ENGINEERING SYSTEMS AND MANAGEMENT

ESM504 SYSTEM DYNAMICS FOR BUSINESS POLICY

ASSIGNMENT #7

UNDERSTANING *COST AND OVERRUN* ON PRODUCT DEVELOPMENT PROJECTS

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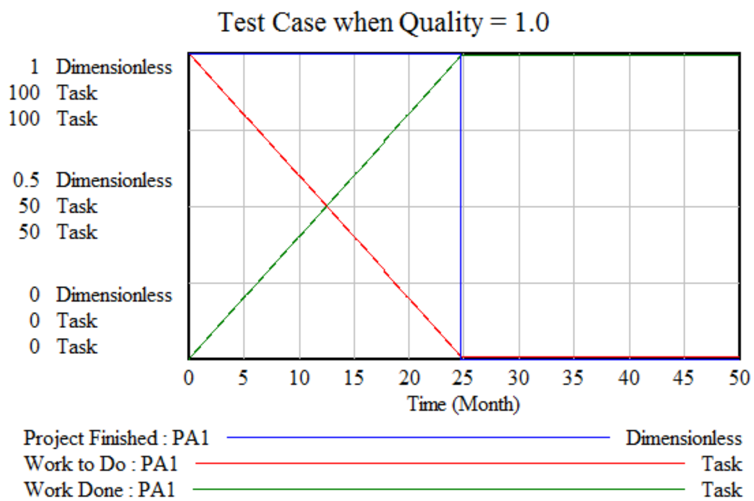
Understanding Cost and Overrun on Product Development Projects

A. The Rework Cycle

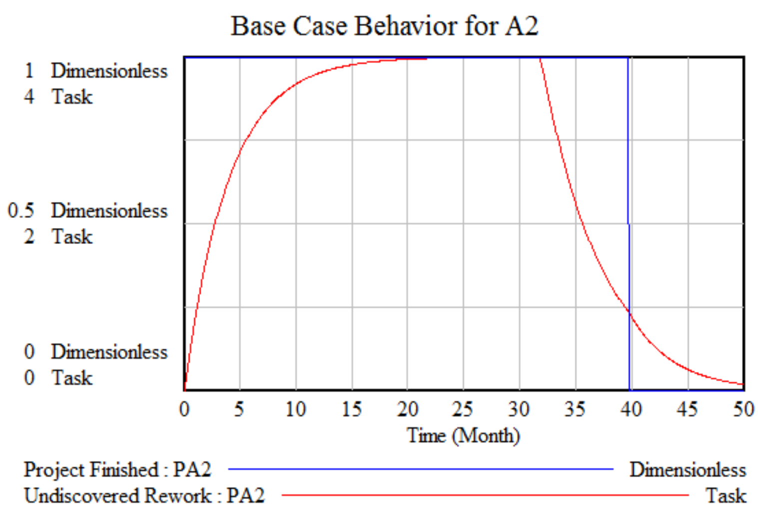
A.1. Quality = 1.0



Intuitively: Setting the quality equal to 1.0 means that the work accomplished by the staff is error free, and therefore there should be no rework needed. Since there are 100 tasks on the project, productivity of 1 task per month, and 4 staff on the project, we would assume the project to finish in 25 months. The work to do and the work done would behave in exactly the opposite way since there is no rework generation; the work to do would linearly decrease and the latter would linearly increase until the 100 tasks are completed in the 25 month period.

Simulation: The simulation is in agreement with our intuitive guess.

A.2. Base Case for Analysis



Changing the quality of work to 0.75 causes the project to complete in 40 months. This is a time increase of 60% over the test case where the quality of work equals 1.0. This can be explained by the undiscovered rework and the rework generation rate, which causes the Work to Do stock to increase. The undiscovered rework overshoots and collapses because of the reduction in quality which reduces the rate of rework discovery (determined by the time to discover rework).

A.3. Most important Factors in Determining Project Completion

The most important in determining project completion time is the quality of work. The quality of work affects the Work Accomplishment Rate, Rework Generation rate and therefore the time it takes to complete the project. This is supported by the results of the previous two points.

A.4. Sensitivity Tests to Determine Effects of Productivity, Work Quality and TDR

Table 1 – Sensitivity Tests			
Variable Tested	**Tested Variable Change**	**Project Completion Date (Rounded Up)**	**Total Work Done (Rounded Up)**
Productivity	Base Case (Value of 1.0)	40	132
	33% (Value of 1.33)	33	132
	-33% (Value of 0.67)	54	132
Work Quality	Base Case (Value of 0.75)	40	132
	33% (Value of 1)	25	99
	-33% (Value of 0.5)	64	198
TDR	Base Case (Value of 4)	40	132
	33% (Value of 5.33)	44	132
	-33% (Value of 2.67)	37	132

Table 1 summarizes the results of the sensitivity test conducted in determining the effects of productivity, work quality and TDR on the project completion date and total work done. Clearly, the sensitivity test shows us that work quality is indeed the most important variable in determining project completion and total work done. Changing the work quality affects both project completion date and total work done. Increasing work quality decreases project completion time and total work done, and decreasing work quality reverses the effect.

Next to be noted is the effect of the productivity. Increasing the productivity decreases project completion time but no effect is seen on the total work done. Decreasing productivity reverses the effect.

Increasing the TDR increases the project completion time but again no effect is seen on the total work done. Decreasing the TDR reverses the effect.

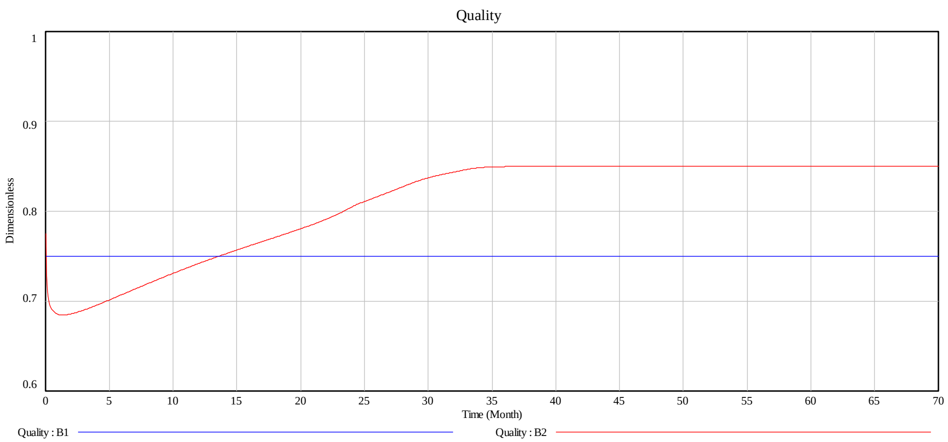
B. Extending the Model: Adding Variable Rework Discovery Time and Quality on Quality Feedback

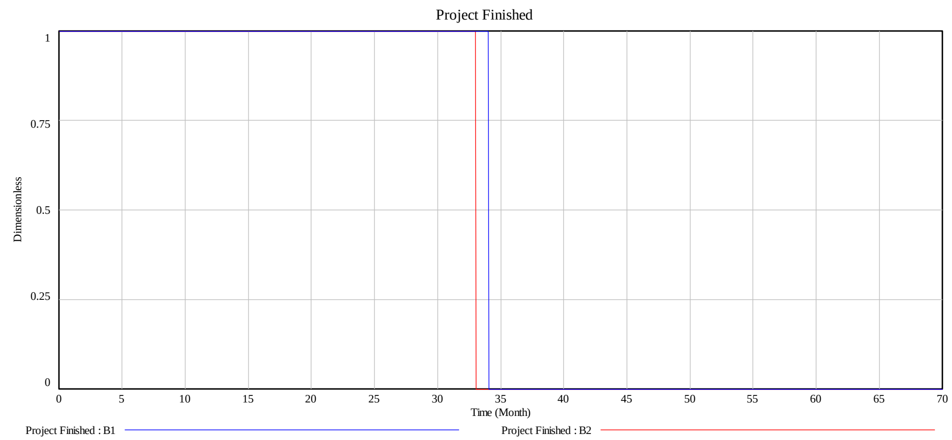
B.1. Constant TDR vs. Decreasing TDR

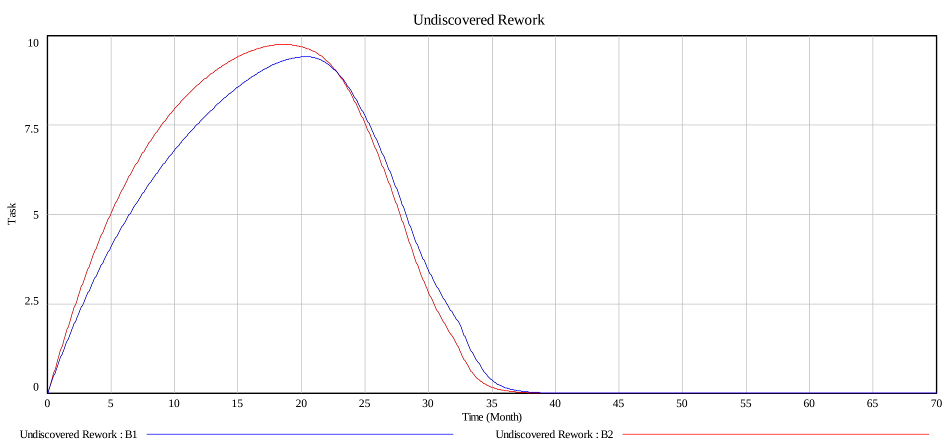
In Part A, the TDR was set to about 4 months, allowing the project completion time to be approximately 40 months. When the model was adjusted to include a TDR that decreases (it starts off at about 12 and then decreases to about 1 month), the completion time is reduced and the slope of the work backlogs reached almost zero quicker than when it was a constant. In fact, it is interesting to note that setting the TDR time to approximately 1.5 months still causes the work backlog to decrease slower (not much slower though) than when the normal TDR is set to 12 months and allowed to decrease. Quality is not affected and remains constant at 0.75.

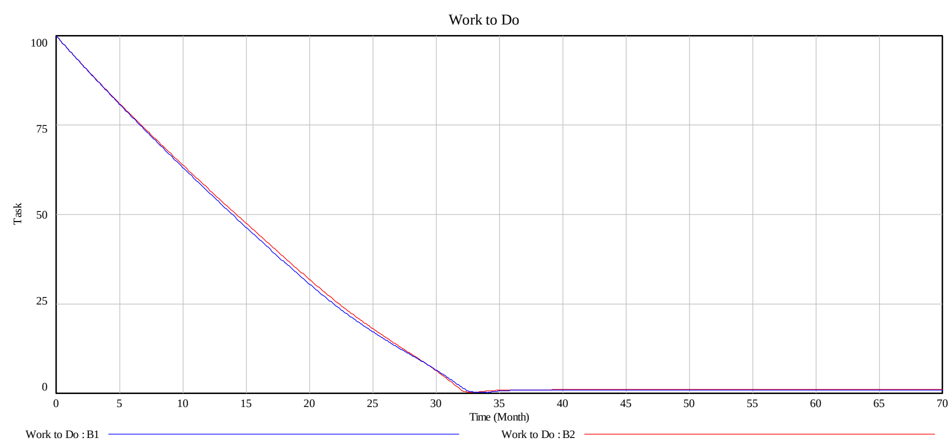
B.2. Quality-on-Quality

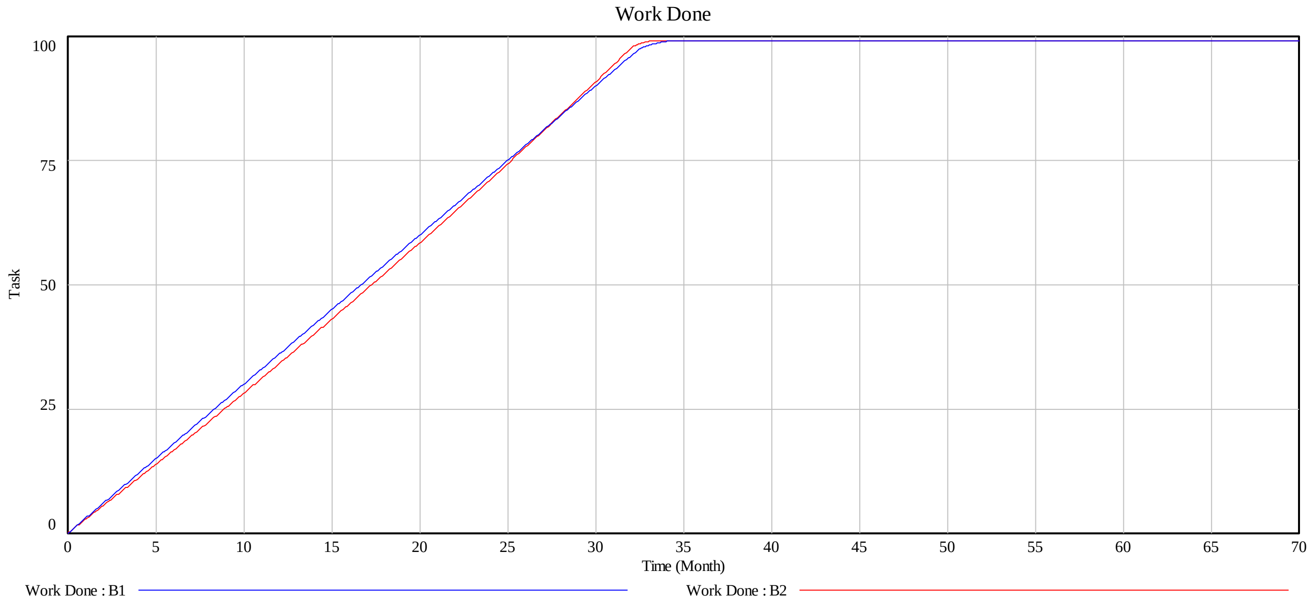
After the inclusion of the quality-on-quality feedback, the project finishes sooner than in the previous case, after 33 months. Quality will sharply fall in the beginning, but then it will recover and rise to the 0.85 target level. Initially, the Undiscovered Rework rises quicker (with a higher initial slope) than in the previous case, but as quality increases, it stars also to fall quicker. The Cumulative Work Done, as well as the Cumulative Effort Expended is lower than in the previous case.

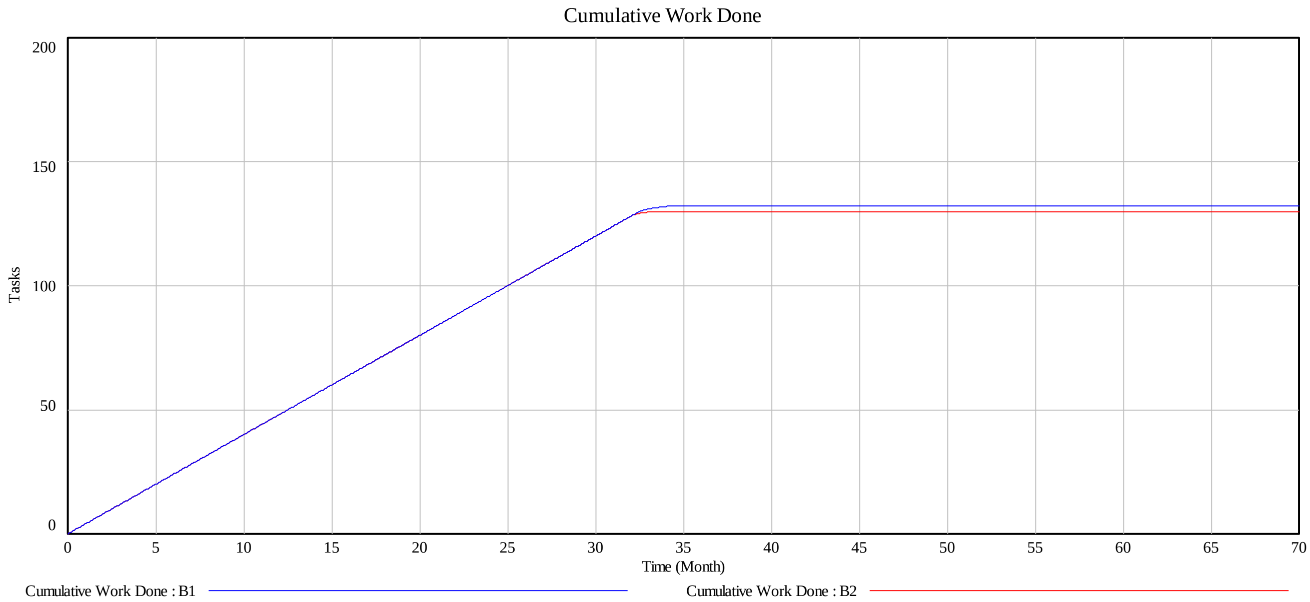

Quality
Dimensionless
Time (Month)
Quality : B1
Quality : B2

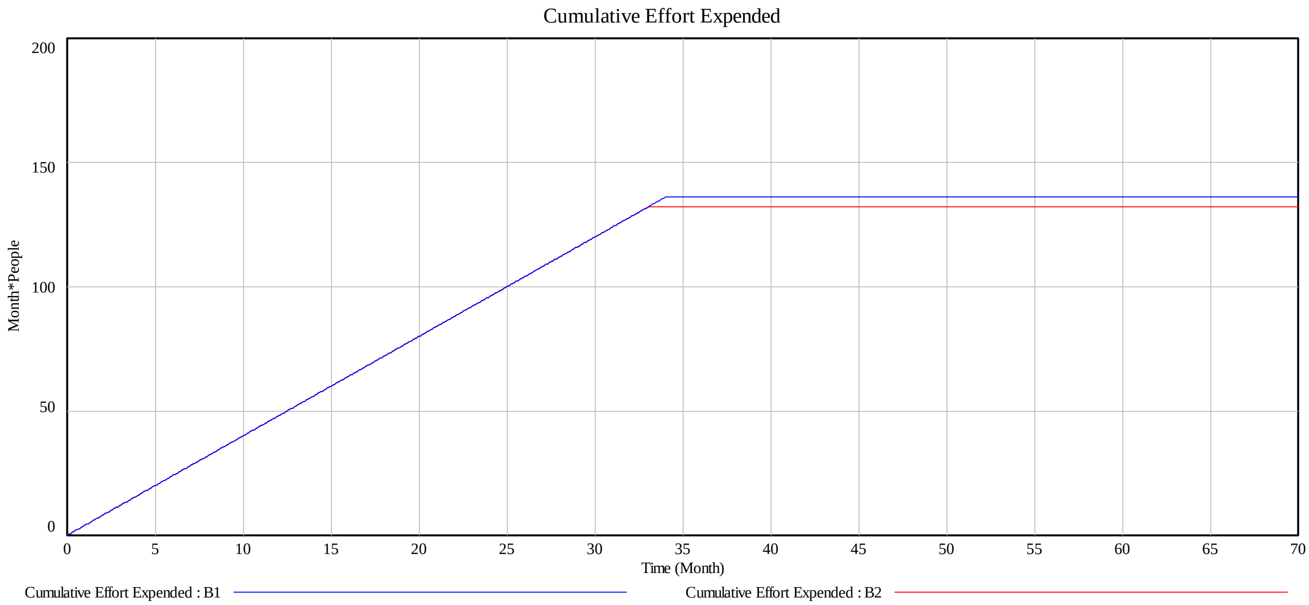

Project Finished
Dimensionless
Time (Month)
Project Finished : B1
Project Finished : B2


Undiscovered Rework
Task
Time (Month)
Undiscovered Rework : B1
Undiscovered Rework : B2


Work to Do
Task
Time (Month)
Work to Do : B1
Work to Do : B2


Work Done
Task
100
75
50
25
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Time (Month)
Work Done : B1
Work Done : B2


Cumulative Work Done
Tasks
200
150
100
50
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Time (Month)
Cumulative Work Done : B1
Cumulative Work Done : B2


Cumulative Effort Expended
Month*People
200
150
100
50
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Time (Month)
Cumulative Effort Expended : B1
Cumulative Effort Expended : B2

B.3. Model Equations

(01) Average Work Quality=XIDZ(Work Done, Work Believed to Be Done, 0.85)

Units: Dimensionless

(02) Cumulative Effort Expended= INTEG (Effort Expended, 0)

Units: People*Month

(03) Cumulative Work Done= INTEG (Rate of Doing Work, 0)

Units: Tasks

Cumulates the total amount of work done, counting rework as well as original work.

(04) Effect of Work Progress=Table for Effect of Work Progress(Fraction Perceived to Be complete)

Units: Dimensionless

(05) Effect to Prior Work Quality on Quality=Table for Effect of Prior Work Quality on Quality(Average Work Quality)

Units: Dimensionless

(06) Effort Expended=Project Finished*Staff Level

Units: People

(07) FINAL TIME = 70

Units: Month

The final time for the simulation.

(08) Fraction Perceived to Be complete=Work Believed to Be Done/Initial Work to Do

Units: Dimensionless

(09) INITIAL TIME = 0

Units: Month

The initial time for the simulation.

(10) Initial Work to Do=100

Units: Task

(11) Minimum Time to Perform a Task=0.25

Units: Month

(12) Normal Productivity=1

Units: Task/(Month*Person)

(13) Normal Quality= 0.85

Units: Dimensionless

(14) Normal Time to Discover Rework= 12

Units: Month

(15) Potential Work Rate=MIN(Staff Level*Productivity,Work to Do/Minimum Time to Perform a Task)

Units: Task / Month

Maximum rate at which work can be accomplished. Normally this equals productivity multiplied by staff level. However, in some cases the available stock of work and the minimum time to perform a task can constrain the maximum rate of progress.

(16) Productivity=Normal Productivity

Units: Task / (Person * Month)

The number of tasks accomplished per month per person. Some of this work will contain errors.

(17) Project Finished= IF THEN ELSE(Work Done>99,0,1)

Units: Dimensionless

Sets a "switch" to 0 when work done exceeds 99 tasks.

(18) Quality=Normal Quality*Effect to Prior Work Quality on Quality

Units: Dimensionless

Fraction of work that is complete and correct.

(19) Rate of Doing Work=Rework Generation+Work Accomplishment

Units: Tasks/Month

(20) Rework Discovery=Undiscovered Rework/Time to Discover Rework

Units: Task / Month

The rate of discovering rework, using a first-order delay formulation.

(21) Rework Generation=(1-Quality)* Potential Work Rate*Project Finished

Units: Task / Month

Rate of work being done incorrectly.

(22) SAVEPER = TIME STEP

Units: Month

The frequency with which output is stored.

(23) Staff Level=4

Units: People

The number of people working on the project.

(24) Table for Effect of Prior Work Quality on Quality

([(0,0)-(10,10)],(0,0.1),(0.1,0.25),(0.2,0.35),(0.3,0.45),(0.4,0.55),(0.5,0.65),(0.6,0.725),(0.7,0.8),(0.8,0.875),(0.9,0.95),(1,1))

Units: Dimensionless

(25) Table for Effect of Work Progress

([(0,0)-(2,2)],(0,1),(0.1,1),(0.2,1),(0.3,1),(0.4,1),(0.5,1),(0.6,0.95),(0.7,0.8),(0.8,0.45),(0.9,0.2),(1,0.1))

Units: Dimensionless

(26) TIME STEP = 0.0625

Units: Month

The time step for the simulation.

(27) Time to Discover Rework=Normal Time to Discover Rework*Effect of Work Progress

Units: Month

Average number of months required to discover rework.

(28) Undiscovered Rework= INTEG (Rework Generation-Rework Discovery,0)

Units: Task

Work that contains errors which have not yet been discovered.

(29) Work Accomplishment= Quality*Potential Work Rate*Project Finished

Units: Task / Month

Rate of work being done correctly.

(30) Work Believed to Be Done=Work Done+Undiscovered Rework

Units: Task

(31) Work Done= INTEG (Work Accomplishment,0)

Units: Task

Work completed correctly.

(32) Work to Do= INTEG (Rework Discovery-Rework Generation-Work Accomplishment, 100)

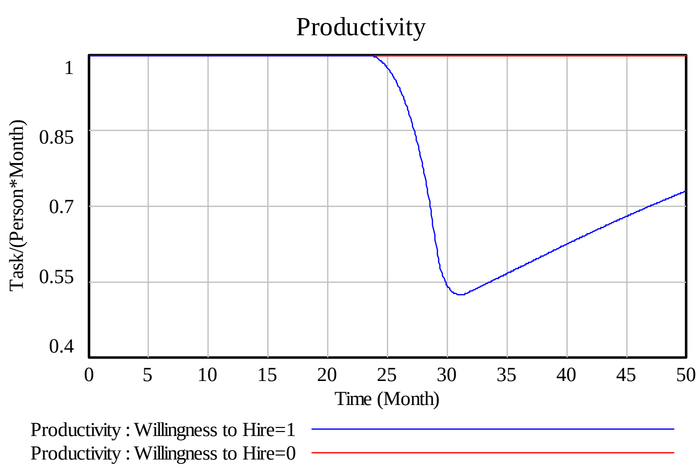
Units: Task

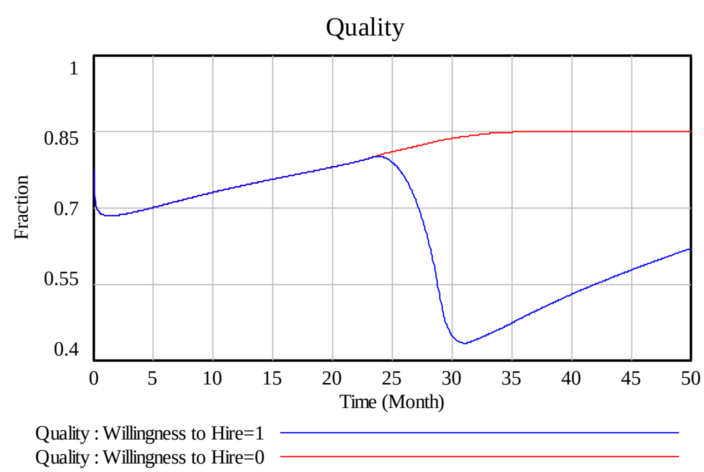
Work that needs to be done for either the first time, or redone because it contains errors.

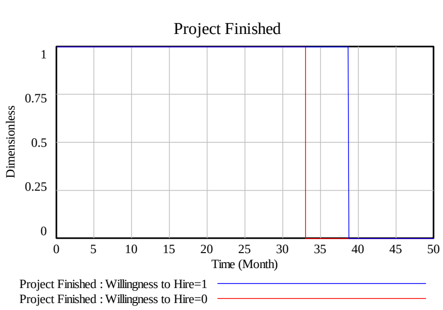
C. Extending the Model: Allowing for Increased Staff

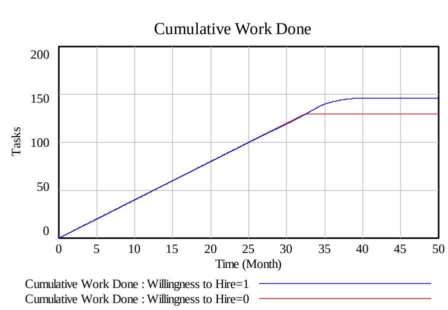
C.1. Behavior

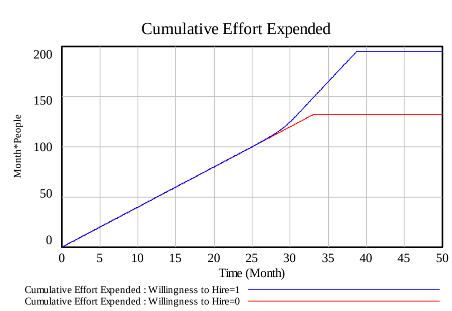
When staff are increased in order to meet the originally scheduled date, the project finishes later than in the case when staff are not added to the project. Specifically, when the Willingness to Hire is set to 0 the project is completed in 33.0625 months, whereas when the Willingness to Hire becomes 1 the project finishes in 38.75 months. It is clear that both policies fail to make the project finish on time. When new staff are hired, there is a time delay for them to gain experience and also the Productivity and Quality decrease because experienced staff have to spend time in training new staff. As soon as new staff start gaining experience, Productivity and Quality start increasing again. As a result, in 33.0625 months, the Cumulative Work Done and Cumulative Effort Expended on the project have already larger values when new staff are hired than when there is no hiring. However, even when the department is not hiring, the project still doesn't finish on time because of the time spent on discovering rework.











C.2. Recommended Policies

Based on our previous analysis, we can see that when new staff are hired the project takes even longer time to finish and hiring decision should be made after considering the time needed for new staff to gain experience and the impact on Quality and Productivity. Based on that, our suggestion is to hire the number of people needed and train them before they start working on the project. By implementing this policy, the new staff could receive intensive training for 6 or 12 months and get ready to collaborate efficiently with the experienced staff already on the project. Such a policy integrates new staff without compromise in experienced staff Quality of work and Productivity, as well as in overall Quality and Productivity. This way, the time needed for the project to finish can be significantly reduced.

D. Policy Analysis: When Does Adding Labor Make Sense

D.1. Summary

At this point we conducted a series of experiments, varying each of the following parameters ceteris paribus:

- Relative productivity of new staff
- Relative quality of new staff
- Effect of new staff on productivity of experienced staff
- Effect of new staff on quality of experienced staff
- Time required for new staff to get up to full productivity and quality
- Time required to increase staffing
- Initial number of staff

The following table summarizes the results of the experiments:

Table 2 – Sensitivity analysis results: *see next 3 pages*.

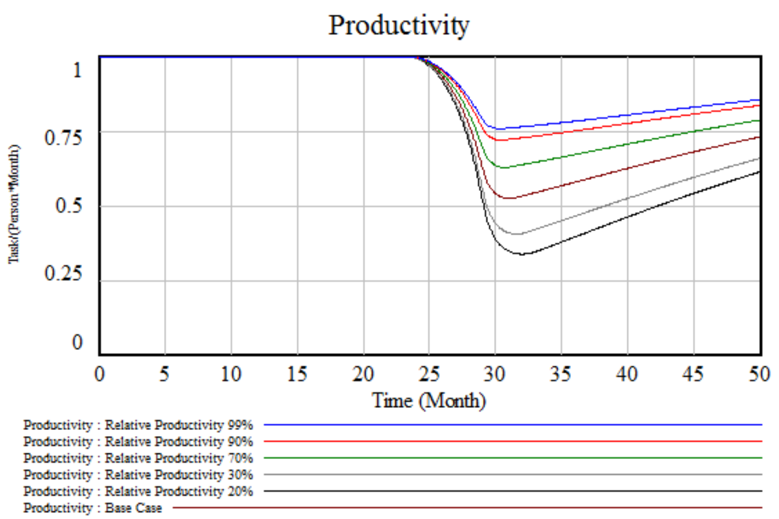
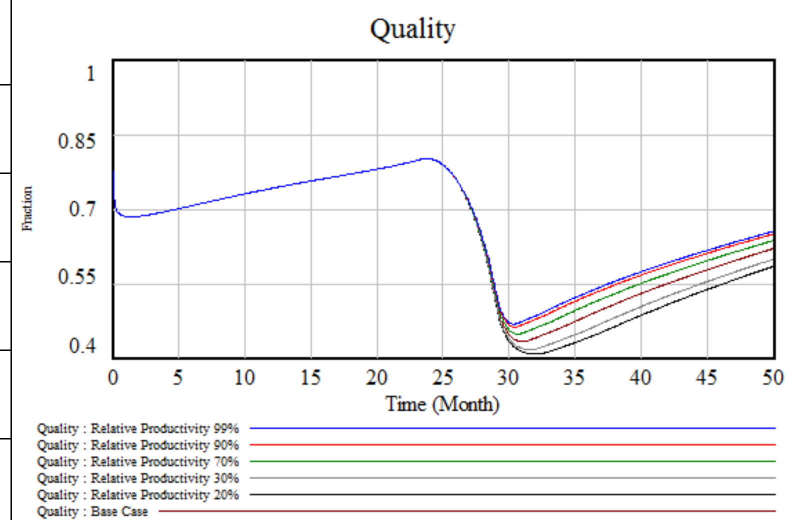
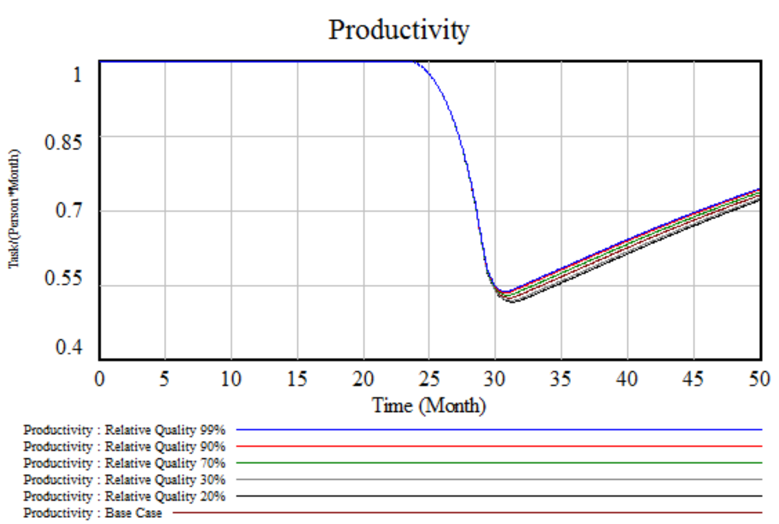
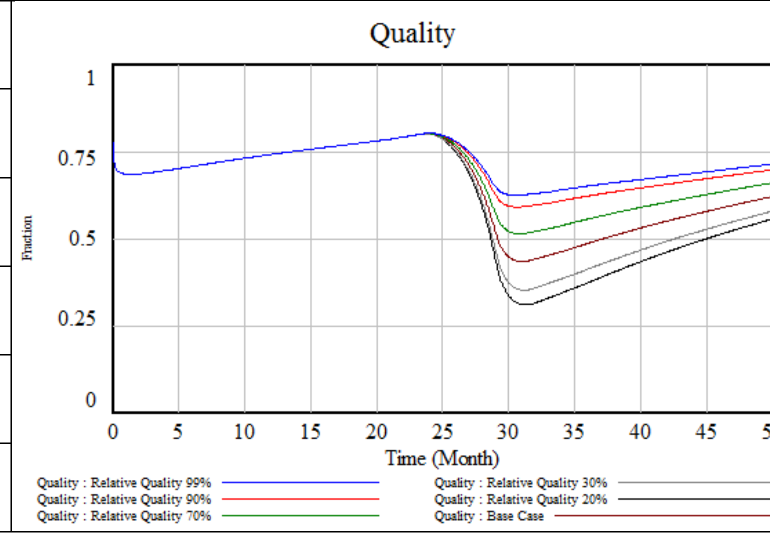
From the sensitivity analysis, one can conclude that significant reduction in project completion time can only be achieved by raising the Initial Staff level. A short Time to gain experience for New Staff is also an advantage. The Relative Productivity or Quality of New Staff does not lead to significant reductions in completion time, even if we assume the unreal case that newcomers have almost the same (99%) Productivity/Quality. The Effect of New Staff on the Productivity/Quality of Experienced Staff is somewhat more significant, leading to shrinkage of the completion by 8% (35.68 months instead of 38.75 months), considering that only every fifth rookie affects the experienced workers. Quartering the Time to gain experience reduces completion time by 6.5% to 36.25 months but halving it only leads to a reduction of 2.9%, thus making it an inefficient and hard way to reduce project completion time. Initial Staff of the project is probably the most significant variable, as it leads to much shorter completion times. Increasing the Initial Staff by 50% (from 4 to 6) results in a completion time of 23.56 months, a 39.2% reduction!

It is important to point out that except in the case of a higher Initial Staff, the project finished later in all of the cases, thus leading to the conclusion that in case of an IT project hiring extra staff along the way does not make sense if their characteristics are according to the predefined parameters of the model. Just slightly higher Initial Staff though can lead to significantly shorter delivery times.

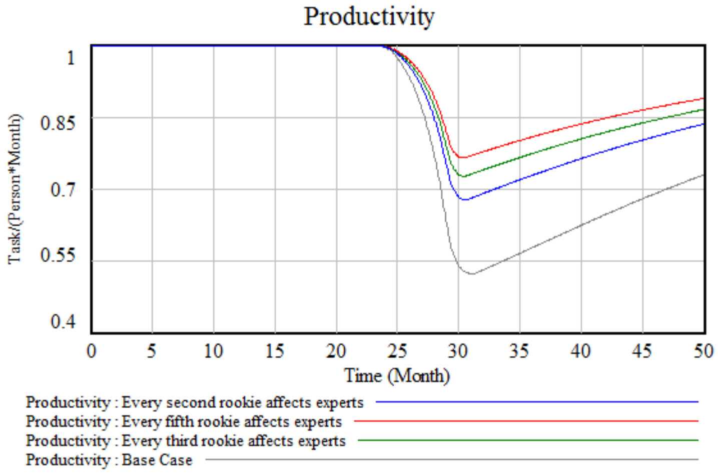
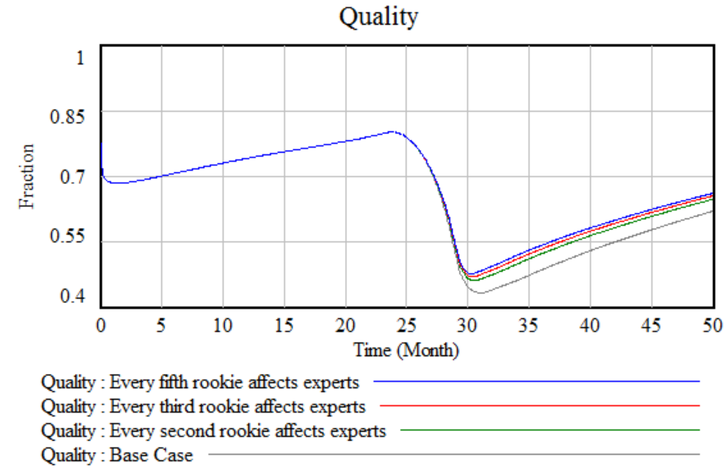
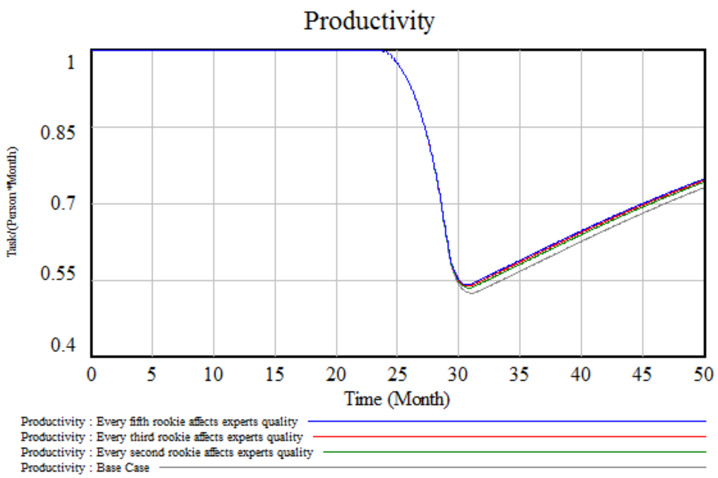
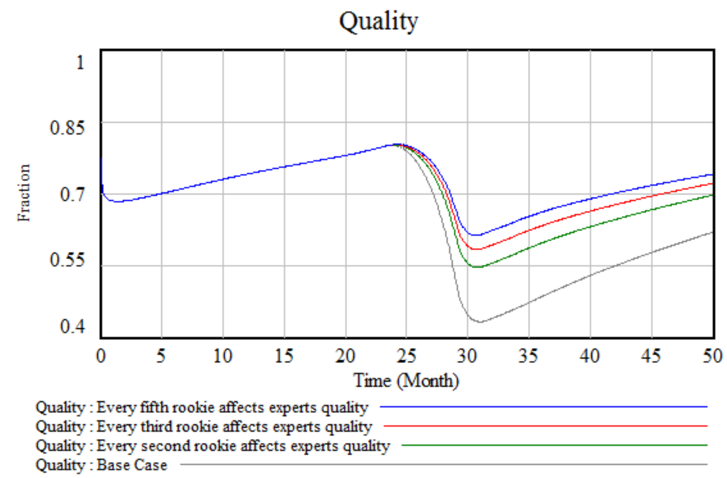
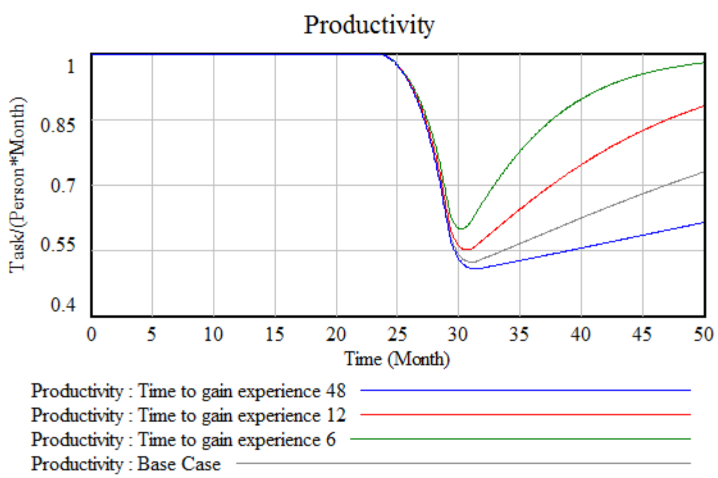
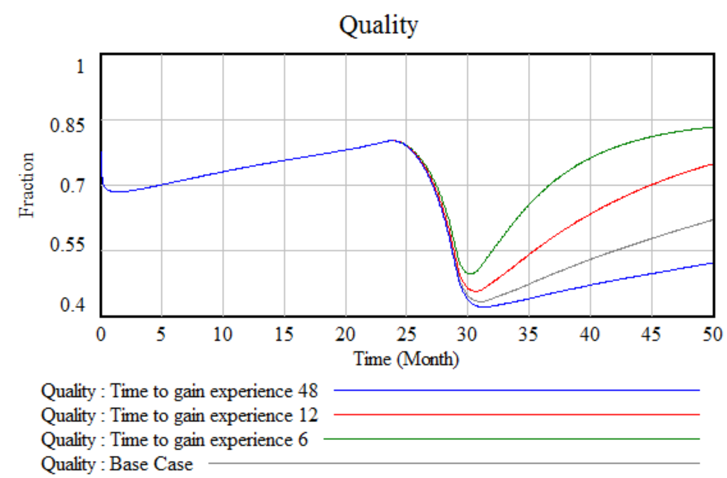
A few comments on the Productivity and Quality curves' behavior in the "bounce back" region (after ~ 30 months, the scheduled completion date):

- New Staff Relative Productivity/Quality leads to the same behavior of the Productivity/Quality curves: a linear behavior with higher starting values and lower gradients as the parameter increases.
- Effect of new staff on Productivity/Quality of experienced staff has a similar effect as New Staff Relative Productivity/Quality, the only difference being the constant gradient of the curves, regardless of the parameter value.
- A higher Time to gain experience leads to a more linear behavior, and also lower initial "bounceback" gradient. The curve gradient decreases over time, exhibiting a goal-seeking behavior. Because of the significant differences in initial curve gradients, final values are more dispersed than in the previous cases.
- Longer Hiring Time leads to higher Productivity/Quality. The relationship is quasilinear. The curves exhibit a linear behavior, with a constant gradient that is unrelated to the parameter value.
- Initial Staff has a significant effect on the times when the Productivity and Quality start to decrease than increase. A more populous starting staff leads to a quicker achieved and maintained Normal Quality, whereas a smaller staff leads to quicker decline of Quality and with a higher gradient. After the bounceback, the gradient is constant and the behavior is quasilinear. The Productivity curve exhibits a similar behavior.

Table 2 – Sensitivity analysis

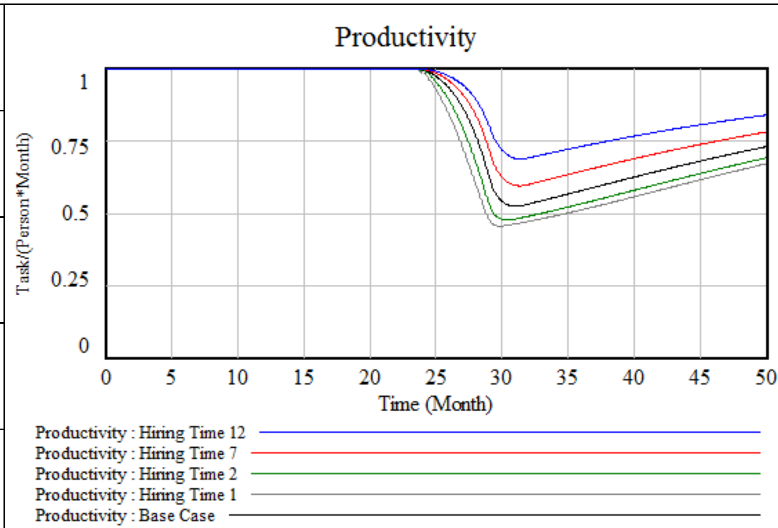
Exp. No.	Trial Variable	Value	Completion Time	End Productivity	Productivity Behavior	End Quality	Quality Behavior
1.	New Staff Relative Productivity	0.2	**40.93**	0.61		0.58	
2.		0.3	**40**	0.65		0.60	
3.		0.5 (Base)	**38.75**	0.73		0.62	
4.		0.7	**37.93**	0.78		0.64	
5.		0.9	**37.31**	0.83		0.65	
6.		0.99	**37.06**	0.85		0.66	
7.	New Staff Relative Quality	0.2	**41.56**	0.720		0.55	
8.		0.3	**40.56**	0.723		0.57	
9.		0.5 (Base)	**38.75**	0.730		0.62	
10.		0.7	**37.37**	0.735		0.66	
11.		0.9	**36.18**	0.741		0.69	
12.		0.99	**35.75**	0.743		0.71	

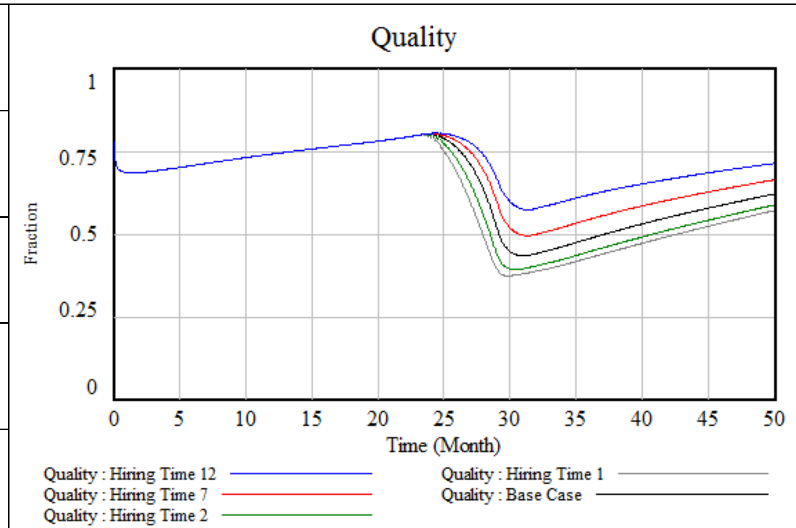
As expected, the higher the Relative Productivity or Quality of the New Staff, the project finishes sooner (they both influence Work Accomplishment Rate). They have roughly the same weight on completion time. When Productivity is varied, Quality is quasi-steady, and vice-versa, when Quality is varied, Productivity stays quasi-steady (not constant because of the slight influence through Undiscovered Rework).

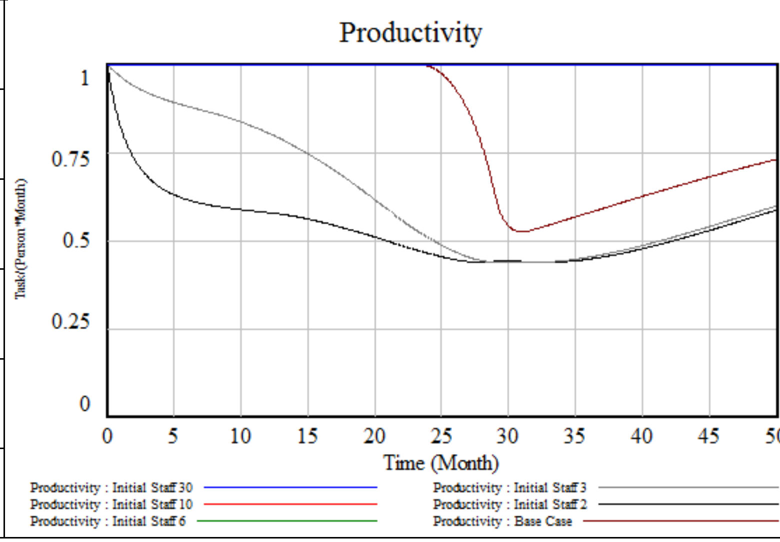
13.	Effect of new staff on productivity of experienced staff	Every (Base)	**38.75**	0.73		0.62	
14.		2nd	**37.43**	0.83		0.64	
15.		3rd	**37.06**	0.86		0.65	
16.		5th	**36.81**	0.89		0.66	
17.	Effect of new staff on productivity of experienced staff	Every (Base)	**38.75**	0.730		0.62	
18.		2nd	**36.68**	0.741		0.69	
19.		3rd	**36.06**	0.744		0.72	
20.		5th	**35.68**	0.747		0.74	
21.	Time to gain expereince	6	**36.25**	0.98		0.83	
22.		12	**37.63**	0.88		0.74	
23.		24 (Base)	**38.75**	0.73		0.62	
24.		48	**39.5**	0.61		0.52	

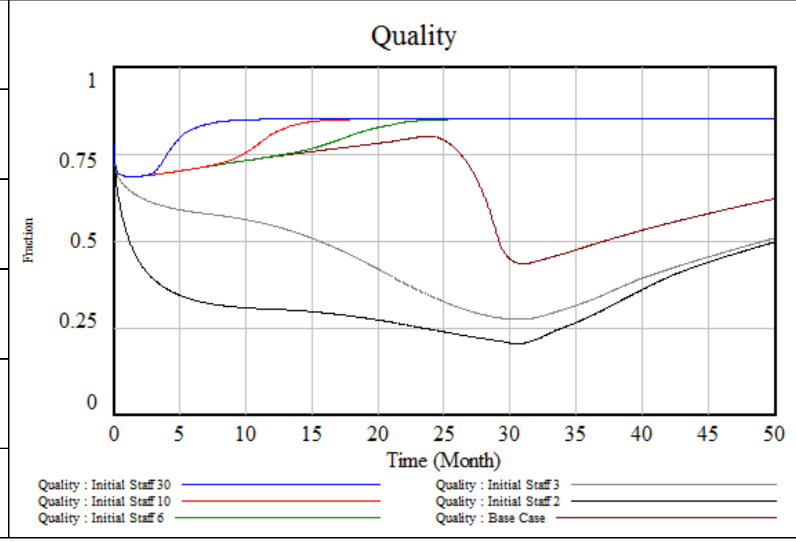
The Effect of New Staff on the Productivity/Quality of Experienced Staff exhibits a similar behavior to New Staff Relative Productivity/Quality. As expected, the higher the lower the effect, the project finishes sooner (they both influence Work Accomplishment Rate). This behavior has been modeled by emphasizing that only every second/third or fifth person of New Staff affects the Productivity/Quality of the Experienced Staff. Again, they have roughly the same weight on completion time with Quality being slightly more significant than Productivity. Similar to the previous case, when Productivity is varied, Quality is quasi-steady, and vice-versa, when Quality is varied, Productivity stays quasi-steady (not constant because of the slight influence through Undiscovered Rework). The Time to gain experience is clearly one of the most important variables influencing Productivity and Quality. It does not lead however, to significantly shorter completion time. A 4-flod reduction of Time to gain experience leads to a shortening of 2.5 months.

25.	Hiring Time	1	**39.93**	0.67	0.57
26.		2	**39.62**	0.69	0.58
27.		4 (Base)	**38.75**	0.73	0.62
28.		7	**37.56**	0.78	0.66
29.		12	**36.25**	0.84	0.71
30.	Initial Staff	2	**50+**	0.58	0.49
31.		3	**47.93**	0.60	0.50
32.		4 (Base)	**38.75**	0.73	0.62
33.		6	**23.56**	1	0.85
34.		10	**16.06**	1	0.85
35.		30	**9.25**	1	0.85









Increasing the Hiring Time Delay would potentially lead to faster completion dates, contrary to popular belief, as in this case the experienced staff would not be inhibited by the newcomers for a longer period of time. The number of Initial Staff present on the project is probably the most significant variable, as it leads to significantly shorter completion times. Increasing the Initial Staff by 50% (from 4 to 6) results in a completion time of 23.56 months, a 39.2% reduction! Varying other parameters has the potential to reduce Completion time by only a few percent. However, this parameter is critical (given its power of influence on completion time) as an initial understaffing can lead to never-ending projects. A 25% staff reduction (from 4 to 3) leads to 23% increase in completion time (47.93 months)!

While the ceteris paribus tests of the various parameters did not lead to significant improvements, a combination of the factors can lead to shorter completion times. The shortest time achieved with physically acceptable parameter values was 32.25 weeks, which is a reduction of 16.8% from the Base Case when people are hired, but only 2.4% decrease compared to the case when no people are hired (33.06 weeks). The results of the combined tests are presented in the table below. It can be concluded that hiring staff along the way on an IT project only makes sense when the tasks for which the people are hired are easy to learn, so that they can gain experience quickly, they are skilled, so that their Relative Productivity and Quality are almost the same as those who have been working on the project from the beginning and the firm can hire people quickly, so that the Hiring Delay is small. However, even a best case scenario combination of these factors does not lead to significant reductions in project completion time.

Table 3 – Best case scenarios

Exp. No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
New Staff Relative Productivity	0.7	0.7	0.8	0.8	0.8	0.9	0.99	0.99
New Staff Relative Quality	0.7	0.7	0.8	0.8	0.8	0.9	0.99	0.99
Effect of New Staff of Productivity of Experienced Staff	1/3	1/3	1/6	1/6	1/6	1/10	1/100	1/100
Effect of New Staff of Quality of Experienced Staff	1/3	1/3	1/6	1/6	1/6	1/10	1/100	1/100
Hiring Delay	4	8	4	2	1	1	1	0.1
Time to Gain Experience	6	6	6	6	3	2	2	0.1
Completion Time	33.56	33.5	33	32.87	32.56	32.25	32	31.875

Interestingly enough, given the current characteristics, apparently, the project cannot be completed on time. However, it can be observed that Completion Time exhibits a goal seeking behavior. Its asymptotic value is the Scheduled completion rate of 30 months. It can be proven that without modifying the Initial Staff, the project will always overrun. A possible way to get the project done ahead or on schedule might be to hire "geniuses", who have the ability to work with higher Quality and higher Productivity than 1 (Experienced Staff level) and instantly get themselves familiarized with the project.

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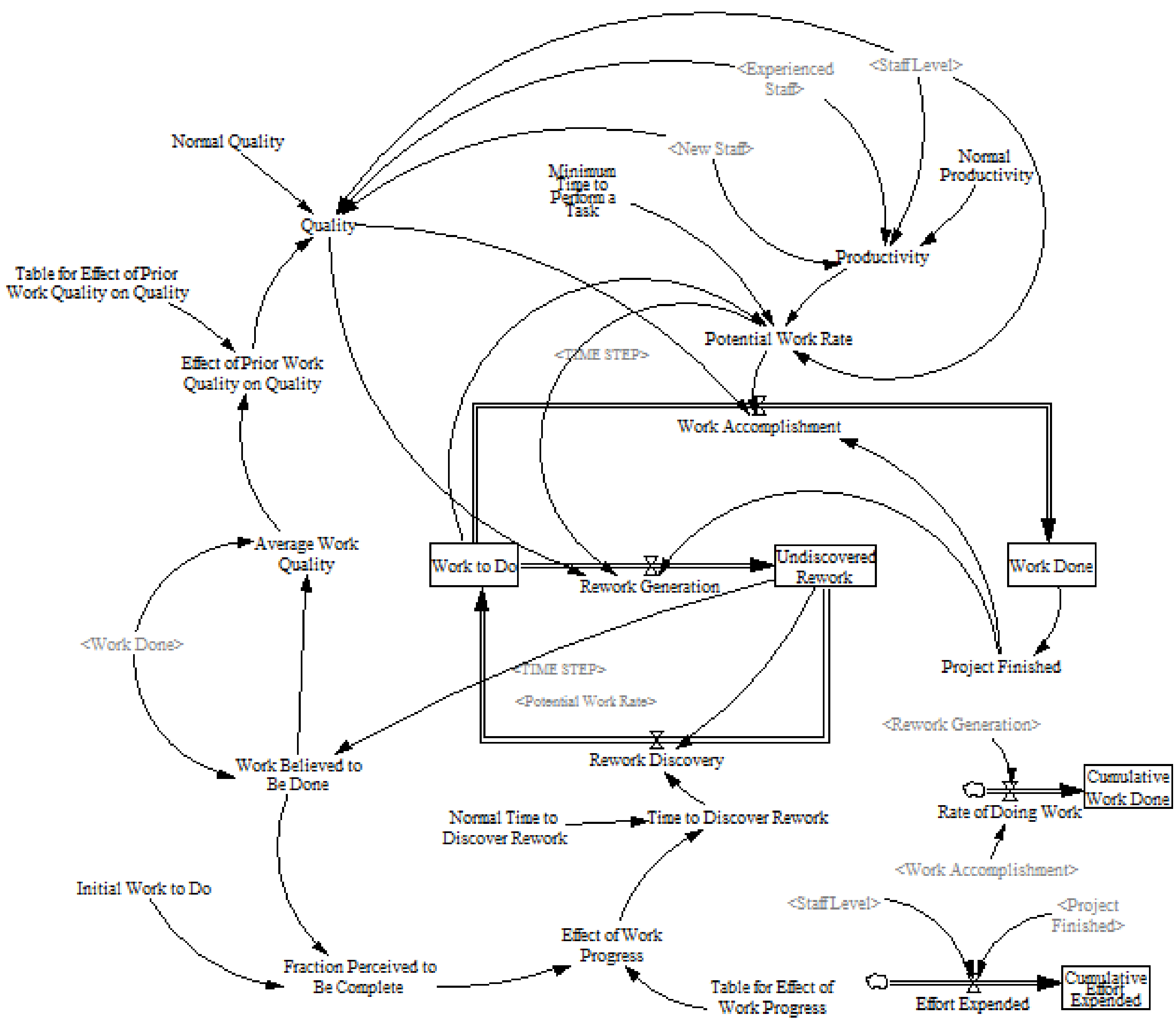
E. Synthesis of Policy Analysis and Recommendations

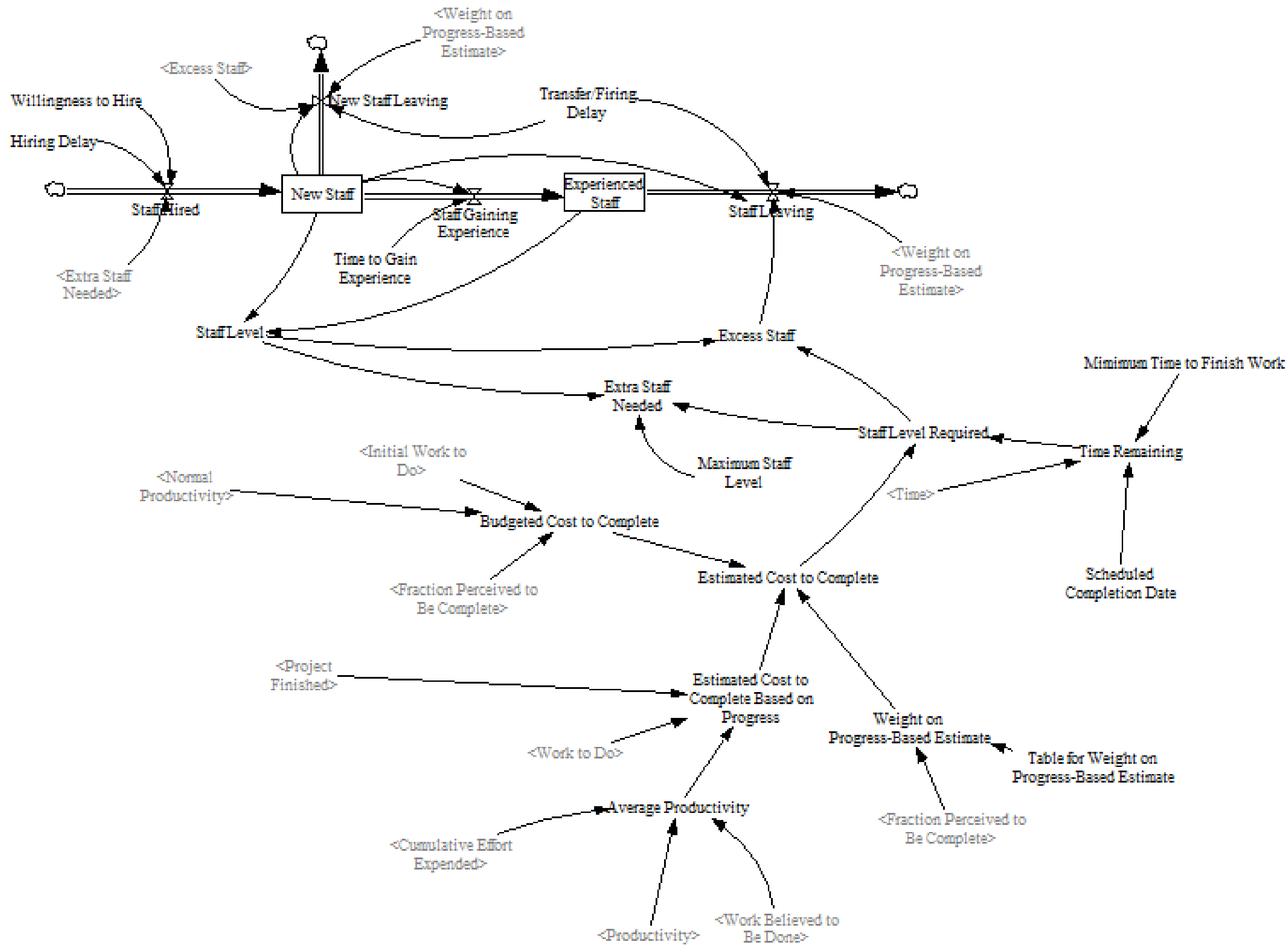
E.1. Suggestions

The experiments run on the model developed suggest that it is best to employ the staff you need at the beginning of the project. The effect on project time by adding new staff during the project decreases as time goes on, and therefore we recommend that hiring for any project is done at the beginning of the project before it begins to allow productivity and work quality to be at its highest. Since our model assumes that all employees are of equal value (productivity being a function of time spent at the firm rather than taking education and abilities into account), we see a decrease in productivity. We therefore recommend that staffing policies be as follows:

a) Develop project contracts with as many initial expert employees as possible.
b) Pressure Human Resources department to further network with headhunting agencies and talent databases to reduce the hiring delay for the projects that IT undertakes.

E.2. Diagram and Equations





(01) Average Productivity=IF THEN ELSE (Cumulative Effort Expended>0, Work Believed to Be Done/Cumulative Effort Expended,Productivity)

Units: Task/(Month*Person)

A good estimate of the average productivity on project work to date is given by work believed to be done (tasks) divided by cumulative effort (person-months). In order to avoid division by 0 and a discontinuity in average productivity, the average is set to actual productivity before work starts.

(02) Average Work Quality=XIDZ(Work Done, Work Believed to Be Done , 0.85)

Units: Dimensionless

(03) Budgeted Cost to Complete=(Initial Work to Do/Normal Productivity)*(1-Fraction Perceived to Be Complete)

Units: Person*Months

Managment's initial estimate for cost in person-months is given by initial work to do divided by productivity. As progress is made and fraction complete increases, the estimate of effort remaining based on the budget decreases.

(04) Cumulative Effort Expended= INTEG (Effort Expended,0)

Units: People * Month

(05) Cumulative Work Done= INTEG (Rate of Doing Work,0)

Units: Tasks

Cumulates the total amount of work done, counting rework as well as original work.

(06) Effect of Prior Work Quality on Quality=Table for Effect of Prior Work Quality on Quality(Average Work Quality)

Units: Dimensionless

(07) Effect of Work Progress= Table for Effect of Work Progress(Fraction Perceived to Be Complete)

Units: Dimensionless

(08) Effort Expended=Staff Level*Project Finished

Units: People

(09) Estimated Cost to Complete=Budgeted Cost to Complete*(1-"Weight on Progress-Based Estimate")+Estimated Cost to Complete Based on Progress*"Weight on Progress-Based Estimate"

Units: Month*Person

Estimated cost to complete is management's estimate of the person-months of work remaining to complete the project. Early in the project, management bases its planning on the budget. As progress is made, however, and management can determine the true scope and productivity on the project, the estimated cost to complete moves toward that based on actual progress.

(10) Estimated Cost to Complete Based on Progress=(Work to Do/Average Productivity)*Project Finished

Units: Month*Person

Work to do divided by average productivity to date provides an estimate of how many person-months of effort remain to complete the project. Because actual project scope (including the amount of rework) and actual productivity are hard to determine early in the project, this estimate may not accurately reflect true cost until the project has made some progress.

(11) Excess Staff=Max(Staff Level - Staff Level Required, 0)

Units: People [0,?]

(12) Experienced Staff= INTEG (Staff Gaining Experience-Staff Leaving,4)

Units: People

(13) Extra Staff Needed=IF THEN ELSE(Staff Level Required-Staff Level>0, IF THEN ELSE(Staff Level Required

<Maximum Staff Level, Staff Level Required-Staff Level, Maximum Staff Level-Staff Level),0)

*considering that the Maximum Staff Level is practically infinite in this case, an implementation with the following formula could also work: MAX(MIN(Maximum Staff Level,Staff Level Required-Staff Level) , 0)

Units: People

(14) FINAL TIME = 50

Units: Month

The final time for the simulation.

(15) Fraction Perceived to Be Complete=Work Believed to Be Done/Initial Work to Do

Units: Dimensionless

(16) Hiring Delay=4

Units: Month

Set to 4 months from problem statement

(17) INITIAL TIME = 0

Units: Month

The initial time for the simulation.

(18) Initial Work to Do=100

Units: Task

(19) Maximum Staff Level=1e+006

Units: People

(20) Mimimum Time to Finish Work=1

Units: Month

When the project is experiencing a schedule overrun, the minimum time to finish the remaining work specifies, for staffing purposes, over what time duration management would like to complete that remaining work.

(21) Minimum Time to Perform a Task=0.25

Units: Months

(22) New Staff= INTEG (Staff Hired-Staff Gaining Experience-New Staff Leaving, 0)

Units: People

(23) New Staff Leaving=(1-"Weight on Progress-Based Estimate")*MIN(Excess Staff,New Staff)/"Transfer/Firing Delay"

Units: **undefined**

(24) Normal Productivity=1

Units: Task/(Person*Month)

(25) Normal Quality= 0.85

Units: Fraction

(26) Normal Time to Discover Rework= 12

Units: Month

(27) Potential Work Rate=MIN(Staff Level*Productivity,Work to Do/Minimum Time to Perform a Task)

Units: Task / Month

Maximum rate at which work can be accomplished. Normally this equals productivity multiplied by staff level. However, in some cases the available stock of work and the minimum time to perform a task can constrain the maximum rate of progress.

(28) Productivity=New Staff/Staff Level*0.5*Normal Productivity+Experienced Staff/Staff Level*Normal Productivity*(1-New Staff/(1*Staff Level))

Units: Task / (Person * Month)

The number of tasks accomplished per month per person. Some of this work will contain errors.

(29) Project Finished= IF THEN ELSE(Work Done>99,0,1)

Units: Dimensionless

Sets a "switch" to 0 when work done exceeds 99 tasks.

(30) Quality=Effect of Prior Work Quality on Quality*(New Staff/Staff Level*0.5*Normal Quality+Experienced Staff/Staff Level*Normal Quality*(1-New Staff/(1*Staff Level)))

Units: Fraction

Fraction of work that is complete and correct.

(31) Rate of Doing Work=Rework Generation+Work Accomplishment

Units: Tasks/Month

(32) Rework Discovery=Undiscovered Rework/Time to Discover Rework

Units: Task / Month

The rate of discovering rework, using a first-order delay formulation.

(33) Rework Generation=(1-Quality)* Potential Work Rate*Project Finished

Units: Task / Month

Rate of work being done incorrectly.

(34) SAVEPER = TIME STEP

Units: Month

The frequency with which output is stored.

(35) Scheduled Completion Date=30

Units: Month

(36) Staff Gaining Experience=New Staff/Time to Gain Experience

Units: People/Month

(37) Staff Hired=IF THEN ELSE(Willingness to Hire=0, 0 , Extra Staff Needed/Hiring Delay)

Units: People/Month

Rate at which new staff is hired. Controlled by Willingness to Hire variable.

(38) Staff Leaving=(1-"Weight on Progress-Based Estimate")*MIN(Excess Staff,New Staff)/"Transfer/Firing Delay"

Units: People/Month

(39) Staff Level=New Staff+Experienced Staff

Units: People

The number of people working on the project.

(40) Staff Level Required=Estimated Cost to Complete/Time Remaining

Units: People

How many people are required to complete the remaining work (estimated cost to complete is person-months of effort) in the time remaining.

(41) Table for Effect of Prior Work Quality on Quality([(0,0)-(10,10)],(0,0.1),(0.1,0.25),(0.2,0.35),(0.3,0.45),(0.4,0.55),(0.5, 0.65),(0.6,0.725),(0.7,0.8),(0.8,0.875),(0.9,0.95),(1,1))

Units: Dimensionless

(42) Table for Effect of Work Progress([(0,0)-(10,10)],(0,1),(0.1,1),(0.2,1),(0.3,1),(0.4,1),(0.5,1),(0.6,0.95), (0.7,0.8),(0.8,0.45),(0.9,0.2),(1,0.1))

Units: Dimensionless

(43) "Table for Weight on Progress-Based Estimate"

([(0,0)-(1,1)],(0,0),(0.1,0),(0.2,0),(0.3,0.1),(0.4,0.25),(0.5,0.5),(0.6,0.75),(0.7,0.9),(0.8,1),(0.9,1),(1,1))

Units: Fraction

Early in the project, management uses the original budget to estimate effort remaining. Therefore, the weight on estimates indicated by real progress is 0. As progress on the project occurs (fraction complete increases), management progressively increases the weight applied to effort remaining as given by tasks remaining and perceived productivity.

(44) Time Remaining=Max(Mimimum Time to Finish Work,Scheduled Completion Date-Time)

Units: Month

Time remaining to finish the work given scheduled completion date. As long as simulated time is less than scheduled completion time, time remaining is simply scheduled completion date minus current simulated time. However, if the project overruns, time can exceed the schedule and time remaining would be negative. In this situation, management strives to finish all remaining work in a small minimum time.

(45) TIME STEP = 0.0625

Units: Month

The time step for the simulation.

(46) Time to Discover Rework=Normal Time to Discover Rework*Effect of Work Progress

Units: Month

Average number of months required to discover rework.

(47) Time to Gain Experience= 24

Units: Month

Time it takes new staff to gain experience

(48) "Transfer/Firing Delay"= 4

Units: Month

(49) Undiscovered Rework= INTEG (Rework Generation-Rework Discovery,0)

Units: Task

Work that contains errors which have not yet been discovered.

(50) "Weight on Progress-Based Estimate"="Table for Weight on Progress-Based Estimate"(Fraction Perceived to Be Complete)

Units: Fraction

(51) Willingness to Hire=1

Units: Dimensionless

Multiplier reflecting management's willingness to hire new staff. 0 represents no desire and causes staff hired rate to be zero. 1 causes staff hiring to be extra staff needed divided by hiring delay.

(52) Work Accomplishment=Quality*Potential Work Rate*Project Finished

Units: Task / Month

Rate of work being done correctly.

(53) Work Believed to Be Done=Work Done+Undiscovered Rework

Units: Task

(54) Work Done= INTEG (Work Accomplishment,0)

Units: Task

Work completed correctly.

(55) Work to Do= INTEG (Rework Discovery-Rework Generation-Work Accomplishment,100)

Units: Task

Work that needs to be done for either the first time, or redone because it contains errors

References

[1] John D. Sterman , *System Dynamics for Business Policy*, McGraw-Hill, 2000