of the plant, for the Crown, Celsior, and Lexus lines.

The Quality Circle was composed of 8 workers, 1 sub-leader (Mr. Mori, who ran the slide projector), and 1 leader (Mr. Nagata, the presenter). Their average age was 26. They focused on problems that occurred in forming molded foam parts. The first problem they addressed was bleeding at the seams of the mold. This caused non-value adding trimming after the part was removed from the mold. The team experimented with several types of lining materials to reduce the leakage, both that which occurred at the mold seams, and that which occurred through holes in the part. After conducting initial trials that compared alternative lining materials, the team settled on vinyl as the most promising choice. These initial test results, excerpted from the team's presentation, are summarized in the next table.

	Leakage	Abrasion	Leakage through holes	# of tests	Result
All-felt surface	×	◎	× ×	5	×
Saran Wrap	×	×	△	7	×
Partial vinyl	×	×	○	10	△

◎ Very good ○ Good △ Fair × Bad

Figure 151: NHK -- Experiments in liner material

After choosing vinyl as the liner material, the team addressed a second problem. A pin ejected the part from the mold. However, the pin caused the lining material to weaken and tear, thereby contributing to surface quality and cost problems being addressed by the team. In another set of experiments, the team tested different types of material and experimented with an alternative shape for the ejector pin. These results are summarized in the next table, also excerpted from the team's presentation.

	Leakage	Abrasion	Leakage through holes	# of tests	Result
Partial vinyl	✕	✕	○	10	✕
All-vinyl, 0.05 t	✕	✕	◎	20	✕
Re-shaped pin	△	✕	◎	35	△

◎ Very good ○ Good △ Fair ✕ Bad

Figure 152: NHK -- Experiments to prevent pin punch-through

It is worth noting that the team modified the design of its experiments as it changed the focus of its efforts. In the initial series of experiments, the number of test cycles was relatively few (7 to 10 for each material) as the team focused on the leakage problem. However, in subsequent trials, the team's concern shifted from leakage to liner tearing. With this shift, the number of test-cycles increased so the team could do failure analysis. For example, notice that the partial vinyl was tested on 10 cycles, the all-vinyl on 20 cycles, and the all vinyl with a different pin was tested on 35 cycles.

The team conducted several other experimental series. In one, they tried thicker vinyl (88 tests) which proved to be both more durable and better at reducing leakage at the mold seams. In another series, the team adjusted the shape of the liner to achieve greater consistency. In a third set of experiments, the team experimented with the number and location of ports in the mold to achieve a more even and more consistent distribution of material.

The experiments led to demonstrable cost and quality improvements. For example, the defect rate was reduced to 11% of its initial level, and the number of parts that were so defective that they could not be used was reduced to 33% of its initial level. The amount of material needed for each piece was reduced to 40% of the initial level.

The team concluded its improvement activities by developing a set of standardized procedures so that the changes they developed could be incorporated into the standardized work (e.g., structured, self-diagnostic activities) of the cold foam-molding department. Thus, they did not complete their work upon discovering valuable changes. Rather, they completed their work only after incorporating the changes into the routine work of the production setting.

TEACHING AT ACME

The norm that the person who does an activity should be capable of and responsible for improving it was evident elsewhere. I had been documenting the efforts of a Toyota Supplier Support Center team to promote TPS at a factory that rebuilds starter motors and alternators. The team had been composed of people with varying experience at Toyota. Some had worked for a few years in North American transplants; others had worked for more than a decade in Toyota's Japan plants and TPS promotion office, the Operations Management Consulting Division. On multiple occasions over a year and a half, I observed the TSSC people teaching TPS to people at this plant. Typically, three to five Toyota people worked with 10 to 15 plant people on problem-solving activities.

Consistently, it appeared that the less experienced TSSC people tended to focus on solving technical problems, spending a small portion of their time coaching and guiding the plant people. In contrast, the more experienced TSSC people seemed to spend a greater portion of time guiding the plant people in solving problems rather than solving the problems directly themselves.

To test if this were true, I took advantage of a shop floor training exercise to collect evidence. The group was divided into five teams. Each team had a TSSC person as a team leader, and one more senior Acme person and one more junior Acme person as team members. During the morning, each team was given an identical assignment to collect cycle times at each of twelve process steps in a particular production cell. For 50 minutes that morning, I recorded where each person was standing. For instance, in the following chart, we see that at 11:05 AM, the Leader of Team 2 (TL2) was at the test stand with the senior member of the team (S2), and the junior member of the team (J2). Likewise, the chart shows that at the same time, the Leader of Team-5 (TL5) was at location 2 while the senior (S5) and junior (J5) members of Team-5 were at Location-1. Every two minutes, I noted where each person was.

	TL1	J1	S1	TL2	S2	J2	TL3	S3	J3	TL4	S4	TL5	S5	J5
11:04	1	1	1	pack	Pack	?	sub	?	sub	talk	talk	2	1	1
11:05	comp.			test	test	test	sub	?	sub	2	2	2	1	1
11:07	comp.			test	test	work	sub	sub	sub	2	2	2	1	1
11:09	1	1	1	test	test	work	sub	test	sub	2	2	1	1	1
11:12	comp.			test	test	work	sub	sub	sub	1b	2	1b	1	1
11:15	comp.			test	test	test	drill	drill	drill	1b	1b	1b	1	1
11:16	Drill	Drill	Drill	test	test	test	drill	drill	drill	2b	2b	2	1	1
11:19	Drill	Drill	Drill	test	test	test	drill	drill	drill	pack	pack	2b	1	1
11:24	Drill	Drill	Drill	test	test	test	1	1	1	pack	1	2b	1	1
11:25	comp.			2b	2b	work	1	1	1	notes	notes	pack	1	1
11:26	2b	2b	sub	2b	2b	?	1	1	1	notes	notes	pack	1	1
11:29	Fritts	2	sub	2b	2b	work	1	eric	1	notes	notes	2b	2b	2b
11:31	sub	sub	1	1b	1b	work	1	1	1	2b	2b	stores	2b	2b
11:35	sub	sub	2	2b	2b	work	1	1	1	1	2b	stores	away	away
11:36	2b	2b	2b	1	1	work	1	1	1	1	1	stores	1	1
11:39	2b	2b	2b	1	1	work	1	1	work		1	1	stores	1
11:41	2b	2b	test	1	1	work	1	1	1	1	1b	?	stores	stores
11:45	2b	2b	test	1	1	work	1	1	1	1	2b	?	?	?
11:47	2	2	test	sub	sub	work	1	1	1	Raul	1	sub	?	?
11:49	1b	1b	?	sub	sub	work	1b	sub	sub	talk	1	2	?	?
11:51	1b	1b	?	sub	sub	work	1b	1b	sub	pack	pack	1	?	sub
11:53	1b	1b	test	Drill	Drill	work	1b	1b	sub	Pack	pack	1	sub	sub
11:55	1	1	pack	Test	Test	work	1b	sub	1b	Pack	pack	2	sub	sub

Figure 153: Process Study: Who worked with whom

Based on the observations of who was with whom, where, I calculated the percentage of observations that the team-leader was with the senior and junior Acme members of the team. For example, Team Leader 2, was with the senior Acme person for all (100%) of the observations. In contrast, Team Leader 5 was in the same location as the senior and junior members of the team only 9% of the time.

	1	2	3	4	5
Sr.	57%	100%	74%	#N/A	9%
Jr.	96%	#N/A	83%	74%	9%
Avg	76%	#N/A	78%	#N/A	9%

[Note: the junior member of team-2 was called away to address an equipment problem, hence the N/A entry there, and Team 4 had only one team member, hence only one entry there.]

Figure 154: Process Study: Time spent by Team Leader with Team Members

When the exercise was complete, each team had to report the cycle times they calculated for each of the 12 process steps. The next table summarizes this, showing that Team-2 calculated cycle times for 100% of the process-steps, whereas Team-5 calculated only 25%.

	1	2	3	4	5
1a	•	•	•	•	•
1b	•	•	•	•	•
1c	•	•	•	x	x
2	x	•	•	x	x
3	x	•	•	•	•
4	x	•	•	•	x
5	•	•	•	•	x
6	•	•	x	•	x
7	•	•	x	•	x
8	•	•	x	•	x
9	x	•	x	x	x
10	x	•	x	x	x
	58%	100%	58%	67%	25%

Figure 155: Percent of work-elements studied by each team

I compared this outcome with the time the TSSC team leader spent with the Acme team member. The result was striking. Those teams that adopted a divide and conquer strategy actually divided more and conquered less than the team in which the team leader was with the team members more consistently.

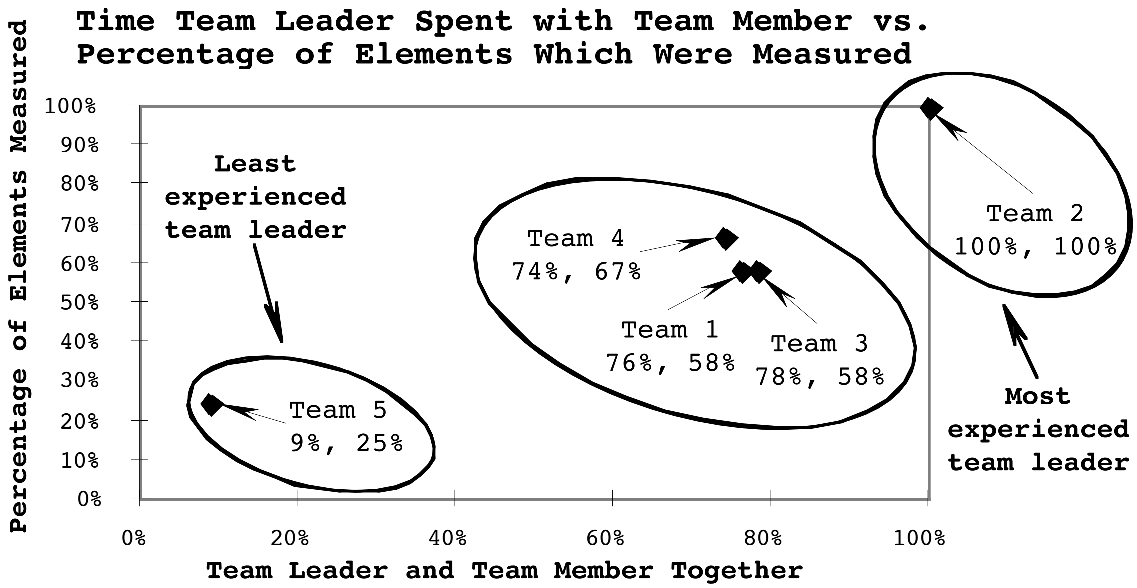

Figure 156: Time together and work-elements studied

For instance, TL-1 was with S1 57% of the observations, and with J1 96% of the observations (75% average). Team 1 collected cycle times for 58% of the process steps. At one extreme, the leader of Team-5 spent 9% of the time with team members. As a group, they collected cycle times for only 25% of the process steps. In contrast, the leader of Team-2 spent 100% of the time with his team members, and, as a group, they collected cycle times for 100% of the process-steps.

After lunch, each team was given some portion of the production cell in which they were to try and make changes to reduce the cycle time at those particular process-steps. Again, for 40 minutes, I recorded the location of each person every few minutes, as summarized in the next table.

	TL1	J1	S1	TL2	S2	J2	TL3	S3	J3	TL4	S4	TL5	S5	J5
1:30	1	2b	1	?	?	1	1b	1b	1b	Test	Test	Sub	2b	2b
1:33	1	1	1	?	?	Test	1b	1	1b	Test	Test	Sub	2b	2b
1:35	1	1	1	Casing	?	Casing	1b	1b	1b	Test	Test	Sub	2b	2b
1:37	1	1	1	Casing	?	Casing	1b	1b	1	Test	Test	Sub	2b	2b
1:39	1	1	1	Casing	?	Casing	1b	1b	1b	Test	Test	Sub	2b	2b
1:41	1	2b	1	Casing	?	Casing	2		2	Test	Test	Sub	2b	2b
1:43	1	1	1	Casing	?	Casing	rack	rack	idle	Test	Test	Sub	2b	2b
1:45	1	2b	1	Casing	?	Casing	rack	rack	rack	Test	Test	Sub	2b	2b
1:47	1	2b	1b	Casing	w/s	Casing	rack	rack	idle	Test	2b	Sub	?	?
1:51	1	1	1	Casing	w/s	Casing	1b	1b	test	Test	Test	Sub	2b	2b
1:54	1	1	1	Casing	w/s	Casing	off	off	Test	Test	Test	Sub	2b	Pack
1:57	1	1b	1	Casing	w/s	Casing	off	off	Test	Test	?	talking	talking	talking
1:59	1	1	1	Casing	?	Casing	w MH	w MH	drill	Test	?	2	2b	2b
2:01	1	1	1	Casing	?	Casing	2	2	Test	Test	?	2	2b	2b
2:05	1	2b	1	Casing	?	Casing	2	2	sub	Test	Test	sub	2b	2b
2:11	1	1	1b	Casing	drill	Casing	2	away	2b	Test	Test	1b	2b	?

Figure 157: Process change: Who worked with whom

For the afternoon observations too, I noted the percentage of time each team leader spent with the two members of his team. Again, TL-2 was at one extreme, in the same location as J2, 88% of the time (in the afternoon, S2 was called away for a break-down elsewhere in the plant). At the other extreme, TL-5 was with each of Team-5's senior and junior members 6% of the time.

	1	2	3	4	5
Sr.	88%	#N/A	88%	#N/A	6%
Jr.	63%	88%	38%	75%	6%
Avg	75%	#N/A	63%	#N/A	6%

Figure 158: Process change: Time spent by Team Leader with Team Members

On the third day of the exercise, each of the teams reported on the counter-measures they had tried and the results they had achieved at each of the production-cell segments for which they were responsible. The next chart summarizes which member of each team made the presentation. Note that the leader of Team-2 did not make the presentation, unlike all the other team leaders.

	Team 1	Team 2	Team 3	Team 4	Team 5
Team Leader	Yes		Yes	Yes	Yes
Senior team member		Yes	Yes		
Junior team member	Yes	Yes	Yes		

Figure 159: Who presented improvement ideas: Teacher or student?

Finally, I asked each of the TSSC people what they thought they had accomplished during the 3-day training exercise and what they would do the following day if they were managing the cell. With one exception, the universal answers focused on technical issues. Four of the five Team Leaders emphasized whether or not they had achieved one piece flow, whether or not they had reduced the cycle time and achieved a production rate equal to the rate of customer demand, whether or not they had removed wasteful activities such as sorting for parts in a container or walking back and forth between two areas. For, the next day, they all recommended that the cell manager make permanent what was temporary, for instance by making from metal what was tested in cardboard and welding what was temporarily affixed with duct tape.

The Leader of Team-2 suggested a different approach. His first step the next day, he said, would be to explain to the workers in the cell the changes that had been made. Then, he would solicit their initial opinion on what had occurred. Finally, he said he would spend the remainder of the day monitoring the cell to see if the operators actually maintained the changes and to see if the production results through an entire day matched those generated during the training event. On his own, he did not volunteer that he would act on the equipment. When I asked if this would be a priority, he offered that it might be, if he had time and if his observations and conversations showed that the changes made during the training exercise had value in sustained operation.

Team Leader 2, as reflected in his behavior and voiced recommendations, took a decidedly different approach to the training and process improvement exercise than did his colleagues. Whereas four of the five focused on technical details of production, he focused on teaching his team members to focus on the details of the production process. This was evident in that he was rarely separated from the members of his team. This was evident in that he allowed the members of his team to make the final presentation whereas the other TSSC people did some or all of the presentation. This was evident in his recommendations for the day after.

Not only was the behavior different but the outcome was different. Team-2 alone was able to calculate all of the cycle times during the morning of the first day. Furthermore, their calculations were the most accurate. Second, the experience of the Acme people on each team was different. At the end of the first morning, the exercise coordinator asked everyone what were their feelings of the cycle-time collection exercise. Immediately, the senior member of Team-5 volunteered: “Traumatic!" a view seconded by the junior member, who shook her head vigorously in agreement.

Throughout, this dissertation has been describing the Rules-in-Use as the unstated norms by which TPS-managed organizations operate. In seeking to explain the differences in behavior among the team leaders, I have focused on the differences among the team leaders in how they have been acculturated to TPS management. Team Leader 2 is the only one of the group to have been acculturated to TPS in Japan. He joined Toyota in 1984, and spent time in production engineering as a tooling specialist. In 1994, he was assigned to the Miyoshi plant's Machining and Manufacturing Engineering Division where, according to Team Leader 2, he "learned the operator's point of view in this period." He was always on the shop floor, responsible for equipment maintenance and new product introductions. In 1998, prior to his assignment to the Toyota Supplier Support Center in North America, he spent 6 months at TSSC's parent organization in Japan, the Operations Management Consulting Division, refining his knowledge of TPS by promoting it at the Miyoshi plant and at two supplier plants.

In contrast, none of the other four TSSC people who served as team leaders during this exercise have had nearly the same acculturation. Of the four, one is an employee of a Toyota supplier (also a TSSC project company), and -- at the time of this training exercise -- he had been on-loan to TSSC for the first of three years. Another of the four has worked at a Toyota subsidiary in California, and he was doing TSSC projects part time as preparation for a new assignment at his parent plant. A third of the four was from Toyota's Canadian subsidiary and had been at TSSC for less than six months. The last of the four had been a ten-year employee of the Toyota/General Motors NUMMI joint venture before joining TSSC six months prior to this training exercise.

COUNTER-EXAMPLE: ACTIVITY-CHANGES NOT DONE BY ACTIVITY-DOER

The contrast between Team Leader-2 and the other Team Leaders during the training exercise added to the conclusion that norms in TPS settings are to train the activity-doer to be the activity-improver and to train through directed solving of production and delivery related problems. Team Leader-2's approach of teaching his Acme-students mirrored the accounts I had gathered at Aisin, Taiheiyo, and other suppliers in Japan, reported earlier in this chapter.

A separate set of observations at Acme provided a counter-example. Early on in the Acme-TSSC relationship, several Acme supervisors and managers tried to redesign a work cell on behalf of, rather than in consultation with the workers in the cell.

Several of the Acme managers decided to a new layout in the final assembly area for a small family of products. In the original layout, operators did batch production. They would take 50 casings (the exterior of a starter motor), carry them to the first processes (Grinders, etc.), and complete the batch of 50 at that station. Then, they would spread the 50 pieces out on the rails of the "fixture holder" and progressively build up the alternators and then they would test the batch before packing all the units at once and sending them to shipping.

There were several problems with this approach, not the least of which is the large amount of work in process. Simply reducing the batch size proved to be an ineffective alternative. It caused workers to spend most of their time walking the 40-foot length that separated the tester and the grinder.

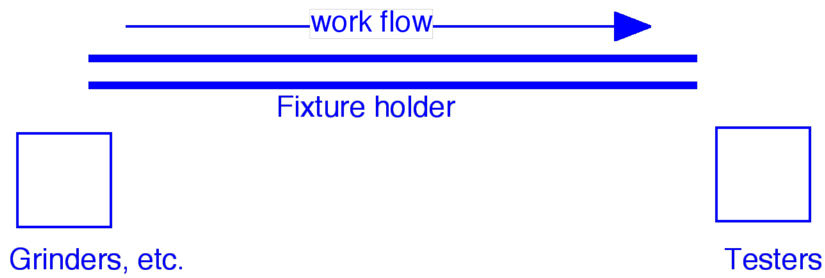

Figure 160: Original production-line layout

As a second approach, managers decided to create a "U-shaped" cell to reduce the amount of walking and so make smaller batches more feasible. Therefore, a U-shaped cell was constructed from utility benches. The necessary power and air lines were installed, and the necessary equipment such as grinders and testers were added to the cell.

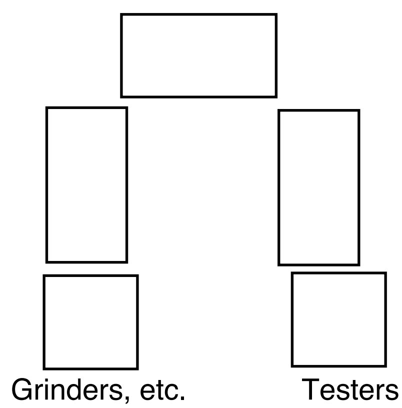

Figure 161: Initial re-design as a production-cell

Though managers didn't follow a Tayloresque approach of detailing exact movements for the operators to follow, the managers took much of the responsibility and the authority for designing the work site. In other words, in Acme's first attempt at developing a production cell, the design of the work, and the doing of the work were separated. The managers designed the cell, and the physical design of the cell forced some actions and limited others. The operators had to adapt accordingly.

As it turned out, the initial U-Shaped was not as successful as hoped. Though it reduced the amount of walking required of operators and so allowed single piece flow through the cell, there were a number of ergonomic difficulties which affected production, cutting it from the previous level of 100 units per day to half that. The utility benches, which were used because they were convenient, were actually too deep to be used effectively. Aida, Mary, and the other workers had to reach three feet each time they needed a screw, bolt or washer, well beyond the range which is comfortable. A second problem with the table was that the top was not rigid, so it was not possible to hammer parts on it. At one point, I observed that Asok, another of the workers -- was holding an assembly in his left hand and hammering with his right.

With the second attempt with the U-shaped cell, the design of work and the doing of work were much more closely colocated. Rather than the supervisor deciding how the cell should be arranged, the operators were involved in redesigning the layout. The second cell was much more a product of the workers' design. As the physical layout of the cell greatly affected the way in which work was done, there was a greater overlap between who designed the work and who performed the work.

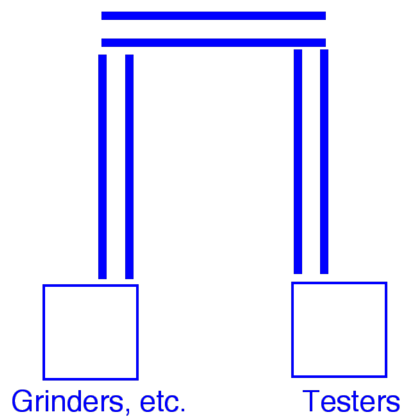

Figure 162: U-shaped production-cell, second try.

One of the major changes they made, for instance, was to reconfigure the original fixture holder rails so that they maintained the U shape, but now had a solid base on which to hammer, and a narrower platform across which to reach for parts. Furthermore, the last round of changes made the cell more productive, not less than its original formulation.

CRITERIA FOR JUDGING IMPROVEMENT IN PRODUCTION AND DELIVERY

The preceding section presented accounts that led to my conclusion that in TPS-managed organizations improvement is part of each person's work, that learning to improve is done through directed problem-solving, and that the direction comes from the person next in the hierarchy. This last requirement defines teaching of direct reports as one managerial responsibility. This section shifts from emphasizing who does improvement activities to the standard by which improvement efforts are judged.

Consistently, TPS-trained people considered a change in an activity to be an improvement if it accomplished at least one of six objectives:

- reduced the number and frequency of defects.
- decreased the batch size in which the good, service, or information was produced and delivered.
- decreased the amount that was produced in anticipation of customer need and increased the degree to which production and delivery occurred on demand, in response to an actual customer need.
- decreased the time between a request and a response.
- decreased the waste associated with performing an activity in the form of unnecessary motion, material, etc.
- increased the supplier's physical, emotional, or professional safety.

Eventually, I concluded that within the community of those acculturated in the norms of TPS, there is a common definition for an IDEAL activity or system of activities that produce and deliver goods, services, and information. This IDEAL is:

- production and delivery of *defect-free* goods, services, and information,
- *piece by piece* (or service by service) in batches of one,
- performed *on-demand* and not in anticipation of demand,
- with *immediate* responses to requests,
- *without waste* on the part of the supplier, and
- without threats to the supplier's physical, emotional, or professional *safety*.

Evidence for each of these dimensions will be presented separately. Some, such as defect-free will require relatively little elaboration since that factor was addressed in explaining the development of the Rules. Others, such as no-waste and safety will require slightly longer explanation.

DEFECT-FREE

The idea that IDEAL production and delivery should be defect-free has been alluded to at great length in Chapter 7.1's presentation of the evidence that contributed to Rule-1. My observations led to the conclusion that the best possible activity-design, in the eyes of TPS-trained people, is one in which the activity doer can immediately distinguish between a defective and a defect-free outcome. If all work should be designed so that the customer is never aware of defects produced by the supplier, then it stands to reason that the IDEAL supplier is one who always responds with goods, services, and information that are defect-free in meeting the expectations built into a customer's request.

ON-DEMAND

Just as Defect-Free as a dimension of the IDEAL was implied throughout the discussion of Rule-1, On-Demand as a dimension of the IDEAL was implied through out the discussion of Rule-2. Rule-2 requires that the customer-supplier connection be designed and operated so that the supplier's activities are triggered by the customer's requests. In other words, the supplier's production and delivery of goods, services, and information should occur based on [the] demand of the customer.

Chapter 7.2 contained a number of accounts that contributed to the conclusion that the customer-supplier connection should operate on-demand. As additional evidence, this chapter shares another account from my experience promoting TPS at a Toyota supplier. The problem we encountered was that even when the press team was capable of doing a die-change in only a few minutes, often times the stamping-die that the team needed was not available. There was a discrepancy between what the team needed and what the tool and die repairman provided. Our response -- as formulated by Bryant, the more experienced TSSC member who was my teacher -- was to link the press shop with the tool shop, so that the maintenance and repair services of the tool-and-die shop occurred based on [the] demands of its customer, the press shop.

CONVERTING DIE PREPARATION TO ON-DEMAND

To produce a defect-free part -- free of burrs, deformations, etc. -- the press operator had to install a multi-ton die into the press. This tool had to be prepared properly. Even if the die was 'set' correctly in the press, parts would be defective if the die has rough surfaces, dull cutting edges, or broken punches, etc. As a result, it was possible that the press operator and die setter would fixture a die in the press, begin stamping parts and discover that there was some defect. Even though they had used the tool as it should have been used, the press shop workers had been supplied with a defective die, one not capable of producing defect-free parts.

In such cases, the tool-and-die maker would examine the die while it was in the press, determine why the die was generating defective parts, and take remedial action. This might include grinding a surface, replacing a pin, etc.

One of the underlying reasons that dies arrived at the press not ready for use is that the die specialist, Jim, had no way to know the sequence and priority he should give to each die. Consequently, he found himself working on dies that were not needed while other dies, that both needed repair and that also were needed for production, sat unattended on the storage shelf.

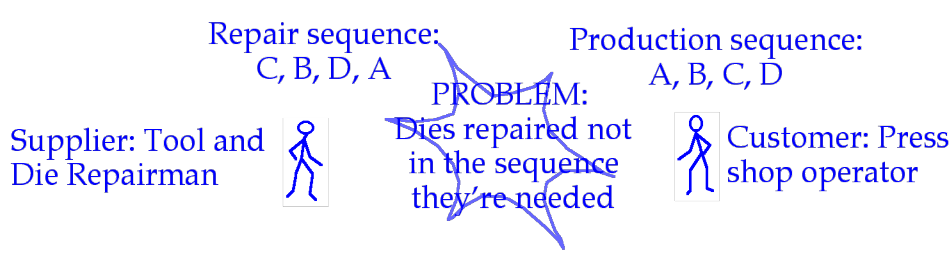

Figure 163: Die-Repair not well coordinated with Production Needs

To improve the situation, we worked with the die-specialist and the press operator to develop a mechanism that would help coordinate the efforts of the die-specialist with the needs of the press operator.

ONE-BY-ONE PRODUCTION AND DELIVERY

The processes about which I collected data can be divided into one of two groups: those in which there is no cost for switching from the production and delivery of one item to another type, and those for which there is a switching cost. Observations about both types of processes contributed to the conclusion that IDEAL production and delivery, in the eyes of those trained in TPS, is that which is done piece by piece.

PROCESSES WITH COST-FREE CHANGEOVERS

First, consider those activities -- such as some assembly processes for instance -- for which there is no switching cost. In my experience, TPS promoters *always* try to move from batch to piece by piece production. For example, earlier I referred to Acme's initial practice of assembling starter motors and alternators in large batches. Typically, there would be a large basket of parts at each assembly line, and each worker would have five to ten units in front of him or her, in various stages of completion. One of the first steps encouraged by the TPS teachers was to limit each operator to a single unit at a time. (It was emphasis of this point that led to the iterative attempt by the Acme managers and supervisors to develop a U-shaped cell that allowed piece by piece flow). Likewise, in the first process step at Acme, tear-down, the normal practice had been for a worker to take 22 of the same type of motor out of a basket, arrange these on a work bench and then perform the same process-step on each. For example, the tear down workers would first remove the bolts from all 22 motors.

Then, they would open the casings on all 22 motors. Then, they would remove bearings from all 22.

In April, under their own initiative, a team of five people tried to take lessons learned with TSSC in the final assembly area and apply them to creating a piece by piece process in the tear down area. In what they did (aspire to piece by piece production without waste) and how they how the did it (close study of the work as it is performed followed by repeated experimental changes), the Acme team's behavior reflected the norms they had absorbed from working with TSSC for 18 months.

For example, a senior manager compiled comments and observations made by members of the improvement team. One supervisor made the following observations, which I've quoted from a fax sent by the company on April 30, 1999.

> "Observation: Too much time spent walking around looking for tools, pallet jacks, and baskets for parts. The baskets and parts are disorganized. Machines are scattered throughout the area. Wrong tools were used on different applications. No continuous flow of materials.
>
> "It was difficult to take cycle times of the operator because of the above noted observations. Cycle times fluctuated from 9 seconds to 15 seconds because of tooling problems such as a rod getting stuck in a nose housing.

"After employees went home, Jesse and I proceeded to move machines in the Nose Housing and Plate area around in a u-shaped cell to create a *continuous flow* of materials and *one by one production*.

"The next day the operator commented that he was unhappy ... because he had to work from right to left. We changed the operation to satisfy the employee and also added slides for discharging parts and added a lift so the employee would no longer have to bend over to pick up parts form the basket.

"Cycle time changes:

Before:	9	15	10	12	14	11	10	12	14	12	11.0 average
After:	6	5	6	6	6	5	6	6	5	6	5.7 average

"Lessons learned from Toyota about TPS:

Identifying problems

Continuous improvement

Input from people on floor is extremely valuable

Operations constantly change, must be on floor to understand the problems

Batching product is unproductive

Fix problems 1 x 1

Problem-solving technique: grasp the situation, investigate, breakdown, point of cause

Evaluate cycle times to know how many employees are needed to produce a certain quantity of parts."

Another cell supervisor who was a member of the improvement team recorded the following accomplishments and learning points:

"Cycle time before kaizen: 70.0 seconds

"Cycle time after kaizen: 67.3 seconds (With added operation)

"Improve by cycle time reduction

"Eliminate waste of walking and reaching by better tool placement

"Get input from the operator and work together

"TPS: one at a time, able to identify problems before they get out of hand

Converting a process from batch production to piece by piece production was not unique to Acme. At *all* the TPS-managed sites at which I collected data, a universal characteristic was that products proceeded piece by piece through processes rather than in batches. This single piece flow was evident at Injex (auto interiors), Johnson Controls (auto seats), Summit Polymers (in assembly for dashboard components), Aisin-Nishio (door handles), Aisin-Shinkawa (window regulators), Araco (car seat mechanisms), NHK Toyota (car seat-frame welding and assembly), Toyoda Boshuko (filter assembly), Aisin-Anjo (mattresses), Toyota Homes (pre-fabricated housing assembly), Acme (starter motor and alternator tear down, cleaning, and assembly), United Electric (assembly of temperature and pressure gauges).

PROCESSES WITH NON-ZERO CHANGEOVERS

Processes in a second class are those that impose a cost in switching from one item or item type to the next. Examples of this type include stamping and injection molding because of die changes, robotic operations because of reprogramming, painting because of the need to clean hoses, and welding because of the need to change fixtures and welding tips. Even when non-zero changeovers prevented single piece production, the consistent emphasis in TPS-managed organizations was to reduce the changeover duration in order to reduce lot size closer and closer to single piece production.

The emphasis on decreasing lot sizes was implied in the calculation by which lot sizes were determined. Consider, for instance, a process that has a cycle time of one part per minute, and demand on the process is 100 pieces of Item-A each day, and 300 units of Item-B each day. Therefore, in a shift with 480 working minutes, there are 400 minutes required for production, leaving 80 minutes for doing changes.

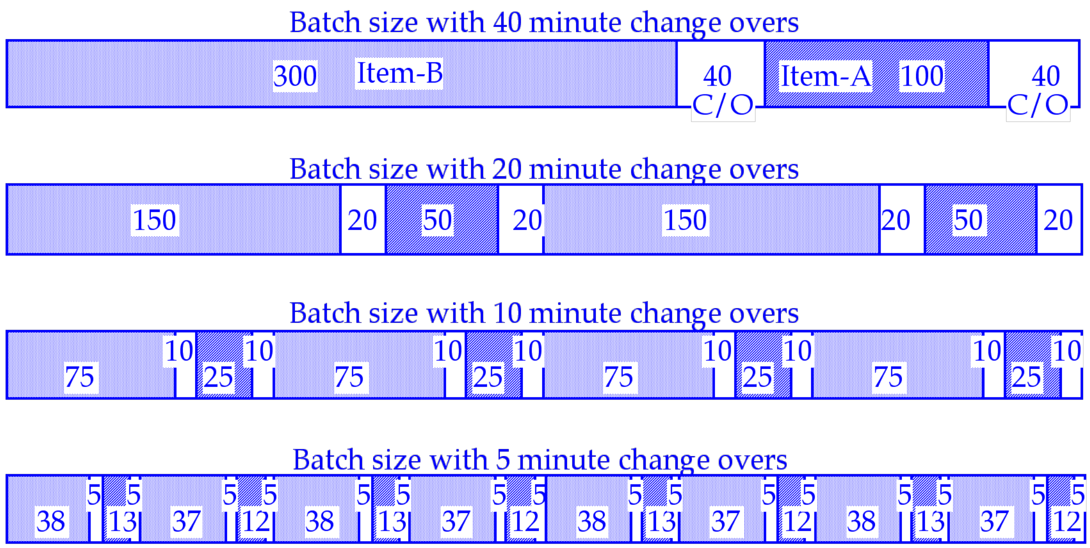

Figure 164: Lot size as a function of set-up time, daily demand, and cycle time

If each changeover required 40 minutes, then a TPS-managed shop would do two changes each day. Improving the changeover process so that it took 20 minutes would allow the number of changeovers to double, and the parts per batch to be halved. The same approach is taken with each reduction in changeover times. Given a demand per day on a process, and a cycle time per part, the remainder of the time should be used to do as many changeovers as possible to continually reduce the number of parts per batch (with one by one as the objective).

The calculation in this simple example exactly reflects what we were trying to accomplish while I was part of a TSSC effort to promote TPS at a supplier plant. The same rationale of reducing batch sizes (and inventory store size) by reducing changeover times is what motivated the Toyoda Boshuko people (mentioned in Chapter 7.1) to reduce the injection molding die change from 5 minutes to 3 minutes.

NUMMI

During a 1998 visit to the Toyota/General Motors joint venture, NUMMI, we were shown a recent innovation in how material was delivered to the pick-up truck assembly line. Previously, steering wheels had been delivered container by container. However, this required that there be at least one container of each steering wheel type by the line side. The problem -- as it was explained to us -- was that this required too much floor space. This put pressure on the off-line operators -- who supplied the wheels -- to develop a mechanism so that they could deliver the wheels in the same sequence that they would be used in the trucks. The key point, we were told during the tour, is that the supplier of steering wheels had to find a way to deliver the steering wheels in a way that more closely reflected the needs of his customer.

IMMEDIATE

I observed two ways in which suppliers worked to reduce the time it took them to respond to a request. One approach was to improve work methods to reduce cycle times. For example, cycle time reduction (in addition to one-piece flow and other metrics), had been an objective in every training exercise conducted by TSSC at Acme. It was clearly a point emphasized enough that when Acme conducted its own improvement effort in the tear down area, cycle time reduction and single piece flow were the dominant objectives.

Even with extensive cycle time reduction, most production and delivery processes have cycle times greater than zero. Therefore, small stores of inventory are often kept so that the supplier can create the *impression* of an immediate response.

Because inventory as a counter-measure is explored more completely in Chapter 8, details won't be provided here. However, I learned of a particularly interesting approach to cycle time reduction while visiting a Toyota Homes plant in 1998.

REDUCING LEAD TIMES AT TOYOTA HOMES

When I visited the plant, Toyota Homes was producing modules for pre-fabricated housing. The plant itself showed many features of TPS-managed organizations: structured, self-diagnostic activities in assembly; direct, binary, self-diagnostic links between customers and suppliers in the plant; and simple flow-paths over which the house was constructed.

The problem was though, that the time spent in the factory, one week, was a small portion of the total time required to provide a make-to-order home to a customer. The on-site construction, two months, was a much larger portion of the time from when a house is ordered until it is completed.

From Toyota's perspective, shortening the response time was doubly problematic. The biggest portion of the cycle time took place outside the plant. The work outside the plant was not done by Toyota employees but by independent construction contractors. Nevertheless, the Toyota Homes people, with the help of members of Toyota's Operations Management Consulting

Division, studied the on-site assembly process and discovered a problem that could be remedied in the factory.

The modules were shipped with hardware, fittings and other finishing materials. They were packed and stored in such a way and in such locations that the construction workers had to do non-value-added walking to retrieve parts from one location to be used in another location. The improvement team's study of the assembly process led to a redesign in the packaging of parts and materials. This was meant to reduce the wasted effort at the construction site, and to close the gap between the time actually required by Toyota and the contractor and an *immediate* response.

NO WASTE

One of my earliest impressions was that the primary objective of the Toyota Production System is to reduce waste in production and delivery. My first exposure to TPS was on a visit to two non-Toyota plants in the summer of 1995. I toured the plants with Hajime Ohba, head of the Toyota Supplier Support Center. At the end of the tour he shared his observations with the plant manager and several corporate executives. Many of his comments criticized practices that caused material to idle while it waited to be processed or which caused people to wait idly for work to do.

DISTANCE TRAVELED BY ROBOT ARM

For example, at one point, Mr. Ohba noticed that a robot was used to pick parts from a holder and insert them into a work piece. The robot's hand (which could hold more than one part at a time) traveled a distance greater than needed to accomplish a complete cycle. This increased the cycle time, decreased the capacity of the robot, and lengthened lead times for the part being made.

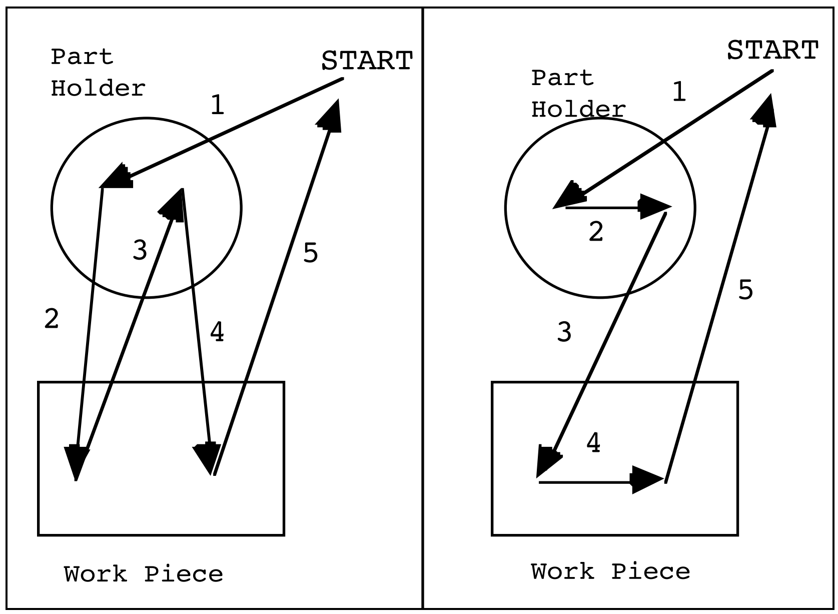

Figure 165: Suggested change in robot-hand travel-path to reduce waste

<u>PRODUCTION EQUIPMENT LAYOUT</u>

Mr. Ohba objected to placing workers on opposite sides of a conveyor. He felt that this prevented the operators from performing adjacent tasks. Since they were constrained (unnecessarily), responsibility could not be redistributed in response to changes in the mix or volume of demand for the product made on this line. This left some workers under loaded, causing them to idle each cycle.

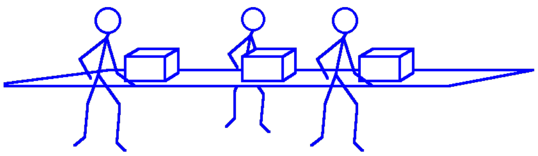

Figure 166: Actual Layout

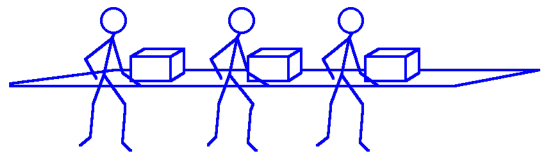

Figure 167: Recommended Layout

Mr. Ohba objected to another layout. Part storage and work areas acted as barriers between workers. This compromised communication and prevented task loads from being shifted effectively from one operator to others in response to adjustments in production rate and mix.

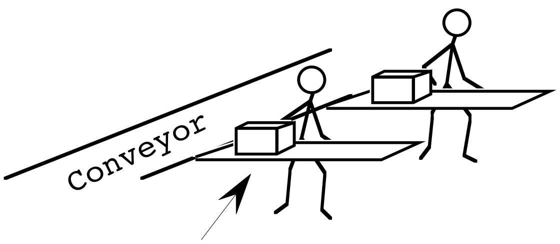

Figure 168: Actual Layout

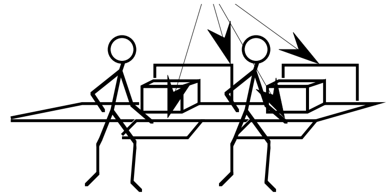

Figure 169: Recommended Layout

<u>CELL LAYOUT AND WASTE REDUCTION</u>

The following diagrams show a layout to which Mr. Ohba objected, also because it required costs greater than necessary. In this situation, operations performed by people were interspersed in a sequence of automated processes. The actual layout on the left was inherently inflexible. Regardless of the demand level, four people were required in the cell. Because of the distances between stations, demand would have to drop considerably before someone could be reassigned from one area to another.

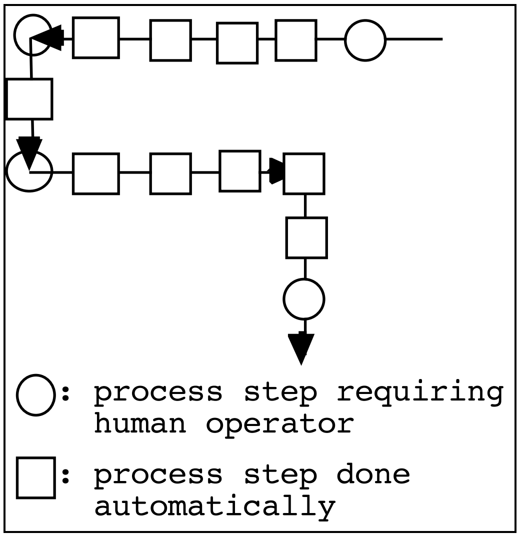

Figure 170: Actual process flow

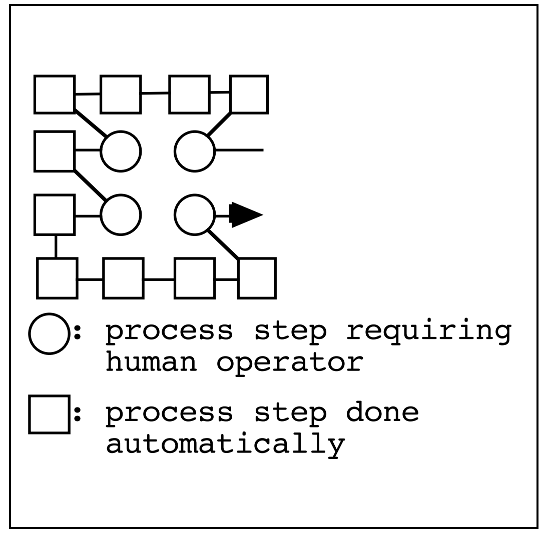

Figure 171: Recommended process flow

In contrast, Mr. Ohba suggested that the layout on the right is inherently more flexible because the work stations are in close physical proximity. When demand is heavy, a worker can be assigned to each of the four stations. If demand should fall for that particular product, workers can be reassigned with one worker covering more than one station.

Mr. Ohba suggested altering another layout. His objections were two-fold: intertwined flows (i.e., Rule-in-Use 3) and inflexibility in assigning the work to people.

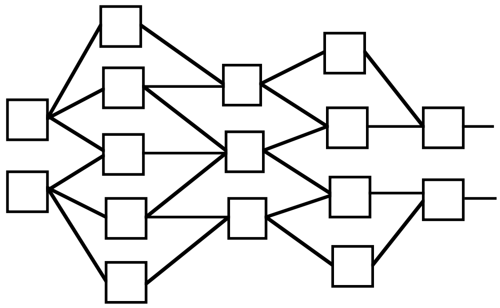

Figure 172: Actual: Intertwined flows

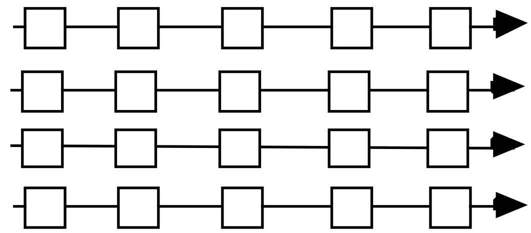

Figure 173: Recommended: Simple flows

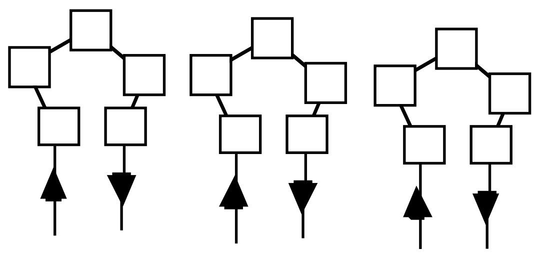

Figure 174: Recommended Final Form: Simple, U-shaped flows

In the final layout, one operator can monitor all the steps, and if not, is next to other operators for learning, assistance, etc. Neither of the other layouts permit this.

The examples from this plant are particularly illustrative. There is a consistent theme to the objections, and they were raised by someone who I concluded -- based on his history with Toyota and the responsibilities with which he was charged (promoting TPS in the North American supplier base) had an exceptionally deep knowledge of 'good TPS.' Consequently, we considered these comments to be particularly relevant in our effort to develop an explicit codification of the Toyota Production System.

I encountered many other instances in which changes were made in the design and performance of an activity to remove waste. These changes include:

- reducing the distance someone's hands had to travel to do work,
- balancing the work between left and right hands so one hand would not be idle while one worked,
- reducing the number of letters printed on a test report to reduce the cycle time and increase the throughput of a test device,
- changing the work layout so that tasks could be reassigned flexibly to reduce the amount that any person was idle,
- developing address systems so people would not have to search for parts,
- adding communication devices to reduce the wait for assistance.

SAFETY

I concluded that physical, emotional, and professional safety are critical elements of the IDEAL production and delivery system to those acculturated to good TPS. By physical safety, I mean that when work is performed, it doesn't pose a threat to the health of the worker. By emotional safety, I mean that the discovery of a problem (either in an activity, connection, or flow-path) and the attempted resolution of a problem (even if unsuccessful) be done in a way that is blame-free and does not diminish the individual who discovers the problem. By professional safety, I mean that improvement does not result in someone losing his or her job. I concluded that physical, emotional, and professional safety are aspects of the IDEAL for the following reasons.

<u>PHYSICAL</u>

In gathering data, I encountered a number of situations in which changes were made in the work place specifically to make the work place less threatening and more pleasant. For example, at Taiheiyo, a stated purpose of developing the spatter and fume cleaners was to increase the comfort in the work place.

Also, at Taiheiyo, a worker-designed device that improved workplace comfort was widely used and prominently displayed in the plant. The Taiheiyo plant had many machines that include pneumatic valves. The compressed air that was used to open and close the valves made a loud hissing noise that was magnified by the hundreds of values being powered. An employee designed a simple muffler made from a metal soft drink can, a plastic liter soda bottle, and some inexpensive wadding. This low-cost device nearly silenced the pneumatic valves. In the plant I visited, all the valves were muffled in this fashion, and in two locations there were display boards explaining how the device works and crediting its inventor for its development.

Observations at Toyota assembly plants also contributed to the conclusion that physical safety is an essential element of an IDEAL production and delivery system. As explained earlier, I learned that the new-hire training placed a heavy emphasis on decreasing ergonomic threats. New workers had to develop their strength and flexibility before being assigned production-related jobs.

Increasingly at Toyota, jobs have devices to make the task physically less demanding and stressful. In the plants I visited, Toyota has installed powered hoists to help the operator carry the seat from the seat conveyor to the car. Elsewhere on the line, Toyota has tested 'raku-raku' (convenience) seats. An operator sits on these and is suspended in the car to do under the dash board installation work. The purpose of the seat is to eliminate reaching and twisting that would be necessary if the worker were to reach into the car. At the Georgetown plant, we observed the addition of stands that allow each worker to adjust the height at which he or she works relative to the car to ease the stress on shoulders and neck. [36]

EMOTIONAL

I concluded that emotional safety (i.e., the ability to work in a blame-free environment) was a characteristic of an IDEAL production and delivery system. Part of this conclusion was based on the deductive reasoning that if the system is designed to identify problems in every activity, connection, and flow-path with each operation, people have to feel that they are not going to be accused of either slacking or incompetence when problems are discovered.

Furthermore, in gathering data, I was struck by the patience managers exhibited in training workers in problem-solving skills. The Ito-Team at Aisin began working together in 1993, gradually developing their capabilities over a four-year period. At Taiheiyo, the Quality Circle was allowed two years to

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[36] Fujimoto details the introduction of devices that reduce the load on people in his book The Evoluation of a Manufacturing System at Toyota.

address the welding robot spatter and fume problem without someone else intervening to solve the problem for them. During my stay in the Toyota Supplier Support Center, Mr. Ohba and the other experienced Toyota employees challenged me, in a Socratic fashion. During my time in the supplier plant, they rarely told me what the right answer was, choosing instead to allow me to learn through trial-and-error, experimentation, and personal discovery.

Fujimoto has observed that Toyota's new Kyushu plant has certain design details that distinguish it from other Toyota plants. One of these distinctive features is the length of assembly line segments. According to Fujimoto, the norm in Toyota plants is 3 segments. In contrast, the Kyushu plant is designed with 11 segments, with buffers between each.

In the summer of 1998, I had an opportunity to tour the Kyushu plant and speak with the plant manager, Mr. Kato, who was actively involved in designing the plant prior to its construction. According to Mr. Kato, he and the other plant designers chose to divide the line into smaller segments with small buffers in between each for a very specific reason. They wanted to give each group leader the opportunity to do more local problem-solving than would be possible with longer segments. In the more standard design, the segment length is equivalent to the span of responsibility of an assistant manager. According to Mr. Kato, because there is no buffer between groups, group leaders are under pressure to keep the line moving. By creating buffered segments that correspond to a group leader's span of responsibility, not that of an assistant manager's, Mr. Kato expected the group leaders would be under less pressure to keep the line moving and would feel more secure in addressing problems as the arose.

When the topic of buffers and segment lengths came up, Mr. Ohba, who was traveling with us, offered that this design decision was debated and discussed within Toyota. Ultimately, it was tried as a useful experiment, particularly since the Kyushu plant, located in a new area, is staffed with many young workers. Shorter, buffered line segments seemed a reasonable means of giving group leaders more discretion and opportunity to assist and train without the risk that they would shut down the entire assembly line. Furthermore, Mr. Kato told us that because of the experiments with mini-lines being conducted at Kyushu, some of the practices were being transferred back to older Toyota plants such as Motomachi.

Counter-examples bolstered the affirmative evidence that emotional safety is a necessary element of an IDEAL production and delivery activity or system. Sadie's discomfort, for instance, when I mis-designed the model-line customer-supplier connections, was palpable.

In the same supplier plant in which I worked, we encountered a number of difficulties because of the way in which management was structured. The plant manager was new, hired by the corporate vice president for manufacturing. Shortly after he was given responsibility for returning the plant to profitability, the same vice-president assigned a consultant to the plant with the ambiguous objective of 'getting results.' Soon there after, a new production manager was introduced. However, he had not been hired by the plant manager either. Rather, he had been transferred from one plant to another, again by the corporate vice president. The situation couldn't have been more tense. Three managers were all answerable to the same corporate superior without clearly defined domains or objectives. What we found is that, predictably, they undercut each other as each tried to score a win that could be clearly attributed to him alone.

The effect appeared to be most pronounced on the outside consultant. For instance, I recorded the following account in my journal.

> "As for [Joe], he is going batty now. With this much corporate presence and no results to show for his time here since December, he has been rocketing around again. Seeing that we were paying attention to die preventative maintenance in the last few days of last week, he has shipped fourteen dies out for sharpening on Monday. In doing so, he nearly shut down Georgetown though. He sent a die (with instructions to return it within four weeks) for a part that the plant was already short. There was some hurrying up, and we got the die back, fortunately. It costs bucks to shut down an auto plant and idle its forty five hundred employees."

<u>Professional</u>

In studying the Toyota Production System, it was impressed upon me that people had to feel professionally secure if they were going to contribute freely towards improving the efficiency of the work place. This message was reinforced in a number of ways. First, I learned that the Toyota Supplier Support Center makes a particular requirement of companies that are interested in becoming project companies. If accepted they have to sign a contract that they will not fire people due to gains in productivity. This, of course, obligates the managers to increase their business to absorb the people who are freed by improvements in activities and systems of activities.

As it was explained to us, Aisin's venture into the mattress business was a result of productivity improvements. With excess capacity and extra employees, the company needed to find outlets for its extra resources.

SCIENTIFIC/EXPERIMENTAL METHODS FOR IMPROVEMENT

Chapter 7.4 emphasizes several aspects of improvement when done according to TPS norms. Activity improvement should be part of the work content of the activity performer, people should learn to improve by addressing production-related problems, and problem-solving should be directed and facilitated by a capable teacher. The investment by suppliers judged to be examples of 'good TPS' by Toyota's own TPS experts was offered as evidence, as were examples of Toyota Supplier Support Center consultants. Another aspect of improvement is that it should be directed towards the IDEAL.

The final aspect of activity improvement -- when done according to the TPS norms that I've codified as Rule-in-Use 4 -- is that changes in production and delivery activities should be designed and performed as experiments. In some ways, this last point is self-evident. Improvement of an activity is also an activity. If behavior in TPS-managed organizations is to be consistent, an improvement-activity like any other activity must then be designed so that it is structured and self-diagnostic, i.e., hypothesis-testing.

Behavior in TPS-managed organizations is consistent, and improvement-activities, like other activities, are designed and performed as hypothesis-testing experiments. For example, consider the Taiheiyo example of building a spatter and fume control system for the welding robots. That team, over the course of two years, engaged in a series of experiments to address a spectrum of design problems. Aisin's Ito Quality Circle also took a scientific approach to problem-solving, as evidenced in the fish-bone, root-cause analysis it constructed, and a series of subsequent counter-measures they attempted to address each of the potential root causes. A similar experimental approach was used by NHK-Toyota's foam-molding improvement team.

In my experience, improvement activities specifically, and learning-activities more generally, were designed as experiments. At the supplier plant in which I worked, I learned how to observe a process closely, construct a *current condition*, a diagrammatic and textual representation of how work was actually performed, and propose *counter-measures* to remove the problems I had identified. Before actually making a change, I was forced to state a hypothesis:

current condition + counter measures ---yields---> target condition (predicted results).

It was not only shop floor change that required a clear statement of refutable hypotheses. With the exception of my first set of plant visits in Japan in 1996, the Research and Training people at the Toyota Supplier Support Center would not make plant visit arrangements for me until I had stated clearly what I had expected to learn. This, at first, was enormously frustrating. I would object that if I knew what I was going to learn during the plant visit, it wouldn't be necessary for me to go in the first place. I came to recognize and appreciate the point of this (at times painful) exercise. The TSSC people were forcing me to make explicit my expectations of what I was going to see. These expectations were reflections of what my conception of TPS was at the time. Then, we could compare what I actually saw with what I expected to see and identify the gap that existed and the incremental learning that had occurred.

EXAMPLE: LEARNING TO CONSTRUCT AND CONDUCT EXPERIMENTS [37]

To make changes, people are expected to present a detailed theory and the hypotheses underlying the changes. For example, Hajime Ohba, general manager of the Toyota Supplier Support Center, was visiting a factory in which one of TSSC's consultants was leading a training and improvement activity. The consultant was helping factory employees and their supervisor reduce the manufacturing lead-time of a particular line, and Ohba was there to evaluate the group's progress.

The group began its presentation by describing the steps by which their product was created -- delineating all the problems they identified when they had first studied the changeover process, and explaining the specific changes they made in response to each. They concluded by saying, "When we started, the changeover required 15 minutes. We were hoping to reduce that by two-thirds-- to achieve a five-minute changeover -- so that we could reduce batch sizes by two-thirds. Because of the modifications we made, we achieved a changeover time of seven and a half minutes -- a reduction of one-half."

After their presentation, Ohba asked why the group had not achieved the five-minute goal they had originally established. They were a bit taken aback.

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[37] Dr. John Kenagy reported this, based on his first hand observations. It was confirmed with Christine Parker, manager of the Toyota Supplier Support Center's Research and Training Group. It appears in "Decoding the DNA of the Toyota Production System," Harvard Business Review, Sept/Oct 1999, co-authored with Kent Bowen.

After all, they had reduced the changeover time by 50%, yet Ohba's question suggested he had seen opportunities for even greater improvement that they had missed. They offered explanations having to do with machine complexity, technical difficulty, and equipment upgrade costs. Ohba responded to these replies with yet more questions, each one meant to push the consultant and the factory people to articulate and challenge their most basic assumptions about what could and could not be changed -- assumptions that both guided and constrained the way they had solved their problems. Were they sure four bolts were necessary? Might the changeover be accomplished with two? Were they certain that all the steps they included in the changeover were needed? Might some be combined or eliminated? In asking why they had not achieved the five-minute goal, Ohba was not suggesting that the team members had failed. He was trying to get them to realize that they had not fully explored all of the improvement opportunities because they had not questioned their assumptions deeply enough.

There was a second reason for Ohba's persistence. He was trying to show the group that their improvement activity had not been carried out as a bona fide experiment. The group had established a goal of five minutes based on the premise that faster changeovers and smaller batches are preferable to slower changeovers and larger batches, but here they were confusing targets with predictions based on hypotheses. The target was not a prediction of what the group believed would be achieved as a result of the specific improvement steps they planned to take. As a result, the group had not designed the improvement effort as an experiment with an explicit, clearly articulated, testable hypothesis of the form: "If we make the following specific changes, we expect to achieve this specific outcome." Although the group had reduced the changeover time considerably, they had not tested the hypotheses implicit in their effort. For Ohba, it was critical that the team members realize that *how* they made changes was as important as *what* changes they made.

<u>COUNTER-EXAMPLE:</u>
<u>"KAIZEN" AT A NON-TPS 'LEAN' MANUFACTURER</u>

To see if the patterns I observed in activity-improvement were characteristic of TPS-managed settings or were more generally practiced, I interviewed MBA students who have worked at two large, high-tech manufacturing companies, both of which have employed prominent lean manufacturing consulting firms. Neither student described experiences that involved the qualities I have attributed to TPS-managed activity improvement. There was not an emphasis on teaching the activity doer, improvement was not directed towards the IDEAL, improvement-activities were not designed as experiments, and they did not occur frequently. Close study of the shop floor, clear articulation of problems, and explicit statement of the expected result of applying counter-measures were not emphasized. Details of one improvement activity, which the student felt was representative of his experience, follows.

The student had managed a production cell. The plant manager would establish a goal on the number of kaizen events that were to occur during the year, leaving it to each business unit manager to decide where the events were going to occur. A typical goal was six per year per business unit, or slightly less than one event per cell per year. Managers tried to bunch their kaizen events to a time when outside consultants were on site, to take full advantage of the consultant's time. A kaizen event might take two weeks and involve 2 to 3 operators, a supervisor, and people from outside the cell. In the first week, there would be classroom training involving lectures and simulations. There were no test to confirm that people had acquired particular skills or knowledge.

In the second week, the initial step was to generate a mission statement with "specific goals and objectives" such as "reduce radial grinder set-up time with minimal costs." After the goals were established, operators and lead men from the production cell would explain the process to other members of the kaizen team. At the end of the first day, the team would decide on a strategy, such as whether or not it would use "point-of-use" tooling or emphasize the orderliness of the work site. The team would also learn from the business manager or from the plant manager what the budget would be for the improvement effort. Also, the process was video-taped for analysis. On the second day, the video-tape would be analyzed and "low hanging fruit would be identified." On the third day, the team would make equipment and work-site changes to take advantage of the opportunities identified in the video-tape. Those opportunities that could not be tackled during the kaizen event were recorded in a 'kaizen newspaper,' however, "there were problems getting things done after the event." Without follow through, operators grew skeptical about the process. "That's where the process breaks down."

During the kaizen event, production suffered, so expediters became important. Nevertheless, "you make [only] 80% of what you were supposed to make." This made the kaizen event more of a burden than an opportunity in the eyes of the business unit manager who was responsible for ensuring that it was carried out. Those who didn’t “buy-in" didn’t pursue the open items identified in the kaizen newspaper. Furthermore, because the kaizen event was disruptive, the business unit managers “spread the hurt among all the cells.”

The contrast between the improvement-process experienced by this student and the improvement process at Aisin, Taiheiyo, NHK, and Acme is striking. In the non-TPS-managed setting, improvement did not occur frequently. It was an episodic experience. Therefore it could not be a primary mechanism by which the capabilities of people are increased.

The business unit managers were inclined to “spread the hurt.“ The production workers were disenchanted with the lack of follow-through. These are not indicative of a safe work environment.

The training activity was not designed as a structured, self-diagnostic activity. Though there was a week-long class room module, there was no test that the training activity had conveyed skills, knowledge, or capabilities.

Improvement was not done as an experiment. Rather than first ‘grasping the current condition’ of how work was being done before proposing counter-measures, the first step was to establish objectives denominated in performance measures. Only at the end of the first day did the team even study the process.

In sum, this company’s improvement activities bore little resemblance to those performed in TPS-managed settings in terms of frequency, process, intent, participants, or outcomes.

CHAPTER 7.5:

DATA AND ANALYSIS CONTRIBUTING TO RULE-5:

CONNECTION AND FLOW-PATH IMPROVEMENT

INTRODUCTION

RULE STATEMENT

Rule-5 guides improvement of connections between activities and of flow-paths constructed from connected activities. Rule-5 determines who is responsible for improvement, the standards for judging changes in connections and flow-paths, and the methods by which improvement activities are designed and performed.

Rule-5 states:

- Connections and flow-paths should be improved in the smallest group that contains the connection or flow-path, by the person responsible for managing the group.
- Individuals should be formed into small groups and small groups should be formed into larger groups based on the nature and the frequency with which problems are expected to occur.
- A change is a connection or a flow-path is an improvement if production and delivery is moved closer to the IDEAL.
- Changes for the sake of improvement should be made so that the hypotheses implicit in the connection's or the flow-path's new design (and in the design of the improvement activity) are refutable.

RULE EFFECT

Rule-5 has many of the same effects as Rule-4. It pushes problem-solving to the smallest possible organizational unit. Therefore, like Rule-4 that couples activity-performance with activity-improvement, Rule-5 couples responsibility for connection and flow-path operation with connection and flow-path improvement. This contributes to the *nested* modularity of TPS-managed organizations. Baldwin and Clark have explained that modularity allows local experimentation and change that is consistent with and not contrary to system-level objections. Therefore, like Rule-4, Rule-5 provides option value that is created when local action is consistently aligned with global aims.

Rule-4 imposes the IDEAL as a source of tension for improvement -- beyond that necessary to meet the immediate demands, needs, and requirements of customers. Rule-5 also imposes the IDEAL as a source of tension.

Rule-5 requires that improvement activities (with connections and flow-paths as the design objects) be done as structured experiments in which hypotheses can be tested. Therefore, like Rule-4, Rule-5 provides a mechanism by which training through problem-solving leads to process improvement, and problem-solving aimed at process improvement also develops the capabilities of the organization's members.

One implication of Rule-5 is that an organization's structure determines who will solve problems as they arise. This is consistent with much of what has been written about overlapping loci of knowledge and problem-solving (i.e., von

Hippel) and the role of architecture on increasing or decreasing the value of skills and competencies (i.e., Henderson and Clark).

A more profound implication of Rule-5 is that who should solve problems should determine the structure of the organization. In effect, Rule-5 implies that there is no single best structure based on product, process, or function. Rather, which people and the number of people to join into a small group and which groups the number of groups to join into larger groups are all decisions to be made based on the nature and frequency with which each activity, connection, and flow-path is expected to demand attention. This aspect of Rule-5 was discussed at some length in Chapter 5.

DERIVATION OF RULE-5

Rule-5 was inductively derived from data gathered by observing people in the course of doing their work and from first hand accounts of people describing their work. Several events were especially persuasive evidence.

The animated debate between two floor supervisors in a plant that was just being to learn the Toyota Production System alerted me to a critical fact. If an organization is designed as a system of connected components, then someone must be responsible for managing the components (i.e., designing, performing, and improving individual activities). However, someone must also be responsible for managing the system of components (i.e., designing, operating, and improving connections and flow-paths). At the time of the observation, I didn't know who specifically that had to be, but it had to be someone.

Learning about changes in the production system at Aisin helped clarify who should be responsible for improving connections and flow-paths according to TPS norms. The Ito Quality Circle contributed to the conclusion that in TPS-managed organizations the activity-doer should be capable and responsible for activity improvement. Learning about the consolidation of three specialized assembly lines at Aisin into two general-purposes lines provided insight into connection and flow-path management.

Chapter 7.4 discussed evidence that contributed to including 'safety' as an element of the IDEAL. Among this evidence was the decision to design the Kyushu assembly plant with short line segments so that group leaders would be better able to do real-time problem identification, diagnosis, and remediation. This evidence also contributed to the conclusion -- articulated in Rule-5 -- that connection and flow-paths be managed in the smallest possible group.

During a 1998 plant visit, I learned and later confirmed that the Kamigo plant had experimented with different organizational designs in each of its machining divisions. This account -- given in more detail in an earlier chapter --also contributed to the formation of Rule-5.

PRESENTATION OF EVIDENCE

This chapter will be the shortest of the five presenting data and analysis. There are two reasons. First, Rule-5 echoes parts of Rule-4. Both require that improvement efforts move production and delivery closer to the IDEAL. Since this particular conclusion was defended with evidence in Chapter 7.4, it would be redundant to do so here. Likewise, both Rules 4 and 5 require that improvement activities be designed and performed as hypothesis-testing experiments. Since that conclusion too was defended with evidence in Chapter 7.4, it would be redundant to do so in length here too (though the following Aisin account captures some of the structured experimentalism that is the TPS approach to process change).

THE NECESSITY OF INTERFACE MANAGEMENT: ACME

This account illustrates what occurs when responsibility for managing the interfaces between connected activities has not been clearly assigned.

I documented an effort by a team from the Toyota Supplier Support Center to introduce TPS as the management system in a plant that rebuilds starter motors and alternators. During one exercise, plant people and 3 Toyota people were broken into three teams. One team was responsible for redesigning the work done in an assembly cell. Another team was given responsibility for designing a material-handling activity to move the product through the various cells in which it is processed.

During the exercise, I observed two plant people -- Dave and Bill -- engaged in a passionate disagreement. Their team was responsible for improving the work done within the cell with a particular emphasis on decreasing cycle times and increasing productivity. In studying the process, they discovered that one of their big problems was the form in which the parts and materials came to the cell from the immediately preceding process. Realizing this, one of them advocated accepting the material in the form in which it arrived, whereas the other one preferred to change the form in which the cell was supplied. Though they went back and forth on this with some vigor, they never reached an acceptable resolution. Eventually, they temporarily agreed to design the very first process step so that it converted the parts from the form in which they arrived to the form in which Dave and Bill wished they had arrived.

The point that I found most striking is that the two of them devoted time and more than a minor amount of passion exclusively to determining where a problem should be addressed and by whom. Their discussion didn't address the nature of the problem at all, nor the nature of a solution that would affect cost, quality, batch size, or some other characteristic that would affect the utility of the customer or the profitability of the supplier. By the time they moved on, they were a bit spent. It was not until later in the day, when the three teams reconvened that Dave and Bill were again able to raise the issue with the team as a whole. On reflection, it struck me that because they didn't start with a common notion of where and how interface issues should be resolved, they spent more time struggling to define the nature of the problem (i.e., activity vs. connection) and spent less time struggling to arrive at a resolution (i.e., a particular change in an activity or interface design). This particular exchange increased my sensitivity to interface management issues as I collected new data and revisited observations made previously.

AISIN SYSTEM REDESIGN

Bill and Dave struggled to determine the appropriate locus for solving a particular problem. I concluded that this was less of a struggle at Aisin. The Ito Quality Circle, discussed in Chapter 7.4, was a mechanism for increasing the capability of production workers to improve production activities. It appears that this investment freed those more senior to address problems that required a broader perspective. This included the design of connections between sequential flow-paths and the allocation of productive resources and work-loads across parallel flow-paths.

In 1997, during the same visit in which I learned about the Ito Quality Circle, I also learned of the process by which three specialized assembly lines were consolidated into two general purpose line. Simultaneously, productivity was increased (i.e., cost was decreased), variety was increased, and production volume was increased.

The next diagrams are translated excerpts from documents provided by Aisin managers. These summarize the redesign process and compliment a presentation and discussion we had during my two-day plant visit in 1997. In discussing these diagrams, several points will be emphasized:

- Presentation of the information: The summary is written as an experimental report. For example, the 'before condition' lists five specific factors and the three negative consequences they cause. The 'after condition' indicates the five specific changes and effect each has on performance.

- Nature of the problems being addressed:

  This summary does consider some process level factors that affect quality and cost. However, it addresses factors, to a much greater extent, that only someone with a broader span of responsibility and authority can resolve. These factors include physical layouts and coordinative mechanisms.

SYSTEM REDESIGN AS AN EXPERIMENT WITH REFUTABLE HYPOTHESIS

The next diagram shows the main sections of the improvement activity summary. This illustrates the experiment imbedded in the redesign process through contrasts between:

- *methods* used before the improvement activity (section 5) with methods used after the improvement activity (section 6).
- *performance* before and after the improvement process (sections 4 and 7).
- *actual* performance gain with the *predicted* gain in performance (section 4).
- primary changes in equipment, training, and methods (sections 5, 6, and 8).

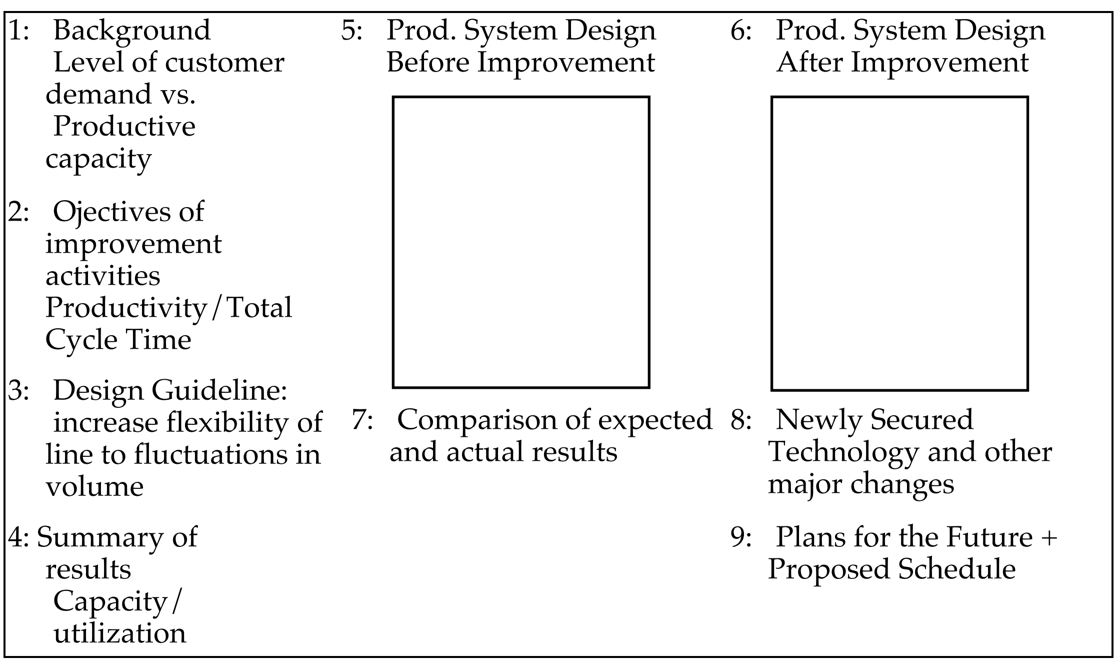

Figure 175: Aisin's summary of process improvement efforts

The next diagram is Section-5 from the summary document, the production system before it was changed. Several points are worth noting.

- The people who worked on the process improvement (Group Leaders, Assistant Manager, and the TPS promotion expert - [according to managerial account, summer 1997]) identified three symptoms that diminished performance. These include the inability to respond to fluctuations in volume, volatility in cycle times, and an inability to keep the production pace tuned to the rate of demand.

- Each symptom corresponds to some aspect of the IDEAL. Inability to respond to fluctuations corresponds to an inability to respond *on-demand* and *immediately*. Volatility caused workers and machines to block and starve each other. This is a source of *waste*. The lack of a pacing mechanism compromised the system's ability to produce *on-demand*, at a rate that matched the customers' rate of need.

- For each symptom, the process redesigners identified at least one process feature as the root-cause. For example, the diagram attributes the system's inflexibility to each line's size-specialization (so a rise in the demand for small mattresses could not be absorbed by one of the other two lines). This diagram, then, states the group's sense of cause and effect.

- The diagram shows where on the shop floor the root-cause feature is observable.

This diagram can be read in the following fashion:

"We [the people who developed the diagram] believe that the system's performance suffers in three ways because of five specific conditions. These five particular conditions can be observed by going to specific locations in the process so that *any* observer can connect actual behavior to actual outcome."

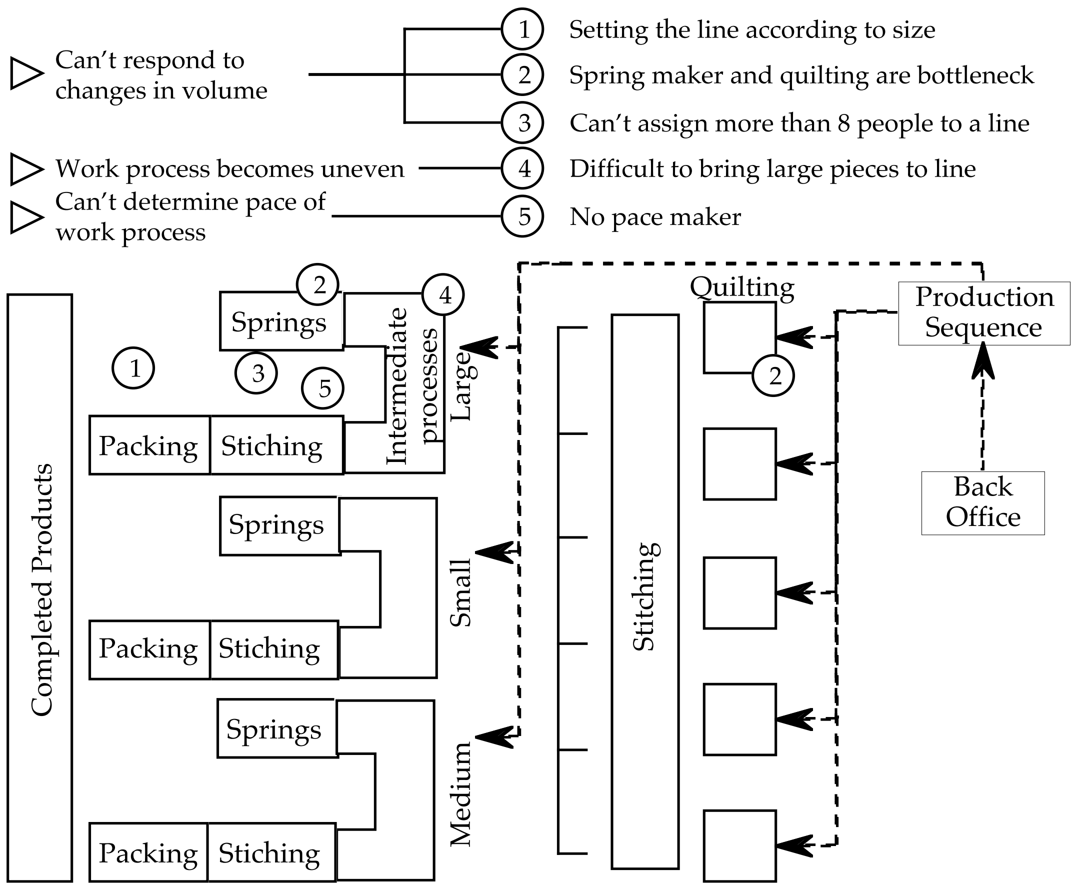

Figure 176: Section 5 of Aisin document (before-condition diagram)

The next diagram is also a translated excerpt from the Aisin summary document. Here again, several points are worth noting.

- For each root-cause in the 'before condition' diagram, there is a particular change (counter-measure) in the design and operation of an activity (Items 2, 3, and 4), connection (Items 4 and 5), or flow-path (Items 1 and 2).
- Each of the counter-measures is credited for relieving a specific symptom that was identified in the 'before-condition' diagram.
- How each counter-measure was enacted is explained. Flexibility was achieved by altering the spring forming process and by separating spring making from assembly with a buffer. The buffer prevented volatility in one from blocking or starving the other. Flexibility was further achieved by dividing work processes so people can be added and subtracted easily. (Chapter 7.2 explains the indicator that tells the group leader to add or subtract someone from assembly.)

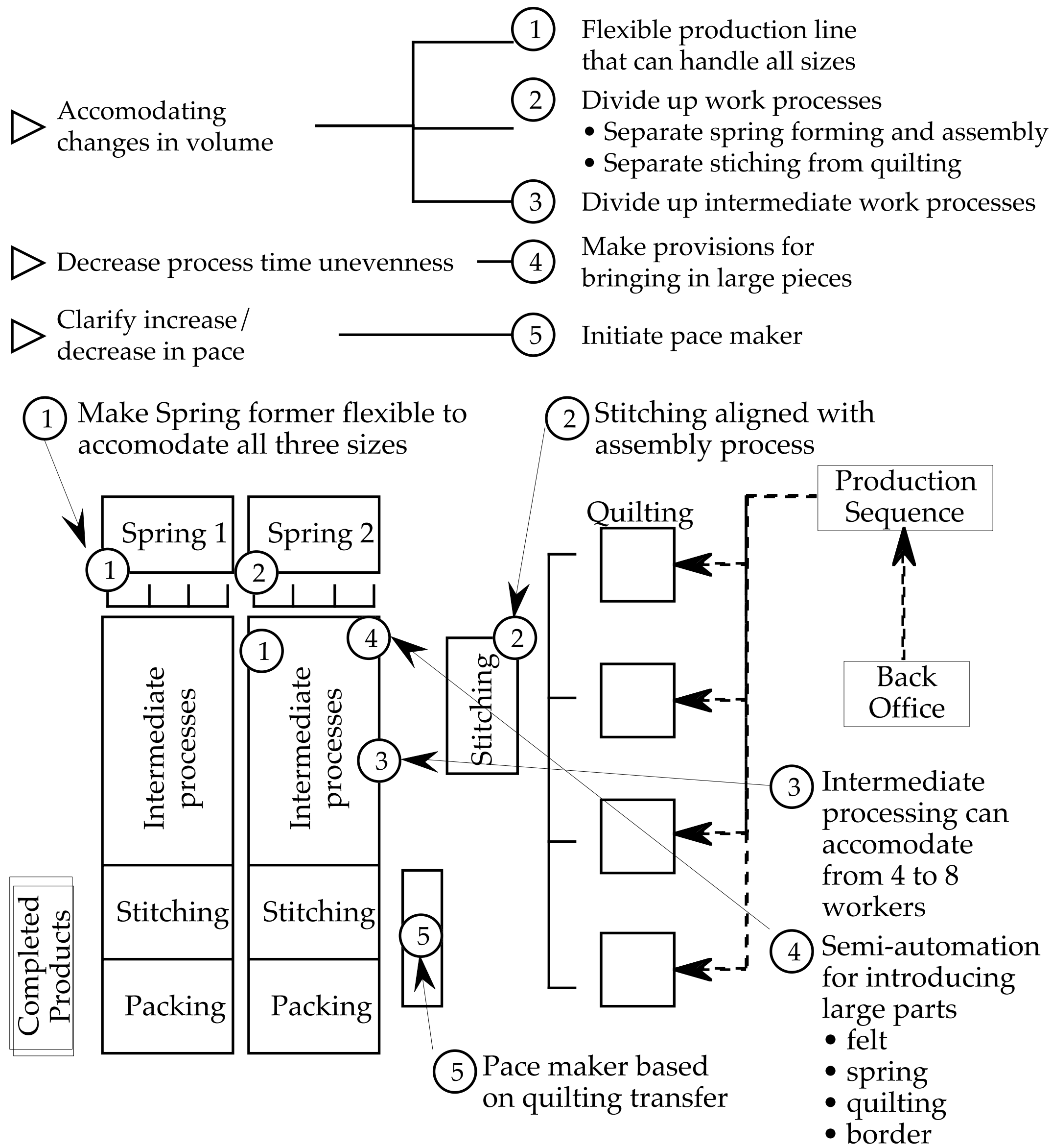

Figure 177: Section 6 of Aisin document (*expected* after- condition diagram)

In effect, this diagram can be read in the following fashion:

"We [the people who redesigned the production system] conducted the following experiment. When we studied the system, we found three reasons to be disappointed with its performance. We traced these three disappointments to five root-causes. Therefore, to improve the system's performance, we addressed each of these five root-causes.

"The counter-measure for Cause-1 is redesigning spring making.

"The counter-measure for Cause-2 is separating stitching from quilting and spring making from assembly by small buffers so that volatility from one doesn't block or starve the other.

"The counter-measure for Cause-3 is redesigning work so that people can be more easily added and subtracted from the line.

"The counter-measure for Cause-4 is adding some semi-automated equipment to make it easier for the operators to lift large, bulky pieces such as frames, quilting, and felt liners and carry them from line-side stores to the work-site.

"The counter-measure for Cause-5 is changing the information connection between assembly and quilting so that assembly [the downstream process] determines the pace of quilting [the upstream process].

"From this diagram, *any* observer can go to the shop floor, study the counter-measures we implemented, and decide if we achieved our stated (i.e., expected or predicted) objectives."

The document indicates an additional experiment. When in the plant, I observed that each line had some automation applied in different locations. For example, on one line, a robotic device lifted and placed felt liners onto the mattress during assembly. The other line did not have this device. My interpretation of this was that the production system, with counter-measures added, was configured so that one line was receiving the 'experimental treatment' whereas the other line was acting as the control.

Section 5 and 6 of the summary document capture the line redesign as an experiment. This is an experiment in which the 'scientists' quantified the expected outcome (objective/goal) and compared this to the actual change in performance. This comparison between prediction and actual outcome is also contained in the diagram.

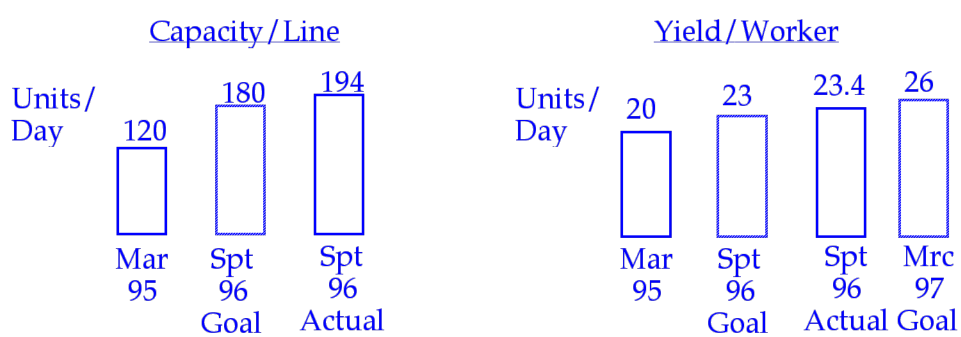

Figure 178: Comparisons: Before vs. After; Expected vs. Actual

THE OBJECTIVE OF IMPROVEMENT

I concluded that the changes were aimed at moving production and delivery towards the IDEAL. This conclusion was based on the objectives of reducing waste through increased flexibility and thereby increasing capacity utilization and of decreasing process lead-time (as reflected in the increase in units produced per shift). Some of the changes, particularly those geared towards pace making, created connections that were direct, binary, and self-diagnostic. In the 'before condition,' the production sequence was released to two locations in the line. In the 'after condition,' the production sequence is released only one time, to quilting, with the pace being determined by removal of completed products from the assembly line for delivery to the shipping-staging area. This simplified the flow of information, as well as material.

WHO MADE WHAT TYPE OF CHANGES

According to the managers whom I interviewed, the process improvement team included people at the group leader level and above. The changes these people made in the system are almost exclusively changes in connections and flow-paths.

For example, one of the major changes (#5) was to add a mechanism by which the assembly step (the customer) could determine the pace of the quilting step (the supplier). That was an interface redesign. Another major change was to introduce a small buffer between final assembly and the spring making process, and to introduce a trigger mechanism so that assembly could establish the pace at which spring-frames are manufactured. This too was an interface redesign. A similar interface change in both material and information was the introduction of a small buffer between quilting and stitching with a trigger mechanism connecting the two processes. Another interface change was the addition of the semi-automatic equipment by which large, awkward parts are brought to the assembly line. Flow-paths were redesigned also, as three lines were consolidated to two.

I learned that the interface and flow-path changes were not executed solely by a technically specialized organization such as production engineering. Rather, the people who managed routine production were also responsible for redesigning the production system, with the support of technical specialists as suppliers of expertise. This evidence and that Aisin invested in developing the capability of its line workers contributed to the conclusion that in an organization that practices 'good TPS' at an exceptional level, problem-solving is located in the smallest possible organizational unit.

LEARNING TO MAKE IMPROVEMENTS: OMCD AT AISIN

A critical discovery is that TPS-managed organizations develop people through frequent, structured problem-solving facilitated by a capable teacher. I reached this conclusion based on what I learned of Aisin's Operations Management Consulting Division and its role in improving people's problem-solving capabilities by teaching them to resolve production-related problems.

This portion of Chapter 7.5 describes Aisin's OMCD based on information I gathered during my 1997 plant visit. This suggests an opportunity for further research to explore the role of OMCD specifically and problem-solving activities more generally in promoting TPS at Aisin, at Toyota, and at Toyota suppliers. This may be an important component in our next phase of study: determining the mechanisms by which this organization's capabilities specifically and other capabilities more generally can be developed, expanded, exploited, maintained, and transferred.

I learned that Aisin's Operations Management Consulting Division had 3 general managers, 3 assistant managers and 88 other members. Some of these were technical experts, older than 55 years old, and permanently assigned to OMCD. Some were at OMCD for a 2 to 3 year stay, during which they deepened their TPS knowledge before returning to their home plant. The rest of the 88 had graduated from the Aisin college (a developmental program for those hired into Aisin with no advanced education). They spent 2 to 3 years at Aisin's OMCD. During their stay, the 88 temporary members of OMCD participated in improvement activities, each of which lasted from one to three months. Upon completion of their tenure at OMCD, the temporary members were reassigned to Aisin plants as TPS promotion experts.

According to the explanation given by OMCD head, Mr. Torii, the 3-year curriculum had a logical progression. In the first year, OMCD students focused on process improvements. They advanced to system level projects in the second year. I interpreted this to mean that the OMCD member advanced from component to interface and architecture improvement. In the third year, the students would oversee improvement activities, both to solidify their own knowledge and to acquire the teaching skills necessary for their roles as TPS champions in their home plants.

As explained earlier, Aisin's OMCD played several critical roles. It evaluated the effectiveness of each production line, it established performance improvement goals, and it supported improvement efforts by identifying opportunities for fruitful change. Each of these activities were a venue in which people could hone their problem-solving skills, removed from positions of operational responsibility. Aisin's OMCD was also a source of people who had the expertise and the responsibility to challenge and teach senior employees such as production and plant managers.

As a venue in which TPS expertise can be developed and as a mechanism by which senior managers can be challenged and taught by a pre-specified, competent supplier of training, Aisin's OMCD is not alone. I learned that Toyota also had an Operations Management Consulting Division. Toyota's OMCD supported plant people in improvement activities and provided a venue in which people could become more expert through frequent problem-solving. For example, during my 1997 research trip to Japan, one of my hosts was Mr. Numa. He had worked for Toyota for 16 years, much of it in the Quality Control Division and was in his first year at OMCD. He had projects at three sites, one Toyota plant and two supplier plants. He supervised more junior Toyota people in the process of improving activities, connections, and flow-paths. Mr. Numa's experience at OMCD -- learning TPS by solving production-related problems -- was shared by other Toyota people whom I met during my data gathering.

CHAPTER 8:

INVENTORY AS AN EXAMPLE OF

COUNTER-MEASURE DESIGN AND USE

DEFINING "IMPROVEMENT"

According to the Rules, a change in an activity, in a customer-supplier connection, or in a flow-path (e.g., a system of connected activities) is an unambiguous improvement if and only if production and delivery is moved closer to the IDEAL of defect-free, one-by-one, on-demand, immediate, waste-free, and safe supplier responses to customer requests.

COUNTER-MEASURES: IMPERMANENT RESPONSES TO PROBLEMS

In gathering data, I found that within the Toyota system, changes that were meant to move activities, connections, and flow-paths closer to the IDEAL were viewed as *counter-measures* rather than as *solutions*. This implied that the new tool or practice was a temporary response to a specific problem resulting from current supplier capabilities and customer needs. The counter-measure was not viewed as being permanent, nor was it otherwise viewed as a fundamental feature of the Toyota Production System. Therefore, though outside observers have devoted attention to the artifacts commonly observed in TPS-managed settings such as kanban cards, andon cords, flow racks for parts, and cells, within Toyota, these are treated as convenient but non-essential responses to problems. I concluded that using artifacts is not a sign that TPS is actually being used to manage production and delivery. The absence of any particular artifact is not a sign that TPS is not being used correctly or effectively.

INVENTORY AS A TYPE OF COUNTER-MEASURE

In production, many factors contribute to preventing IDEAL responses to requests. In some cases, material-goods inventories are used as counter-measures to these factors to create the impression of IDEAL supplier performance, even when the supplier (i.e., an individual person, a cell, a line, a plant) is not actually IDEAL. This section will discuss material-inventory as a counter-measure.

At the TPS-managed plants in which I gathered data, inventory was used as a counter-measure in several circumstances.

Non-zero production cycle times prevented suppliers from providing an immediate response to a customer request. Therefore, in many TPS-managed settings, *supplier-held stores* were used to give the impression of an immediate response. For example, Ora-Lee and Sadie each had a few containers of parts (up to one hour's worth of demand) so that when Doris collected parts each hour, she could get what she needed, immediately.

Non-zero delivery cycle times prevented a supplier from providing an immediate response to a customer request. Therefore, in many TPS-managed settings, *customer-held stores* were used to give the impression of an immediate response. For example, both Sadie and Ora-Lee had a few containers of material because it was impossible for Stanley -- the material handler who brought parts from stamping -- to supply them the moment that they needed new material.

Non-zero set-up times prevent the supplier from providing an immediate response, on demand. Therefore, batch sizes greater than one (with supplier-held stores) were used as a counter-measure to give the impression of an immediate response. Even Toyota Boshuko, with its 3 minute injection molding die-changes, produced in lots greater than 1. Aisin, even though it is making mattresses to order, batched production because of the non-zero changeover times at the quilting process.

Unpredictable down-time or *volatile cycle times* prevented a person or a machine from responding, on-demand (timing), when a request was made. Therefore, *safety stock* was held by the person who was responsible for ensuring machine or process reliability. This gave the impression that the process was always reliable. Buffers between each group's line segment at the Kyushu plant hid supplier process-volatility from the knowledge of customers. This gave the appearance that the customer segment was getting what it needs, immediately, even though the supplier segment occasionally may not have been capable of providing an immediate response.

Unpredictable yields prevented a person or machine from responding with a predictable quantity when a request was made. Therefore, *safety stock* was held by the person responsible for ensuring machine or process reliability, to give the impression that the process was consistent.

Volatility in the mix and volume of customer demand prevented the supplier from responding on demand (timing and quantity). Therefore, *buffer stock* was kept at or near the shipping point to give the impression of an on-demand response. For instance, Summit Polymers, which provides injection molded parts to two Toyota plants, another Toyota organization, and 14 other non-Toyota factories, had containers of parts located against its back wall, immediately next to the shipping door. These buffers were used in response to fluctuations caused by the customer. For example, the customer might have requestd a volume unexpectedly greater than the plant is equipped to provide during normal production. The truck that carried parts to the plant might have arrived earlier than expected. This would reduce the time in which parts could be produced, so the buffer stock was a temporary source of material that could be replaced gradually in the next period.

In sum, I concluded that inventory was not used arbitrarily in TPS-managed settings. Rather, inventory was viewed as a counter-measure. Just as specific counter-measures were developed at Aisin for each of the conditions that negatively affected the performance of its make-to-order production system, specific types of inventory were used as counter-measures for conditions that compromised the system's ability to respond to customer requests on-demand, immediately. The variety of ways in which inventory was used as a counter-measure is summarized in the next table and in the diagram that follows.

Condition	Response	'Owner'	Effect-Impression
Non zero production cycle time	Supplier held store	Supplier	Immediate response
Non-zero delivery	Customer held	Customer	Immediate

cycle time	store		response
Non-zero set up time	Batches greater than one. Supplier-held stores.	Supplier	One by one, on-demand response.
Unpredictable down-time	Safety stock (1)	Equipment supplier (i.e., prod. engineer)	100% up-time
Unpredictable yields	Safety stock (2)	Process-supplier (i.e., process engineer)	Predictable yields
Volatility in demand mix and volume	Buffer stock	Shipping (as proxy for customer)	Level demand; on-demand response

Figure 179: Inventory: prompting conditions, responses, 'owners,' and effects.

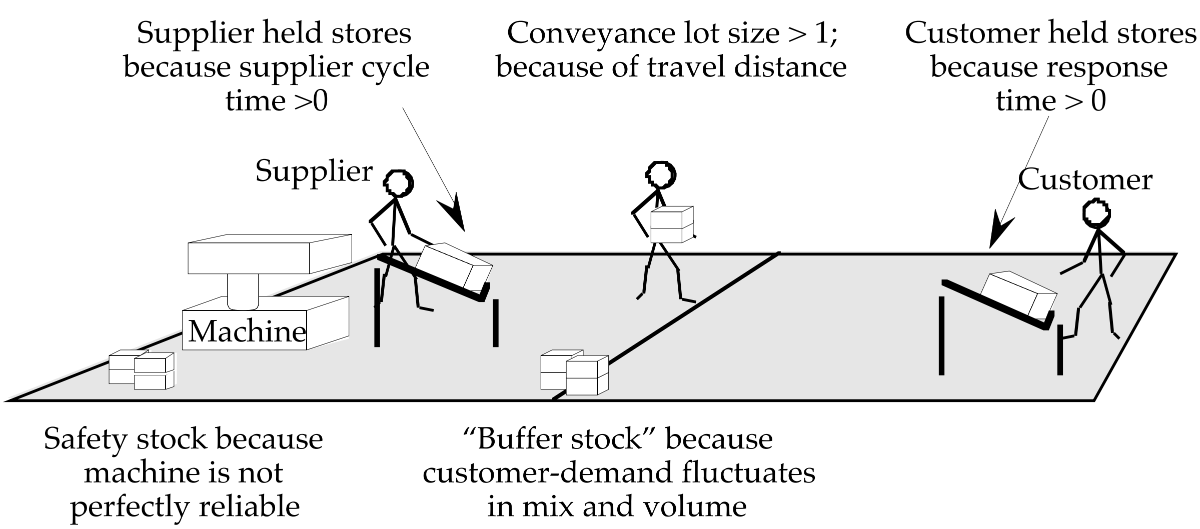

Figure 180: Various uses of inventory in TPS-managed setting

<u>Note: Acting contrary to a commonly held management heuristic</u>

The preceding diagram is unusual. The cause of safety stock -- process unreliability -- and the cause of buffer stock -- fluctuations in customer demand -- are not statistically correlated. Therefore, when the safety stock and the buffer stock are held separately, more material is required than if the safety and buffer stocks were combined into a single inventory.

Though pooling would reduce short-term inventory levels, this option was not exercised in the TPS-managed plants where I gathered data. This behavior is apparently paradoxical. A management system known for low inventory levels encourages the use of inventory at levels higher than might be expected. This rationale for this apparently paradoxical behavior is explained below.

Note: When Inventory is an Inappropriate Counter-Measure

In gathering data, I observed situations in which inventory was not viewed as an appropriate counter-measure. Typically, in these situations, the supplier either provided a broad mix of responses each in a low volume, or otherwise holding inventory was expensive. In these cases the tension for immediate response was out-weighed by the tension to minimize costs. Chapter 7.2 ("Sending Requests When Variety is High and Lead-Time is Long") explains the method used under such conditions.

In the specific case of inventory used as a counter-measure to problems in production and delivery:

- Each type of inventory corresponded to a specific problem.
- Inventories were designed so that customer-supplier connections adhered to rule-2's requirement for direct, binary, self-diagnostic links. When material was withdrawn in response to a yes/no signal to perform an activity

(deliver), the withdrawal of material triggered a yes/no signal to perform some other activity (produce).

- Inventories were designed and used to give the impression that the supplier was responding on-demand, immediately to customer-requests even when the supplier was not actually capable of IDEAL responses.

- Inventories were designed, located, and used so they acted as a reminder to eliminate problems (i.e., Reduce cycle-times, reduce set-up times, reduce batch sizes, and reduce defect rates, increase yields). Therefore, though stores may have been appropriate at a particular time, they also signaled the need for process improvements that reduced the size and the number of stores that were used as counter-measures.

In the case of counter-measures more generally:

- *Counter-measures were meant to address a specific problem.*
  This was evident in the Aisin production-system redesign where causes and counter-measures were matched one-to-one.

- *Counter-measure moved production and delivery closer to the IDEAL and supported management by the five Rules-in-Use.*
  For example, error proofing devices made production and delivery increasingly defect-free; kanban cards and andon lights made the connection between a customer and a supplier more direct and binary. Rapid-die

changes were used to reduce the size of production batches closer to one by one. Inventory was used to increase the immediacy of responses.

- *A counter-measure acts as an irritant for further improvement*.

  Throughout, this dissertation has emphasized the point that *counter-measures*, the tools and practices that are observable during plant tours and visits are not fundamental elements of TPS management. Rather, they are commonly used responses to commonly occurring problems in the production and delivery of goods, services, and information. The very existence of a counter-measure is a sign that some underlying problem has not been resolved and removed. Therefore, the counter-measure is a sign that further problem-solving and improvement (of activities, connections, and flow-paths) is warranted.

BIBLIOGRAPHY

TOYOTA PRODUCTION SYSTEM/LEAN MANUFACTURING/JUST-IN-TIME

1. Adler, Paul S., and Robert E. Cole. 1993. "Designed for Learning: A Tale of Two Auto Plants." Sloan Management Review, Vol. 34, No. 3 (Fall), pp. 85-94.
2. Adler, Paul S.; Goldoftas, Barbara; Levine, David I.; "Ergonomics, employee involvement, and the Toyota production system: A case study of NUMMI's 1993 model introduction"; Industrial & Labor Relations Review; 50(3): 416-437. 1997 Apr.
3. Adler, Paul; "Time and Motion Regained"; Harvard Business Review; January-February 1993; pg. 97.
4. Berggren, Christian; Adler, Paul S. Cole. Robert E.; "NUMMI vs. Uddevalla; Rejoinder"; Sloan Management Review; 35(2): 37-49. 1994 Winter.
5. Besser, Terry L.; Team Toyota : Transplanting the Toyota Culture to the Camry plant in Kentucky; State University of New York Press; c1996.
6. Boccard, Ronald R.; Push vs. Pull: Is One Better than the Other?; Production & Inventory Management Review & APICS News. 10(2): 39-40. 1990; Feb.
7. Cusumano, Michael A.; "Manufacturing Innovation: Lessons from the Japanese Auto Industry"; Sloan Management Review: Fall 1988; page 29-39.
8. Cusumano, Michael; The Japanese Automobile Industry: Technology and Management at Nissan and Toyota; Harvard University Press; 1989.
9. Deleersnyder, Jean-Luc. Hodgson, Thom J. Muller (-Malek), Henri. O'Grady; Peter J.; "Kanban Controlled Pull Systems: An Analytic; Approach"; Management Science. 35(9): 1079-1091. 1989 Sept.
10. Cusumano, Michael A.; "Manufacturing Innovation: Lessons from the Japanese Auto Industry"; Sloan Management Review: Fall 1988; page 29-39.
11. Cusumano, Michael; The Japanese Automobile Industry: Technology and Management at Nissan and Toyota; Harvard University Press; 1989.

12. Deleersnyder, Jean-Luc. Hodgson, Thom J. Muller (-Malek), Henri. O'Grady; Peter J.; "Kanban Controlled Pull Systems: An Analytic; Approach"; Management Science. 35(9): 1079-1091. 1989 Sept.

13. Fujimoto, Takahiro; The Evolution of a Manufacturing System at Toyota; Oxford University Press; 1999

14. Gershwin, Stanley B. Schick, Irvin C.; "Modeling and Analysis of Three-Stage Transfer Lines with Unreliable Machines and Finite Buffers"; Operations Research. 31(2): 354-380. 1983 Mar-Apr.

15. Gershwin, Stanley B.; "Assembly/Disassembly Systems: An Efficient Decomposition Algorithm for Tree-Structured Networks;" IIE Transactions. 23(4): 302-314. 1991 Dec.

16. Hirano, Hiroyuki; JIT Factory Revolution; Productivity Press; 1988.

17. Krafcik, John F.; "Triumph of the Lean Production System"; Sloan Management Review; Fall 1988; page 41-52.

18. Krafcik, John; Comparative Analysis of Performance Indicators at World Auto Assembly Plants; MS Thesis MIT 1988.

19. Lee, L C.; "A Comparative Study of the Push and Pull Production Systems"; International Journal of Operations & Production Management. 9(4): 5-18. ; 1989.

20. Lu, David J.; Kanban: Just In Time At Toyota; Japan Management Association; Productivity Press; 1989.

21. MacDuffie, John Paul; "The Japanese Auto Transplants: Challenges to Conventional Wisdom"; Industrial and Labor Relations Report; 26(1): 12-18. 1988 Fall.

22. MacDuffie, John Paul; "The Road To Root Cause: Shop-Floor Problem-solving at Three Auto Assembly Plants"; Management Science; Vol. 43, No. 4; April 1997.

23. MacDuffie, John Paul; Helper, Susan; "Creating lean suppliers: Diffusing lean production through the supply chain"; California Management Review; 39(4): 118-151. 1997 Summer.

24. MacDuffie, John Paul; Kochan, Thomas A.; "Do U.S. firms invest less in human resources? Training in the world auto industry"; Industrial Relations; 34(2): 147-168. 1995 Apr.

25. Miller, Jeff G.; Supporting JIT Manufacturing with a JIT Organization.; Manufacturing Systems. 8(9): 24-30. 1990 Sept. .

26. Monden, Yasuhiro; Toyota Production System : An Integrated Approach To Just-In-Time 2nd Ed. Norcross, Ga. : Industrial Engineering and Management Press.

27. Ohno, Taiichi; Just-in-Time: For today and tomorrow; Productivity Press; 1988.

28. Ohno, Taiichi; Toyota Production System: Beyond Large Scale Production; Productivity Press; 1988.

29. Ohno, Taiichi; Workplace Management; Productivity Press; 1988.

30. Parker, Mike; Slaughter, Jane "Management By Stress"; Technology Review; Cambridge, Oct. 1988 Volume: 91 Issue: 7 Page: 36.

31. Rinehard, James; Huxley, Christopher; Robertson, David; Just Another Car Factory?: Lean Production and its Discontents; ILR Press/Cornell University Press; 1997.

32. Sarker, Bhaba R.; "Simulating a Just-in-Time Production System"; Computers & Industrial Engineering; 16(1): 127-137. 1989. .

33. Shingo, Shigeo; A revolution in manufacturing : the SMED system; Stamford, Conn.; Productivity Press, [1985?].

34. Shingo, Shigeo; Non-Stock Production: The Shingo System For Continuous Improvement; Cambridge, MA; Productivity Press, 1988.

35. Shingo, Shigeo; Zero Quality Control : Source Inspection And The Poka-Yoke System; translated by Andrew P. Dillon; Stamford, Conn.; Productivity Press, c1986.

36. Womack, James P.; Jones, Daniel T.; Roos, Daniel; The Machine That Changed The World; Rawson Associates, 1990.

TECHNOLOGY AND OPERATIONS MANAGEMENT

37. Hayes, Robert; Wheelwright, S.; Clark, K.; Dynamic Manufacturing; Free Press; 1988.

38. Hayes, Robert; Wheelwright, Steven; Restoring Our Competitive Edge; Wiley; 1984.

39. Hounshell, David A.; From The American System To Mass Production, 1800-1932; Johns Hopkins University Press, 1984.

40. Jaikumar, Ramachandran; Bohn, Roger; "A Dynamic Approach to Operations Management: An Alternative to Static Optimization"; International Journal of Production Economics; 27 (1992) 265-282; Elsevier Science Publishers.

41. Jaikumar, Ramachandran; Bohn, Roger; "Intelligent Manufacturing Control"; The Competitive Edge; Research Priorities for U.S. Manufacturing; National Research Council; National Academy Press; 1991.

42. Jaikumar, Ramachandran; Bohn, Roger; "The Development and Use of Intelligent Systems for Industrial Use: A Conceptual Framework"; Research On Technological Innovation, Management, and Policy; Vol. 3, pages 169-211; 1986; JAI Press.

43. Jaikumar; "Post-Industrial Manufacturing"; Harvard Business Review, Nov.-Dec. 1986, page 69.

44. Jordan, William C.; Graves, Stephen C.; "Principles on the Benefits of Manufacturing Process Flexibility"; Management Science; Vol. 41, No. 4, April 1995.

45. Skinner, Wickham; "The Focused Factory"; Harvard Business Review; May-June 1974; pg. 113-21.

46. Upton, David; "Flexibility As Process Mobility"; Journal of Operations Management; 12 (1995) 205-224.

47. Upton, David; "Process Range in Manufacturing: An empirical study of flexibility"; Management Science; August 1997.

48. Upton, David; "The Management of Manufacturing Flexibility"; California Management Review: vol. 36, no. 2; Winter '94; pg. 72.

49. Upton, David; "What Really Makes Factories Flexible"; Harvard Business Review; July-August 1995; page 74.

ROLE OF MIDDLE MANAGERS AND CORPORATE STAFF

50. Bower, Joseph L.; Managing the Resource Allocation Process; Harvard Business School Press; 1986.

51. Chandler, Alfred DuPont; The Visible Hand: the Managerial Revolution in American Business; Belknap Press; 1977.

52. Taylor, Frederick Winslow; The Principles of Scientific Management; New York: Norton, 1967, c1947

53. Weber, M; The Theory of Social and Economic Organization; 1947

RESEARCH METHODOLOGY

54. Barley, Stephen R.; "Images of Imaging: Notes on Doing Longitudinal Field Work"; Organization Science; Vol. 1 No. 3, August 1990.

55. Barley, Stephen R.; "Technology As An Occasion For Structuring: Evidence from Observations of CT Scanners and the Social Order of Radiology Departments"; Administrative Science Quarterly; 31 (1986) pg. 78-108.

56. Campbell, Donald T.; "III Degrees of Freedom and The Case Study"; Comparative Political Studies; Vol. 8, No. 2 (July) pp. 178-193; Sage Publications; Reprint Harvard Business School 1-592-071 (12 June 1992).

57. Campbell, Donald T.; Stanley, Julian C.; Experimental and Quasi-Experimental Designs for Research; Houghton-Mifflin; 1963.

58. Cook, T.D. and Campbell, D.T.; "Validity"; Quasi-Experimentation; Houghton Mifflin; 1979 pp. 37-94; Harvard Business School Reprint: 1-593-074 (8 Jan. 1993).

59. Heilman, Samuel; Defenders of the Faith: Inside the world of ultra-orthodox Jewry; Schocken books Inc.; New York; 1992

60. Heilman, Samuel; The gate behind the wall : a pilgrimage to Jerusalem; New York : Summit Books, c1984

61. Kirk, Jerome; Miller, Marc L.; Reliability and Validity in Qualitative Research; Sage Publications; 1986.

62. Kornblum, William; Blue Collar Community; University of Chicago Press; 1974.

63. Kuhn, Thomas; The Structure of Scientific Revolutions - 3rd Edition; University of Chicago Press; 1996.

64. Strauss, Anselm; and Juliet Corbin; Basics of Qualitative Research; Sage Publications; 1990.

65. Whyte, William F.; Hamilton, Edith L.; Action Research For Management; Irwin-Dorsey Series in Behavioral Science; 1965.

66. Whyte, William F.; Street Corner Society : The Social Structure Of An Italian Slum-4th Edition; 1993.

67. Yin, Robert K.; Case Study Research: Design and Methods; Second Edition; Sage Publications; Applied Social Research Methods Series Volume 5; 1994.

PRODUCT DESIGN AND MODULARITY

68. Baldwin, Carliss; Clark, Kim; Design Rules; MIT Press; 1999.

69. Christensen, Clay; "Exploring the Limits of the Technology S-Curve: Part I: Component Technologies"; Production and Operations Management; Vol. 1, No. 4; pg. 334 Fall 1992.

70. Christensen, Clay; "Exploring the Limits of the Technology S-Curve: Part II: Architecture Technologies"; Production and Operations Management; Vol. 1, No. 4; pg. 358; Fall 1992.

71. Christensen, Clayton; "The Drivers of Vertical Disintegration"; Harvard Business School Division of Research Working Paper; September 1994.

72. Clark, Kim; Chew, W. Bruce; Fujimoto, Takahiro; Product Development In the World Auto Industry: Strategy, Organization and Performance; Undated working paper.

73. Clark, Kim; Fujimoto, Takahiro; Product Development Performance: Strategy, Organization and Management in the World Auto Industry; "Chap. 7: Manufacturing Capability: A Hidden Source of Advantage."

74. Clark, Kim; Fujimoto, Takahiro; Product Development Performance: Strategy, Organization and Management in the World Auto Industry; "Chap. 9: Leadership and organizations: The Heavyweight Product Manager."

75. Eppinger, Steven D.; Whitney, Daniel E.; Smith, Robert P.; Gebala, David A; "A Model-Based Method For Organizing Tasks In Product Development"; Research in Engineering Design; (1994) 6:1-13; Springer-Verlag.

76. Henderson, R. H. and Clark, K. B.; "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms"; Administrative Science Quarterly; 35, pg. 9-30; 1990.

77. Hoffman, Daniel; "On Criteria of Module Interfaces"; IEEE Transactions On Software Engineering; Vol. 16. No. 5; May 1990.

78. Koget, Bruce; Bowman, Edward; "Modularity and Permeability as Principles of Design"; Redesigning the Firm; 1995; Oxford University Press.

79. Kogut, Bruce; Zander, Udo; "Knowledge of the Firm, Combinative Capabilities and the Replication of Technology"; Organization Science; V 3, n. 3 Aug. 1992; pg. 383.

80. Lew, Ken S.; Dillon, Tharam; Forward, Kevin; "Software Complexity and Its Impact on Software Reliability"; IEEE Transactions on Software Engineering, Vol. 14, No. 11; Nov. 1988.

81. Liker, Jeffrey; Sobek, Durward; Ward, Allen; Cristiano, John; "Involving Suppliers in Product Design in the United States and Japan: Evidence for Set Based Concurrent Engineering"; IEEE Transactions on Engineering Management; Vol. 43, No. 2, May 96.

82. McCord, Kent R; Eppinger, Steven D.; Managing the Integration Problem in Concurrent Engineering; MIT-Sloan Working Paper WP #3594-93-MSA August 1993.

83. Morelli, Mark D.; Eppinger, Steven D.; Gulati, Rosaline K.; Predicting Technical Communication In Product Development Organizations; MIT-Sloan Working Paper WP #3602-93; 26 May 95.

84. Parnas, David Lorge.; Clements, Paul C.; Weiss, David M.; "The Modular Structure of Complex Systems"; IEEE Transactions on Software Engineering.; SE-11(3): 259-266. 1985 Mar.

85. Rice, M.D. and Seidman, S.B.; "A Formal Model for Module Interconnection Languages"; IEEE Transactions on Software Engineering; Vol. 20, No. 1; Jan. 1994; Page 88.

86. Sanchez, Ron and Joseph T. Mahoney; "Modularity, Flexibility, and Knowledge Management in Product and Organization Design"; Strategic Management Journal; Vol. 17 (Winter), 63-76 (1996).

87. Sanchez, Ron; "Strategic Flexibility in Product Competition"; Strategic Management Journal; Vol. 16, 135-159; (1995).

88. Sobek, Durward; "A Set Based Model of Design"; Mechanical Engineering; July 1996; page 78.

89. Sobek, Durward; Principles That Shape Product Development Systems: A Toyota-Chrysler Comparison; Doctor of Philosophy Dissertation, Univ. of Michigan, 1997.

90. Sobek, Durward; Ward, Alan; Liker, Jeffrey; "Toyota's Principles of Set-Based Concurrent Engineering"; Sloan Management Review; Vol. 40, No. 2; Winter '99.

91. Ulrich, Karl and Steven D. Eppinger; Product Design and Development; R.R. Donnelly and Sons; 1995.

92. Ulrich, Karl; "The role of product architecture in the manufacturing firm"; Research Policy; 24 (1995); 419-440.

93. Ward, Liker, Cristiano, Sobek; "The Second Toyota Paradox: How Delaying Decisions can Make Better Cars Faster"; Sloan Management Review; Spring 1996, page 43.

INFORMATION THEORY, LEARNING, AND PROBLEM SOLVING

94. Argyris, C.; Integrating the Individual and the Organization; Transaction Publishers; 1990.

95. Argyris, C.; Overcoming Organizational Defenses 1990.

96. Geertz, Clifford; Local Knowledge; Basic Books; 1983.

97. Itami, H.; Mobilizing Invisible Assets; Harvard University Press; Cambridge; 1987.

98. Jaikumar, Ramachandran; Personal interview; Harvard Business School; Boston, Massachusetts; April 1997

99. Khanna, Tarun; Nanda, Ashish; From Project Management to Project Stream Management: Implications of the Resource Based View; draft working paper; 11 August 1994.

100. Kotovsky, Kenneth; Simon, Herbert; "What Makes Some Problems Really Hard: Explorations in the Problem Space of Difficulty"; Cognitive Psychology; 22, 143-183; 1990.

101. McCloud, Scott; Understanding comics : the invisible art; New York : HarperPerennial, 1994, c1993.

(repeated entry) MacDuffie, John Paul; "The Road To Root Cause: Shop-Floor Problem-solving at Three Auto Assembly Plants"; Management Science; Vol. 43, No. 4; April 1997.

(repeated entry) MacDuffie, John Paul; Helper, Susan; "Creating lean suppliers: Diffusing lean production through the supply chain"; California Management Review; 39(4): 118-151. 1997 Summer.

102. Nanda, Ashish; Resources, Capabilities and Competencies; HBS Working Paper 94-035; November 1993.

103. Nelson, Richard; Winter, Sidney; An Evolutionary Theory Of Economic Change; Harvard University Press; 1982.

104. Ogata, K.; Modern Control Engineering; Prentice-Hall; 1970.

105. Ogata, Katsuhiko; Modern Control Engineering: 2nd Edition; Prentice-Hall; 1990.

106. Pisano, Gary; "Knowledge, Integration, and the Locus of Learning: An Empirical Analysis of Process Development"; Strategic Management Journal, Vol. 15 85-100; 1994.

107. Pisano, Gary; "Learning Before Doing In The Development of New Process Technology"; Working Paper 96-013; Division of Research; Harvard Business School.

108. Senge, Peter; The Fifth Discipline; Currency Doubleday; 1994.

109. Shannon, Claude; Weaver, Warren; The Mathematical Theory of Communication; Illini Books; 1963.

110. Simon, Herbert; "Prediction and Prescription in Systems Modeling"; Operations Research; vol. 28, No 1, Jan.-Feb. 1990.

111. Simon, Herbert; Administrative Behavior: A Study of Decision Making Processes In Administrative Organizations; Free Press; 1976.

112. Teece, D.J. and Pisano, G.; "The Dynamic Capabilities of Firms: An Introduction"; Industrial and Corporate Change; v3 n3 1994; pg. 537-56.

113. Tyre, Marcie; "Managing the Introduction of New Process Technology: International Differences In Multi-Plant Network"; Research Policy; 20; (1991) pg. 57-76.

114. von Hippel, Eric; "Sticky Information And The Locus Of Problem-solving: Implications For Innovation"; Management Science; 4 April 1994; pg. 429.

115. von Hippel, Eric; MarcieTyre; "How Learning Is Done: Problem Identification in Novel Process Equipment; Research Policy 24; '95; pg. 1-12.

116. Winter, Sidney; "Knowledge and Competence As Strategic Assets"; The Competitive Challenge; edited by Teece, David; Ballinger Pub. Co.; 1987.