Appendices for:

A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation

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Appendix A: Derivation of *f(•)* functions

In this appendix, a more complete derivation of the equation for *w* the sign and strength of word-of-mouth is presented.

$$w = \omega[f_r\{p\} + f_a\{a\}] \qquad (4.1)$$

The strategy is first to assume that *w* is determined by a linearly separable function of the two pieces of information: the normalized rate of productivity improvement *p* ("does the program work?"), and the current adequacy of resources to support the improvement effort *a* ("are our efforts being supported?; does this program increase my normal work level?"). The parameter ω represents the intensity of communication in the particular area.

The assumption of linear separability allows the "sign and strength" of word of mouth to be fully determined by simple linear inequalities when the two information streams are evaluated at the possible combinations of extreme values. Qualitative data (e.g. field studies and interviews) can then be used to determine the sign of each inequality, and upper and lower bounds for each function are chosen to satisfy the assumed relations.

At intermediate points, each function, although separable from the other one, will, in general, be a complicated function of the given input. The choice of functional form is restricted to a class whose properties are consistent with the available qualitative information, and then scaled to the established bounds. Specifically, each function *f{.}* is assumed to have the following general form:

$$f\{\} = (B^u + B^l)\varphi\{\} - B^l, \quad 0 \le \varphi\{\} \le 1$$

which, given the constraint on $\varphi\{\}$, is bounded from above and below by B^u and B^l respectively. These bounds are established using rank ordering arguments based on the beliefs generated by the two underlying information streams evaluated at their extreme values.

Low resource availability is assumed to dominate any positive effects of results. If the group in question believes it is not being supported, then any positive effects resulting from results will be outweighed by frustration.

$$B_r^u + B_a^l < 0$$

Results are also assumed to be a necessary condition for positive word of mouth. Even if job resources are fully adequate, results play a key role in the formation of preferences over continuing the program. The workforce will not spend a significant amount of time pursuing an improvement program that has not demonstrated its usefulness. Thus support cannot overcome the negative effect of poor results:

$$B_r^l + B_a^u < 0$$

If a program generates strong results and has adequate support then word of mouth will be positive, so:

$$B_r^u + B_a^u > 0$$

With the extreme condition combinations established, the functions $\varphi_r\{p\}$, $\varphi_a\{a\}$ need to be specified. A similar approach is used for each.

Qualitative information suggests that the effect of p on beliefs is monotonically increasing, $f'_r\{p\} > 0$. This gives an improvement program its true power–initial results demonstrate the validity of the approach and beget more results. Without this effect management would have a difficult time developing such program due to the substantial time required to individually enlist each member of the workforce in the program. In the neighborhood of $p=1$ the second derivative is assumed to be strictly negative, $f''_r\{1\} < 0$ since improvement measures are likely to be noisy and small deviations from the prediction will be discounted. These two conditions restrict the function to being either strictly concave and increasing or s-shaped and increasing. The s-shape is chosen, $f''_r\{0\} > 0$, and is represented by the logistic curve

$$f_r\{p\} = (B_r^u + B_r^l)\left(\frac{\exp(4\gamma(p-\delta_r))}{1+\exp(4\gamma(p-\delta_r))}\right) - B_r^l \quad \text{(A1)}$$

This specification takes the value B_r^u for $p=1$ and the value B_r^l for p=0. The inflection point is at p_n=δ and the slope at the inflection point is $\gamma(B_r^u - B_r^l)$. The inflection point is assumed to be at δ=.5.

A similar procedure is used to specify the function that reflects the effect of resource availability. Workers, in order to participate effectively in an improvement program, require resources in the form of management's attention and a reduction in their current responsibilities. This suggests that the effect of resource adequacy on beliefs is monotonically increasing, $f'_a\{a\} \geq 0$. As management increases its willingness to support the effort, workers become more committed. In the neighborhood of $a=1$, the second derivative is assumed to be negative, $f''_a\{1\} < 0$, implying a diminishing marginal return to additional support near the requirement level. These requirements restrict the functional form to being either strictly concave and increasing or s-shaped and increasing. Again, the s-shaped function is chosen, $f''_a\{0\} > 0$, and represented by the logistic curve with a similar parameterization.

$$f_a\{a\} = (B_a^u + B_a^l)\left(\frac{\exp(4\gamma\,(a-\delta_a))}{1+\exp(4\gamma\,(a-\delta_a))}\right) - B_a^l \qquad \text{(A2)}$$

The inflection point is assumed to be at δ=.5.

Appendix B: Parameter Values for Simulations

Single Program Model

Parameter	Value
φ (for 9 month half-life)	.077 (1/months)
D Initial	100 (defects)
D Minimum	10 (defects)
τ_C	12 (months)
ω	.5
C Initial	0

Two Program Model

Parameter	Value
φ_1	.077 (1/months)
φ_2	.0192 (1/months)
D_1,D_2 Initial	100 (defects)
D_1,D_2 Minimum	10 (defects)
τ_θ	12 (months)
ω_1	.5
C Initial	0
C*	0 until time=12, then 1
L	100 (people)
ρ_1,ρ_2	1 (hours/person/month)
α	25
β	1
R	160 (expert's hours/month)

Appendix C: List of Model Equations in VENSIM

The model is written using the VENSIM simulation software produced by Ventana systems (more information available at www.vensim.com. The syntax of each entry is as follows:

VARIABLE X = f(VARIABLE A,…,VARIABLE Z)
~ Units of Measure
~ Comments |

A simulating version of the model in the written in the VENSIM software is available at <web.mit.edu/nelsonr/www>.

****
.definearea
***~
This sector defines the number of areas, denoted *n* in the main text, in the simulated organization.|

area:one,two
~
~ |

****
.defects
***~
This section contains the equations that generated the number of oustanding defects and the rate of improvement.|

Defects[area]=INTEG(Change in Defects[area],Init Defects[area])
~ Defects
~ The stock of outstanding defects, denoted D is the text. |

Change in Defects[area]= -(Defects[area]-min defects[area])*Actual Improvement Fraction [area]*Commitment[area]
~ Defects/month
~ The rate of defect reduction.|

Predicted Defects[area]=INTEG(Chng in Predicted Defects[area],Init Defects[area])
~ Defects
~ Level of Defects Predicted by the naïve half-life model.|

Chng in Predicted Defects[area]=-(Predicted Defects[area]-min defects[area])*Expected Improvement Fraction [area]*Management Goal for Commitment[area]
~ Defects/month
~ The change in the level of predicted defects.|

Actual Improvement Fraction[area]=ln(2)/Actual Area Half Life[area]
~ |1/month
~ The expected fractional improvement rate based on the half-life model.||

Expected Improvement Fraction[area]=ln(2)/Expected Area Half Life[area]
~ 1/month
~ The expected fractional improvement rate based on the half-life model.|

Historical Defects[area]=
SMOOTH(Defects[area],Defect Smooth Time)
~Defects
~ The historical defect level is determined by smoothing the actual defect level.|

Defect Improvement Rate[area]=((Historical Defects[area]-Defects[area])/Historical Defects[area])/Defect Smooth Time
~ 1/months
~ The calculated improvement rate.|

Ratio Actual to Predicted Results[area]=Defect Improvement Rate[area]/Expected Improvement Fraction [area]
~ dimensionless
~ |

****
.commitment
***~

This sector contains the equations that determine the level of commitment.|

Commitment[area]= INTEG(Change in Commitment from Management Push[area]+ Change in Commitment from Results[area],0)

~ dimensionless

~ Commitment to using the innovation in a given area, denoted *C* in the text.|

Change in Commitment from Management Push[area]=

(Management Goal for Commitment[area]-Commitment[area])/Time for Mgt to Train[area]* (1+Step(-1,Time to Turn off Mgt Push))

~ 1/month

~ The change in commitment generated by normative sources.|

Change in Commitment from Results[area]=
Word of Mouth[area]*(1-Commitment[area])
~ 1/month
~ The change in commitment resulting from instrumental motivation.|

Word of Mouth[area]=(resource switch*Effect of Support on Commitment[area]+ Effect of Results on Commitment[area])*Sensitivity to Communication[area]
~ 1/months
~ word of mouth related to the efficacy of the innovation. |

Sensitivity to Communication[area]=Commitment[area]*communication intensity
~ 1/months
~ |

Effect of Results on Commitment[area]=Max Efct of Results*EXP(Normal Slope Results*(Ratio Actual to Predicted Results[area]-0.5))/(1+EXP(Normal Slope Results*(Ratio Actual to Predicted Results[area]-0.5)))-EXP(Normal Slope Results*(-0.5))/(1+EXP(Normal Slope Results*(-0.5))) +Min Efct of Results
~dimensionless
~ this equation generates the s-shaped look-up function used to relate results to work of mouth. See appendix B for more details. |

Effect of Support on Commitment[area]=
Max Efct of Support*EXP(Normal Slope Support*(Ratio Support Allocated to Required[area]-0.5))/ (1+EXP(Normal Slope Support*(Ratio Support Allocated to Required[area]-0.5)))-Max Efct of Support
~dimensionless
~this equation generates the s-shaped look-up function used to relate support to work of mouth. See appendix B for more details
|

****
.supportreqs
***~
The sector contains the equations that determine the level of support required in each area.|

Support Required[area]=Commitment[area]*staff[area]
*Req Support per staff[area]
~ hours/month
~ |

Ratio Support Allocated to Required[area]=Min(zidz(Support Allocated[area],Support Required[area]),1)

~ dimensionless

~ |

****

.supportalloc

**~

This section contains the equations the represent the experts' decision process in allocation their support resources.|

Support Allocated[area]=Fraction of Support Allocated[area]*Total Support Resources

~ hours/month

~ |

Fraction of Support Allocated[area]=zidz(Attractiveness of Area[area],total attract)

~ dimensionless

~ |

Attractiveness of Area[area]=Indicated Fraction of Support[area]*Effect of Improvement Rate on Attract [area]

~ dimensionless

~ |

total attract=SUM(Attractiveness of Area[area!])

~dimensionless

~ |

Indicated Fraction of Support[area]=(Support Required[area]/Total Support Required)^Sensitivity to Resources

~dimensionless

~ |

Total Support Required=SUM(Support Required[area!])

~ hours/month

~ |

Effect of Improvement Rate on Attract[area]=(1+Defect Improvement
Rate[area])^Sensitivity to Improvement
~ dimensionless
~|

ratio total support to support reqs=Total Support Required/Total Support Resources
~dimensionless
~|

****
.parameters
**~
This section contains the parameters used in the simulations.|

Actual Area Half Life[one]=9
~months
~|

Actual Area Half Life[two]=36
~months
~ |

Expected Area Half Life[one]=9
~months
~|

Expected Area Half Life[two]=36
~months
~ |

communication intensity=.5
~1/months
~
|

Defect Smooth Time=3
~ months
~ |

min defects[area]=10,10
~defects
~ |

Init Defects[area]=100,100
~ defects
~ |

Time for Mgt to Train[area]=12,12
~ months
~ |

Management Goal for Commitment[area]=Step(Goal for Management Commitment,
Time To Launch Effort\ [area])
~ dimensionless
~ |

Time To Launch Effort[one]=12
~months
~
|

Time To Launch Effort[two]=12
~ months
~ |

Goal for Management Commitment=0.995
~dimensionless
~ |
Req Support per staff[area]=1,1
~ hours/person/month
~ |

Sensitivity to Improvement=50

~ dimensionless
~ |

Sensitivity to Resources =1
~ dimensionless
~ |

staff[area]=100,100
~people
~ |

Total Support Resources=160
~ hours/month
~ |

****
.lookupfunctionparameters
**~
This section contains the parameters used in the look-up functions.|

Normal Slope Results=8
~dimensionless
~ |

Normal Slope Support=8
~dimensionless
~ |

Max Efct of Results=2
~ dimensionless
~ |

Min Efct of Results=-0.5
~ dimensionless
~ |

Max Efct of Support =3
~ dimensionless

~ |

Min Efct of Support =-3
~dimensionless
~ |

****
.switches
***~
This section contains the parameters used to switch between the based model and the extended model and the switch used to turn-off management's normative pressure.

resource switch=0
~ dimensionless
~ use this to switch between TQM model one and TQM model two
|

Time to Turn off Mgt Push = 1e+009
~ months
~ |

****
.Control
***~
Simulation Control Parameters
|

FINAL TIME = 120
~ month
~ The final time for the simulation.
|

INITIAL TIME = 0
~ month
~ The initial time for the simulation.
|

SAVEPER = 1
~ month
~ The frequency with which output is stored.
|

TIME STEP = 0.125
~ month
~ The time step for the simulation.
|