

The Impact of Engineering Process on the Construction Cost of HVDC Offshore Wind Energy Converter Station: A system dynamics approach

By:

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ABSTRACT

Aibel As, a Norwegian based service company, which has core businesses on the oil, gas and renewable energy sectors, needed improved work performance with a reduced cost of construction. For the purpose the company requested an in depth study to one of its first wind energy project, DolWin Beta. A recent internal study of the company shows that the man-hours used in recently completed projects and on projects that are near to their completions, have significantly increased compared to similar previous projects. This is of concern because the engineering processes are the cornerstones that all the company's activities are founded on. A multiphase system dynamic model that represents the engineering process of the company was built on the basis of previously developed and tested project structures. Simulations describe the behavior generated by the interaction of customized engineering phases and a project management structure. Each phase explicitly models the impacts of work process, resource capacity, scope, and targets on three engineering activities: regular processing, quality assurance, and rework. Project performance is measured in cost, cycle time, and quality. The model was calibrated to the DolWin Beta project of Aibel AS. Sensitivity tests indicate that two of performance measures (cost and quality) are more sensitive to the work precedence relations and minimum quality assurance parameters. Comparison between the simulated and historical record of the DolWin Beta engineering process shows that the model replicates the actual work progress during most of the development period. The model was also applied to the investigation of schedule completion date policies for improved project performance. Seven different schedule completion scenarios were tested. Model simulations indicate that internal deadlines, in addition to project deadline, are vital for the successful completion of engineering works. We found that project could be more benefited when internal deadlines for engineering process is set to around 1/5 of the planned project deadline.

KEYWORDS

Project management, system dynamics, phase dependency, process, resource, scope, and target.

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Chapter 1

1. Introduction

1.1 Problem Context

Aibel As, a Norwegian based service company, which has core businesses on the oil, gas and renewable energy sectors, needed improved work performance with a reduced cost of construction. The company provides engineering, construction, upgrading, and maintenance services for both onshore and offshore systems. Despite the company has a presence in around half of the oil and gas offshore installation in the Norwegian continental shelf and in more than four onshore facilities in Norway, the current insurgence of South East Asian companies in the business area, together with a huge reduction of investment from the major players of the industry, has posed a halt to its fast growth (Interviewee 1; Interviewee 2; Abel News, March, 2013). Internal reports show that the company has faced strong competition in the business areas in which it has been well represented and even led them to lose some of the strong bids the company recently made. This has forced the company to consider several potential paths, such as search for some promising business areas and intensify its investigation of its own project execution strategies.

A recent internal study shows that the man-hours used in recently completed projects and on projects that are near to their completions, have significantly increased compared to similar previous projects. A study on four similar projects shows that, during the past 10 years, the man-hours used for engineering processes have increased up to 182%. The study also indicated that the discrepancy between initially estimated engineering man-hours and actually spent man-hours have increased from nearly 36% to 134% in the past 10 years. This is of concern because the engineering processes are the cornerstones that all the company's activities are founded on.

On the other hand, the search for promising business areas led to the identification of the renewable business area as one core business sector. Currently, the company is engaged in its first offshore wind energy project under an Engineering, Procurement, Construction and Installation (EPCI) turnkey contract together with two other companies.

Since the commencement of the first offshore wind energy project in 1991, 2.5 km off the Danish coast at Viendby, commercial scale offshore wind facilities have been operating around the world, mainly in Europe (GWEC, 2012). However, the first decade of the offshore wind power sector growth was irregular and mainly restricted to small near-shore projects in Danish and Dutch waters featuring wind turbines with a capacity of less than 1 MW (Arapogianni, et.al., 2011). But the increasing demand for energy and raising concern over greenhouse gases, together with advancements in offshore wind energy technologies and shortage of nearby coastal lines, have been pushing the development of offshore wind energy in an increasing rate to ever deeper, increasingly further shores and to technologically complex locations (Arapogianni, et.al.,2011).

Offshore wind energy (OWE) is becoming one of the main power sources in many countries. According to Global Wind Energy Council (GWEC, 2012) statistics, global offshore wind power installations increased by 1,295.6 MW in 2012, bringing the total installed OWE capacity up to 5,415 MW, a 31.45% increase above the 4,119.3 MW installed at the end of 2011. Europe is the world leader in OWE, with installed capacity of 4, 995 MW (more than 90% of the world total) at the end of 2012 (GWEC, 2012). An additional 35, 000 MW is planned to be installed by the European countries at the end of 2020 and a further 110, 000 MW of offshore wind capacity is expected to be added in European waters between 2020 and 2030 (Arapogianni, et.al., 2011).

The enormous potential of OWE, which could meet Europe's energy demand seven times over (EEA, 2009) and United States' energy demand four times over (Schwartz et.al., 2010), is attracting huge investments in this sector. According to the 2013 European Wind Energy Association (EWEA) report, 293 new offshore wind turbines, in 9 wind farms, representing investments of around €3.4 bn to €4.6 bn, were fully grid connected between 1 January and 31 December 2012 in Europe. This annual investment in OWE is expected to increase to €10.4 bn in 2020 and €17 bn in 2030.

The construction of OWE turbines at sites further from shores, however, requires High Voltage Direct Current (HVDC) converter stations. Because High Voltage Alternating Current (HVAC) transmission systems that connects the OWE turbines with onshore grids are not economically

effective for distances above 60 to 70 km, mainly due to the associated high energy losses during transmission (Bresesti et.al., 2007; Stamatious et.al., 2011). In line with this, a number of HVDC converter substations are under construction and competition across companies in the supply chain for offshore wind is increasing with an influx of new entrants (Arapogianni, et.al., 2011).

Aibel AS is one of the few companies engaged in the construction of HVDC converter substations for the OWE sector. In its first OWE project, Aibel builds DolWin Beta together with ABB and Drydocs for a large wind farm cluster in the German sector of the North Sea. DolWin Beta will receive alternating current from three wind farms (a total of 240 wind turbines), and convert it into direct current before sending it onshore through subsea cables. It will have a capacity of 924 MW.

DolWin Beta is the size of a football field. It is 70 meters tall, 74 meters wide and 99 meters long. Structurally, DolWin Beta has two main parts, HVDC converter and a supporting structure. The supporting structure, in addition to the compartments for the HVDC converter, has separate living quarters for 24 people, a helipad and two lifting cranes.

Aibel is designing and building the platform, whilst ABB has overall project responsibility and is supplying cables and the conversion equipment. Drydocs world, a subcontract for Aibel, constructs the substation in Dubai.

However, according to Interviewee 1, “the high costs associated with the construction of the substation have been creating problems in the company’s competitiveness” in this rapidly growing market.

There are several alternative explanations for the high cost of offshore wind platform construction, including the immaturity of the technology in the subfield, an increase in the prices of construction materials, specifically, copper and steel, a shortage of construction yards for such huge platforms, a need for high standardization since the platforms are towed in very hostile environments, and problems associated with supply chain and project management (Garrad Hassan, 2010; Arapogianni, et.al.,2011).

According to Interviewee 1, although there are “promising signs in the technological cost reductions of wind turbines”, which could possibly pave directions for cost reductions in other substructures, the “technological efforts made towards achieving a 30% to 40% cost reduction for converter stations weren’t yet successful. Rather, the cost has increased by an additional 30%”.

Furthermore, most of the technologies under use in the construction of HVDC offshore wind energy converter stations are those adapted from the offshore oil and gas (EWEA, 2011). However, unlike offshore oil and gas, which could be “customized based on clients’ specifications and site requirements, offshore wind energy converter stations need to be standardized” (Interviewee 1). Thus, Aibel AS managers are currently focusing on standardizing their project management methods, mainly by relying on already proven technologies and managing the construction value chains. That way, the company could offset the high cost associated with the constructions through lessons learnt, improved reliability and structural efficiency.

Literature show that managing projects of such a kind is usually difficult because large-scale projects are extremely complex and highly dynamic (Abdel-Hamid & Madnick, 1991; Streman, 1992; Cooper & Lee, 2009; Arapogianni, et.al., 2011). Moreover, such projects involve both multiple feedback processes and nonlinear relationships (Abdel-Hamid & Madnick, 1991; Streman, 1992; Cooper & Lee, 2009). Thus, decisions made, solely based on human mental models, in managing such projects “cannot hope to account accurately for the myriad interactions, which jointly determine the outcomes of the projects” (Sterman, 1992). But the use of system dynamics tools can help managers identify the problems occurred in the workflows and their associated costs across the entire life of the projects (Abdel-Hamid & Madnick, 1991; Cooper & Lee, 2009). Because “system dynamics is the application of feedback control systems, principles, and techniques to managerial, organizational, and socioeconomic problems”(Roberts, 1981, cited in Abdel-Hamid, 1984).

Given the company’s desire to investigate the high construction cost of HVDC offshore wind energy converter stations from a project management perspective and the problems that the company has discovered in its recent internal study, associated with one of its core business,

engineering, this research has focused on investigating the impact of the engineering process on the construction cost of HVDC offshore wind energy converter stations with the help of a system dynamics model.

1.2 Research Objective

The main objective of this research effort is to investigate the impact of the engineering process on the construction cost of HVDC offshore wind energy converter stations by developing and testing a system dynamics model of the engineering process, which would provide us with the understanding and insight about the drivers for the high construction cost from a project management perspective.

The first and primary purpose of the model is to enhance our understanding of the engineering process. Dubin (1971), cited in Abdel-Hamid (1984), claim that the “locus of understanding in a scientific model is to be found in its laws of interaction”. Hence, with the help of the model, we wanted to gain a detailed understanding of how the various variables that constitute the engineering process interact with each other and explore what govern their interactions.

The second purpose of the model is to foster learning. Lyneis and Ford (2007) claim that one of the important applications of system dynamics models is fostering learning. Because the models help managers assess what went right and what went wrong in a project, model analysis may provide valuable insight of relevance in future projects. Hence, through examining how the engineering process of the DolWin Beta project evolves, we want to facilitate organizational learning.

1.3 Research Question and Hypothesis

The underlining problem in this research is the high construction cost of HVDC offshore wind energy converter substations. Although there are numerous factors that could potentially contribute to the high construction cost, as discussed when setting the problem context, we intend in this research work, to assess the impact of the engineering process on the construction cost. Hence, our main research question is, “how does the engineering process impact the cost performance of HVDC offshore wind energy converter substation construction?”

We hypothesize that the cost performance of HVDC offshore wind energy converter substation construction could be affected by two kinds of factors, the factors that govern the flow of the engineering work across different phases of the engineering phases and the factors that govern the flow of the engineering work within a single engineering phase.

From designing the architecture of the HVDC offshore converter substation on paper to 3D modeling of the substation structure, the engineering work passes through various engineering phases. The first activity in the engineering process is understanding what the project shall produce. In order to foster such understanding, system descriptions are created on the basis of a study of functional requirements. Such descriptions are illustrated with schematic drawings (usually on paper) and descriptive texts. Once the system descriptions are ready, equipment that will constitute the final product will be ordered. The materials in the list are also predefined for 3D modeling. On the basis of the system description and the information about the equipment and part, a 3D model of the design is produced. Descriptions about how parts shall be assembled are also produced together with the 3D model.

However, the work process in an engineering design is not unidirectional. For example, if the materials in the description list are either not available in the market or do not fit with the standards of the manufacturing companies, the description list and/or the schematic drawings need to be revised. Unless the standard of the specified materials is assured and their availability in the market is not confirmed, both the schematic drawings and the 3D designs cannot be approved for construction. Hence, the work progresses of the architectural design on paper and material specifications constraint the progress in the 3D modeling. In the same token, if the material specifications are not to the standard and the lists are not available in the market, the architectural design needs to be revised.

In addition to the work process constraints mentioned above, the work progress in a single engineering phase (say an engineering phase that produces a 3D model, or one that produce schematic drawings and material specification) could be constrained by a number of factors that determine its progress within its boundary. Literature claim that at least four major factors; the actual work process in a particular phase, the scope of the engineering work, the resource allocated to the engineering work and the target set to be achieved in that particular phase constrain the progress of an engineering phase (Ford, 1995).

The performance of an engineering phase can be constrained by the availability of engineering work. For example, in the discussion above, a 3D modeling activity cannot be started before schematic drawing and material specifications are produced. On the other hand, even if, the engineering work is made available, the engineering work cannot be processed unless the required labor force is allocated. Of course, not only the allocation of the labor force, the productivity level of the allocated labor force also constrains the rate at which the engineering works are processed as shown Figure 1.1.

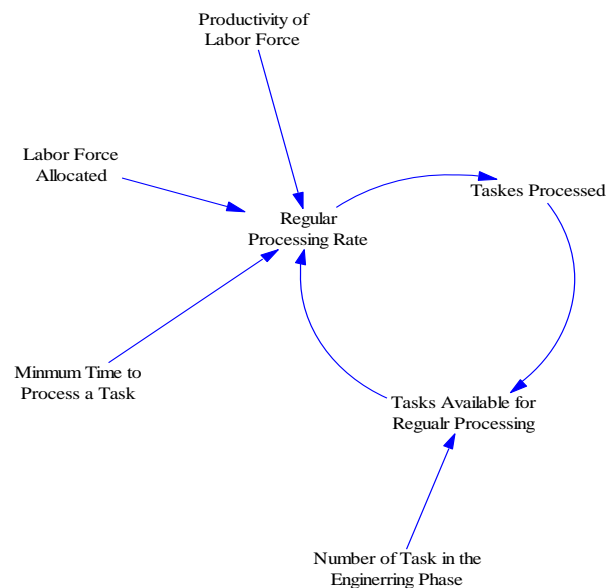


Figure 1.1 Work Process Interaction

The amount of available engineering work, the number of the available labor force, and the productivity of the labor force together with the minimum amount of time required per unit of engineering work, determine the work process rate in a single engineering phase. The quality of practice in the engineering work, furthermore, determines whether the processed engineering work requires additional rework or not. The targets set for quality and budget, together with the planned project completion time, moreover constrain the progress of the phase and its cost performance (Abdel-Hamid, 1984; Homer et. al., 1985; Ford, 1995; Cooper & Lee, 2009).

Hence, in this research, we intend to investigate the effects of these various interactions at the level of a single engineering phase and across different engineering phases, and to determine how it affects the cost performance of the HVDC offshore converter substation construction.

1.4 Research approach

In order to answer our research question and carry out both structural and behavioral analysis to our hypotheses, we adopted the system dynamics methodology. System dynamics offer a way of studying and managing complex business and other social system problems with through modeling, simulation and analysis. (Abdel-Hamid, 1984, Ford, 1995; Sterman, 2000; Lyneis and Ford, 2007). It is a tool to help address complex issues involving cause and effects, feedbacks, delays, and nonlinearities (Sterman, 2000).

In our work, stocks and flows are used to model the flow of engineering work and human resources through the engineering phases. Information feedback loops are used to model project management policies and the associated decision processes. Time delays are used to capture time lags, say, between the desire for labor force and its availability produced by recruitment processes. Nonlinear equations help us understand the synergy between various aspects of a project, say schedule pressure and labor force productivity. In general, the methodology provides us with the means for describing the engineering process of the DoWin Beta project.

1.5 Organization of the study

This thesis is organized in six chapters. Chapter one and two serve as a background and an introduction. The first chapter presents the background of the problem and the thesis objective. The second chapter offers basic definition of terms used in the thesis. Concepts of project management scope of work and project phases are presented in this chapter.

Chapter three is on model development. The sources of information, the model boundary and a detailed description of the model and its equations are presented in chapter three.

In chapter four, we discuss the results of the model and compare it to historical values. Sensitivity analysis and initial results of the model are also presented in this chapter. Future policy options and their testing under various scenarios are also presented in the fifth chapter. The conclusion and limitations of the study are presented in the final chapter of the thesis.

Chapter 2

2 Basic Concepts and Definitions

In this chapter we have presented the basic concepts and definitions, which we are going to use throughout the thesis.

2.1 What is Project Management?

According to Project Management Institute (PMI, 2013), project management is “...the application of knowledge, skills, tools and techniques to project activities to meet project requirements” (p.5). Although this definition is straightforward, it encompasses two strong phrases that need explanation; ‘project activities’ and ‘project requirements’.

PMI (2013) define project activities as “...temporary endeavors undertaken to create a unique product or service” (p. 3). They are temporary because they have a specific beginning and end. However, the word temporary doesn’t necessarily mean short in duration, there are projects that take several years (PMI, 2013).

Project requirements, on the other hand, are the objectives set for the projects in terms of scope, schedule, and cost (PMI, 2013; Cleland & Ireland, 2002). Thus, project management could be redefined as a discipline of planning, organizing and controlling of resources in order to move a specific task toward completion based on its set objectives.

2.2 What is Scope of Work?

Scope of work also referred as ‘project scope’ is the amount of work that needs to be accomplished to deliver a product, service, or result with the specified features and functions (PMI, 2013). Determination of project scope is part of project planning that involves determining and documenting a list of specific project goals, deliverables, tasks and deadlines.

In the real world, scope changes can be expected during the life cycles of most projects. Scope changes implemented once work has begun will have a greater effect on the project schedule

and cost than changes implemented during the project initiation or planning phase; therefore, it is imperative that the project scope be well defined before the project work begins (PMI, 2013).

2.3 Project Phases

A phase, or stage, represents a group of similar activities (PMID, n.d). The interaction between two or more than two phase defines a project. Phases in a project interact to each other through dependency relations. Dependencies are logical relationships between phases, activities or tasks that influence the way in which a project will be undertaken.

A phase that constraints the activities of the current phase from the upper side is referred in this research paper as “Upstream Phase”. The current phase, which depends by on the “Upstream” phase is referred as “Downstream Phase”.

Phases are very important for project managers. By thinking in terms of phases, managers can ensure that the deliverables produced at the end of each phase meet their purpose, and that project team members (or sub-teams) are properly prepared for the next phase.

Chapter 3

3 Model description

3.1 Introduction

As stated in chapter 1, the objective of this research is to develop and test a system dynamics model for the engineering process in the construction of HVDC offshore wind energy converter station, - one that would provide us with the understanding and insight about the drivers underlying the high construction cost of the HVDC converter station as seen from project management perspective.

Providing a complete picture of the engineering process requires descriptions from several perspectives. In the following section of this chapter, we begin this process by discussing the sources of information we have used when building the model. In the next stage, the model itself is framed by defining its boundaries and level of aggregation. In the fourth and largest section of this chapter, the structural components of the model are presented in increasing details in the form of a description of each phase, subsystem and sector.

3.2 Sources of Information

To build the structural components of the model and to test outputs, we went through four information-gathering steps:

First, we conducted a series of six interviews with business unit managers, engineering managers, line managers, personal, finance and planning department heads of the company between the periods of May 2013 to September 2013. The main purpose of this set of interviews was to pinpoint the main problem of the company and to gain a general insight into how projects are managed in the company.

Siting the works of Forrester (1979), Abdel-Hamid (1984) refers to the fact that

“the system dynamics approach starts with the concepts and information on which people are already acting. In general, sufficient information exist in the descriptive knowledge possessed by the active practitioners to serve the model builder in all his initial efforts” (pp.98).

As part of the first phase data gathering, we also studied various documents that describe the company’s project execution strategies. To further acquaint ourselves with the company’s project execution strategies, we took two online training courses on project execution.

The information collected in this first phase was the basis for formulating the main stock and flow structures of the system dynamics model for the engineering process.

In the second step of our data gathering, we conducted an extensive review of related literature. The “skeletal” structure formulated in the first data-gathering step was a useful road map for carrying out the literature reviews. Abdel-Hamid (1984) recommends that

“... starting the extensive review of the literature with the initial model serving as the road map has several important advantages... It is helpful in organizing the findings and in integrating them into the initial model. Moreover, it prompts us to broaden our horizon and look into other relevant fields for ideas” (pp.103).

Examples of the main literature, we reviewed, include: Software project management model of Abdel-Hamid (1984); Pulp and Paper Mill Construction project model of Homer et al. (1985); New product development model of Ford (1995); a model developed for the Strategic management of complex projects by Lyneis, Coopera & Elsa (2001); and a model developed for managing the dynamics of projects and changes at Fluor by Cooper and Lee (2009).

In the third stage of our data gathering, we distributed a fourteen questions survey to the mangers of the company at various posts, - later followed up by informal interviews. The main objective of the data gathering at this stage was to expose the model for “criticism and revision” so that the various variables of the model introduced during the first and second stages of data gathering could further be fine-tuned. Highlighting the importance of this stage of data gathering, Roberts (1981) sited in Abdel-Hamid (1984) stated that

“The model is exposed to criticism, revised, exposed again and so on in an iterative process that continues as it proves to be useful. As the model is improved as a result of successive exposure to critics, a successively better understanding of the problem is achieved by the people who participated in the process” pp.97.

The results of the survey and interviews are summarized and presented in the tables presented chapter 4, whereas, the survey questions are documented in appendix B. However, due to the agreement made with the company, the names of the interviewees are kept anonymous. Furthermore, some sensitive information of the company that could benefit competitors are not included in our documentations.

In the fourth and final step of our data gathering, we collected historical data from the project we are investigating. These historical data are used to compare against the simulation results produced by the model.

3.3 Model Boundary and Level of Aggregation

To obtain a complete picture and detail understandings of the drivers for the high construction costs of HVDC offshore wind energy converter stations we would have to perform analyses from a variety of vantage points. Two prominent perspectives would be the technological point of view and the project management point of view.

Since the commencement of the first offshore wind energy project in 1991, there have been a lot of efforts in the “technological cost reduction of wind turbines and other substructures” (Interviewee 1). According to Interviewee 1, although there are “promising signs in the technological cost reductions of wind turbines”, which could possibly pave directions for cost reductions in other substructures, the “technological efforts made towards achieving a 30% to 40% cost reduction for converter stations were yet not successful. Rather, the cost has increased by an additional 30%”.

Furthermore, most of the technologies under use in the construction of HVDC offshore wind energy converter stations are those adapted from the offshore oil and gas (EWEA, 2011). However, unlike offshore oil and gas that could be “customized based on clients specifications

and site requirements, offshore wind energy converter stations need to be standardized” (Interviewee 1). Thus, Aibel AS managers are currently focusing on standardizing their project management methods, mainly by relying on already proven technologies and managing the construction value chains. So that the company could offset the high cost associated with the constructions, through lessons learnt, improved reliability, and structural efficiency. Consequently, the focus area of our research has excluded the technological vantage point, and that aspect remains outside our model boundary.

As we narrow down our boundary to the project management vantage point, we find the type of project the company is engaged with. The company is engaged under Engineering Procurement Construction and Installation (EPCI) turnkey contracts with ABB and Drydocks World companies for the construction of a DolWin Beta, HVDC offshore wind energy converter station. Structurally, DolWin Beta has two main parts, a HVDC convertor and a supporting structure. Aibel is designing and building the convertor substation, whilst ABB has the overall project responsibility and is supplying cables and the conversion equipment. Drydocs world, a subcontract for Aibel, constructs the substation in Dubai.

According to Smith (2002) EPCI projects usually pass through the following five phases: front end engineering design (FEED), detail design engineering, fabrication, assembling, to testing. Companies under such contracts are responsible for the complete works starting from the planning to the final delivery of the project to owners (EWEA, 2011). Any problem that occur across the different phases of the project or on the work performance of partner companies, if not dealt with on time and appropriately, could have a significant effect on the project completion time and the quality of the work, - which will further have significant cost implications (Cooper & Lee, 2009).

The FEED study of the DolWin2 project is carried out before the contract is awarded the companies. Thus, the FEED study is outside of our model boundary. Through detail investigation of contract documents and work execution strategies of our parent company, we found four different phases that the DolWin2 project must pass through. This includes Engineering, Procurement, Construction and System Completion. Under these four project phases, we found 12 sub-phases; 3 for Engineering, 4 for Procurement, 3 for Construction and

2 for System Completion, that demand a great deal of project managers attention. However, due to time constraint and the level of engagement of Aibel As, our research focus has further narrowed down to the engineering phase of the project.

Underscoring the importance of focusing on the engineering process, a manager in the company (Interviewee 1) claims that,

“...the engineering process, which only consumes around 20% of a project cost, determines how the remaining 80% of the project cost could be expended. Thus, understanding the main drivers for cost in the engineering process and minimizing their impact is key for the cost reduction of the entire project”.

A motto on the company's front page further reaffirms this stance,

“...Engineering is the cornerstone that all of Aibel's activities are founded on. Our engineers always strive to identify good technical and optimal cost-effective solutions to our customers”.

Hence, our model is delimited to the engineering process. The engineering process in Aibel AS is divided into three broad units, System Engineering, Engineering for Procurement, and Area Engineering. Under each engineering unit, there are up to 10 different disciplines, some are core disciplines to a specific engineering unit, and some cut across more than one unit. However, for ease of representation, we have aggregated the different disciplines into the three engineering units, so that we can discuss only at the level of the engineering unit.

In the actual setup, there is division of responsibilities between the engineering unit teams and discipline teams. The engineering unit teams are responsible for budget, progress and quality of the engineering works, whereas, the discipline teams are responsible for supplying the three engineering units with the correct personnel, work procedures and tools and for verifying whether the work performed complies with the quality goals and procedures set. However, in the model all these responsibilities are assigned to the engineering units themselves.

Although the structural setup is the same across the three engineering units, each of them process different engineering activities. System Engineering unit is responsible for producing the system descriptions that give insights about what the company produces under a particular project contract. This is illustrated with schematic drawings and descriptive texts. Once the

system descriptions are in place, the company starts to buy equipment/ parts that will form the final product. The Engineering for Procurement unit is responsible for these activities. This unit is also responsible for predefining materials for 3D model use in the third engineering unit. On the basis of the system description and information about equipment and parts, the Area Engineering unit produces 3D model of the design. This engineering unit is also responsible for producing descriptions of how materials shall be assembled.

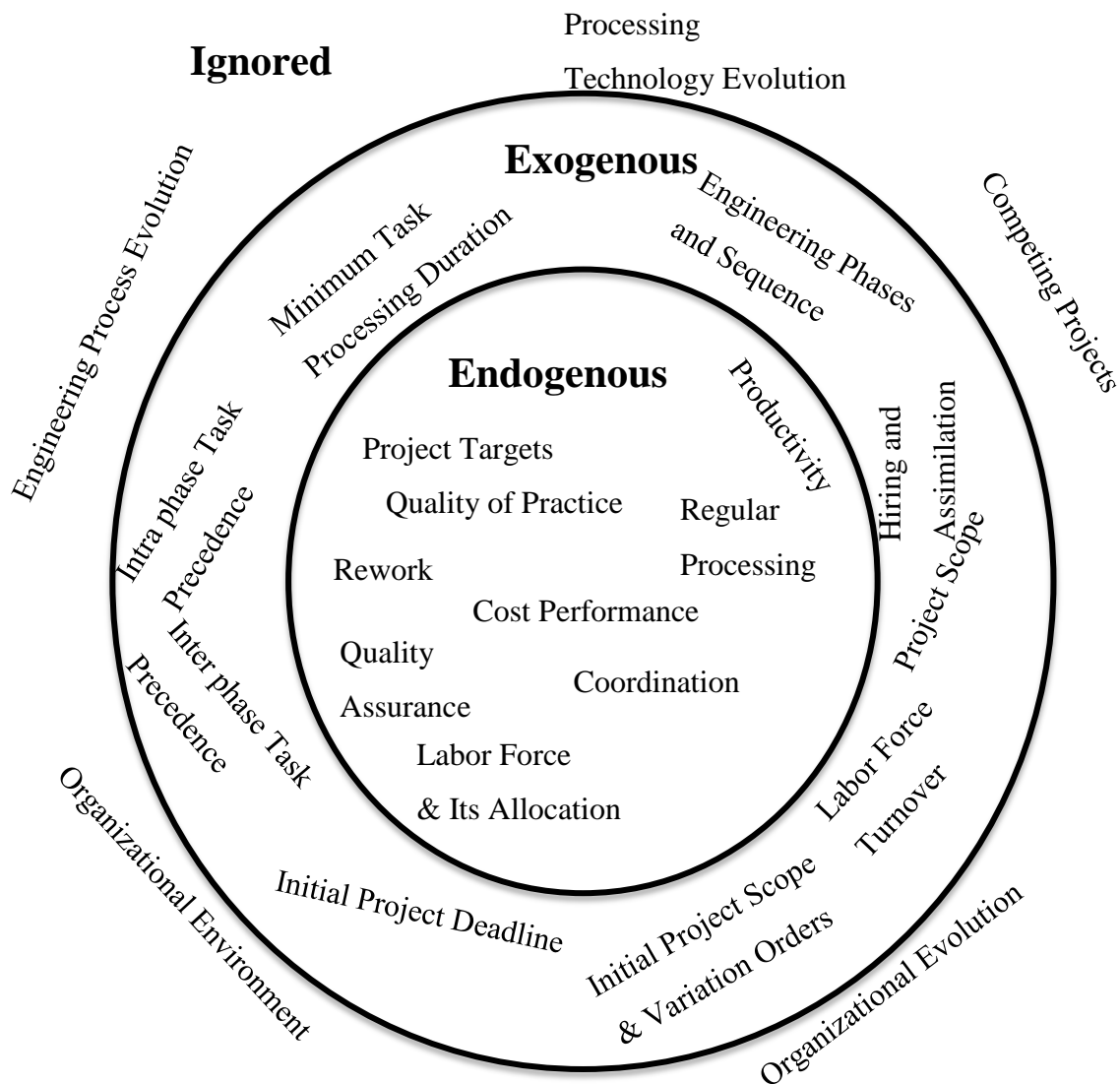


Figure 3.1 Model boundary

In general, the engineering process focuses on the optimal work process and information flow within each engineering unit and between the engineering unit interfaces. Thus, those factors that have been identified as having a potential influence on the flow of the engineering works, within the engineering units and across the engineering units, are included within our model boundary.

Figure 3.1 summarizes the scope and focus of our model, such as the primary factors included (endogenous), factors assumed of having constant effect (exogenous) and factors excluded (ignored) from our model boundary.

3.4 Model Structure

In our model, we represented the three engineering units as three different phases of the engineering process. Each phase is customized to represent a specific stage of the engineering process. A phase dependence network describes the flow of information across the engineering units. Figure 3.2 represents the interaction across the three engineering phases.

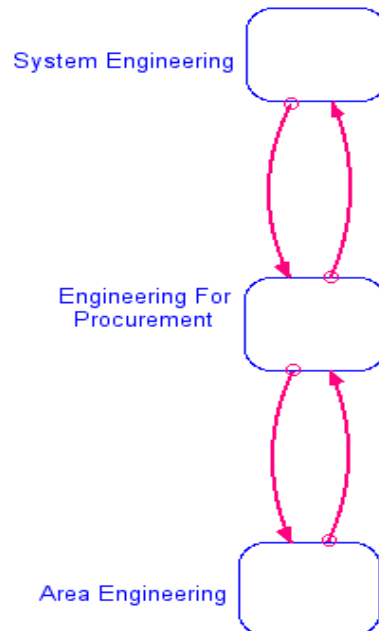


Figure 3.2 Interaction across engineering phases

The underlying assumptions regarding the interaction of the three engineering phases are as follows:

- The work progress in one engineering phase constrains the progress of a dependent engineering phase. The dependency network is shown with the arrows in Figure 3.2.
- The amount of engineering work in a phase is measured with a unit called Tasks. A task can be anything, producing a drawing, finding analytical solution, coding a 3D model, producing material specification document, ... etc. A detail description of tasks is presented in the Human Resource subsystem. Tasks flow within a single phase. However, Tasks do not flow across phases, - rather the information about the fractional progress flow across phases.
- The fractional values of the scope of work completed operates across related engineering phases, i.e. a 100% scope of work of an upstream engineering phase is equivalent to a 100% scope of work of a dependent, downstream engineering phase. However, the actual number of Tasks in these dependent phases could be different.
- Errors inherited by downstream engineering phases from upstream phases corrupt downstream work.
- Inherited errors that are discovered by downstream phases are returned to the phase where they are generated for a change.

Each of the three engineering phases has their own subsystem; a work process subsystem, a scope subsystem, a human resource subsystem and a target subsystem. Each subsystem is a representation of the four hypotheses we proposed in chapter one, as a possible explanation for the project's cost performance. The subsystems are further subdivided into sectors. The interaction among the sectors and across the subsystems defines a phase.

Figure 3.3 represents the interactions among the subsystems of a single engineering phase. The underlying assumptions in the interactions of the subsystems are the following ones:

- The rate of flow of tasks across the work process subsystem, which comprises regular processing, quality assurance, and rework, constrains the progress of the engineering works in a single phase.
- Availability of tasks and labor force together with the productivity level of the labor force and the quality of practice determines the rate of flow of tasks.

- Internal and External task precedence relations together with the phase's scope constrain the availability of tasks, whereas, the hiring and firing decisions determine the labor force size.
- Poor performance on project targets affects the productivity of the labor force and the quality of practice of the engineering process, which, in turn, constrains the rate of flow of tasks and the phase's progress.

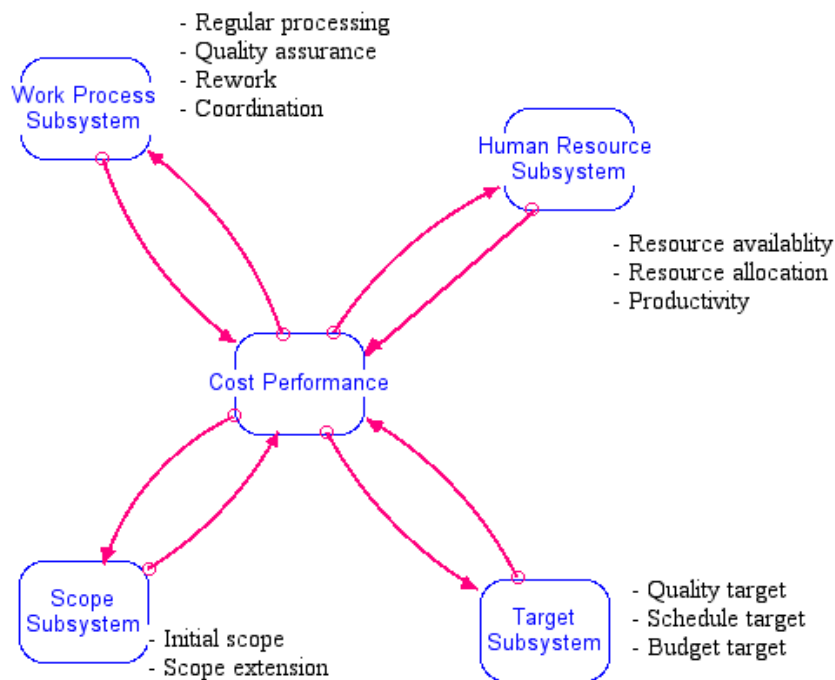


Figure 3.3 Interaction between subsystems in a single phase

The subsections below describe in detail how the model is built. For descriptive purpose, most of our discussions concentrate on the subsystems and sectors of a single engineering phase. However, on areas, where discussions at phase level are required, we expand our portrayal of the model.

3.4.1 Work Process Subsystem

The work process and scope subsystems describe the nature of the engineering process and the amount of engineering work in a single phase, respectively. The first subsection describes the structural components of the work process subsystem, which include regular work processing, quality assurance, and rework activities of the engineering work. The second subsection is

devoted for the structures that describe the initial scope of the phase and its extensions due to variation orders and discoveries of additional works.

3.4.1.1 The Work Process Subsystem

Figure 3.4 depicts the main stock and flow structures that capture the engineering work process in a particular engineering phase. The core structural components of the work process subsystem are adopted from the new product development model of Ford (1995), with some modifications. The discussion below explains the principal interactions among the stocks and flows.

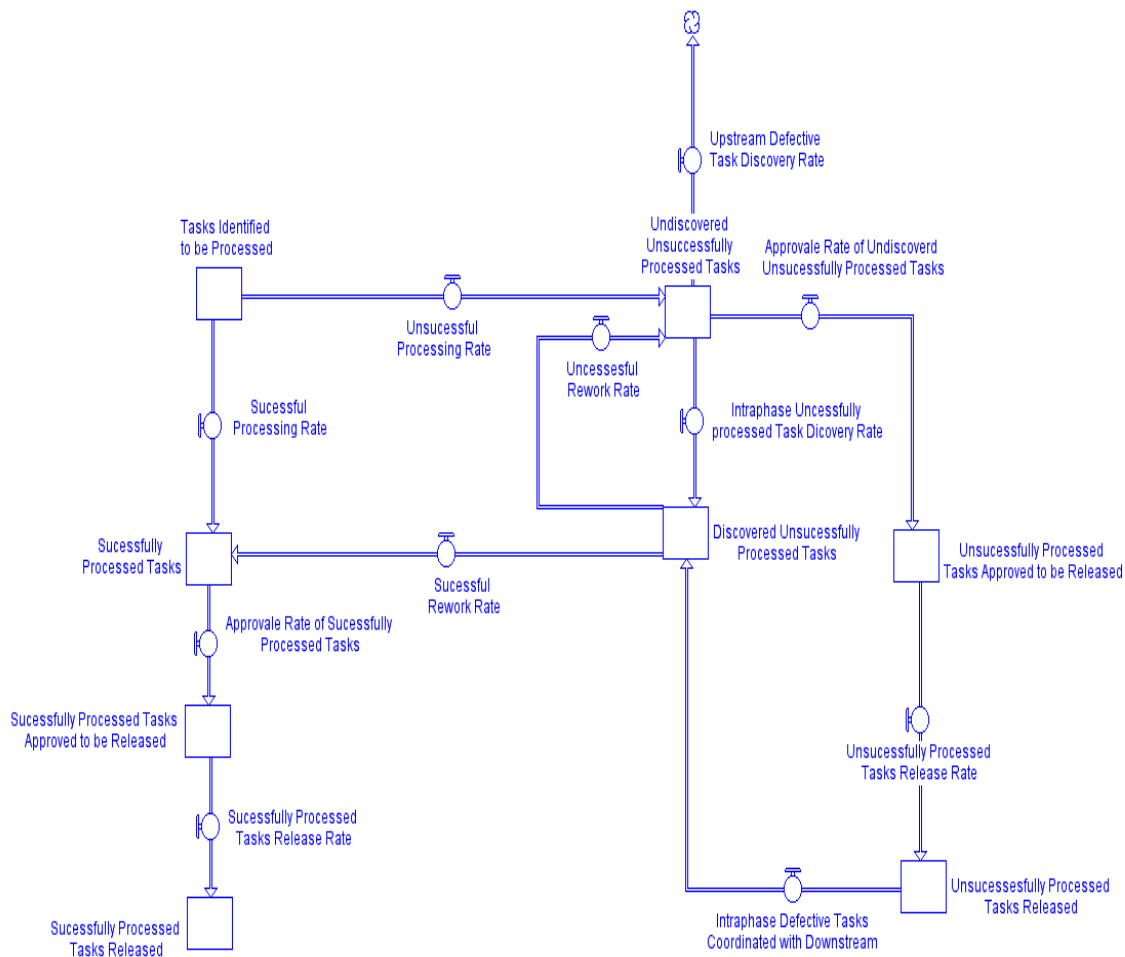


Figure 3.4 Stock and flow structures of the work process subsystem in a single phase

In a single phase, all the engineering works, which are measured in Tasks, must pass through a minimum of four stocks before they have been completely processed and released to the downstream phase.

Initially, all the tasks of a phase, those that are identified during the contract award and those discovered at later stages of the phase, accumulate in the “Task Identified to be Processed” stock. Depending on the performance of the task processing rate and the quality of practice in processing, the tasks then move onto either the “Undiscovered Unsuccessfully Processed Tasks” stock or to the “Successfully Processed Tasks” stock. All the processed tasks then pass through a quality assurance activity. The quality assurance activity has two objectives, the first one is to approve successfully processed task and the second one is to uncover unsuccessfully processed task.

If the quality assurance activity discovers unsuccessfully processed tasks and if the errors are generated within the phase, the flawed tasks move to the “Discovered Unsuccessfully Processed Tasks” stock for rework. Successfully reworked task then move to “Successfully Processed Tasks” stock and the unsuccessful ones back to the “Undiscovered Unsuccessfully Processed Tasks” stock for further inspection. If the errors are made outside the phase, then the flawed tasks move to the “Discovered Unsuccessfully Processed Tasks” stock of the upstream phase so that they can be reworked in the phase in which they were generated.

On the other hand, undiscovered unsuccessfully processed tasks accumulates temporarily in the “Unsuccessfully Processed Tasks Approved to be Released” stock to be delivered to the downstream phase. Similarly, successfully processed tasks that pass through the quality assurance activity accumulate in the “Successfully Processed Tasks Approved to be Released” stock for release. The temporarily accumulated tasks are then released to downstream phases.

One of the structural differences between Ford’s (1995) and ours model is that our model, for operational reasons, does not mix successfully and unsuccessfully processed tasks in the later stages of the work process. Operationally, stocks allow complete mixing of their contents (Sterman, 2000). Thus, if we did not disaggregate successfully and unsuccessfully processed tasks, there could be residuals inside the stocks that accumulate the two types of processed

tasks. However, disaggregation of the two types of processed tasks gives us an opportunity to investigate the sole effect of flawed tasks on the progress of the engineering phase, in particular and on the entire project progress as a whole. It also allows us to investigate the sole impact of flawed tasks on the nonconformance of the engineering phase to its targets.

A second structural difference between our model and Ford's is that in our model we have not explicitly describe a possible coordination that could exist across phases, particularly when a downstream phase identifies errors done by an upstream phase. This is for a good reason of simplicity. From our discussions with the company's managers, particularly with Interviewee 2, and from our document analysis, we have learned that employees are "not interested in registering neither the errors they made nor the errors done by their work colleagues". Although, they are supposed to register the errors discovered in a "Non-Confirmatory Report", this practice seem to be neglected. According Interviewee 2, the employees "did not want to look as stupid" by either registering their own errors or those of their work colleagues'. They, rather, immediately update each other so that the people who generate the errors can act on them. Furthermore, there are "no incentives for registering errors" as the customers are not "responsible for compensation of quality costs". Thus, in our model, discovered flawed tasks are sent immediately to the appropriate destinations for rework.

The complete model structure of the work process subsystem is relatively large and not well suited for portrayal in a single picture. We, thus, present the model components in ~~smaller~~ pieces, as we discuss on the equations incorporated.

In a single engineering phase, the three engineering activities; Regular Processing, Quality Assurance, and Rework, define the 'Work Process Subsystem'. Regular processing is the first engineering activity of the three. Here, tasks are processed for the first time. However, tasks pass through the other two engineering activities for additional engineering works. The processing rate of tasks, in all the three engineering activities, is determined by the minimum of two factors the processing limit from resources and the processing limit from task availability, as formulated with the following equations.

Regular_Processing_Rate = MIN (Regular_Processing_Limit_from_Resource,
Regular_Processing_Limit_from_Task_Availability)

Rework_Rate = MIN (Rework_Processing_Limit_from_Resources,
Rework_Processing_Limit_from_Task_Availability)

Quality_Assurance_Rate_1 = MIN (Quality_Assurance_Processing_Limit_from_Resources_1,
Quality_Assurance_Processing_Limit_from_Task_Availability_1)

Quality_Assurance_Rate_2 = MIN (Quality_Assurance_Processing_Limit_from_Resources_2,
Quality_Assurance_Processing_Limit_from_Task_Availability_2)

The “Processing Limits from Resource”, in each of the three engineering activities, represents the potential completion rate based on the size and productivity of the labor force. Labor force and productivity are described in the human resource subsystem.

Regular_Processing_Limit_from_Resource
= Daily_Labor_Force_to_Regular__Processing*Labor_Force_Productivity

Rework_Processing_Limit_from_Resources
= Daily_Labor_Force_to_Rework*Productivity_in_Rework

Quality_Assurance_Processing_Limit_from_Resources_1
= Daily_QA_Labor_Force_for_UnSuccessfully_Processed_Tasks*Productivity_in_Quality_Assurance

Quality_Assurance_Processing_Limit_from_Resources_2
= Daily_QA_Labor_force_to_Successfully_Processed_Tasks*Productivity_in_Quality_Assurance

On the other hand, the “Processing Limit from Task Availability” represents the maximum completion rate based on the number of tasks in the backlogs of each engineering activity and the minimum time required to process a task in that particular engineering activity.

Regular_Processing_Limit_from_Task_Availability
= Tasks_Available_for_Regular_Processing/Minimum_Regular_Processing_Duration_per_Task

Rework_Processing_Limit_from_Task_Availability
= Discovered_Unsuccessfully_Processed_Tasks / Minimum_Rework_Duration_per_Task

Quality_Assurance_Processing_Limit_from_Task_Availability_1
= Undiscoverd_Unsuccessfully_Processed_Tasks / Minimum_QA_Duration_per_Task

Quality_Assurance_Processing_Limit_from_Task_Availability_2
= Successfully_Processed_Tasks / Minimum_QA_Duration_per_Task

Based on the performance of the regular processing rate and the quality of practice (this is described in detail in the human resource section), a task can either be successfully processed or unsuccessfully processed. Tasks that are successfully processed accumulate to the successfully processed tasks stock, while the unsuccessful once accumulate in the

unsuccessfully processed tasks stock.

In order to disaggregate these two tasks, in the model, we first multiply the “Regular Processing Rate” with the fraction of unsuccessfully processed tasks that are inherited from the upstream engineering phase. This allows us to disaggregate the corrupted tasks of the downstream phase due to inherited errors from the upstream phase. The overall result then multiplies with the value of the quality of practice, “Probability to be Defective Task”. Figure 3.5 portrays these structural components. The equations that determine the rate of the two flows are shown below.

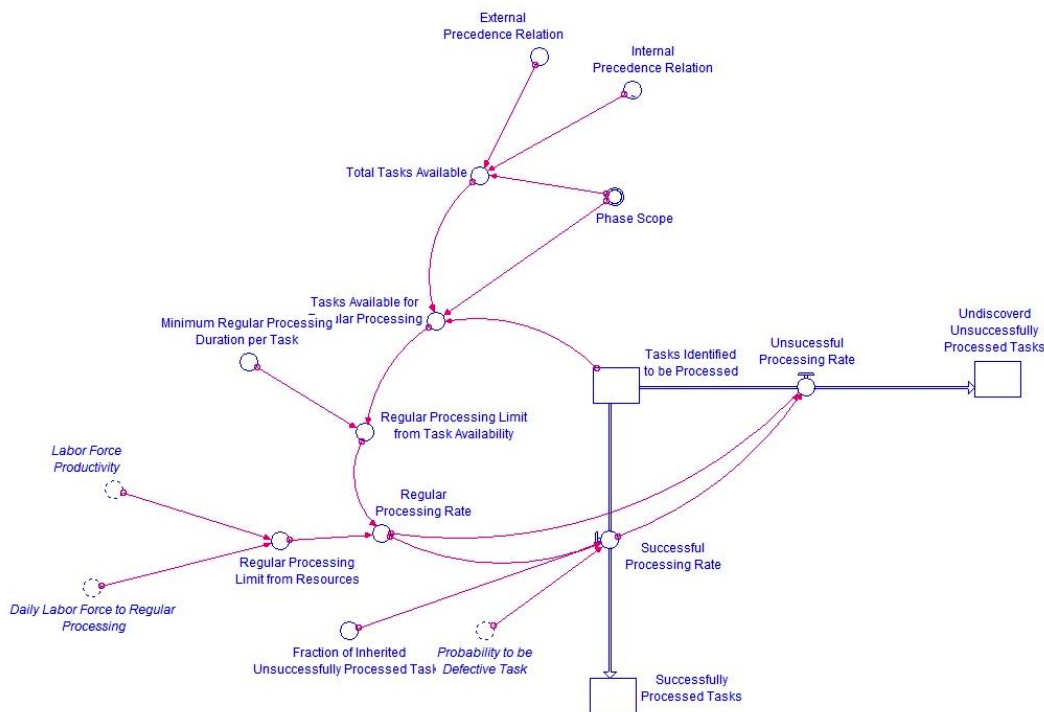


Figure 3.5 Regular Processing structure

$$\text{Successful_Processing_Rate} = \text{Regular_Processing_Rate} * (1 - \text{Fraction_of_Unsuccessfully_Processed_Upstream_Tasks_Released}) * (1 - \text{Probability_to_be_Defective_Task})$$

$$\text{Unsuccessful_Processing_Rate} = \text{Regular_Processing_Rate} - \text{Successful_Processing_Rate}$$

If an engineering phase is not dependent on any upstream phase, the fractional value of the inherited unsuccessful tasks is zero.

The two accumulated tasks then pass through the quality assurance activity. Pressman (1982) cited in Abdel-Hamid (1984) defined quality assurance as “a set of activities performed in conjunction with (development activities) to guarantee the outputs of the development activities meet the specific (set) standards” pp.200.

Several techniques are used in the company including self-check (by individual’s who carry out the task), intra disciplinary check (by team members from the same discipline),and interdisciplinary check (by team members from other disciplines).

In the model, the quality assurance activity determines four flows of the work processes subsystem model (Approval Rate of Successfully Processed Tasks, Approval Rate of Undiscovered Unsuccessfully Processed Tasks, Intraphase Unsuccessfully Processed Task Discovery Rate and Upstream Defective Task Discovery Rate). The structural components that make up the quality assurance are portrayed in the top right and bottom left corners of Figure 3.6.

Structurally, the simplest flow of the four is the “Approval Rate of Successfully Processed Tasks”. Here, the main responsibility of the quality assurance activity (Quality Assurance Rate 2) is only to approve successfully processed tasks. This is mainly because, we assume that tasks that do not require changes will not mistakenly considered to be in need of correction or improvement. Hence, the equation used in this flow is same as the equation used in Quality Assurance Rate 2.

$$\text{Approval_Rate_of_Successfully_Processed_Tasks} = \text{Quality_Assurance_Rate_2}$$

The other three flows are the result of the quality assurance activity in uncovering unsuccessfully processed tasks (Quality Assurance Rate 1). This effort is determined by the processing speed of “Quality Assurance Rate 1” and its effectiveness. The effectiveness of “Quality Assurance Rate 1” is measured in terms of the probability of finding unsuccessfully processed tasks. The value of this probability is calculated based on the ratio of the labor force allocated to the quality assurance activity to its labor force need (this is described in the Human resource subsystem). The rate of uncovering unsuccessfully processed tasks is portrayed by the equation,

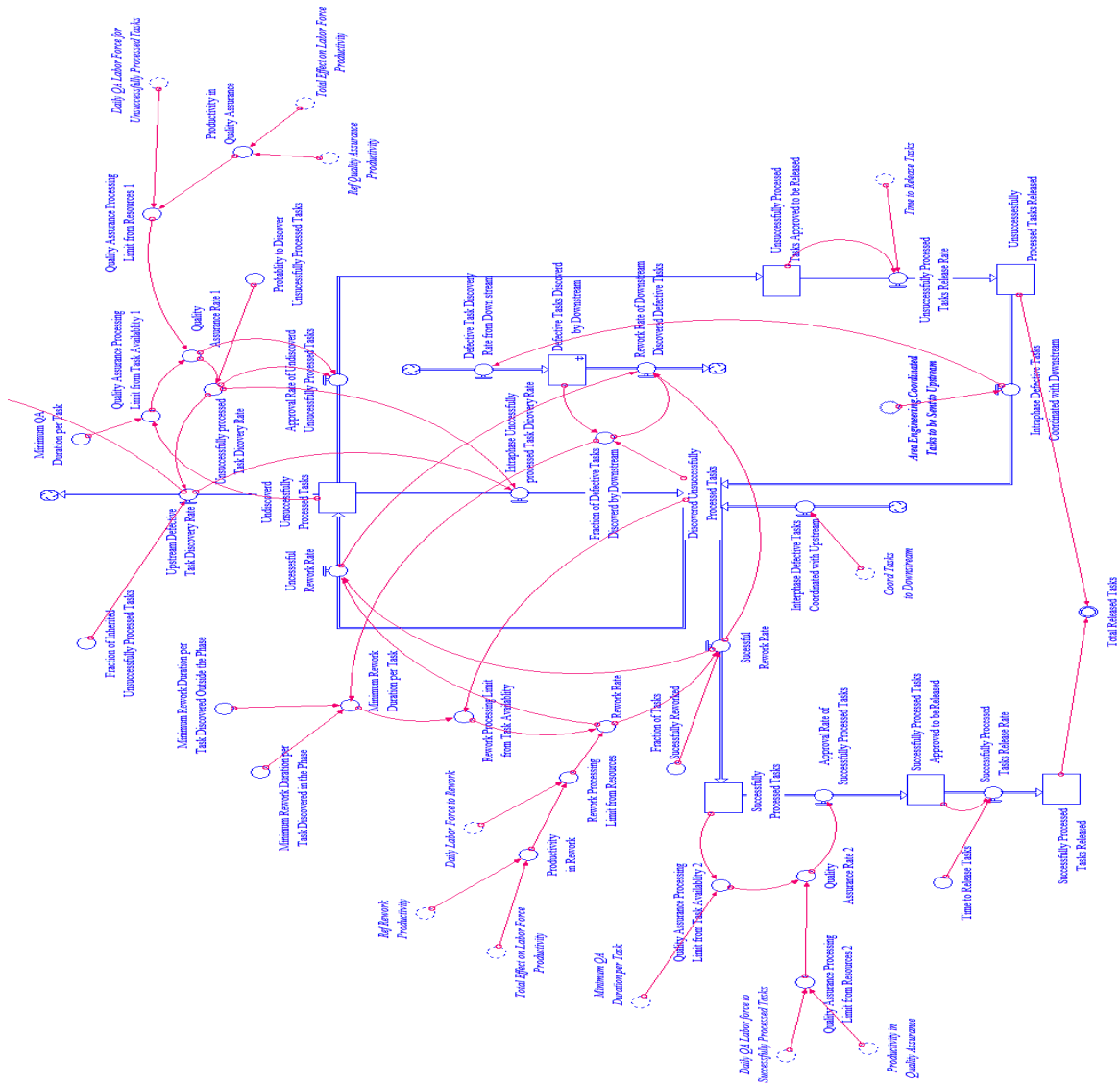


Figure 3.6 Quality Assurances and Rework Structure

$$\text{Unsuccessfully_processed_Task_Discovery_Rate} = \text{Quality_Assurance_Rate_1} * \text{Probability_to_Discover_Unsuccessfully_Processed_Tasks}$$

In its next step, the quality assurance activity identifies the phases where the detected errors are generated, so that they can be returned and reworked in the appropriate phase.

If the errors are generated within the phase, the flawed tasks accumulate in “Discovered Unsuccessfully Processed Tasks” stock to be reworked within the current phase. However, if

the errors are generated in the upstream phase, the flawed tasks are sent to the phase where they are generated.

The fractional value of inherited unsuccessfully processed tasks is used to disaggregate flawed tasks generated in the upstream phase from the once generated within the current phase. The assumption behind this formulation is that the number of detected upstream flawed tasks in the downstream phase is proportional to the number of flawed tasks released from the upstream phase. The equations for the two flows are shown below.

$$\text{Upstream_Defective_Task_Discovery_Rate} = \frac{\text{Fraction_of_Inherited_Unsuccessfully_Processed_Tasks} * \text{Unsuccessfully_processed_Task_Discovery_Rate}}$$

$$\text{Intraphase_Unsuccessfully_Processed_Task_Discovery_Rate} = \frac{\text{Unsuccessfully_processed_Task_Discovery_Rate} - \text{Upstream_Defective_Task_Discovery_Rate}}$$

Note here that, in our model, tasks do not move across phases. Instead, information about the size of flawed tasks is conveyed to the upper stream phases through the equation below.

$$\text{Defective_Tasks_to_be_Sent_to_Upstream} = \text{Upstream_Defective_Task_Discovery_Rate} * (\text{Upstream_Phase_Scope} / \text{Phase_Scope})$$

With the help of the information conveyed from downstream, flawed tasks are then subtracted from the stock of “Unsuccessfully Processed Tasks Released” of the upstream phase and sent to the “Discovered Unsuccessfully Processed Tasks” stock for rework.

Furthermore, since the total number of task in a phase need always to be equal to the scope of the project, we accumulate tasks that are equivalent to those sent to upstream in the “Tasks Identified to be Processed” stock by taking the co-flow of “Upstream Defective Task Discovery Rate”.

The fourth flow driven by the quality assurance activity is the release of undetected errors. Tasks that escape the quality assurance activity and mistakenly have been approved as successfully processed tasks, temporarily accumulate in the “Unsuccessfully Processed Tasks Approved to be Released” stock before they are released to downstream phases. The equation of this fourth flow is shown below.

$$\text{Approval Rate of Undiscovered Unsuccessfully Processed Tasks} = \text{Quality_Assurance_Rate}_1 - \text{Unsuccessfully_processed_Task_Discovery_Rate}$$

Finally, all detected flawed tasks need to be reworked. The performance of the rework rate and the quality of practice in rework determine the flow rates of successfully and unsuccessfully reworked tasks, as is shown in the equations below.

$$\text{Successful_Rework_Rate} = \text{Rework_Rate} * \text{Fraction_of_Tasks_Successfully_Reworked}$$

$$\text{Unsuccessful_Rework_Rate} = \text{Rework_Rate} - \text{Successful_Rework_Rate}$$

However, unlike the regular processing and quality assurance activities, inherited upstream errors have no effect in determining the rework flow rates. But, the speed of the rework activity could be affected by additional rework time demands of those tasks returned from downstream phases (Interviewee 2). The next paragraphs deal with these required processing times.

The “Minimum Processing Duration per Task” is the minimum amount of time required to process a task under an engineering activity by an experienced labor force, assuming no resource constrain. It describes the “purest time constraint, which an engineering activity imposes on progress” (Ford, 1995, PP.70). The value for “Minimum Processing Duration per Task” varies among the three engineering activities. We obtained these values from managers estimations during the second data collection phase.

The managers estimate the “Minimum Regular Processing Duration per Task” to be 1 workday and “Minimum QA Duration per Task” as 1 hour (0.13 workdays). The “Minimum Rework Duration per Task” varies. However, based on where the flawed tasks have been generated (Interviewee 2; Interviewee 3; Interviewee 4). If the error is made within the current phase, the value of the “Minimum Rework Duration per Task” is 1 hour (0.13 workdays). If it is made outside the current phase, the “Minimum Rework Duration per Task” is 0.5 workdays. In the company, 1 workday is equivalent to 7.5 hours.

As we discussed above, the “Processing Limit from Task Availability” is a function of “Task Availability”. The “Task Availability” in Quality Assurance and Rework activities refers for those tasks that have been processed at least once and then accumulated in the stocks of the engineering activities for further engineering works. The availability of these tasks is therefore

predominantly dependent on the processing rates of the preceding engineering activities and the engineering activity in which they are accumulated.

However, in regular processing, the backlog of tasks refers to those tasks that will be processed for the first time, and their availability is a function of various factors.

In the model, we have formulated “Tasks Available for Regular Processing” as the difference between those tasks that could be processed and those tasks that have been processed at least once, with the equation shown below.

$$\text{Tasks_Available_for_Regular_Processing} = \text{MAX}(0, \text{Total_Tasks_Available} - (\text{Phase_Scope} - \text{Tasks_Identified_to_be_Processed}))$$

The “Total Tasks Available” refers for those tasks that could be processed based up on the fraction of tasks that are perceived satisfactorily processed and released. This constraint is a function of the scope of work and associated work process precedence relations. We will address this issue in details in a short while.

Tasks that have been processed at least once, on the other hand, include the tasks in the two engineering activities, Quality Assurance and Rework, and those tasks that are released. In short, it refers for the difference been the “Phase Scope” and “Tasks Identified to be Processed”. If this difference is zero, then there are no tasks that are processed at lest once.

Getting a large number of flawed tasks while the regular processing rate is low may reduce the fraction of tasks that are perceived satisfactorily processed. This can in turn reduce the “Total Tasks Available” to a level below the number of tasks that are processed, causing an “infeasible negative number of tasks” available for the regular processing. “In actual projects this reflects a condition in which tasks requiring changes must be worked on before more tasks can be processed” (Ford & Sterman, 1998, pp.44). Thus, the maximum function in the above equation is introduced to incorporate a constraint that answers.....

As shown in the equation below, the “Total Tasks Available” is defined as the minimum amount of engineering work that can be processed based on the total scope of work of the engineering phase and the work process precedence relations.

$$\text{Total_Tasks_Available} = \text{Phase_Scope} * \text{MIN}(\text{Internal_Precedence_Relation}, \text{External_Precedence_Relation})$$

The precedence relations mainly determine “what percent of the phase’s scope is available for regular processing based upon the percent of tasks that are perceived satisfactorily processed and released” (Ford, 1995, pp.77).

There are two kinds of precedence relations, internal and external. The internal precedence relation describes the “work availability constraint that an engineering phase imposes as on itself by answering the question, how much work can be processed based upon how much work has been processed”. On the other hand, the external precedence relation describes the amount of work that can be processed in an engineering phase based on the percentage of work released by another engineering phase on which it is dependent. It is a “dependency between two phases” (Homer, et.al., 1985; Ford, 1995).

Ford (1995) used an example of a ten-story building construction to explain the precedence relations. In the construction of the building, the internal precedence relationship could capture the physical constraint that “the floors must be completed sequentially one at a time from the ground up because lower floors support those above” (pp.72). In our case, the external precedence relation could capture the constraint that procurement of construction materials cannot begin until the material specifications are available. These constraints may act as a bottleneck in the availability of work.

Introducing internal and external precedence relations into project management models has a number of benefits (Homer, et.al., 1985; Ford, 1995; Ford and Sterman (1998). For example, introducing internal precedence relations to a model alleviate us from making the assumption that all unprocessed tasks could be available for processing. Because, in big projects, “work process can and frequently do internally constrain the availability of work” (Ford, 1995, pp.72). In other words, internal precedence relationships signify the presence of interdependency between project tasks and that all tasks of a project cannot be processed in parallel.

On the other hand, the presence of external precedence relationships in a project model help us better understand why projects are behaving the way they do. This is mainly because external precedence relations can “represent the work process dependencies better than traditional

project management methods, such as the Critical Path Methods (CPM) and Program Evaluation and Review Technique (PERT)” (Ford & Sterman, 1998, pp.47). For example, unlike CPM and PERT methods,

- External precedence relations describe the “dependency between two phases along the entire duration of the phases instead of only at the start and finish of the phases”.
- External precedence relationships can be “non-linear”.
- External precedence relations describe a “dynamic relationship” between the engineering phases by allowing the output to vary over the life of the project, depending on the current conditions of the project. For example, if design drawings are returned from A real Engineering (the downstream phase) to System Engineering (the upstream phase) for rework, then the work available to A real Engineering is reduced, possibly requiring A real Engineering activities to cease until the drawings have been changed and rereleased. In contrast, “the precedence relationships used in many CPM and PERT methods are “static” (Ford & Sterman, 1998, pp.47).

In the model, both internal and external precedence relations are defined with table functions. The table functions are generated based on the company’s project execution philosophy, “Priority Matrix”, and data from DolWin2 project. We have also consulted literature to obtain “realistic graphical regions”, in which precedence relations could be represented. For example, a table function that describes an internal precedence relation “cannot lay below a 45⁰ lines”, otherwise the engineering “work cannot be processed until it is already processed” (Ford & Sterman, 1998, pp.45).

The three table functions below represent the internal precedence relations in the System Engineering, Engineering for Procurement and Area Engineering phases, respectively.

Internal_Precedence_Relation = GRAPH (Fraction_of_Tasks_Perceived_Completed)
GRAPH (Fraction_of_Tasks_Perceived_Completed) =
(0.00, 0.026), (0.1, 0.17), (0.2, 0.376), (0.3, 0.573), (0.4, 0.658), (0.5, 0.796),
(0.6, 0.868), (0.7, 0.91), (0.8, 0.953), (0.9, 0.986), (1.00, 1.00)

Internal_Precedence_Relation = GRAPH (Fraction_of_Tasks_Perceived_Completed)
GRAPH (Fraction_of_Tasks_Perceived_Completed) =
(0.00, 0.042), (0.1, 0.241), (0.2, 0.457), (0.3, 0.628), (0.4, 0.753), (0.5, 0.846),
(0.6, 0.904), (0.7, 0.94), (0.8, 0.972), (0.9, 0.994), (1.00, 1.00)

Internal_Precedence_Relation = GRAPH(Fraction_of_Tasks_Perceived_Completed)
GRAPH (Fraction_of_Tasks_Perceived_Completed) =
(0.00, 0.034), (0.1, 0.208), (0.2, 0.421), (0.3, 0.583), (0.4, 0.675), (0.5, 0.788),
(0.6, 0.852), (0.7, 0.899), (0.8, 0.941), (0.9, 0.98), (1.00, 1.00)

The “Fraction of Tasks Perceived Completed” refers to the ratio between the tasks that are

perceived as satisfactorily processed in the phase and the scope of work in that phase. The “Tasks Perceived Completed” includes all processed tasks other than those recognized to contain with flaws.

$$\text{Fraction_of_Tasks_Perceived_Completed} = \text{Tasks_Perceived_Completed} / \text{Phase_Scope}$$

$$\begin{aligned} \text{Tasks_Perceived_Completed} = & \text{Sucessfully_Processed_Tasks} + \\ & \text{Undiscoverd_Unsucessfully_Processed_Tasks} + \\ & \text{Sucessfully_Processed_Tasks_Approved_to_be_Released} + \\ & \text{Unsucessfully_Processed_Tasks_Approved_to_be_Released} + \\ & \text{Sucessfully_Processed_Tasks_Released} + \\ & \text{Unsucessfully_Processed_Tasks_Released} \end{aligned}$$

The external precedence relation is defined as the minimum of all the process precedence relations upon which an engineering phase is dependent. In the model, an engineering phase could be constrained by the workflow of its upstream and downstream phases. Therefore, the external precedence relation is formulated with the equation shown below.

$$\text{External_Precedence_Relation} = \text{MIN}(\text{External_Precedence_from_Down_stream}, \text{External_Precedence_from_Up_stream})$$

External precedencies, both from upstream and down-stream, are represented by table functions of the “Fraction of Released Tasks” of their respective phases. For example, the “Fraction of Released Tasks” from upstream phase is the ratio of the number of tasks released by the upstream phase to the scope of the upstream phase.

Note that the external precedence relation is 1 for a phase that is not constrained by another phase.

3.4.1.2 The Scope Subsystem

The scope subsystem in our model represents the total amount of engineering work to an engineering phase. The amount of work to an engineering phase changes when additional work is discovered in the later stages of the phase or when the customer asks additional work in the project and that work is recorded and settled as variation order.

In the model, we have captured the initial scope of work and the later changes as the function of the overall scope of work. We assumed that the determination of the initial scope of work the

company and/or the customer under estimated the total (overall) work and, hence at the later stages this work will pop up as the project progress. Thus, we defined the initial scope of work as ‘Current Scope’, which later changes as the number of tasks processed and released increases, or in short when the projects progress increase. We used the equation below to represent the scope of work and its change in the model.

$$\text{Scope_of_Work} = \text{GRAPH}(\text{Total_Released_Tasks} / \text{Total_number_of_Tasks})$$

$$\text{Current_Scope} = \text{Scope_of_Work}$$

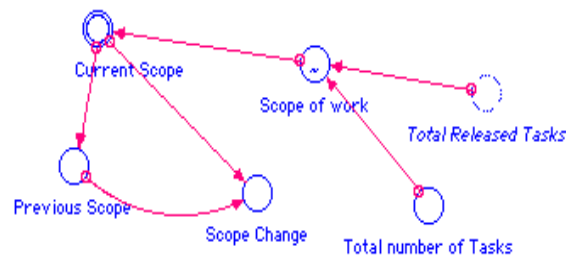


Figure 3.7 The scope structure

3.4.2 The Human Resource Subsystems

The human resource subsystems describe the labor force, their productivity and their quality of practice in the engineering activities of a single phase. The first subsection describes the labor force and its allocation into the different activities of an engineering phase. In the second subsection, we discuss the labor force productivity and the factors that affect productivity. In the third subsection of the resource subsystem, we discuss on the quality of practice of the labor force in different engineering activities.

3.4.2.1 The Labor Force

The Labor force subsection of the human resource subsystem deals with the composition and quantity of the labor force and their allocation to different engineering activities. The structural components of the labor force sector are based on previously developed system dynamics models, mainly, model components developed by Abdel-Hamid (1984).

3.4.2.1.1 Composition of the Labor Force

The total labor force of the company can be classified into two broad categories, Company Employees and External Hired-Ins. The company employees are those who have long-term contracts (also referred as permanent contracts). They are usually recruited based on the company's long-term capacity building. On the other hand, external hired-ins are recruited for a short time. They are usually recruited to carry out specific and specialized jobs. Moreover, compared to company employees, the cost of external hired-ins is high.

In the model, these two broad categories of the labor force are further disaggregated to five groups, three under company employees and two under external hired-Ins. Thus, in a single engineering phase, the "Total Labor Force" is the sum of "New Employees", "Transferred-in Company Employees", "Experienced Employees", "New Hired-In Externally" and "Experienced Hired-In Externally". Figure 3.8 and 3.9 shows both company employees and externally hired-ins. There are two basic reasons for the additional disaggregation of the labor force, difference in productivity and difference in hiring and assimilation times. In the sections below we will discuss these differential factors in details.

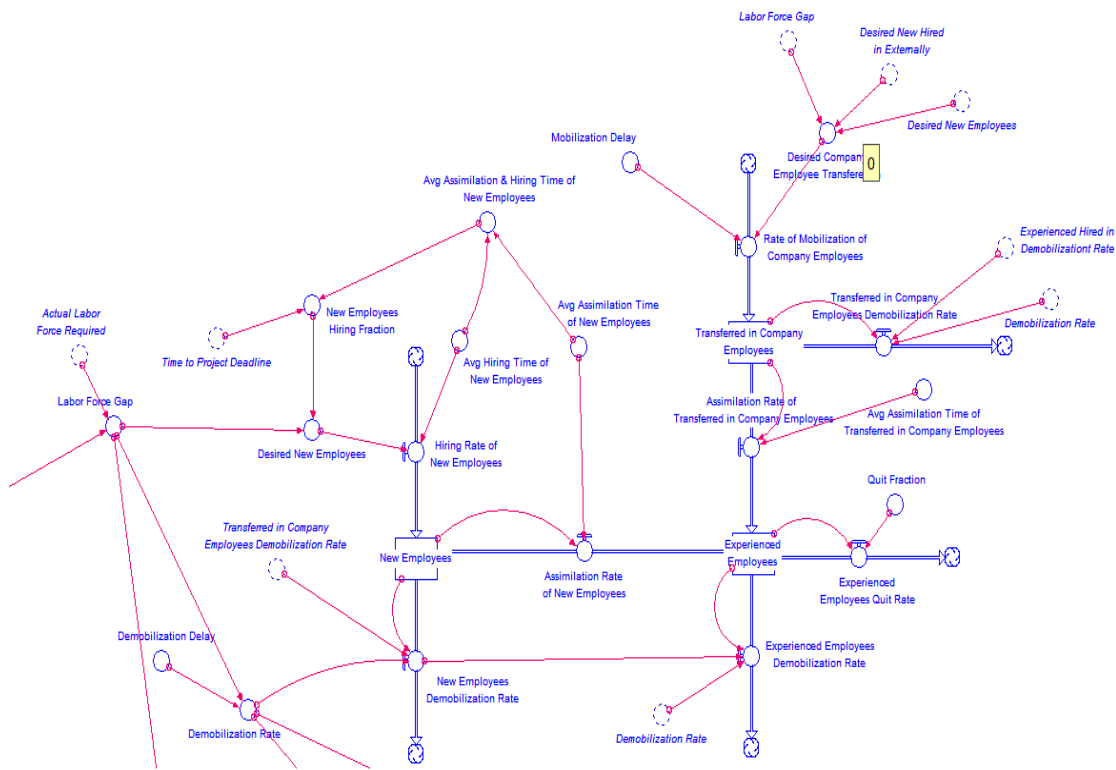


Figure 3.8 Company Employees

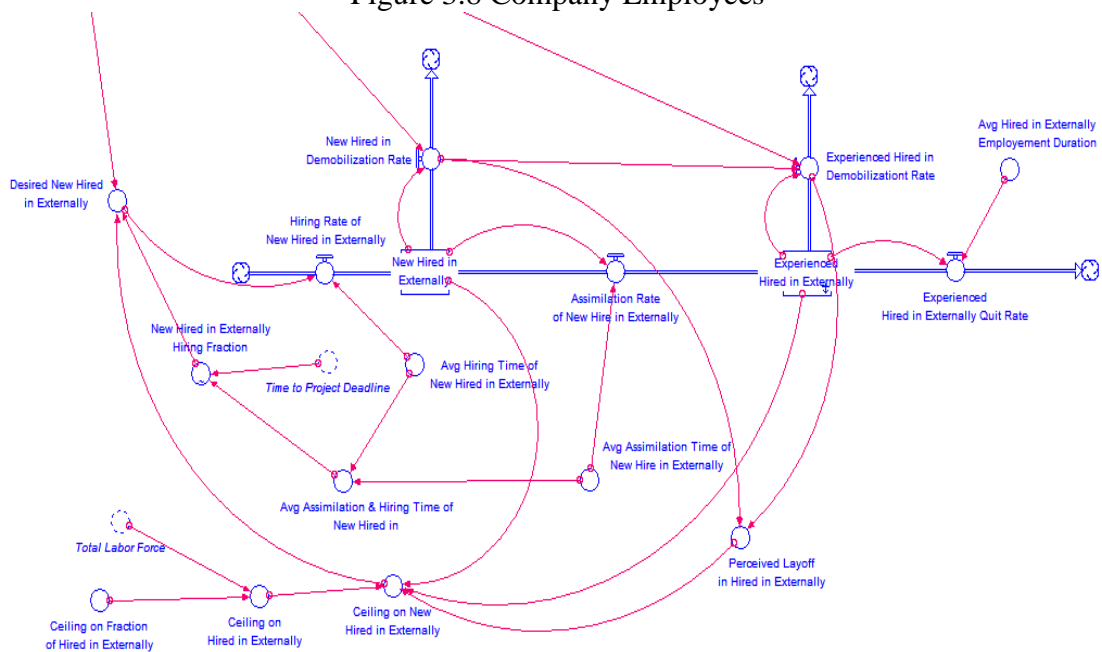


Figure 3.9 Externally Hired-Ins

In a single engineering phase, the number of “Experienced Employees” increases, when either “New Employees” are hired and assimilated or when “Transferred-in Company Employees” are mobilized and assimilated to the project team. The “Demobilization Rate” and the “Quit Rate” reduce the number of experienced employees in the project. Similarly, the number of “Experienced Hired-In Externally” increases when “New Hired-In Externally” are recruited and assimilated to the project and their number decreases when they either “Quit” the project or when they are “Demobilized”.

When a new project member joins the labor force (whether he/she is a new company employee, or is transferred in from another project of the company, or is a new external hired-In), he/she passes through “project orientation period” (assimilation period) (Abdel-Hamid, 1984). During the orientation period, the new project member learns about “the project’s ground rules, the goals of the effort, the plan of work, and all the details of the system” on the expenses of experienced project members project time (Thayer and Lehman, 1997 cited in Abdel-Hamid, 1984, pp.123). In this assimilation period, the new project member is less productive than the experienced one (detail discussion is presented in the labor force productivity sector). This productivity difference is one of the reasons for separating the new labor force members from the experienced once.

The second reason for the disaggregation of the labor force is the additional assimilation time required by “New Employees”. In addition to “project orientations”, the new company employees require additional “social” and “technical” trainings than “Transferred-in Company Employees” (Abdel-Hamid, 1984, Interviewee 2). Thus, the new employees have longer assimilation periods (Interviewee 2; Interviewee 3; Interviewee 4). In the model, the values for the assimilation periods are taken from managers’ estimations. The average value of the managers’ estimations for the “Assimilation Time of New Employees” is 60 workdays, for the “Assimilation Time of Transferred-in Company Employees” and “Assimilation Time of New Hire in Externally” is 20 workdays (Interviewee 2; Interviewee 3; Interviewee 4). The equations for the assimilation rates of the three labor force groups are shown below.

$$\text{Assimilation_Rate_of_New_Employees} = \frac{\text{New_Employees}}{\text{Avg_Assimilation_Time_of_New_Employees}}$$

$$\text{Assimilation_Rate_of_Transferred_in_Company_Employees} = \frac{\text{Transferred_in_Company_Employees}}{\text{Avg_Assimilation_Time_of_Transferred_in_Company_Employees}}$$

$$\text{Assimilation_Rate_of_New_Hire_in_Externally} = \frac{\text{New_Hired_in_Externally}}{\text{Avg_Assimilation_Time_of_New_Hire_in_Externally}}$$

The number of “New Employees” and “New Hired-In Externally” increases in an engineering phase, when they are hired. Their numbers decrease when they are, either assimilated with the experienced labor force or when they are demobilized from the project. Similarly, the number of “Transferred-in Company Employees” increases, when they are Transferred-in from other projects of the company. Their number decreases when they are, either assimilated with the experienced labor force or when they are demobilized from the project.

The decision for adding or reducing labor force from the project is made based on the values of the “Labor Force Gap”, which is the difference between the “Actual Labor Force Required” in the engineering phase and the “Total Labor Force” of the phase.

In order to determine the level of the “Actual Labor Force Required” to an engineering phase, managers consider various factors. In our model, the following four factors are considered as important determinants.

1. Scheduled completion
2. Labor force stability
3. Training requirement and
4. The trend in labor force demand

The first of the four factors is the scheduled project completion date. The difference between the scheduled completion date and the current simulation time gives the time remaining to complete an engineering phase. It is formulated, not as an actual calendar date, but as a number of working days.

In the model, an engineering phase has two deadlines, internal deadline and project deadline. The internal deadline serves as a reference date for completing the 70% of the engineering work before construction activities are started, whereas, the project deadline is a contractually

agreed date for completing the entire engineering work. The project deadline is a fixed deadline, whereas, the internal deadline is, somewhat flexible. Hence, the scheduled completion date varies on the basis of the deadlines, which we are refereeing (detail discussion is presented in the ‘Schedule Target’ section of the Target subsystem).

On the basis of these two deadlines and the “Expected Average Productivity” (see productivity section) of the labor force, the managers determine the level of the labor force, “Indicated Labor Force”, whom they believe could complete the remaining tasks of the phase within the scheduled completion time.

$$\text{Indicated_Labor_Force} = (\text{Total_Man_Days_Perceived_Still_Needed} / \text{Time_Remaining_to_Deadline}) / \text{Avg_Daily_Labor_Force_PerStaff}$$

$$\text{Total_Man_Days_Perceived_Still_Needed} = \text{Remaining_Tasks} / \text{Expected_Average_Productivity}$$

The assumption behind the above formulation is that, in the determination of the required labor force, managers do not consider the backlog of works in each engineering activity separately to determine the labor force required to each activity, rather they take the whole backlog of work in an engineering phase, hence, use an average productivity, which we refer as “Expected Average Productivity”. Detail discussion on expected productivity is presented in the productivity sector.

The “Avg Daily Labor Force PerStaff” is used to determine the actual number of the indicated labor force. The value in the numerator, “Total_Man_Days_Perceived_Still_Needed/Time_Remaining_to_Deadline”, only represents the full time equivalent of the labor force (also called budgeted labor force). If actual labor force are not assigned as full time on the project, say if the labor force is participating in more than one project, adjustment should be made. This is achieved in the model by dividing the full time equivalent labor force with the “Avg Daily Labor Force PerStaff”.

In the equation above, the “Remaining Tasks” could refer for two things, the remaining task until the 70% of the phase scope (for the internal deadline) or the remaining tasks until the total phase scope (for the project deadline).

$$\text{Remaining_Tasks} = \text{Phase_Scope} - \text{Total_Released_Tasks}$$

The indicated labor force, however, is not plainly be compared with the total labor force and translated into labor force needs of the engineering phase. Rather, managers also consider labor force stability.

Before recruiting new project members, managers try to contemplate the duration of need for these new members. The relative weighting between the desire for labor force stability on the one hand, and the desire to complete the project on time, on the other, changes with the stage of project completion (Abdel-Hamid, 1984, pp. 259).

Hence, the “Labor Force Needed” is formulated as a weighing average of the “Total Labor Force” and the “Indicated Labor Force”, taking into account the desire for labor force stability and the desire to complete the project within the scheduled time.

$$\text{Labor_Force_Needed} = \frac{\text{MIN}((\text{Willingness_to_Change_Labor_Force_Level} * \text{Indicated_Labor_Force} + (1 - \text{Willingness_to_Change_Labor_Force_Level}) * \text{Total_Labor_Force}), \text{Indicated_Labor_Force})}{1}$$

This formulation only applies as long as the “Indicated Labor Force” is larger than the “Total Labor Force”, indicating additional labor force to be recruited to the project. Otherwise, the “Labor Force Needed” takes the value of the “Indicated Labor Force”. The formulations for the weighting factors are discussed in the schedule target section of Target subsystem.

The third factor that managers consider in the decision regarding the required labor force, is the “projects ability to absorb new project members, to train them and make them as an integral part of a productive team” (Abdel-Hamid, 1984, pp. 129). Here, managers consider the “capacity and comfort” of their experienced labor force to handle new project members (Interviewee 2). In the model, we have captured such a restriction with a variable called “Ceiling on New Labor Force”. The value of this variable is determined by the product of “Full Time Experienced Labor Force”, which is the sum of “Experienced Employees” and “Experienced Hired-In Externally”, and “Max New Recruit Per Full Time Experienced Labor Force”.

$$\text{Ceiling_on_New_Labor_Force} = \text{Full_Time_Equivalent_of_Experienced_Labor_Force} *$$

$$\text{Max_New_Recruit_Per_Full_Time_Experienced_Labor_Force}$$

$$\text{Full_Time_Equivalent_of_Experienced_Labor_Force} = \frac{\text{Max_New_Recruit_Per_Full_Time_Experienced_Labor_Force}}{\text{Experienced_Labor_Force}} * \text{Avg_Daily_Labor_Force_PerStaff}$$

$$\text{Experienced_Labor_Force} = \text{Experienced_Employees} + \text{Experienced_Hired_in_Externally}$$

“Max New Recruit Per Full Time Experienced Labor Force” refers for the maximum number of new project members that a single full time experience labor force can handle effectively. This number varies across experienced engineers, ranging from 1 to 4, and across different engineering phases as well (Interviewee 2; Interviewee 3; Interviewee 4). However, on average, the “Max New Recruit Per Full Time Experienced Labor Force” is 2 for both the System Engineering and the Area Engineering phases, and it is 1 for the Engineering for Procurement phase (Interviewee 2; Interviewee 3; Interviewee 4).

The “Ceiling on New Labor Force” together with the number of “Experienced Labor Force”, then determines the “Ceiling on Total Labor Force”.

$$\text{Ceiling on Total Labor Force} = \text{Ceiling_on_New_Labor_Force} + \text{Experienced_Labor_Force}$$

Finally, the minimum of the “Ceiling on Total Labor Force” and the “Labor Force Needed” determines the “Labor Force Sought” in the engineering phase.

$$\text{Labor_Force_Sough} = \text{MIN}(\text{Labor_Force_Needed}, \text{Ceiling_on_Total_Labor_Force})$$

However, this sought labor force does not still be automatically translate into the recruitment goal of the engineering phase. We assume that the management team also considers at the trends in the labor force sought by the engineering phase, and make decisions on the actual required labor force, which later serves as a recruitment goal. There are two basic reasons behind this assumption.

First, and foremost, the time needed to hire and assimilate a new project member to a labor force is relatively long and the procedures are costly, because the trainee consumes experienced labor force capacity. While “the experienced labor force helps the new labor force learn the job, his own productivity on his other job is reduced” (Abdel-Hamid, 1984, pp.124). In the model, based on managers’ estimations (Interviewee 2; Interviewee 3) and literature findings (particularly of Abdel-Hamid, 1984), a new labor force, on average, consumes the equivalent of

20% of an experienced labor force's daily working time for the duration of the training or assimilation period.

The second reason is that the required engineers, particularly those with the necessary skills, are not always available in the market (Interviewee 2). Hence, project managers may not be interested to release their assets immediately.

We have formulated the “Actual Labor Force Required” with the help of trend functions. According to Sterman (2000),

TREND represents a behavioral theory of how people form expectations and takes into account the time required for people to collect and analyze data, the historic time horizon they use, and the time required to react to changes in the growth rate. The input to the TREND function can be any variable. The output is an estimate of the fractional growth rate in the input variable (pp. 634).

Let us now discuss the basic operation of the trend function before we go to the discussion of the structures and the equations of the trend function in our model. Assume that at time ‘ t_1 ’ the value of the input is ‘A’ and at time ‘ t_2 ’ it is ‘B’. The fractional increase from ‘A’ to ‘B’ is then given by comparing the new value, ‘B’, with its reference value, ‘A’. Hence,

$$\text{Fractional Increase} = (B - A)/A$$

If we divide this fractional increase by the change in time between ‘ t_2 ’ and ‘ t_1 ’, we can get the output, called the trend. Then, in order to find the value of ‘C’ at a later time ‘ t_3 ’, we need to multiply ‘B’ with the rate of change in the fractional increase and the difference in time between ‘ t_3 ’ and ‘ t_2 ’ as shown below.

$$\text{Trend} = \text{Fractional Increase} / (t_2 - t_1)$$

$$C = B * \text{Trend} * (t_3 - t_2)$$

In our model, the input to the TREND function is the “Labor Force Sought” and the output is the fractional growth rate in the labor force sought, “Trend in Labor Force Sought”, as is shown in the equation below. The structural components of the trend function are adopted from

Sterman (2000) and are shown in Figure 3.10.

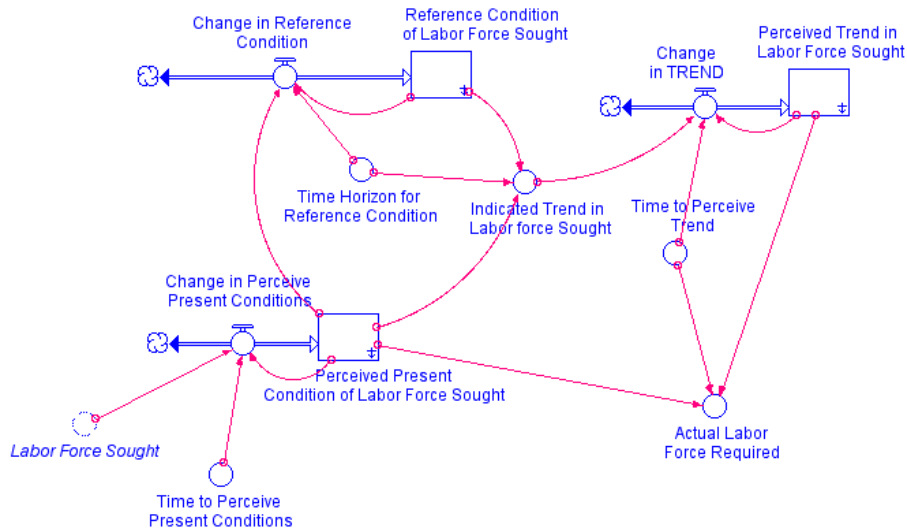


Figure 3.10 Structure of the Trend function

Unlike the above discussion, in the model, all the instantaneous values are smoothed in the formulation of the Trend function. First order smoothing is assumed. Hence, “Perceived Present Condition of Labor Force Sought” is the smoothed value of “Labor Force Sought”, with a smoothing delay, “Time to Perceive Present Conditions”, of one week (5 workdays). This delay is equal to the project reporting time.

$$\text{Perceived_Present_Condition_of_Labor_Force_Sought}(t) = \text{Perceived_Present_Condition_of_Labor_Force_Sought}(t - dt) + (\text{Change_in_Perceive_Present_Conditions}) * dt$$

$$\text{Change_in_Perceive_Present_Conditions} = \frac{(\text{Labor_Force_Sought} - \text{Perceived_Present_Condition_of_Labor_Force_Sought})}{\text{Time_to_Perceive_Present_Conditions}}$$

The “Perceived Present Condition of Labor Force Sought” is compared to its past value, measured by the “Reference Condition of Labor Force Sought”, to see whether there is a change in the “Labor Force Sought”. This change is then adjusted with the “Time Horizon for Reference Condition”. The “Time Horizon for Reference Condition” is taken as two weeks (10 workdays). This is the time horizon, which we assume as relevant for manager to make forecasts about the required labor force. In our discussions with the managers (particularly with Interviewee 2), we have learned that, as a rule-of-thumb, managers should not keep a labor

force neither underloaded nor overloaded for more than two weeks.

$$\text{Reference_Condition_of_Labor_Force_Sought}(t) = \text{Reference_Condition_of_Labor_Force_Sought}(t - dt) + (\text{Change_in_Reference_Condition}) * dt$$

$$\text{Change_in_Reference_Condition} = (\text{Perceived_Present_Condition_of_Labor_Force_Sought} - \text{Reference_Condition_of_Labor_Force_Sought}) / \text{Time_Horizon_for_Reference_Condition}$$

The “Time Horizon for Reference Condition” is also used to discount past values of perceived inputs of the labor force sought (Sterman, 2000). Hence, the indicated fractional growth rate (“Indicated Trend in Labor Force Sought”), which is the most up-to-date on the current fractional change in the input”, is formulated with the equation shown below (Sterman, 2000, pp.636).

$$\text{Indicated_Trend_in_Labor_force_Sought} = ((\text{Perceived_Present_Condition_of_Labor_Force_Sought} - \text{Reference_Condition_of_Labor_Force_Sought}) / (\text{Reference_Condition_of_Labor_Force_Sought})) / \text{Time_Horizon_for_Reference_Condition}$$

The indicated trend then slowly adjusts with the perceived trend to help managers make decisions. The “Time to Perceive Trend”, that is, the time required for a change in the indicated trend to be recognized and accepted by managers as a basis for their actions, is set in the model as 5 working days.

$$\text{Perceived_Trend_in_Labor_Force_Sought}(t) = \text{Perceived_Trend_in_Labor_Force_Sought}(t - dt) + (\text{Change_in_TREND}) * dt$$

$$\text{Change_in_TREND} = (\text{Indicated_Trend_in_Labor_force_Sought} - \text{Perceived_Trend_in_Labor_Force_Sought}) / \text{Time_to_Perceive_Trend}$$

The product between the “Perceived Trend in Labor Force Sought” and the “Perceived Present Condition of Labor Force Sought” together with the “Time to Perceive Trend” determines the “Actual Labor Force Required”.

$$\text{Actual_Labor_Force_Required} = \text{Perceived_Present_Condition_of_Labor_Force_Sought} + \text{Perceived_Present_Condition_of_Labor_Force_Sought} * \text{Perceived_Trend_in_Labor_Force_Sought} * \text{Time_to_Perceive_Trend}$$

Once the “Actual Labor Force Required” is decided, managers face one of the three possible situations. If the difference between “Actual Labor Force Required” and “Total Labor Force”,

“Labor Force Gap”, is positive, the managers make decisions to add additional labor force to the project. If it is negative, project members will be demobilized from the project. If the gap is zero, no further action is necessary.

$$\text{Labor_Force_Gap} = \text{Actual_Labor_Force_Required} - \text{Total_Labor_Force}$$

In the first situation, where the required labor force is higher than the total labor force, the managers need to make decisions about whether to hire “New Employees” or “New Hired-In Externally” or to transfer in company employees from other projects. Such decisions are part of the company’s policy.

As a rule of thumb, whenever there is a need for labor force in a particular project, the company gives the highest priority to the transfer of personnel from other projects (Interviewee 2; Interviewee 3; Interviewee 4). However, as part of its long-term capacity building, the company also hires some new employee from the outside world. Not only this, the company also keeps some positions for external hire ins, because, all personals involved in one project may not be need in others project of the company plus the hiring and firing of company employees costs much more than external hired-ins (Interviewee 2). Besides, certain project jobs demand very specific specializations. Thus, the recruitment efforts need to consider the trade offs between these three policies.

In the model, we have captured such trade offs with three variables “Desired New Employees”, “Desired New Hired-In Externally” and “Desired Company Employee Transferee in”. The desired for new labor force is a function of the “Labor Force Gap” in the engineering phase and a “Hiring Fraction” of the respective labor force.

$$\text{Desired_New_Employees} = \text{Labor_Force_Gap} * \text{New_Employees_Hiring_Fraction}$$

$$\text{Desired_New_Hired_in_Externally} = \text{MIN}(\text{Ceiling_on_New_Hired_in_Externally}, \\ \text{Labor_Force_Gap} * \text{New_Hired_in_Externally_Hiring_Fraction})$$

$$\text{Desired_Company_Employee_Transferee_in} = \\ \text{Labor_Force_Gap} - (\text{Desired_New_Hired_in_Externally} + \text{Desired_New_Employees})$$

Since neither the company’s long-term capacity building nor post-project effects are within the model’s boundary, it is difficult to explicitly define the “Hiring Fraction” among the three new project members, New Employees, New Hired-In Externally and Transferred-in Company

Employees. However, we determine the values of “Hiring Fractions” on the bases of managerial intuitions and some “rules-of-thumb”.

The rules-of-thumb are:

- among new project members, 60% to 80% should be recruited from other projects of the company (Transferred-in Company Employees) (Interviewee 2; Interviewee 3)
- “New Employees” should be recruited in the early periods of the project and their fraction should not be more than one third of new project members (Interviewee 2)
- the total number of external hire ins should not be more than 30% of the total labor force (Interviewee 2)

The managerial intuitions include, “new project members should give services to a project at least twice more that the time they consume during their hiring and assimilation periods” (Interviewee 2; Interviewee 3).

With this background, we formulated table functions for the “Hiring Fractions” of “New Employees” and “New Hired-In Externally” as shown below.

New_Employees__Hiring_Fraction =
GRAPH (Time_to_Project_Deadline / Avg_Assimilation_&_Hiring_Time_of_New_Employees)

GRAPH (Time_to_Project_Deadline / Avg_Assimilation_&_Hiring_Time_of_New_Employees) =
(0.00, 0.00), (0.3, 0.00), (0.6, 0.00), (0.9, 0.00), (1.20, 0.01), (1.50, 0.04), (1.80, 0.08),
(2.10, 0.15), (2.40, 0.25), (2.70, 0.33), (3.00, 0.33)

New_Hired_in_Externally_Hiring_Fraction =
GRAPH (Time_to_Project_Deadline / Avg_Assimilation_&_Hiring_Time_of_New_Hired_in)

GRAPH (Time_to_Project_Deadline / Avg_Assimilation_&_Hiring_Time_of_New_Hired_in) =
(0.00, 0.5), (0.5, 0.5), (1.00, 0.35), (1.50, 0.3), (2.00, 0.25), (2.50, 0.17), (3.00, 0.1),
(3.50, 0.03), (4.00, 0.03)

In the model, the “Hiring Rates” of both “New Employees” and “New Hired-In Externally”, and the “Rate of Mobilization of Company Employees” are formulated as a function of the desired numbers of the respective labor force and their hiring delay.

Hiring_Rate_of_New_Employees =
MAX(0, Desired_New_Employees/Avg_Hiring_Time_of_New_Employees)

Hiring_Rate_of_New_Hired_in_Externally =
MAX(0, Desired_New_Hired_in_Externally /Avg_Hiring_Time_of_New_Hired_in_Externally)

$$\text{Rate_of_Mobilization_of_Company_Employees} = \frac{\text{MAX}(0, (\text{Labor_Force_Gap} - \text{Desired_New_Hired_in_Externally} - \text{Desired_New_Employees}))}{\text{Mobilization_Delay}}$$

The managers estimated the “Avg Hiring Time of New Employees” as 40 workdays, the “Avg Hiring Time of New Hired-In Externally” as 14 workdays and the “Mobilization Delay” as 10 working days (Interviewee 2; Interviewee 3; Interviewee 4). The ‘MAX’ function is used in the above equations to prevent an infeasible flow through the hiring and mobilization rates, particularly, when there is a negative desire of labor force.

When the labor force gap is negative, project members need to be demobilized. In the demobilization effort, “New Hired-In Externally” and “Experienced Hired-In Externally” are the first to leave a project; usually they leave the company for good. If still more demobilization is needed, “Transferred-in Company Employees”, who are yet to be assimilated, will be transferred out to other projects. “New Employees” and “Experienced Employees” are the last to leave a project (Interviewee 2; Interviewee 3; Interviewee 4).

The “Demobilization Delay” (the time needed for paper works and handing project materials to the remaining members) is the same for all employees, 10 working days (Interviewee 2; Interviewee 3; Interviewee 4), hence the “Demobilization Rate” is formulated as,

$$\text{Demobilization Rate} = \text{MAX}(0, -\text{Labor_Force_Gap} / \text{Demobilization_Delay})$$

The equation below shows the demobilization rate for each labor force and the sequence of their demobilization from the project.

$$\text{New_Hired_in_Externally_Demobilization_Rate} = \text{MIN}(\text{Demobilization_Rate}, \text{New_Hired_in_Externally} / \text{DT})$$

$$\text{Experienced_Hired_in_Externally_Demobilization_Rate} = \text{MIN}(\text{Experienced_Hired_in_Externally} / \text{DT}, (\text{Demobilization_Rate} - \text{New_Hired_in_Externally_Demobilization_Rate}))$$

$$\text{Transferred_in_Company_Employees_Demobilization_Rate} = \text{MIN}(\text{Transferred_in_Company_Employees} / \text{DT}, (\text{Demobilization_Rate} - (\text{New_Hired_in_Externally_Demobilization_Rate} + \text{Experienced_Hired_in_Externally_Demobilization_Rate})))$$

$$\text{New_Employees_Demobilization_Rate} = \text{MIN}(\text{New_Employees} / \text{DT}, (\text{Demobilization_Rate} -$$

$$(New_Hired_in_Externally_Demobilization_Rate + \\ Experienced_Hired_in_Externally_Demobilization_Rate + \\ Transferred_in_Company_Employees_Demobilization_Rate)))$$

$$Experienced_Employees_Demobilization_Rate = \\ MIN (Experienced_Employees/DT, (Demobilization_Rate - \\ (New_Employees_Demobilization_Rate + \\ Experienced_Hired_in_Externally_Demobilization_Rate + \\ New_Hired_in_Externally_Demobilization_Rate + \\ Transferred_in_Company_Employees_Demobilization_Rate)))$$

The size of the project members is not only reduced by demobilization rates, but there is also turn over of company employees and expiration of contracts of externally hired-ins.

The turn over rate in the company fluctuates between 4% and 7% in the past five years, but recent internal reports show that the turn over is averaged around 5%. The company calculates turn over rates, only based on its permanent employees. The maximum contractual period for externally hire ins, on the other hand, is 12 months.

We have captured the turn over rates and the rate of contractual expirations through the “Experienced Employees Quit Rate” and “Experienced Hired-In Externally Quit Rate”, respectively. Here, we assume that there is no turn over with, either newly hired employees or Transferred-in company employees. We also assume that, new hire ins will not terminate their contract before its expiration date. The equations for the two rates are shown below.

$$Experienced_Employees_Quit_Rate = Experienced_Employees * Quit_Fraction$$

$$Experienced_Hired_in_Externally_Quit_Rate = \\ Experienced_Hired_in_Externally / Avg_Hired_in_Externally_Employment_Duration$$

3.4.2.1.2 Labor Force Allocation

The Labor force allocation sector (Figure 3.11) calculates the fraction of the daily labor force which managers applies to the regular processing, quality assurance and rework activities. The allocation is carried out based on the backlogs of work pressures. These backlogs of work pressures are calculated based on the work available from the process and the perceived productivity of the labor force in each engineering activity (detail discussion on perceived productivity is presented on the labor force productivity section).

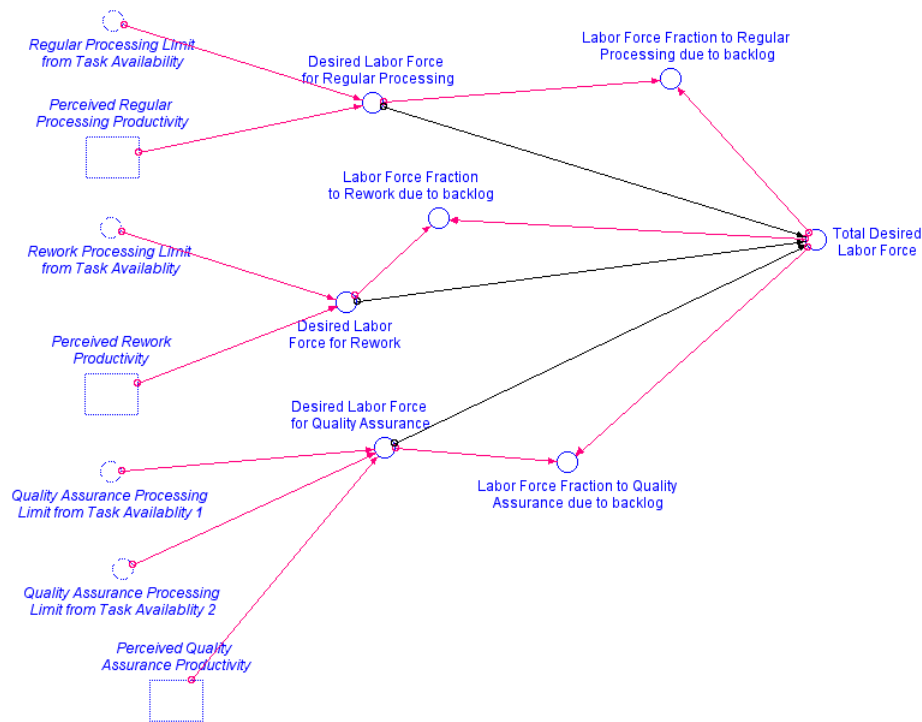


Figure 3.11 Labor Force Allocation Sector

The equations used in the labor force allocation sector are described below.

$$\text{Desired_Labor_Force_for_Regular_Processing} = \frac{\text{Regular_Processing_Limit_from_Task_Availability}}{\text{Perceived_Regular_Processing_Productivity}}$$

$$\text{Desired_Labor_Force_for_Rework} = \frac{\text{Rework_Processing_Limit_from_Task_Availability}}{(\text{Perceived_Rework_Productivity})}$$

$$\text{Desired_Labor_Force_for_Quality_Assurance} = \frac{(\text{Quality_Assurance_Processing_Limit_from_Task_Availability_1} + \text{Quality_Assurance_Processing_Limit_from_Task_Availability_2})}{(\text{Perceived_Quality_Assurance_Productivity})}$$

The desired labor force for each engineering activity is the number of people-days required to complete the available work as determined by the work process limit. The sum of the desired labor force from each engineering activity determines the total desired labor force for all the activities.

$$\text{Total_Desired_Labor_Force} = \text{Desired_Labor_Force_for_Regular_Processing} + \text{Desired_Labor_Force_for_Rework} + \text{Desired_Labor_Force_for_Quality_Assurance}$$

The ratio between the “Total Desired Labor Force” and the individual activities desired labor force determines the labor force fraction to each engineering activity.

$$\text{Labor_Force_Fraction_to_Regular_Processing_due_to_backlog} = \frac{\text{Desired_Labor_Force_for_Regular_Processing}}{\text{Total_Desired_Labor_Force}}$$

$$\text{Labor_Force_Fraction_to_Rework_due_to_backlog} = \frac{\text{Desired_Labor_Force_for_Rework}}{\text{Total_Desired_Labor_Force}}$$

$$\text{Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog} = \frac{\text{Desired_Labor_Force_for_Quality_Assurance}}{\text{Total_Desired_Labor_Force}}$$

The labor force allocated daily to each engineering activity (Figure 3.12) is the product between the labor force fractions to each engineering activity and the total labor force available daily for the engineering activities in the phase.

$$\text{Daily_Labor_Force_to_Regular_Processing} = \text{Daily_Labor_Force_for_Engineering_Activities} * \text{Labor_Force_Fraction_to_Regular_Processing_due_to_backlog}$$

$$\text{Daily_Labor_Force_to_Rework} = \text{Daily_Labor_Force_for_Engineering_Activities} * \text{Labor_Force_Fraction_to_Rework_due_to_backlog}$$

$$\text{Daily_Labor_Force_to_Quality_Assurance} = \text{Daily_Labor_Force_for_Engineering_Activities} * \text{Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog}$$

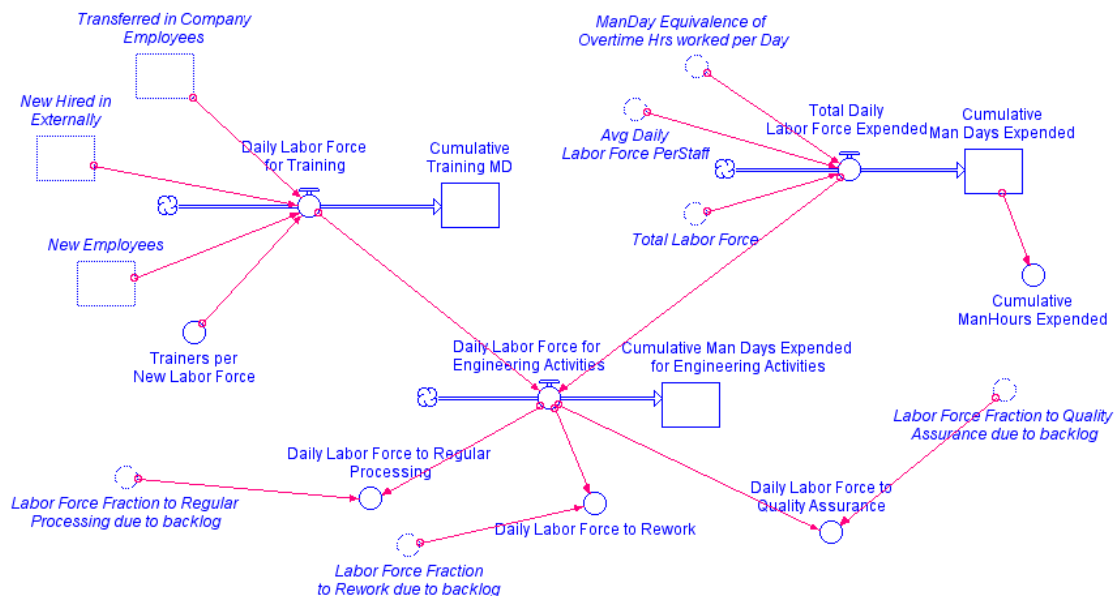


Figure 3.12 Daily Labor Force to Engineering activities

The “Daily Labor Force For Engineering Activities” is the total labor force available daily for the engineering activities after “Daily Labor Force for Training” is subtracted from the “Total Daily Labor Force Expended” in the engineering phase.

$$\text{Daily_Labor_Force_for_Engineering_Activities} = \text{Total_Daily_Labor_Force_Expended} - \text{Daily_Labor_Force_for_Training}$$

The total “Daily Labor Force Expended” is a function of “Total Labor Force” level, “Average Daily Labor Force PerStaff” and “ManDay Equivalence of Overtime Hrs Worked per Day”, if any overtime is done.

$$\text{Total_Daily_Labor_Force_Expended} = \text{Total_Labor_Force} * \text{Avg_Daily_Labor_Force_PerStaff} + \text{ManDay_Equivalence_of_Overtime_Hrs_Worked_per_Day}$$

In some projects of the company, the “Average Daily Labor Force PerStaff” is less than 1, implying a labor force is only spending a fraction of his/her workday to the particular project. In that case, The “Total Daily Labor Force Expended” is less than the “Total Labor Force”, provided there is no overtime activity. However, in the DolWin Beta project the “Average Daily Labor Force PerStaff” is 1 days/days.

The “Daily Labor Force for Training” represents the amount of time each new project member consumes in training. As discussed above in section 3.4.2.1.1, on average each new project member consumes in training overhead the equivalent of 20% of an experienced labor force’s time for the duration of the training (assimilation) period.

$$\text{Daily Labor Force for Training} = \frac{(\text{New_Employees} + \text{New_Hired_in_Externally} + \text{Transferred_in_Company_Employees}) * \text{Trainers_per_New_Labor_Force}}$$

3.4.2.2 Productivity

In this section of the human resource subsystem, we discuss on the different types of productivities under two subsections. In the first subsection, we discuss on the labor force productivity, which is the maximum productivity level of the labor force, and the various factors that affects it. In the second subsection, we discuss on the perceived productivities, expected average productivity and actual productivities of the labor force.

3.4.2.2.1 Labor Force Productivity

The “Labor Force Productivity Sector” represents the productivity level of the labor force. The model in this sector is developed to capture the maximum productivity level of the labor force, which is not constrained by availability of tasks. In the model, we assume that the maximum productivity level of the labor force could potentially be affected by two main variables, average skill of the labor force and factors associated with the status of a project and its work conditions. The section below addresses how a change in the reference (initial) skill level of the labor force, due to project familiarity and a status of a project and its associated work conditions, affects the Labor Force’ productivity.

The model structure is portrayed in Figure 3.13. It is formulated based on interviews with the company’s managers and previous system dynamics models, mainly based on the works of Abdel-Hamid (1984), Homer et. al. (1985) & Ford (1995). The equations incorporated in this model component are described below.

“Labor Force Productivity” is formulated as the product of “Potential Productivity” and “Total Effect on Labor Force Productivity”, where “Potential Productivity” is the average skill of the labor force at any point in time in the project and “Total Effect on Labor Force Productivity” represents the gross effect of various productivity enhancing and limiting factors associated with status of a project and current work conditions.

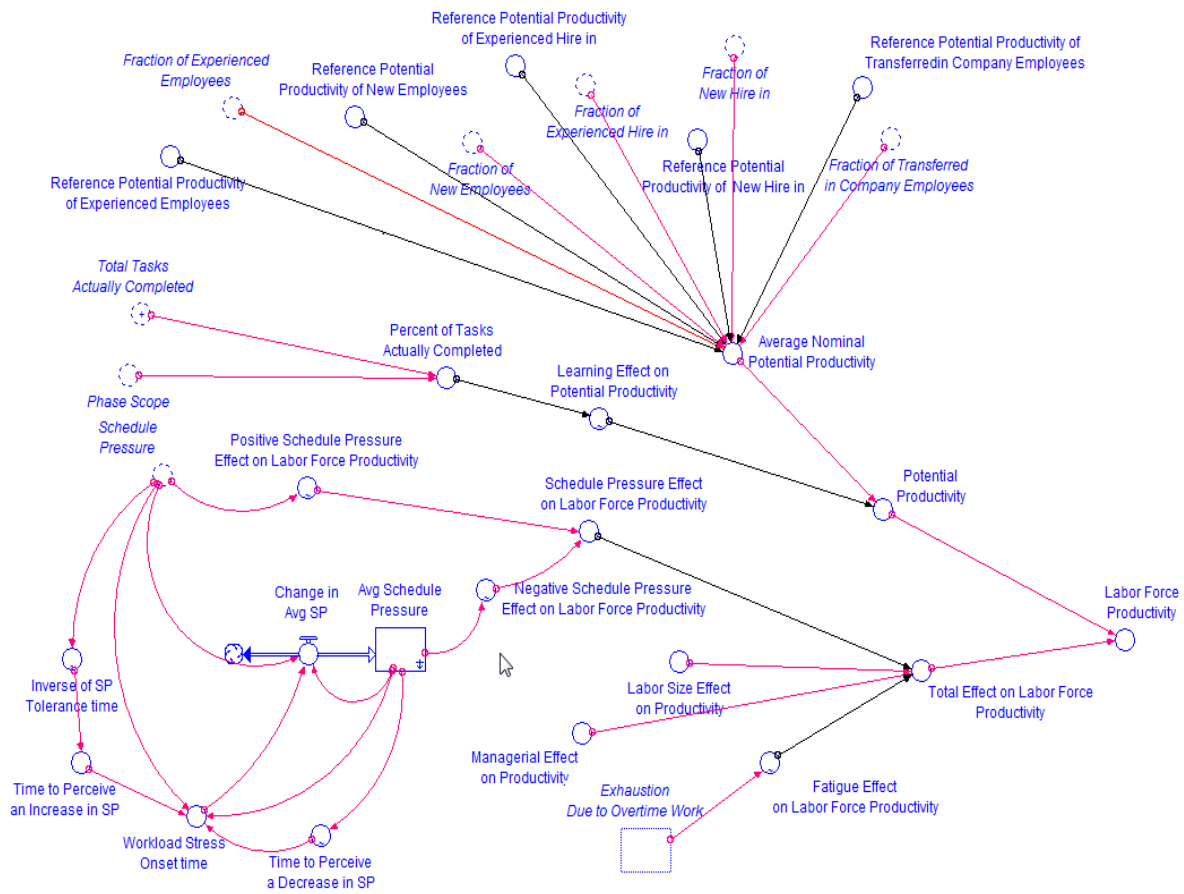


Figure 3.13 Labor Force Productivity Sector

$$\text{Labor_Force_Productivity} = \text{Potential_Productivity} * \text{Total_Effect_on_Labor_Force_Productivity}$$

Let us now explore the two factors separately.

3.4.2.2.1.1 Potential Productivity

“Potential Productivity” is the “level of productivity that will be attained if the labor force makes the best possible use of its resources under regular working condition” (that is, if there is no loss or gain of productivity due to faulty processes and schedule pressures) (Abdel-Hamid, 1984, pp 161).

The value of the “Potential Productivity” changes only when the nominal (reference) potential productivity level of the Labor Force mix, called “Average Nominal Potential Productivity”,

changes due to a change in the labor force mix or when there is an increase in project familiarity due to the learning curve (Abdel-Hamid, 1984).

$$\text{Potential_Productivity} = \frac{\text{Average_Nominal_Potential_Productivity} * \text{Learning_Effect_on_Potential_Productivity}}{\text{Learning_Effect_on_Potential_Productivity}}$$

a) *Average Nominal Potential Productivity*

“Average Nominal Potential Productivity” represents the nominal potential productivity level of the labor force mix at any point in time in the project. The concept of nominal potential productivity is introduced from Abdel-Hamid’s model. Abdel-Hamid (1984) defined “Nominal Potential Productivity” as

“the maximum level of ...productivity that can occur in a regular working condition when an individual employs his/her fund of resources to meet the task demands for ... a specific project within a specific organization” (p.155).

This definition denotes that, under normal work condition, “Nominal Potential Productivity” is influenced by two basic factors in a particular project of a company, ‘Resources’ and ‘Tasks’. First let us define ‘Resources’, taking ‘Tasks’ as a constant.

The model considers that only the human resource factor varies in a particular project of the company. That is, labor force with different experience level could have different “Nominal Potential Productivity”. Given identical tasks under the same work condition, an experienced labor force may process the task much faster than a rookie one. However, all the other resources, such as materials (both in physical & electronic forms), that will be used for processing a task are considered constant and identical across different work groups. The possible introduction of technologically advanced capital that could enhance the productivity level of a labor force in a given task in the course of a particular project are considered to be outside of the model’s boundary.

The second determinant of “Nominal Potential Productivity” is ‘Tasks’. According to Abdel-Hamid (1984), there are two ways to represent the relation between “Nominal Potential Productivity” and “Tasks”. The first one is defining “Tasks” in terms of “Nominal Potential Productivity”, so that a “Tasks” will be m “Nominal Potential Productivity” per workday of a

labor force. The second way is fixing the values of “Nominal Potential Productivity” and changing the values of “Tasks”, so that the “Nominal Potential Productivity” will be x “Tasks” per workday of a labor force.

In this model, we chose the second form of representation and defined “Nominal Potential Productivity” in terms of “Tasks”. This is, because, in the various departments of the company “Tasks” are defined differently with different units of measure. For example, the System Engineering department defined “Tasks” in terms of the number of drawings & the number of material specification documents that need to be produced, the Areal Engineering department defined “Tasks” in terms of the number of 3D models that need to be modeled, the Procurement department defined it in terms of the weight of materials that need to be procured, the Construction department defined it in terms of the weight of steels that need to be cut, prefabricated and assembled (Interviewee 1; Interviewee 2; Interviewee 3). Thus, for the sake of clarity and easy representation we will define the “Nominal Potential Productivity” for the labor force groups to be x Task/People-Day.

With the help of this definition of “Nominal Potential Productivity”, we set the nominal potential productivity level for the average experienced labor force to be 1Task/People-Day. This is then referred with a variable name “Reference Potential Productivity of Experienced Employees”. Note here that the average experience is defined in the model in terms of the ‘relevant experience’ associated with the current project under consideration, not the total number of employment years in the company. By ‘relevant experience’ we mean, project specific experiences achieved through engagement in similar, previous projects of the company.

The reference potential productivities for the other labor force groups, namely the “New Employees”, “New Hired-In Externally”, “Experienced Hired-In Externally” & “Transferred-in Company Employees” are then defined relative to the values taken for “Reference Potential Productivity of Experienced Employees”. The estimated relative values have been provided through the interviews (Interviewee 2; Interviewee 3; Interviewee 5).

The “Reference Potential Productivity of Experienced Hired-In Externally” value is set to be the same as the nominal productivity of the average experienced labor force, 1 Tasks/People-Day. On the other hand, for “New Hired-In Externally” and “Transferred-in Company Employees” the values are set to be 0.8 Tasks/People-Day. Moreover, the value for the “Reference Potential Productivity of New Employees” is set to be 0.5 Tasks/People-Day.

At any point in time in the project, the “Average Nominal Potential Productivity” for the labor force mix is then the weighted average of the reference nominal potential productivity of the labor force groups, weighted with their respective fractions of the labor force (Abdel-Hamid, 1984).

With this background, let us now define “Tasks”. In the model, “Tasks” is a unit for measuring the amount of work of a project. “Tasks” can be anything, drawings, analytical solutions, 3D model codes, material specification documents ... However, for operational reasons “Tasks” are defined as the amount of a project work that requires one “Normal Work Day” of an experienced labor force, who has a “Nominal Potential Productivity” level of one. A “Normal Work Day” in the company is equivalent to 7.5 hours. This definition of “Tasks” allowed us to determine a project scope.

b) Effect of Learning on Potential Productivity

In addition to the “Average Nominal Potential Productivity”, the “Potential Productivity” could also be affected by the learning effect, when there is an increase in project familiarity due to the learning curve (Abdel-Hamid, 1984; Ford, 1995).

The effect of learning is formulated in the model under the variable “Effect of Learning on Potential Productivity”. The assumption behind the formulation of this variable is that more experience always increases productivity and this experience only occurs when a labor force carry out the “Regular Processing” activity. No experience is added through “Rework” or “Quality Assurance” activities. Moreover, conditions such as, major developments in technologies during the project period that could obsolete past experiences, are not represented in the model as they are beyond the model boundary.

The learning curve is represented with a monotonically increasing S-shaped curve, Figure 3.14, that starts with the value 1 at the beginning of the project and peaks at a value of 1.3 at the end of the project.

The peaking value is chosen based on literature and interview results. In the software development model, Abdel-Hamid (1984) expected the learning curve to peak to at 25% above this initial value. Ford (1995) estimated the learning curve to peak at around 33% above its initial value for a new product development model. A manager in the company (Interviewee 2) estimated based on his experience that the learning curve could peak at 30% of its initial value at the end of an engineering project work. Thus, in the model, we set this final value so that the peaking occurs 30% above its initial value.

The equation used to formulate the effect of learning is shown below.

$$\text{Effect_of_Learning_on_Potential_Productivity} = \text{GRAPH}(\text{Percent_of_Tasks_Actually_Completed})$$

$$\text{Percent_of_Tasks_Actually_Completed} = \text{Total_Tasks_Actually_Completed} / \text{Phase_Scope}$$

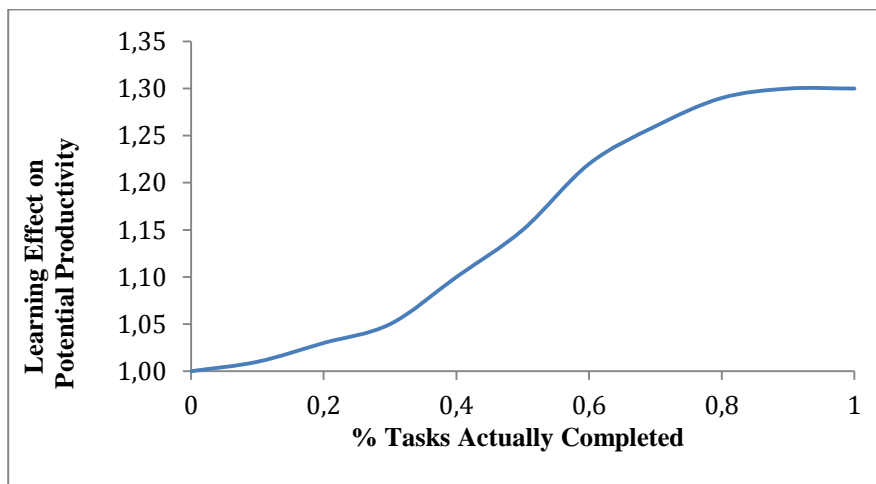


Figure 3.14 Learning curve

3.4.2.2.1.2 Total Effect on Labor Force Productivity

One of the most difficult tasks for managers of complex projects is keeping a project to its set goals throughout its lifetime. When managers perceive that a project is behind schedule, they consider one or more of the following three strategic options to bring it back to its target (Sterman, 2000; Interviewee 1; Interviewee 2; Interviewee 3; Interviewee 4).

- a) Increase the workload of a regular workday (spend less time per task)
- b) Increase the workweek hours (work overtime)
- c) Increase the capacity (hire additional labor force)

Each strategy involves different delays, cost and consequences (Sterman, 2000). Thus, in the model we have first introduced these strategies individually to investigate their effects, subsequently, we merge them to find how they synergize.

In the model “Total Effect on Labor Force Productivity” represents the gross product of the effects of schedule pressure and fatigue due to overtime work on the productivity of the labor force.

$$\text{Total_Effect_on_Labor_Force_Productivity} = \text{Effect_of_Schedule_Pressure_on_Labor_Force_Productivity} * \text{Effect_of_Fatigue_on_Labor_Force_Productivity} *$$

In the absence of such effects the “Total Effect on Labor Force Productivity” takes a value of 1 and the “Labor Force Productivity” equals the “Potential Productivity”. However, during the lifetime of complex projects, the occurrence of both productivity enhancing and diminishing factors is the rule rather than the exceptions (Abdel-Hamid, 1984; Homer et. al., 1985; Ford, 1995; Sterman, 2000). Thus, let us explore the individual effects first and then, finally, the gross effect.

a) *Effect of Schedule Pressure on Labor Force Productivity*

When the company’s managers perceive that a project is behind its schedule, they first check whether the labor force are working at full workload at their full “Potential Productivity” (Interviewee 2; Interviewee 3). They then impose a work pressure so that the labor force process more tasks per regular workday hours than they otherwise would do. Here the increase in throughput is achieved by reducing the time per task, not through overtime work. That is, in such periods the labor force tend to “reduce the standard time allocated for a task” in addition

to reducing their “slack time; time spent in off-project activities such as personal-businesses and non-project communications” so that the total time spent per task will be reduced more than it otherwise would be and the labor force processes more tasks per regular workday hours than they otherwise would do (Abdel-Hamid, 1984; Sterman, 2000).

However, such pressures could only be effective for only limited periods of time given a heightened workload. If the pressures persist, the effect will be diminishing returns. Thus, the negative effects of stress gain strength, eventually causing productivity per person in the labor force to decline more than the increase in schedule pressure (Abdel-Hamid, 1984; Homer et. al., 1985; Sterman, 2000).

In the model, such an effect of schedule pressure is introduced by defining the labor force productivity as a function of schedule pressure.

$$\text{Effect_of_Schedule_Pressure_on_Labor_Force_Productivity} = f(\text{Schedule_Pressure})$$

$$\text{Schedule_Pressure} = \text{Total_Man_Days_Perceived_Still_Needed} / \text{Total_Available_Man_Days}$$

The “Schedule Pressure” is defined as the ratio of the total man-days required to complete the project and the total available man-days until the current project deadline.

In the absence of schedule pressure, which can be either above one (that is, when the project is perceived to be behind its schedule) or below one (that is, when the project is perceived to be a head of its schedule), effect of schedule pressure on labor force productivity is unity.

In the literature it is claimed that schedule pressure has an inverted U-shaped effect on labor force productivity, where the peak of the curve is achieved with an optimal workload (Homer et. al., 1985; Sterman, 2000; Williams, 2001). However, formulating such a curve with a single non-linear equation creates ambiguity (Sterman, 2000). Because, according to Sterman (2000), hump or inverted U-shaped curves indicates the presence of multiple causal pathways between the inputs and outputs. Sterman recommends that each causal path should be represented separately so that the individual effects have a unique, unambiguous polarity. Therefore, in the model, the effect of schedule pressure on labor force productivity is formulated as a product of two monotonic functions, one representing the productivity enhancing positive effect of

schedule pressure and the other one representing the productivity diminishing negative effect of schedule pressure.

Effect of Schedule Pressure on Labor Force Productivity =

$$\frac{\text{Positive_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity}}{\text{Negative_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity}} *$$

Let us now discuss each of these monotonic functions, the positive effect first. The “Positive Effect of Schedule Pressure on Labor Force Productivity” could be explained with two extreme reference policy curves, a reference policy curve of unity and a curve that corresponds to a 45⁰ line (Sterman, 2000).

At one extreme end, the labor force may be completely insensitive to schedule pressure, devoting a standard time to each task (1 People-Day/Tasks for labor force with reference potential productivity of 1Tasks/People-Day), so that the “Labor Force Productivity” equals the “Potential Productivity Level” no matter how large the pressure to increase throughput may be. This policy means the “Positive Effect of Schedule Pressure on Labor Force Productivity” is always unity (Sterman, 2000). At the other extreme, the labor force may adjust their productivity level to the level they perceive is necessary to handle all the perceived man-days needed above or below the available man-days.

To derive this policy, let us assume that the “Regular Processing Limit from Tasks Availability” (section 3.4.1) is not a constraint so that the labor force “Expected Average Productivity-EAP”, $\text{Tasks_Perceived_Completed/Cumulative_Man_Days_Expended}$, equals their “Potential Productivity-PP” and the “Desired Productivity-DP” ($\text{Remaining_Tasks/Total_Available_Man_Days}$) equals the “Labor Force Productivity-LFP”. Hence,

$$\text{LFP} = \text{PP} * f_p^+(\text{SP})$$

where $f_p^+(\text{SP})$ and SP are “Positive Effect of Schedule Pressure on Labor Force Productivity” and “Schedule Pressure”, respectively.

The 45⁰ line implies that $f_p^+(\text{SP}) = \text{SP}$;

$$\text{LP} = \text{PP} * f_p^+(\text{SP}) = \text{PP} * \text{SP} = \text{PP} * [\text{TMDPSN/TAMD}] = \text{PP} * [(\text{Remaining Tasks/EAP})/\text{TAMD}]$$

where $TMDPSN = \text{Remaining Tasks}/EAP$ & $TAMD$ are “Total Man Days Perceived Still Needed” and “Total Available Man Days”, respectively.

Since in our assumption that “Potential Productivity-PP” is equal to the “Expected Average Productivity-EAP”, the above equation reduces to

$$LP = \text{Remaining Tasks}/TAMD = DP$$

Thus, the 45° reference line means that the labor force adjust their productivity level to precisely match the desired productivity level in order to overcome the backlogs of tasks.

These considerations entails that the “Positive Effect of Schedule Pressure on Labor Force Productivity” function must lie in the area between the two reference lines in Figure 3-5. In the region $SP > 1$, indicating a backlog of work, it is unreasonable to assume that the workload would rise more than needed to lift labor force productivity beyond the desired value. Likewise, in the region $SP < 1$, it is unreasonable for the workload to be cut back so much that labor force productivity fall below the desired value. Similarly, excess available man-days (ahead of schedule) should never cause work overloaded, and shortage in man-days (behind schedule) should never lead to underload. The workload must saturate at a maximum value (Sterman, 2000).

Interviews with the company’s managers (Interviewee 2; Interviewee 3) reveal that, under normal workday hours, the labor force could be forced to handle up to a maximum of 30% beyond the standard workload per day (1Tasks/People-Day). That is, under high schedule pressure, a labor force could increase his/her productivity level up to a maximum of 1.3 under normal workday hours by diminishing his/her slack times and by reducing the standard time that must be spent per task. The interview results also indicated the minimum level to which the workload could be cut.

The “Positive Effect of Schedule Pressure on Labor Force Productivity” is captured in the model using a table function shown below.

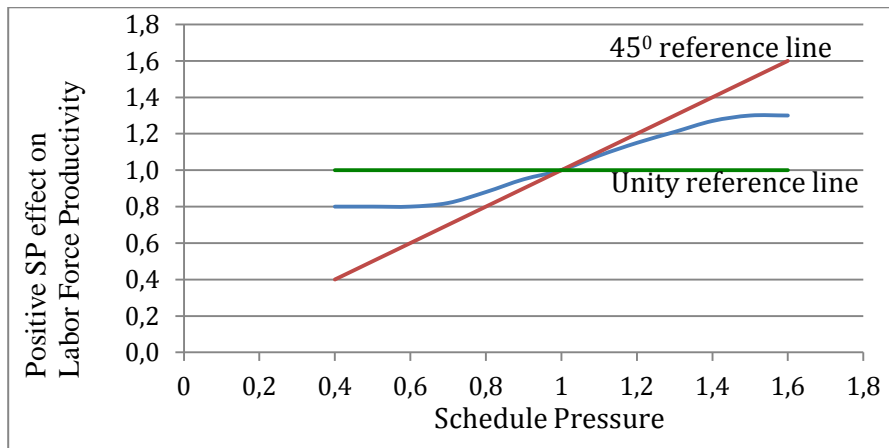


Figure 3.15 Positive SP effect on Labor Force Productivity

Positive_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity = GRAPH(Schedule_Pressure)

GRAPH(Schedule_Pressure) = (0.4, 0.8), (0.5, 0.8), (0.6, 0.8), (0.7, 0.82), (0.8, 0.88), (0.9, 0.95),
 (1.00, 1.00), (1.10, 1.08), (1.20, 1.15), (1.30, 1.21), (1.40, 1.27),
 (1.50, 1.30), (1.60, 1.30)

The formulation for “Effect of Schedule Pressure on Labor Force Productivity” is modified by the negative effect of workload stress on labor force productivity. Workload related stress does not set in immediately, but builds up gradually as the labor force find itself overwhelmed with more tasks than faced under normal work conditions (Sterman, 2000). The “Negative Effect of Schedule Pressure on Labor Force Productivity” is, therefore, a non-linear function of “Avg Schedule Pressure”, a measure of sustained schedule pressure over a time interval given by the “Workload Stress Onset time”.

The equations used to capture the negative effect of schedule pressure on labor force productivity are shown below.

Negative_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity =
 GRAPH(Avg_Schedule_Pressure)

GRAPH(Avg_Schedule_Pressure) = (0.7, 1.00), (0.8, 1.00), (0.9, 1.00), (1.00, 1.00), (1.10, 0.98),
 (1.20, 0.95), (1.30, 0.9), (1.40, 0.8), (1.50, 0.68), (1.60, 0.55),
 (1.70, 0.45), (1.80, 0.4)

Avg_Schedule_Pressure(t) = Avg_Schedule_Pressure(t - dt) + (Change_in_Avg_SP) * dt

Change_in_Avg_SP = (Schedule_Pressure - Avg_Schedule_Pressure)/ Workload_Stress_Onset_time

Workload_Stress_Onset_time = IF (Schedule_Pressure > Avg_Schedule_Pressure)

THEN (Time_to_Perceive_an_Increase_in_SP)
ELSE (Time_to_Perceive_a_Decrease_in_SP)

Reducing the schedule below 1 has no negative effect on the labor force productivity. However, an increase in the schedule pressure has a progressively increasing effect. The rate at which a high schedule pressure erodes labor force productivity is estimated based on interview results (Interviewee 2; Interviewee 3). When the schedule pressure is only slightly above normal, it takes quite a long period of time for the labor force to feel the pressure (9 months or around 180 workdays). In such a situation, the productivity diminishing effect is very small. However, when the schedule pressure is relatively high compared to normal (above 30% of the normal), the labor force feels the pressure within a very short period of time (less than a week or in 5 work days); work related stress arises as the labor force feels overwhelmed with jobs and allow the negative effect to mount its toll on the labor force productivity.

The product of the negative and positive effects of schedule pressure gives us the overall “Effect of Schedule Pressure on Labor Force Productivity”. This formulation also allow us to determine the optimal workload at which the labor force gives the maximum throughput under schedule pressure and also to identify the point at which the negative effect of work stress dominate the increase in productivity (Section 3.5 Sensitivity analysis).

b) Effect of Fatigue on Labor Force Productivity

The second strategy, which the managers employ when they perceive a project behind its schedule, is allowing the labor force to work overtime, so that they can allocate additional man-hours to the project. Although, overtime work helps in boosting the amount of man-days that are available daily for the engineering activities, it has also a negative effect on the productivity of the labor force. Overtime work over some extended period increases the exhaustion level of the labor force, which in turn reduces the productivity level of the labor force, because the labor force are working while they are tired (Abdel-Hamid, 1984; Homer et. al., 1985; Ford, 1995; Sterman, 2000).

In the model, we have captured the effect of fatigue on the labor force’s productivity with a table function as a response to the “Exhaustion Due to Overtime” level, as is shown in the equation below.

Effect_of_Fatigue_on_Labor_Force_Productivity = GRAPH (Exhaustion_Due_to_Overtime_Work)

GRAPH (Exhaustion_Due_to_Overtime_Work) = (0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9),
(20.0, 0.89)

“Exhaustion Due to Overtime” is a level, simply used to measure the amount of fatigue of the labor force due to overtime work over a period of time. The formulation of the “Exhaustion Due to Overtime” is discussed below.

When the managers perceive an engineering phase behind its schedule, they add workload on the labor force under regular work time (as discussed in the section above). If the situation persists, they allow the labor force to work overtime, but only for a limited period, because the labor force “will not be willing to work harder indefinitely” (Abdel-Hamid, 1984). There is a threshold on how long the labor force would be willing to (or should) work at an above-normal rate (Abdel-Hamid, 1984; Norwegian Working Environment Act, Dec, 2012; Interviewee 2). Figure 3.16 portrays the structural components of the model used to formulate the overtime sector. The model is formulated on the basis of Abdel-Hamid (1984) work.

In our model, when the “Total Man Days Perceived Still Needed” to complete the work in an engineering phase is perceived to be greater than the “Total Available Man Days”, two factors determine how much additional man-days could be added to the “Daily Labor Force for Engineering Activities” through overtime. The first is “Perceived Shortage in Man Hours”, that is, the value of the difference between “Total Man Days Perceived Still Needed” and “Total Available Man Days” expressed in working hours. If this difference is below some threshold, then it will all be handled.

$$\text{Perceived_Shortage_in_Man_Hours} = \frac{\text{Perceived_Shortage_in_Man_Days} *}{\text{Normal_Work_Hours_in_a_Day}}$$

$$\text{Perceived_Shortage_in_Man_Days} = \text{Perceived_Net_Shortage_in_Man_Days}$$

$$\text{Perceived_Net_Shortage_in_Man_Days} = \text{Total_Man_Days_Perceived_Still_Needed} - \text{Total_Available_Man_Days}$$

The second is the “Maximum Overtime Hours that Can be Worked” and it consists the threshold mentioned above. Hence, if the “Perceived Shortage in Man Hours” is greater than the maximum value, which the labor force are willing to handle, we assume that the labor force will only be willing to work hard and handle the maximum value and arrange a schedule

extension with the management team to handle the remaining. Detail discussion about possible schedule extension is discussed in the Schedule Target section.

$$\text{Total_Overtime_Hours_that_will_be_Handled} = \text{MAX}(\text{MIN}(\text{Maximum_Overtime_Hours_that_Can_be_worked}, \text{Perceived_Shortage_in_Man_Hours}), 0)$$

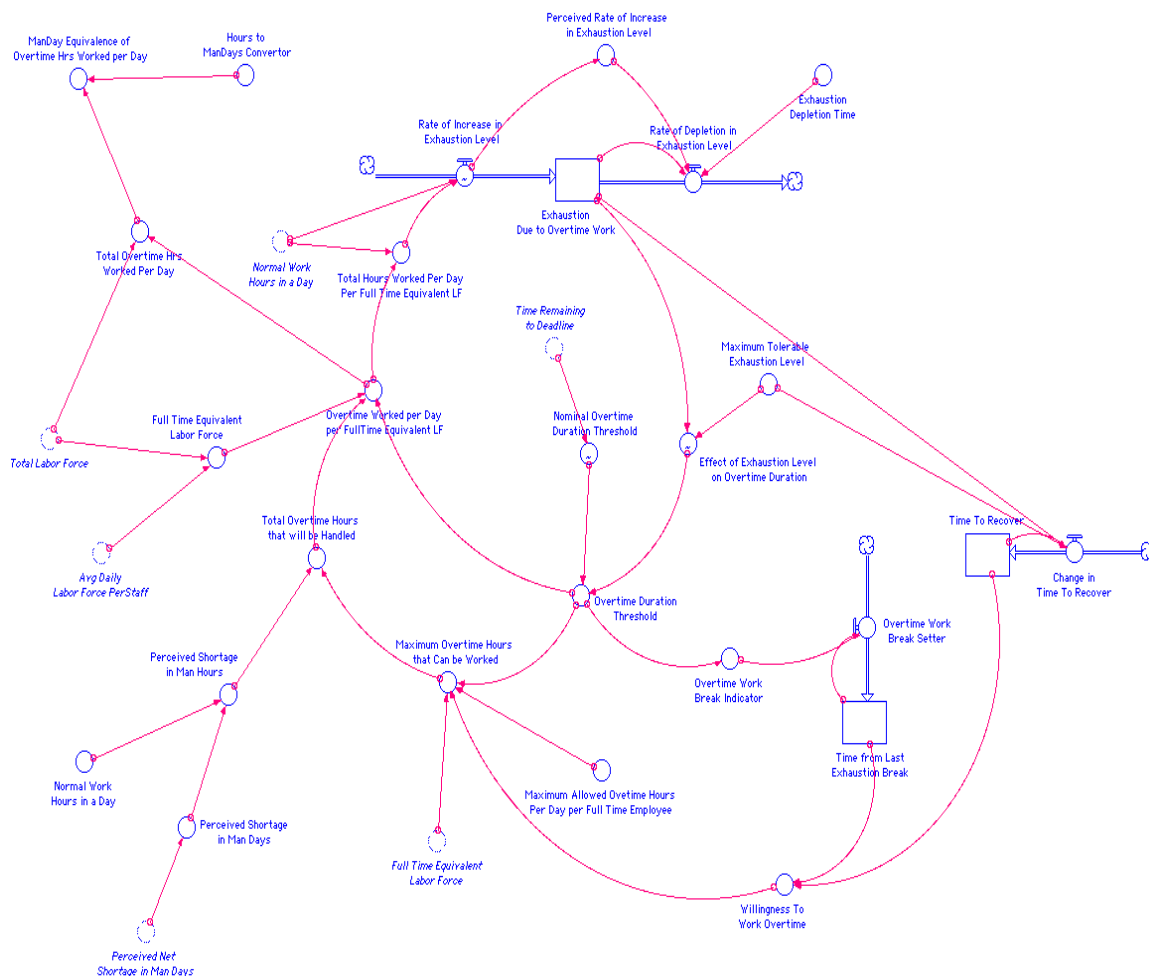


Figure 3.16 Overtime Sector

At any point in time, the “Maximum Overtime Hours that Can be Worked” is determined by four factors, “Overtime Duration Threshold”, “Full Time Equivalent Labor Force”, “Maximum Allowed Overtime Hours per day per Full Time Employee” and “Willingness to Work Overtime”.

$$\begin{aligned} \text{Maximum_Overtime_Hours_that_Can_be_Worked} = & \\ & \text{Overtime_Duration_Threshold} * \\ & \text{FullTime_Equivalent_Labor_Force} * \\ & \text{Maximum_Allowed_Overtime_Hours_Per_Day_per_Full_Time_Employee} * \\ & \text{Willingness_To_Work_Overtime} \end{aligned}$$

As the labor force work harder to handle shortages in man-days, their “tolerance for working harder decreases”, hence, the “Maximum Overtime Hours that Can be Worked” decreases (Abdel-Hamid, 1984, pp.170). There is a “threshold on how long employees should (would be willing to) work”. According to the Norwegian Working Environment Act (Dec, 2012), “Overtime work must not exceed ten hours per seven days, 25 hours per four consecutive weeks or 200 hours during a period of 52 weeks” (pp.27).

In the model, we set the “Overtime Duration Threshold”, which is the maximum remaining duration for which a full time employee would be willing to continue working harder once she/he started working overtime, to be 20 working days (four weeks), with a “Maximum Allowed Overtime Hours per Day per Full Time Employee” of 2 hours above the normal work day hours. The choice for the two values is made based on the above mentioned Norwegian working environment act of overtime. In a working week of the company (which is 5 day), an employee can work a maximum of 10 working hours (=5*2). But these maximum hours should not also be greater than 25 hours in 20 working days (in a month). We have implicitly formulated this limit under the “Overtime Duration Threshold” equation as shown below.

The “Overtime Duration Threshold” is formulated as a nominal value so that a multiplier can adjust it down.

$$\begin{aligned} \text{Overtime_Duration_Threshold} = & \text{Effect_of_Exhaustion_Level_on_Overtime_Duration} * \\ & \text{Nominal_Overtime_Duration_Threshold} \end{aligned}$$

This is achieved through a variable called “Effect of Exhaustion Level on Overtime Duration”, where “Exhaustion” is a level, simply used to represent the amount of fatigue of the labor force due to overtime. But then, the accumulation rate of exhaustion needs to be defined in a fashion that measures the overtime work (Abdel-Hamid, 1984). We have achieved that with the graphical function shown in Figure 3.17.

From Figure 3.17, we can note that when the “Total hours Worked per Day per Full Time LF” is less than or equal to the “Normal Work Hours in a Day”, the rate of increase in exhaustion is zero. However, when the value of the “Total hours Worked per Day per Full Time LF” increases, the rate of exhaustion also increases.

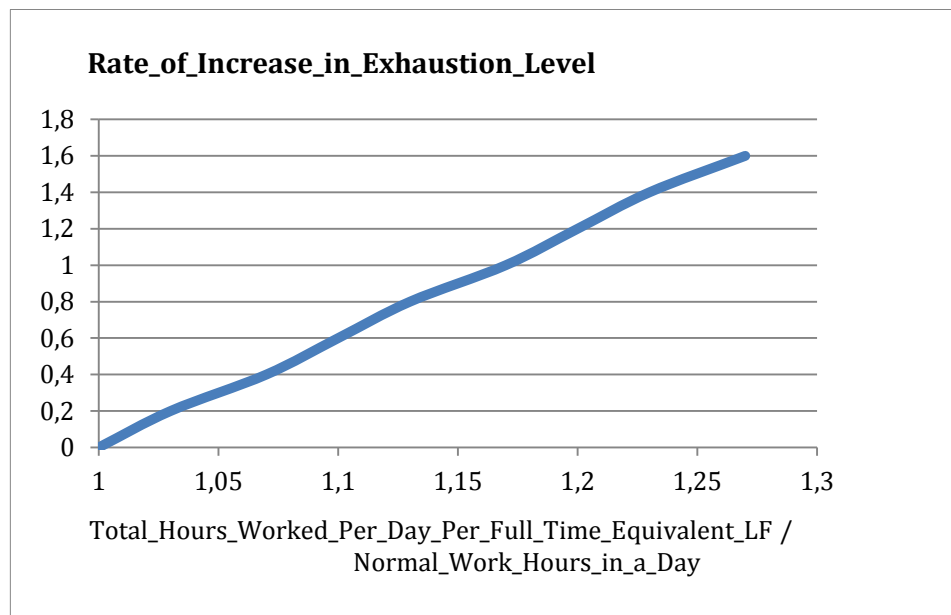


Figure 3.17 Rate of Increase in Exhaustion Level

In our assumption, overtime work is carried out when the managers perceive that the backlog of works could not be completed, despite the labor force is put under work pressure, as discussed in the section above. Hence, the exhaustion we are considering here has both “psychological” (because the labor force are minimizing their “slack time”, the time they spend in non-project issues such as coffee breaks, social communications) and “physiological” (because they work longer hours than they used to) components (Abdel-Hamid, 1984). Thus, the curve in Figure 3.17 increase linearly for the additional hours worked above the normal workday hours.

The values of the exhaustion rate are formulated with the following logic. If a labor force works 1.25 hours of over time every workday, it is under the maximum workweek overtime limit ($1.25 \times 5 = 7.5 < 10$). But it hits the monthly overtime limit on the 20th workday ($1.25 \times 20 = 25$). Hence, a work days that has a 1.25 hours overtime, which is equivalently expressed in the graph as a ratio between total worked hours and normal work hour of $1.7 = (1.25 + 7.5) / 7.5$, has an exhaustion value of 1. After 20 such days, the exhaustion level reach the maximum level

(20), this should be enough to drive the “Overtime Duration Threshold” to zero. The maximum level of exhaustion is referred in the model as “Maximum Tolerable Exhaustion Level”.

If a labor force works at a rate of “2 hours” of overtime per workday, although it complies with the weekly overtime limit of 10 hours, it hits the maximum exhaustion level in only 13 workdays, because a “2 hours” overtime work adds 1.6 Exhaustion every workday. Hence, the “Overtime Duration Threshold” can go to zero in 13 workdays.

The equations we used to formulate the level of exhaustion and its accumulation are shown below.

$$\text{Exhaustion_Due_to_Overtime_Work}(t) = \text{Exhaustion_Due_to_Overtime_Work}(t - dt) + (\text{Rate_of_Increase_in_Exhaustion_Level} - \text{Rate_of_Depletion_in_Exhaustion_Level}) * dt$$

$$\text{Rate_of_Increase_in_Exhaustion_Level} = \text{GRAPH}(\text{Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF} / \text{Normal_Work_Hours_in_a_Day})$$

$$\text{GRAPH}(\text{Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF} / \text{Normal_Work_Hours_in_a_Day}) = (1.00, 0.00), (1.03, 0.2), (1.07, 0.4), (1.10, 0.6), (1.13, 0.8), (1.17, 1.00), (1.20, 1.20), (1.23, 1.40), (1.27, 1.60)$$

When the overtime work period ends, either because the overtime threshold has been reached, or because schedule pressure cease off, the labor force’s exhaustion level will start to deplete. The “Rate of Depletion in Exhaustion Level” is formulated as a first order delay of “Exhaustion Due to Overtime Work” and “Exhaustion Depletion Time” as shown below.

$$\text{Rate_of_Depletion_in_Exhaustion_Level} = \text{IF}(\text{Perceived_Rate_of_Increase_in_Exhaustion_Level} \leq 0.01) \text{ THEN} (\text{Exhaustion_Due_to_Overtime_Work} / \text{Exhaustion_Depletion_Time}) \text{ ELSE} (0)$$

The “200 hours” overtime limit in a year, imposed by the Work Environment Act (Dec, 2012), is used to determine the exhaustion depletion time. In one year there are 48 workweeks. If we assume that a labor force can work the 25 hours monthly overtime limit in 4 weeks, then it can work the 200 hours in 32 weeks, which means after almost every 4 weeks of overtime work, a labor force can have a two weeks break. Thus, we set this two weeks time (10 workdays) as the “Exhaustion Depletion Time”.

During the depletion of the exhaustion, we assume that the labor force will be unwilling to work overtime and we have captured this assumption through the “Willingness to Work Overtime” variable. When the exhaustion level reaches its maximum and the overtime duration went to zero, the “Willingness to Work Overtime” variable switches to zero and stays there until the exhaustion completely depletes. When the exhaustion is completely depleted the “Willingness to Work Overtime” switch on, so that the labor force can carry out overtime works if a need arises.

3.4.2.2.2 Perceived, Actual and Expected Productivities

The “Perceived Productivity” sector models managers’ perceptions about the labor force productivity in the three engineering activities; regular processing, quality assurance and rework. These perceptions are used to determine the desired labor force, which is required to complete the available work, as determined by the work process limit (as discussed in the labor force allocation sector). Figure 3.18 portrays the structural components of the model used to formulate the perceived productivities of the three engineering activities. The structural components of the model are formulated based on interviews and literature, particularly, Ford (1995).

Each perceived productivity is formulated on the basis of the “Reported Productivity” of the labor force in each engineering activity, and altered by the delay in reporting and adjusting the perceived productivity.

The “Reported Productivity” is the smoothed value of “Current Productivity”, which is an “instantaneous productivity”, measured as the ratio of the processing rate of an engineering activity to the daily labor force allocated to that activity (Ford, 1995). The delay for smoothing the instantaneous values, “Report Time”, is taken as one week (5 workdays). This delay is equal to project reporting time.

$$\text{Current_Regular_Processing_Productivity} = \frac{\text{Regular_Processing_Rate}}{\text{Daily_Labor_Force_to_Regular_Processing}}$$

$$\text{Current_Rework_Productivity} = \frac{\text{Rework_Rate}}{\text{Daily_Labor_Force_to_Rework}}$$

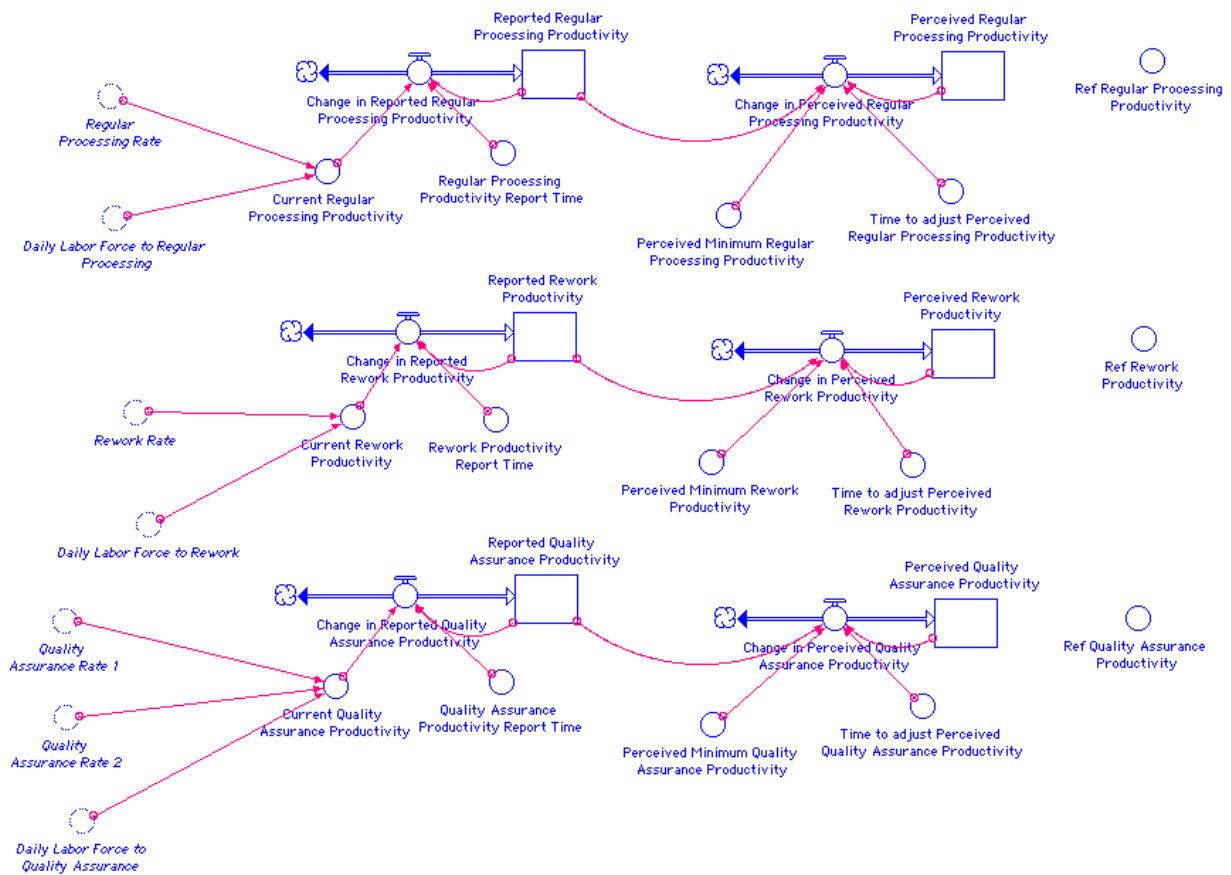


Figure 3.18 Perceived Productivity Sector

$$\text{Current_Quality_Assurance_Productivity} = \frac{(\text{Quality_Assurance_Rate_1} + \text{Quality_Assurance_Rate_2})}{(\text{Daily_Labor_Force_to_Quality_Assurance})}$$

$$\text{Reported_Regular_Processing_Productivity}(t) = \text{Reported_Regular_Processing_Productivity}(t - dt) + (\text{Change_in_Reported_Regular_Processing_Productivity}) * dt$$

$$\text{Change_in_Reported_Regular_Processing_Productivity} = \frac{(\text{Current_Regular_Processing_Productivity} - \text{Reported_Regular_Processing_Productivity})}{\text{Regular_Processing_Productivity_Report_Time}}$$

$$\text{Reported_Rework_Productivity}(t) = \text{Reported_Rework_Productivity}(t - dt) + (\text{Change_in_Reported_Rework_Productivity}) * dt$$

$$\text{Change_in_Reported_Rework_Productivity} = \frac{(\text{Current_Rework_Productivity} - \text{Reported_Rework_Productivity})}{\text{Rework_Productivity_Report_Time}}$$

$$\text{Reported_Quality_Assurance_Productivity}(t) = \text{Reported_Quality_Assurance_Productivity}(t - dt) + (\text{Change_in_Reported_Quality_Assurance_Productivity}) * dt$$

$$\text{Change_in_Reported_Quality_Assurance_Productivity} = \frac{(\text{Current_Quality_Assurance_Productivity} - \text{Reported_Quality_Assurance_Productivity})}{\text{Quality_Assurance_Productivity_Report_Time}}$$

The managers then compare their pervious perceptions about the labor force productivity with the smoothed, “Reported Productivity”, and adjust their perceptions with the changes. The “Time to Adjust Perceived Productivity” is taken as two weeks (10 workdays). In our discussions with the managers (particularly with Interviewee 2), we have learned that, managers are primed about the performance of the labor force a head of “formal” reports. Hence, because of the priming effect, we assume that the two weeks are enough for the mangers to build the newly experienced productivity of the labor force into their expectations about how they will perform in the future. This delay is exactly equal to the “Time Horizon for Reference Condition”, which is the time horizon relevant for manger to make forecasts about the required labor force.

$$\text{Perceived_Quality_Assurance_Productivity}(t) = \text{Perceived_Quality_Assurance_Productivity}(t - dt) + (\text{Change_in_Perceived_Quality_Assurance_Productivity}) * dt$$

$$\text{Change_in_Perceived_Quality_Assurance_Productivity} = \text{MAX}(\left(\frac{\text{Reported_Quality_Assurance_Productivity} - \text{Perceived_Quality_Assurance_Productivity}}{\text{Time_to_adjust_Perceived_Quality_Assurance_Productivity}}\right), \text{Perceived_Minimum_Quality_Assurance_Productivity} - \text{Perceived_Quality_Assurance_Productivity})$$

$$\text{Perceived_Regular_Processing_Productivity}(t) = \text{Perceived_Regular_Processing_Productivity}(t - dt) + (\text{Change_in_Perceived_Regular_Processing_Productivity}) * dt$$

$$\text{Change_in_Perceived_Regular_Processing_Productivity} = \text{MAX}(\left(\frac{\text{Reported_Regular_Processing_Productivity} - \text{Perceived_Regular_Processing_Productivity}}{\text{Time_to_adjust_Perceived_Regular_Processing_Productivity}}\right), \text{Perceived_Minimum_Regular_Processing_Productivity} - \text{Perceived_Regular_Processing_Productivity})$$

$$\text{Perceived_Rework_Productivity}(t) = \text{Perceived_Rework_Productivity}(t - dt) + (\text{Change_in_Perceived_Rework_Productivity}) * dt$$

$$\text{Change_in_Perceived_Rework_Productivity} = \text{MAX}(\left(\frac{\text{Reported_Rework_Productivity} - \text{Perceived_Rework_Productivity}}{\text{Time_to_adjust_Perceived_Rework_Productivity}}\right), \text{Perceived_Minimum_Rework_Productivity} - \text{Perceived_Rework_Productivity})$$

In the model, “Actual Productivity” is defined as the ratio of the number of tasks that are processed and released so far to the number of man-days expended so far. Hence,

$$\text{Actual_Productivity} = \text{Tasks Released} / \text{Cumulative_Man_Days_Expended}$$

This productivity together with initially “Planned Productivity” of the labor force is used to define the “Expected Average Productivity”, which is vital in determining the “Indicated Labor Force” for an engineering phase, as discussed in the ‘Labor Force’ section. The “Planned Productivity” is the managers’ original assumption about the productivity of the labor force prior to the commencement of the engineering work. It is a base for the development of start up plans and recruitment of initial project members.

There are two basic assumptions behind using “Expected Average Productivity” in determining the “Indicated Labor Force”.

The first assumption is that, unlike in the labor force allocation, in the determination of the required labor force to an engineering phase, managers consider the whole backlog of work in an engineering phase rather than the backlog of works in each engineering activity separately. Hence, they use an average productivity, which we refer in our model as “Expected Average Productivity”.

The second assumption is that managers’ expectations about the productivity of their labor force changes as projects progresses, from expecting productivity levels as equivalent as planned productivities during the early phases, to the actual productivity level in the final stages of the project (Abdel-Hamid, 1984).

“Measuring engineering design works is difficult because design is a creative process that involves ideas, calculations, evaluation of alternatives, and other tasks that are not physically measurable quantities. Considerable time and cost can be expended in performing these tasks before end results such as drawings, specifications, reports, etc., which are measurable quantities of work, are ever seen. For this reason, it is difficult to determine how much work has been accomplished during the early phases of a design work” (Oberlender, 2000, pp. 200).

During the early phases of the engineering work, the percent of completions is measured by the rate of expenditure of resources (Interviewee 2). Hence, “status reporting ends up being nothing more than an echo of the original plan”. However, as the engineering design progresses and the

work become relatively more visible, “discrepancies between % of tasks accomplished and % of resources expended become increasingly apparent” (Abdel-Hamid, 1984, pp.235). Hence, managers’ expectations about the productivity level of their labor force change gradually, from the originally planned productivity to the actual value.

We have captured these changing assumptions in productivity in our model with a variable, “Expected Average Productivity”. We have defined “Expected Average Productivity” as a weighted average of “Actual Productivity” and “Planned Productivity”.

$$\text{Expected_Average_Productivity} = \text{Planned_Productivity} * \text{Weight_to_Planned_Productivity} + (1 - \text{Weight_to_Planned_Productivity}) * \text{Actual_Productivity}$$

The weighting factor, “Weight to Planned Productivity” moves from 1 at the beginning of the engineering phase to zero at the end of the phase. We have formulated “Weight to Planned Productivity” as a table function of the engineering phase’s progress, as is shown in the equation below.

$$\text{Weight_to_Planned_Productivity} = \text{GRAPH}(\text{Fraction_of_Released_Tasks})$$

$$\text{GRAPH}(\text{Fraction_of_Released_Tasks}) = (0.00, 1.00), (0.1, 0.9), (0.2, 0.7), (0.3, 0.5), (0.4, 0.3), (0.5, 0.1), (0.6, 0.00), (0.7, 0.00), (0.8, 0.00), (0.9, 0.00), (1.00, 0.00)$$

3.4.2.3 Quality of Practice

The quality of practice section of human resource subsystem models the impacts of experience, schedule pressure, and fatigue on the quality of work performed by the labor force. The structural components of the model (Figure 3.19) in this sector are formulated based on the works of Abdel-Hamid (1984) and Ford (1995).

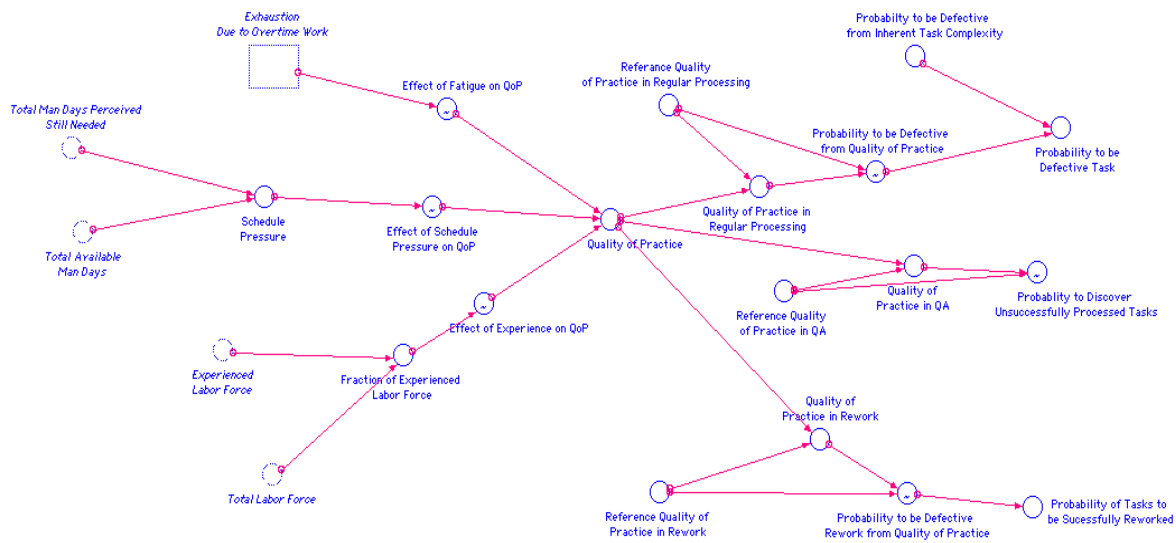


Figure 3.19 Quality of Practice

In the model, we have formulated quality of practice in each engineering activity as a product of a reference level of quality of practice in the engineering activities (taken from the company’s performance in quality during previous EPCI projects) and the three factors mentioned above (experience, schedule pressure, and fatigue).

$$\text{Quality of Practice} = \text{Effect_of_Fatigue_on_QoP} * \text{Effect_of_Experience_on_QoP} * \text{Effect_of_Schedule_Pressure_on_QoP}$$

$$\text{Quality_of_Practice_in_Regular_Processing} = \text{Quality_of_Practice} * \text{Reference_Quality_of_Practice_in_Regular_Processing}$$

$$\text{Quality_of_Practice_in_QA} = \text{Quality_of_Practice} * \text{Reference_Quality_of_Practice_in_QA}$$

$$\text{Quality_of_Practice_in_Rework} = \text{Quality_of_Practice} * \text{Reference_Quality_of_Practice_in_QA}$$

In the labor force section, we have discussed that each engineering phase has five labor force groups, of which three groups are new members of the project team. It was also indicated that the new members of the project pass through “orientation and training phases” during which they are less than fully productive. They are not only less productive, but also more error-prone than their experienced counter parts (Abdel-Hamid, 1984).

In the quality of practice sector, for the sake of convenient representation of the effect of experience, we have regrouped the labor force in an engineering phase into two, new project members and experienced project members. The new project members includes “New

Employees”, “Transferred-in Company Employees” and “New Hired-In Externally”, whereas, the experienced project members consists “Experienced Employees” and “Experienced Hired-In Externally”. With this background, we estimated that a new project member is 1.5 times as error-prone as an experienced counter part would be. In other words, when only new project members work in an engineering phase, the quality of practice in that engineering phase is reduced by 50% from the level it would otherwise be if experienced project members worked on it. To capture the effect of this factor on quality of practice, we formulate a variable, “Effect of Experience on QoP” as a function of “Fraction of Experienced Labor Force”. When the “Total Labor Force” is comprised of only “Experienced Labor Force”, the value of the multiplier is set to 1. And as the fraction of new project members increases the multiplier decreases in a linear fashion, as shown in the table function below.

$$\text{Effect_of_Experience_on_QoP} = \text{GRAPH}(\text{Fraction_of_Experienced_Labor_Force})$$

$$\text{GRAPH}(\text{Fraction_of_Experienced_Labor_Force}) = (0.00, 0.5), (0.2, 0.6), (0.4, 0.7), (0.6, 0.8), (0.8, 0.9), (1.00, 1.00)$$

$$\text{Fraction_of_Experienced_Labor_Force} = \text{Experienced_Labor_Force} / \text{Total_Labor_Force}$$

The second factor that can affect the quality of practice is schedule pressure (Abdel-Hamid, 1984; Ford, 1995). Increasing schedule pressure decreases the quality of practice for two basic reasons. First, an increase in schedule pressure increases the “anxiety level” of the labor force, which “probably reduce the short term memory” of the labor force, there by interfering in the quality of their work performance (Shneiderman, 1980, cited in Abdel-Hamid, 1984). Second, an increase in schedule pressure result an “overlapping of activities that would have been accomplished better sequentially” (Abdel-Hamid, 1984, pp. 197).

Schedule pressure “only hurts and never help the team’s quality of practice” (Ford, 1995). Hence, in the model, the effect of schedule pressure is formulated with a monotonically decreasing table function. However, the function has a lower limit because, even under extreme pressure professional retains some quality of practice (Ford, 1995).

$$\text{Effect_of_Schedule_Pressure_on_QoP} = \text{GRAPH}(\text{Schedule_Pressure})$$

$$\text{GRAPH}(\text{Schedule_Pressure}) = (0.00, 1.00), (0.5, 1.00), (1.00, 1.00), (1.50, 0.94), (2.00, 0.9), (2.50, 0.85), (3.00, 0.79), (3.50, 0.72), (4.00, 0.64), (4.50, 0.55), (5.00, 0.45)$$

The third variable that affects the quality of practice is fatigue due to overtime work. More fatigue decreases the quality of work because the project members are “working while they are tired” (Ford, 1995, pp.102).

In our model, the effect of fatigue on the quality of practice is formulated with a table function as a response to the level of “Exhaustion Due to Overtime”. As discussed in the productivity sector, “Exhaustion Due to Overtime” is the amount of fatigue level of the work force over a certain period of overtime work.

Effect of Fatigue on QoP = GRAPH (Exhaustion_Due_to_Overtime_Work)

GRAPH (Exhaustion_Due_to_Overtime_Work) = (0.00, 1.00), (5.00, 0.94), (10.0, 0.92),
(15.0, 0.9), (20.0, 0.89)

The relationship between the level of fatigue and the quality of practice is nonlinear, with little effect when the exhaustion level near to zero. A maximum effect is reached when the exhaustion level reaches to the “Maximum Tolerable Exhaustion Level” of 20.

The quality of practice influences all the three engineering activities. Quality of practice influences the probability of error generation both in the “Regular Processing” activity and “Rework” activity through a revers “S” shaped curve, which doesn’t increase errors if the quality of practice is above a reference level (Ford, 1995). Excess quality is assumed not hurt a project. The curve rises to a maximum of 50% when the quality of practice is zero.

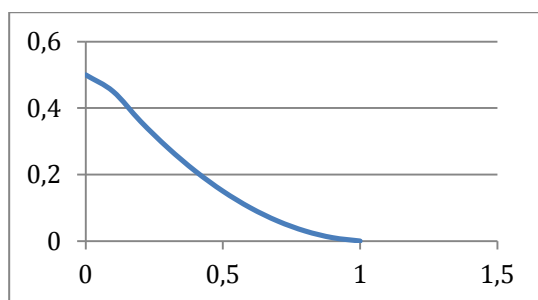


Figure 3.20 Effect of quality of practice on Regular processing and Rework error generation

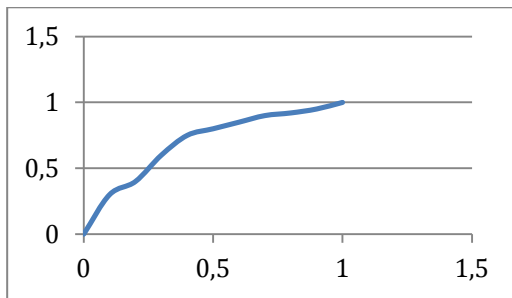


Figure 3.21 Effect of quality of practice in error discovery

$$\text{Probability_to_be_Defective_from_Quality_of_Practice} = \text{GRAPH}(\text{Quality_of_Practice_in_Regular_Processing} / \text{Reference_Quality_of_Practice_in_Regular_Processing})$$

$$\text{Probability_to_be_Defective_Rework_from_Quality_of_Practice} = \text{GRAPH}(\text{Quality_of_Practice_in_Rework} / \text{Reference_Quality_of_Practice_in_Rework})$$

$$\text{Probability_to_Discover_Unsuccessfully_Processed_Tasks} = \text{GRAPH}(\text{Quality_of_Practice_in_QA} / \text{Reference_Quality_of_Practice_in_QA})$$

The quality of practice also influences the quality assurance activity. Quality of practice affects the quality assurance activity by influencing the probability of discovering flawed task. No errors can be found if the quality of practice is zero. This assumes that project conditions can degrade the quality of the work done by the labor force. The probability of finding errors based on the adequacy of the quality of practice increases when the quality of practice rises above a reference value.

3.4.3 The Target Subsystem

The target subsystems describe the schedule, Quality and budget goals of a single engineering phase. The first subsection describes the schedule goals of an engineering phase and the strategies applied in the phase to keep the set schedule goal. In the second subsection, we discuss about the quality target set for an engineering phase and its actual performance. An engineering phases performance in cost is described in the third subsection of the target subsystem. Like the work process and human resource subsystems, the structural components of the target subsystem are formulated based on previous system dynamics models and interviews.

3.4.3.1 The Schedule Target

The schedule target sector describes the schedule goals set to an engineering phase and the strategies applied to comply with the set schedule goals. In an engineering phase there are two schedule deadlines, internal deadline and project deadline.

The internal deadlines serve as a target date for completing a certain portion of an engineering phase's scope of work (specifically, 70% of the works in System Engineering and Procurement for Engineering and 65% of the work in Area Engineering) before construction activities are started. There are two basic reasons behind the company's motive in introducing internal deadlines. The first reason is to minimize the amount of engineering design reworks that could possibly be initiated when engineering design errors are discovered during construction activities. The second reason is to reduce the entire project deadline by allowing the commencement of construction activities as early as possible, with the most readily available and matured engineering designs.

The project deadline refers for the contractually agreed date for completing the entire engineering work and it is the same for all the engineering phases in the DoWin Beta project. The project deadline is a fixed deadline, whereas, the internal deadline is, somewhat flexible. Since the project deadline is a fixed deadline, for every single day the company fails to comply with the deadline, it will pay to its customer a certain amount of money, which was agreed during the contracts award. Thus, there is a very strong emphasis towards complying with the project deadline.

In the model, we have captured both the internal deadline and project deadline with the structural components shown in Figure 3.22. The engineering phases performance in the time domain is measured by comparing both the internal and project deadlines against with their respective initial deadlines. Both the internal and project deadlines are formulated, not as an actual calendar date, but as a number of working days from the beginning of the engineering phase.

$$\text{MIN}((\text{Maximum_Tolerable_Project_Completion_Date} - \text{Project_Deadline_for_the_Phase}) / \text{Project_Deadline_Adjustment_Time}, (\text{Indicated_Completion_Date_for_the_Phase} - \text{Project_Deadline_for_the_Phase}) / \text{Project_Deadline_Adjustment_Time})$$

As we mentioned above the internal deadline has some flexibility, and hence, can be extended for some more days if the project team fails to comply with the initial deadline. However, not indefinitely, the extension period is bounded to the “Maximum Tolerable Internal Deadline”, which is the sum of the “Initial Internal Deadline” and the “Maximum Internal Deadline Extension Dates”. In the project deadline, since it is a fixed deadline, the “Maximum Tolerable Project Completion Date” is equal to the “Initial Project Deadline”, and the “Maximum Project Deadline Extension Dates” is zero.

The “Indicated Completion date for 70% of Phase Scope” in the case of the internal deadline is calculated based on three factors; the current value of “Time” (which represents the number of working days elapsed in a simulation run), the “Perceived Project Completion Time Still Required” (which is the remaining time, in working days, that is perceived to be still required to complete the phase, given its current condition) and the status of the engineering phase. If the progress of the engineering phase is below the 70% mark (which is the scope of work planned to be done within the internal deadline), the “Indicated Completion date for 70% of Phase Scope” will be equal to the sum of “Perceived Project Completion Time Still Required” and the current “Time”, otherwise it will take a value of zero.

$$\begin{aligned} \text{Indicated Completion date for 70\% of Phase Scope} = & \\ & \text{IF (Remaining_Tasks} > \text{Thirty_}\% \text{_of_Phase_Scope)} \\ & \text{THEN (TIME+Perceived_Project_Completion_Time_Still_Required)} \\ & \text{ELSE (0)} \end{aligned}$$

On the other hand, “Indicated Completion Date for the Phase” is only dependent on the “Perceived Project Completion Time Still Required” and the current “Time”. Hence, its value is always equals to the sum of the two values.

$$\begin{aligned} \text{Indicated Completion Date for the Phase} = & \\ & \text{TIME} + \text{Perceived_Project_Completion_Time_Still_Required} \end{aligned}$$

“Perceived Project Completion Time Still Required” is formulated in the model as a difference between “Perceived Project Completion Time Needed” and “Perceived Work Days to be

Recovered Via Overtime” work. “Perceived Project Completion Time Needed” is the remaining time, in working days, that is perceived to be still needed to complete the phase, given the “Expected Average Productivity” level of the work force and the “Actual Labor Force Required” to be recruited. Here, we are assuming that (after discussion with Interviewee 2) the project deadline adjustments are made with full awareness of the recruitment decisions and the possible overtime hours the labor force could do.

As we have discussed in the labor force sector the “Indicated Labor Force”, which the managers believe could complete the remaining tasks of an engineering phase within the scheduled completion time, is calculated on the basis of three variables, the “Expected Average Productivity”, the “Remaining Task”, and the “Time Remaining to Deadline”. The “Expected Average Productivity” refers for the level of productivity that the managers’ use in their decisions about the size of the labor needed to complete the remaining work of the engineering phase.

On the other hand, the remaining task refers to the difference between the “targeted amounts of engineering work” required to be completed and the amount of engineering work that has been already processed and released. For the internal deadline, “the targeted amount of engineering work” is 70% of an engineering phases scope, where as, for the project deadline the “targeted amount of engineering work” is the entire phase scope.

The third variable, “Time Remaining to Deadline”, refers to the difference between the scheduled completion date of the “targeted amount of engineering work” and the current value of “Time”. Hence, for the internal deadline, the remaining time is the difference between the “Internal Deadline” and current value of “Time” and for the project deadline, the remaining time is the difference between “Project Deadline” and current value of “Time”.

With this ground we formulated the “Time Remaining to Deadline” as

```
Time Remaining to Deadline = IF ((0.7* Phase_Scope > Remaining_Tasks)
                               THEN (Internal_Deadline - TIME)
                               ELSE (Project_Deadline_for_the_Phase -TIME)
```


However, in a single project, it is very unlikely that after a lot of efforts to comply with the internal deadline, the labor force of that project will instantaneously be adjusted to a new deadline. We assume that it takes some time before the new deadline is in place and the labor force is adjusted to that new deadline.

Consider, for example a situation, where the project deadline is 600 days and the internal deadline is 200 days. Since the internal deadline is 200 days, the “Time Remaining” to complete the “targeted amount of work” within the internal deadline is 200 days during the commencement of the project. This remaining time goes further down to zero as the current “Time” approaches the 200 mark. But then, if the “targeted amount of work” is processed and released within the set internal deadline, the new project deadline pops up and the “Time Remaining” will instantaneously be changed to 400 days. Which means, the management needs to adjust the labor force automatically to the new remaining time. We assume that projects setups are unlikely to react this way, rather we assume that they adjust to the new deadline through time.

Hence, we have modified the above equation of “Time Remaining to Deadline” by adding an intermediate deadline that adjusts itself from the internal deadline to the project deadline. Further discussion on this is presented in the sensitivity analysis.

3.4.3.2 Quality Target

The quality target sector (Figure 3.23) describes the movement of the project quality goal from its initial level toward the current quality level. Quality is measured as a ratio of discovered flawed task to tasks that are perceived completed successfully.

For an engineering phase, the quality goal moves from its initial value to the current value through “Quality Goal Adjustment Time”. The adjustment time is takes as 20 workdays.

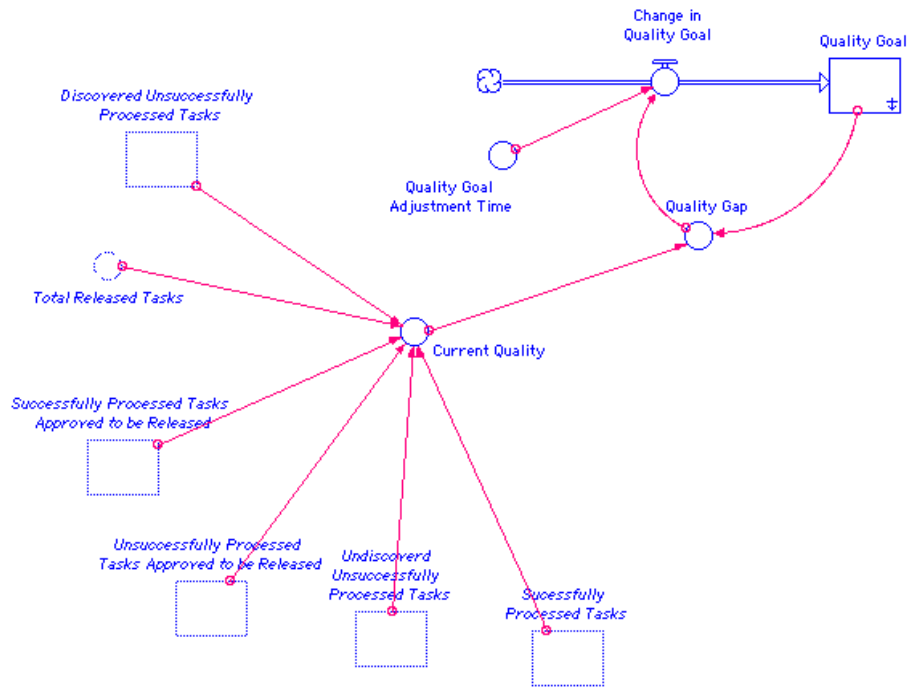


Figure 3.23 Quality goal

$$\text{Quality_Goal}(t) = \text{Quality_Goal}(t - dt) + (\text{Change_in_Quality_Goal}) * dt$$

$$\text{Change_in_Quality_Goal} = \text{Quality_Gap} / \text{Quality_Goal_Adjustment_Time}$$

$$\text{Quality_Gap} = \text{Current_Quality} - \text{Quality_Goal}$$

The current quality of an engineering phase is measured as a ratio of “Discovered Unsuccessfully Processed Tasks” to “Tasks Perceived Completed” in that phase.

$$\text{Current_Quality} = 1 - (\text{Discovered_Unsuccessfully_Processed_Tasks} / (\text{Total_Released_Tasks} + \text{Successfully_Processed_Tasks_Approved_to_be_Released} + \text{Unsuccessfully_Processed_Tasks_Approved_to_be_Released} + \text{Undiscovered_Unsuccessfully_Processed_Tasks} + \text{Successfully_Processed_Tasks}))$$

The quality goal is formulated to analyze future policy options.

3.4.3.3 Cost Target

The cost sector is formulated in order to accumulate the total costs within an engineering phase and across the engineering phases. Here, we only measure costs paid to the labor force until the current project date. The equations used to measure cost are described below.

$$\text{Total_Project_Cost} = \text{SUM}(\text{Phase_Costs_to_Date})$$

$$\begin{aligned} \text{Phase_Costs_to_Date} = & \text{SUM}(\text{Experienced_Employees_Costs_to_Date} + \\ & \text{Transferred_in_Company_Employees_Costs_to_Date} + \\ & \text{New_Employees_Costs_to_Date} + \\ & \text{New_Hired_in_Externally_Costs_to_Date} + \\ & \text{Experienced_Hired_in_Externally_Costs_to_Date} + \\ & \text{Overtime_Costs_to_Date}) \end{aligned}$$

The current cumulative cost of the project is the sum of the current cumulative cost of the engineering phases. The cumulative cost of an engineering phase is the sum of the current cumulative cost of the phase's labor force and the cumulative overtime cost in that phase. A labor force cumulative cost increases with the addition of "Regular Daily Salary" of the labor force, where as, the overtime cumulative cost rises with an addition of "Total Daily Overtime Pay".

$$\begin{aligned} \text{Experienced_Employees_Costs_to_Date} = & \text{Experienced_Employees_Costs_to_Date} + \\ & dt * \text{Regular_Daily_Salary_of_Experienced_Employees} \end{aligned}$$

$$\begin{aligned} \text{Transferred_in_Company_Employees_Costs_to_Date} = & \\ & \text{Transferred_in_Company_Employees_Costs_to_Date} + \\ & dt * \text{Regular_Daily_Salary_of_Transferred_in_Company_Employees} \end{aligned}$$

$$\begin{aligned} \text{New_Employees_Costs_to_Date} = & \text{New_Employees_Costs_to_Date} + \\ & dt * \text{Regular_Daily_Salary_of_New_Employees} \end{aligned}$$

$$\begin{aligned} \text{Experienced_Hired_in_Externally_Costs_to_Date} = & \\ & \text{Experienced_Hired_in_Externally_Costs_to_Date} + \\ & dt * \text{Regular_Daily_Salary_of_Experienced_Hired_in_Externally} \end{aligned}$$

$$\begin{aligned} \text{New_Hired_in_Externally_Costs_to_Date} = & \text{New_Hired_in_Externally_Costs_to_Date} + \\ & dt * \text{Regular_Daily_Salary_of_New_Hired_in_Externally} \end{aligned}$$

$$\text{Overtime_Costs_to_Date} = \text{Overtime_Costs_to_Date} + dt * \text{Total_Daily_Overtime_Pay}$$

The incremental cost of "Regular Daily Salary" for each labor force is the product of the average hourly pay rate for the particular labor force group in Norwegian kroner, the total number of the labor force in that group and the regular daily work hours. On the other hand, the cost incremental in "Total Daily Overtime Pay" is the product of the average hourly pay rate for overtime work in Norwegian kroner and the "Total Overtime Hrs Worked Per Day".

$$\begin{aligned} \text{Regular_Daily_Salary_of_Experienced_Employees} = & \text{Experienced_Employees} * \\ & \text{Experienced_Employee_Avg_Hourly_Pay_Rate} * \\ & \text{Avg_Daily_Labor_Force_PerStaff} * \\ & \text{Normal_Work_Hours_per_Day} \end{aligned}$$

$$\begin{aligned} \text{Regular_Daily_Salary_of_Transferred_in_Company_Employees} = \\ & \text{Transferred_in_Company_Employees} * \\ & \text{Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate} * \\ & \text{Avg_Daily_Labor_Force_PerStaff} * \\ & \text{Normal_Work_Hours_per_Day} \end{aligned}$$

$$\begin{aligned} \text{Regular_Daily_Salary_of_New_Employees} = \text{New_Employees} * \\ & \text{New_Employees_Avg_Hourly_Pay_Rate} * \\ & \text{Avg_Daily_Labor_Force_PerStaff} * \\ & \text{Normal_Work_Hours_per_Day} \end{aligned}$$

$$\begin{aligned} \text{Regular_Daily_Salary_of_Experienced_Hired_in_Externally} = \\ & \text{Experienced_Hired_in_Externally} * \\ & \text{Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate} * \\ & \text{Avg_Daily_Labor_Force_PerStaff} * \\ & \text{Normal_Work_Hours_per_Day} \end{aligned}$$

$$\begin{aligned} \text{Regular_Daily_Salary_of_New_Hired_in_Externally} = \text{New_Hired_in_Externally} * \\ & \text{New_Hired_in_Externally_Avg_Hourly_Pay_Rate} * \\ & \text{Avg_Daily_Labor_Force_PerStaff} * \\ & \text{Normal_Work_Hours_per_Day} \end{aligned}$$

$$\begin{aligned} \text{Total_Daily_Overtime_Pay} = \text{Avg_Hourly_Overtime_Pay_Rate} * \\ & \text{Total_Overtime_Hrs_Worked_Per_Day} \end{aligned}$$

The payment rates used in this model are not actual payment rates, rather they are used to simply demonstrate the possible labor force costs associated to the engineering process. Externally Hired-In employees earn a relatively higher amount of money than the permanent company employees (approximately 25% more than the permanent employee counter part). Moreover, overtime hours are more costly than regular work hours (approximately 50% more costly than the regular hours rate).

In the model, the average hourly pay rates for experienced engineers is set as 650NOK, for experience hired-In externally as 800NOK, for Transferred-in company employees and New Hired-In Externally as 500NOK and for new employees as 400NOK. Moreover, the average hourly pay for overtime is taken as 1000NOK.

Chapter 4

4 Model Validation and Behavioral Analysis

Model validation is one of the important steps in the system dynamics methodology. The purpose of model validation is to build confidence in the usefulness of the model for the intended purpose (Barlas, 1994). Confidence in models can be built by a variety of test that includes model's structural tests, model's behavioral tests and model's policy implications (Forrester & Senge, 1979).

In order to build confidence in our model, we carry out model validation and behavioral analyses under two categories, model structure test and model behavior test.

4.1 Model Structure Test

Tests of model structure assess the structure and parameters of the model directly, without examining relationships between structure and behavior. Structure and parameter verification tests, dimensional test (unit consistency test) and extreme condition test are some of the test that are carried out to build confidence on the structure of the model (Forrester & Senge, 1979)

4.1.1 Structure & Parameter Verification Test

Structure verification test is carried out to compare the structure of the model against the structure of a real system, whereas, parameter verification test is carried out to evaluate the constant parameters against knowledge of a real system, both conceptually and numerically. The two verification tests are usually carried out on the basis of practitioners' knowledge and literature (Forrester & Senge, 1979).

In section 3.4 of chapter 3, we have presented the structural components of the model, with which we described the systemic interaction among various variables, which are hypothesized as cause for the problematic behavior. We have also presented the constant parameters we used in the model. Hence, the validity of the model depends on the validity of the model structure that represents the hypotheses and on the validity of the constant parameters.

The conceptualization and formulation of the model structure and estimation of the values of the constant parameters are based on the interviews with the company's managers and findings of the literature. As documented in the description of the model, results from a series of interviews, surveys, document analyses, and previous research findings are used in the development of the model structure and determination of the constant parameters. The model structure is also exposed to the managers of the company for criticism, then revised, and again and again exposed in an iterative process.

4.1.2 Dimensional Test

One of the model structural tests is checking unit consistency. It is fundamental to check all the units in the model such that they are consistent and are representing exactly the intended variable. In the model we have checked the consistency of all the units. Some of the variables and the associated units are given below in Table 4.1

Table 4.1 Units of some variables

Name of Variable	Type of Variable	Unit
Tasks Identified to be Processed	Stock	Tasks
Successfully Processed Tasks	Stock	Tasks
Unsuccessfully Processed Tasks Released	Stock	Tasks
Cumulative Man Days Expended	Stock	People*Days
Experienced Employees	Stock	People
Experienced Employees Costs to Date	Stock	NOK
Successful Processing Rate	Flow	Tasks/Days
Unsuccessful Rework Rate	Flow	Tasks/Days
Assimilation Rate of New Employees	Flow	People/Days
Total Daily Man Days Expended	Flow	(People*Days)/Days
Regular Daily Salary of Experienced Employees	Flow	NOK/Days
Tasks Available for Regular Processing	Auxiliary	Tasks
Minimum Regular Processing Duration per Task	Auxiliary	Days
Fraction of Released Tasks	Auxiliary	Unitless
Labor Force Productivity	Auxiliary	Task/(People*Days)
Initial internal Deadline	Auxiliary	Days
Effect of Schedule Pressure on Labor Force Productivity	Auxiliary	Unitless

4.1.3 Extreme Condition Test

Another model structure test in system dynamics is extreme condition test. It is a test that involves assigning extreme values to selected parameters and comparing the model-generated behavior to the observed or anticipated behavior of the real system under the same extreme condition (Barlas, 1994). The model should be robust in extreme conditions, meaning the behavior of the model should be realistic in results even under extreme values of the input. However, the extreme condition test does not necessarily imply the conditions exist in real situation (Sterman, 2000).

In this section we test the extreme values of some variables, “Total Tasks Available”, “Total Labor Force”, “Fraction of Released Tasks”, “Probability to be Defective Task”, and “Probability of Tasks to be Successfully Reworked”.

Let us assume that there is no task made available to an engineering phase from its previous engineering phases, that is, the “Total Tasks Available” is zero. From our discussion in chapter 3, we learn that the “Regular Work Processing Rate” is determined by the lesser of the “Regular Processing Limit from Resources” based on the size and productivity of the labor force and the “Regular Processing Limit from Task Availability” based on the number of tasks made available to the current engineering phase and the minimum time required per task. If there are no tasks made available to the current phase from its previous phases, then the regular processing rate will be there, and hence the subsequent process will not be carried out. The same is true if there is no labor force allocated to the activities of the engineering phase. In general, there will be no engineering activity in the work process sector of the model, if either the labor force allocated to the current engineering phase is zero or if the tasks made available are zero. Hence, we expect no progress in the engineering phase. We set the “Total Task Available” to the system engineering phase to zero and the result as shown in Figure 4.1(A-D) with the blue curve confirms our expectation. We did the same to the other two engineering phases and found similar result.

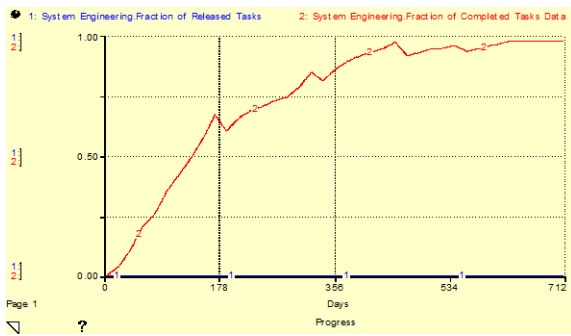


Figure 4.1(A) Work progress in System Engineering phase

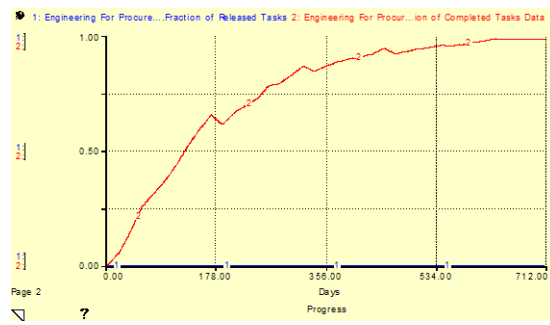


Figure 4.1(B) Work progress in Engineering for Procurement phase

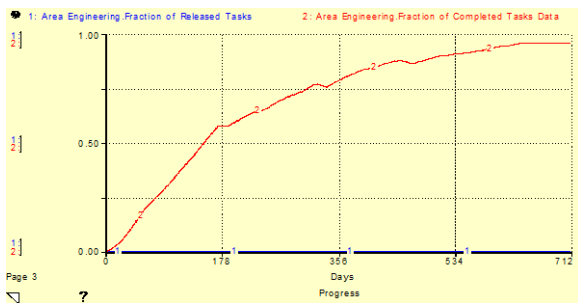


Figure 4.1(C) Work progress in Area Engineering phase

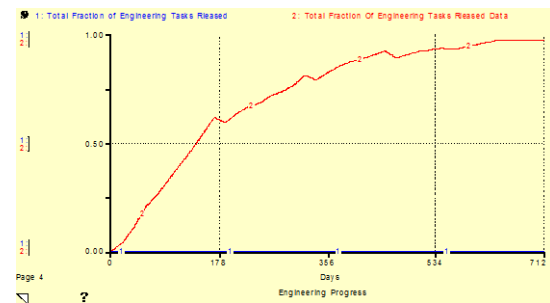


Figure 4.1(D) Work progress in Overall Engineering phase

We also found similar result when we set the “Total Labor Force” to zero as shown in Figure 4.2 (A-D).

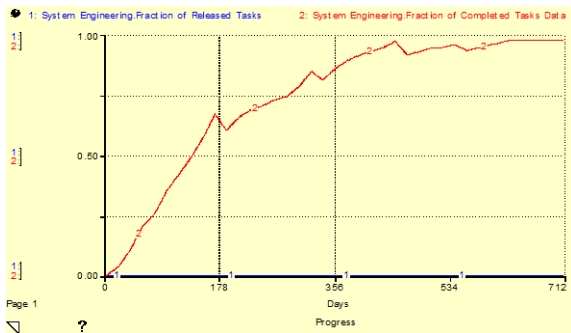


Figure 4.2 (A) Work progress in System Engineering phase

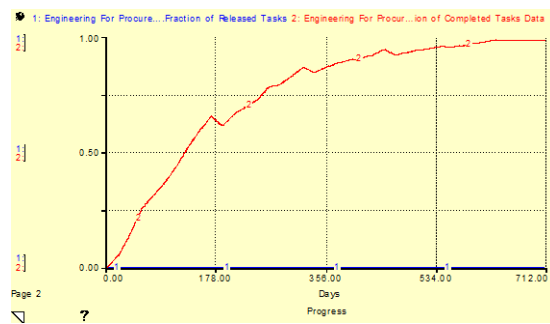


Figure 4.2(B) Work progress in Engineering for Procurement phase

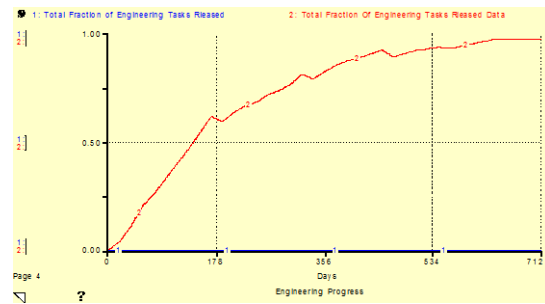
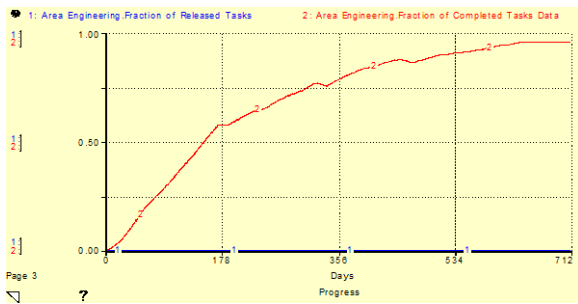


Figure 4.2(C) Work progress in Area Engineering phase Figure 4.2(D) Work progress in Overall Engineering

If the “Fraction of Released Tasks” to a downstream phase is zero then, due to the effect of the work precedence relation, the downstream progress will be restricted to the level, where it can process without the influence of its upstream phase. We set the “Fraction of Tasks Released” from the system engineering phase to be zero, so that the progress of its two downstream phases can be constrained by the work precedence relation as we explained above. And the model outputs showed if Figure 4.3 (A-B) confirms our expectation.

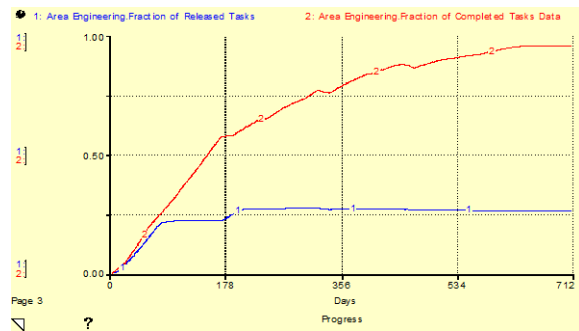
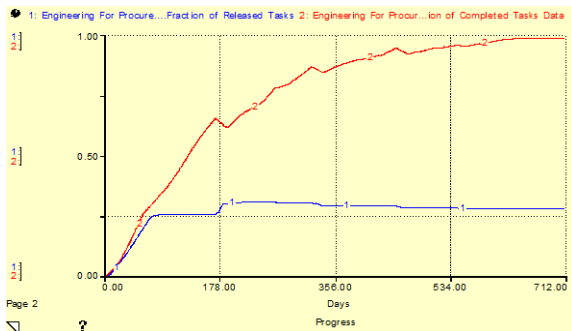


Figure 4.3 (A) Work progress in Engineering for Procurement phase Figure 4.3(B) Work progress in Area Engineering phase

In our finally analysis of extreme condition test, we set the “Probability to be Defective Task” to 1 and “Probability of Tasks to be Successfully Reworked” to zero, so that no task will be “Successfully Completed”. In such extreme condition, the project will not be completed in what so ever time as long as the quality assurance activities discovers flawed task. The outputs of the model shown in figure 4.4 (A and B), which run until 1500 days, confirm our expectation.

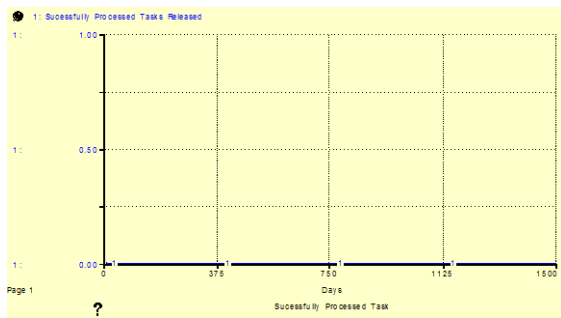


Figure 4.4 (A) Successfully Processed Task

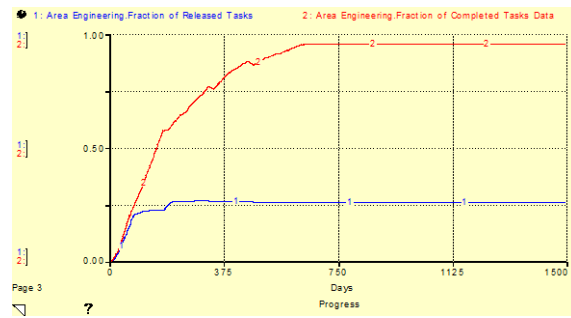


Figure 4.4(B) Work progress in System Engineering phase

4.2 Model Behavior Test

Tests of model behavior evaluates adequacy of the model structure through analysis of the behavior generated by the structure (Forrester & Senge, 1979). There are more than 9 behavior analysis tests (see Forrester & Senge, 1979). In this section, we have considered two behavior analysis tests, behavior reproduction (comparison between simulated and actual behavior) and sensitivity analysis.

4.2.1 Comparison of Model Simulations to DolWin Beta Project

A model validation process includes comparison between the simulated model behavior and the historical behavior. The main objective of this test is to examine the model's ability to reproduce the historical dynamic behavioral patterns observed in the engineering process of the DolWin Beta project.

In order to simulate the model, four sets of parameters need to be set. These four sets consist of parameters that determine the work process subsystem, the project scope subsystem, the human resource subsystem, and the target subsystem. From the interviews and documentation of the DolWin Beta project, we found the following estimates (Tables 4.2–4.5) for the values of the parameters.

Table 4.2 Parameter estimates for the Work Process Subsystem

Parameter	Engineering Phase		
	System Engineering	Procurement for Engineering	Area Engineering
Minimum Regular Processing Duration per Task	1 days	1 days	1 days
Minimum QA Duration per Task	0.13 days	0.13 days	0.13 days
Minimum Rework Duration per Task Discovered in the Phase	0.13 days	0.13 days	0.13 days
Minimum Rework Duration per Task Discovered outside the phase	0.5 days	0.5 days	0.5 days
Time to Release Tasks	5 days	5 days	5 days

Precedence relations in System Engineering phase

Internal_Precedence_Relation = GRAPH (Fraction_of_Tasks_Perceived_Completed)

GRAPH (Fraction_of_Tasks_Perceived_Completed) =

(0.00, 0.026), (0.1, 0.17), (0.2, 0.376), (0.3, 0.573), (0.4, 0.658), (0.5, 0.796), (0.6, 0.868),
 (0.7, 0.91), (0.8, 0.953), (0.9, 0.986), (1.00, 1.00)

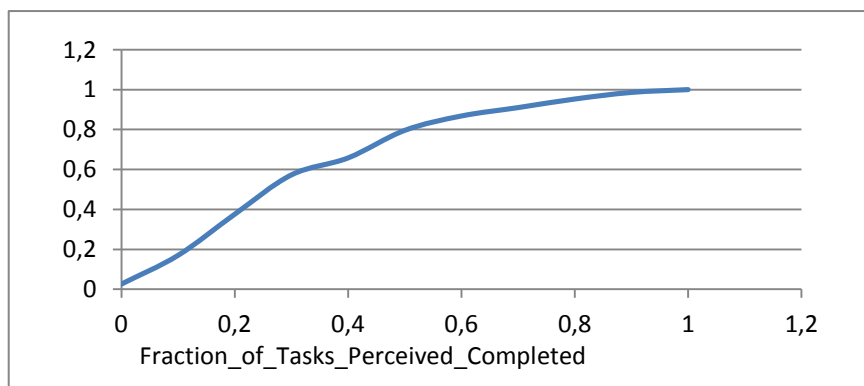


Figure 4.5 Internal Precedence relations in System Engineering

External_Precedence_from_Up_stream = 1

External_Precedence_from_Down_stream =
 GRAPH (Fraction_of_Released_Tasks_from_Downstream)

GRAPH (Fraction_of_Released_Tasks_from_Downstream) = (0.475, 0.7), (0.6, 0.85), (0.7, 1.00)

Precedence relations in Engineering for Procurement phase

Internal_Precedence_Relation = GRAPH (Fraction_of_Tasks_Perceived_Completed)

GRAPH (Fraction_of_Tasks_Perceived_Completed) =
 (0.00, 0.042), (0.1, 0.241), (0.2, 0.457), (0.3, 0.628), (0.4, 0.753), (0.5, 0.846),
 (0.6, 0.904), (0.7, 0.94), (0.8, 0.972), (0.9, 0.994), (1.00, 1.00)

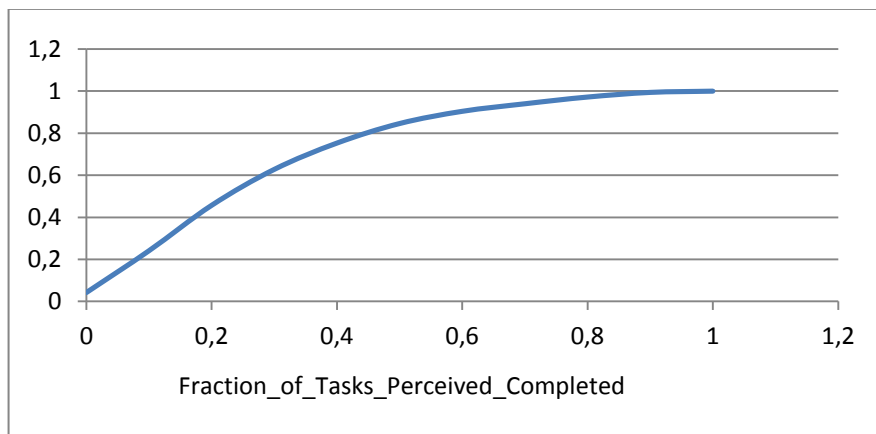


Figure 4.6 Internal Precedence relations in Engineering for Procurement

External_Precedence_from_Up_stream = GRAPH (System_Engineering.Fraction_of_Released_Tasks)

GRAPH (System_Engineering.Fraction_of_Released_Tasks) =
 (0.2, 0.254), (0.376, 0.457), (0.573, 0.628), (0.658, 0.753), (0.796, 0.846), (0.868, 0.904),
 (0.91, 0.94), (0.953, 0.972), (0.986, 0.994), (1.00, 1.00)

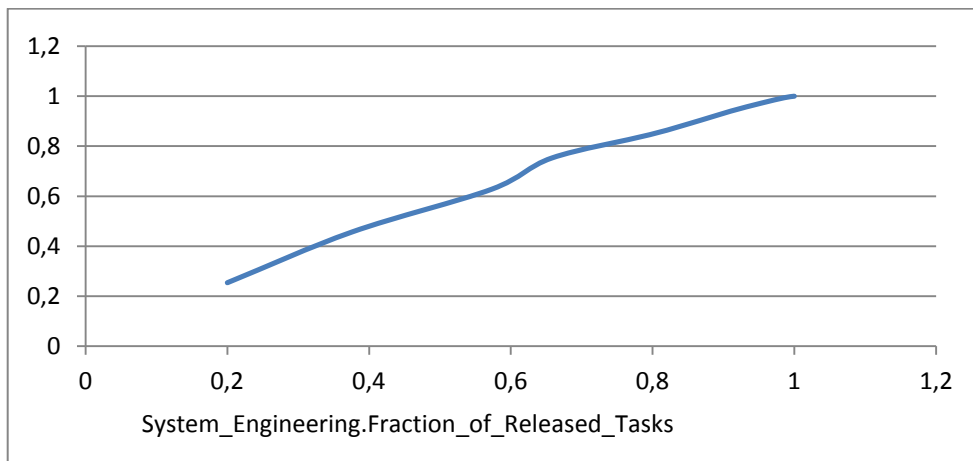


Figure 4.7 External Precedence relations with upstream in Engineering for Procurement

External_Precedence_from_Down_stream =

GRAPH (Fraction_of_Released_Tasks_from_Downstream)

GRAPH(Fraction_of_Released_Tasks_from_Downstream) = (0.15, 0.475), (0.7, 1.00)

Precedence relations in Area Engineering phase

Internal_Precedence_Relation = GRAPH (Fraction_of_Tasks_Perceived_Completed)

GRAPH (Fraction_of_Tasks_Perceived_Completed) =

(0.00, 0.034), (0.1, 0.208), (0.2, 0.421), (0.3, 0.583), (0.4, 0.675), (0.5, 0.788), (0.6, 0.852),
(0.7, 0.899), (0.8, 0.941), (0.9, 0.98), (1.00, 1.00)

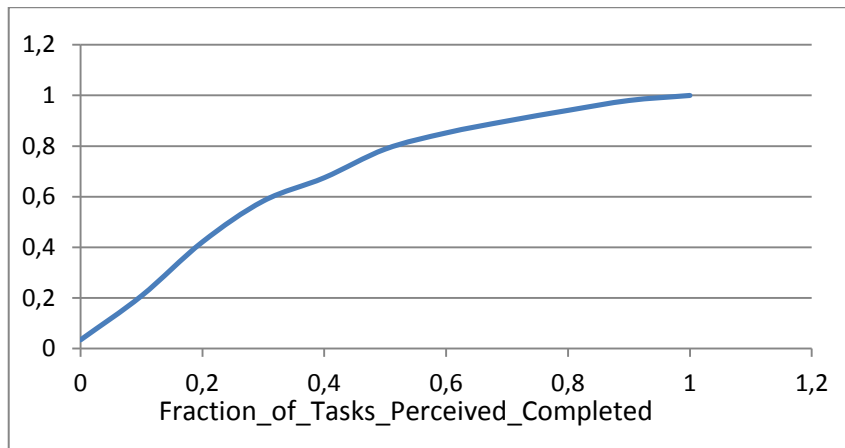


Figure 4.8 Internal Precedence relations in Area Engineering

External_Precedence_from_Up_stream =

GRAPH(Engineering_For_Procurement.Fraction_of_Released_Tasks)

GRAPH (Engineering_For_Procurement.Fraction_of_Released_Tasks =

(0.241, 0.208), (0.457, 0.421), (0.628, 0.583), (0.753, 0.7), (0.846, 0.82), (0.904, 0.852),
(0.94, 0.899), (0.972, 0.941), (0.994, 0.98), (1.00, 1.00)

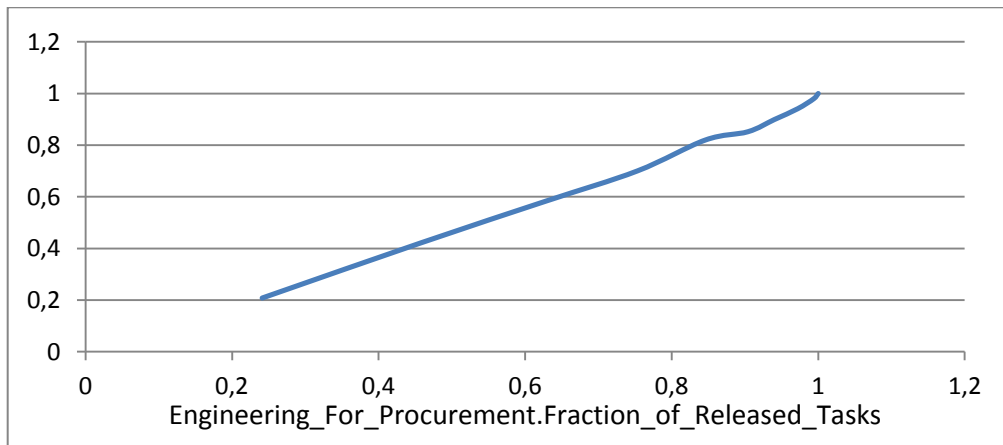


Figure 4. 7 External Precedence relations with upstream in Engineering for Procurement

External_Precedence_from_Down_stream = 1

Table 4.3 Parameter estimates for the Scope Subsystem

Parameter	Engineering Phase		
	System Engineering	Engineering for Procurement	Area Engineering
Initial Phase Scope	8186 Tasks	2651 Tasks	13 439 Tasks

Table 4.4(A) Parameter estimates for the Human Resource Subsystem – Labor Force Sector

Parameter	Engineering Phase		
	System Engineering	Engineering for Procurement	Area Engineering
Initial number of Experienced Employees	25 People	14 people	31 people
Initial number of Transferred-In Company Employees	0 People	0 People	0 People
Initial number of New Employees	0 People	0 People	0 People
Initial number of Experienced Hired-In Externally	6 people	4 people	8 people
Initial number of New Hired-In Externally	0 People	0 People	0 People
Avg Assimilation Time of New Employees	60 days	60 days	60 days
Avg Assimilation Time of Transferred-In Company Employees	20 days	20 days	20 days
Avg Assimilation Time of New Hire-In Externally	20 days	20 days	20 days
Avg Hiring Time of New Employees	40 days	40 days	40 days
Mobilization Delay	10 days	10 days	10 days
Avg Hiring Time of New Hire-In Externally	14 days	14 days	14 days
Demobilization Delay	10 days	10 days	10 days
Avg Employment Duration of Hire-In Externally	220 days	220 days	220 days
Experienced Employee Quit Fraction	0.05/year \approx 0.0002/days	0.0002/days	0.0002/days
Max Hire-In Fraction Allowed	0.3 Unitless	0.3 Unitless	0.3 Unitless
Max New Hires Per Full Time Experienced Labor Force	2 People/People	1 People/People	2 People/People
Avg Daily Labor Force Per Staff	1 days/days	1 days/days	1 days/days
Trainers per New Labor Force	0.2 days/days	0.2 days/days	0.2 days/days
Initial Perceived Trend	0 /days	0.15 /days	0/days

Table 4.4(B) Parameter estimates for the Human Resource Subsystem – Quality of Practice Sector

Parameter	Engineering Phase		
	System Engineering	Engineering for Procurement	Area Engineering
Reference Quality of Practice in Regular Processing	0.8 Unitless	1 Unitless	0.9 Unitless
Reference Quality of Practice in Rework	0.9 Unitless	0.9 Unitless	0.9 Unitless
Reference Quality of Practice in QA	0.9 Unitless	0.9 Unitless	0.9 Unitless
Probability to be Defective from Inherent Task Complexity	0.2 Unitless	0.05 Unitless	0.1 Unitless

Table 4.4(C) Parameter estimates for the Human Resource Subsystem – Productivity Sector

Parameter	Engineering Phase		
	System Engineering	Engineering for Procurement	Area Engineering
Reference Potential Productivity of Experienced Employees	1 Tasks/People-days	1 Tasks/People-days	1 Tasks/People-days
Reference Potential Productivity of Transferred-In Company Employees	0.8 Tasks/People-days	0.8 Tasks/People-days	0.8 Tasks/People-days
Reference Potential Productivity of New Employees	0.5 Tasks/People-days	0.5 Tasks/People-days	0.5 Tasks/People-days
Reference Potential Productivity of Experienced Hire-In Externally	1 Tasks/People-days	1 Tasks/People-days	1 Tasks/People-days
Reference Potential Productivity of New Hire-In Externally	0.8 Tasks/People-days	0.8 Tasks/People-days	0.8 Tasks/People-days
Ref Regular Processing Productivity	0.88 Tasks/People-days	0.88 Tasks/People-days	0.88 Tasks/People-days
Ref Rework Productivity	1.5 Tasks/People-days	1.5 Tasks/People-days	1.5 Tasks/People-days
Ref Quality Assurance Productivity	10 Tasks/People-days	10 Tasks/People-days	10 Tasks/People-days

Schedule Pressure Tolerance – Its value is the same for all the three phases

Schedule Pressure	1	1.1	1.15	1.2	1.3
Tolerance level	No limit	9 months	6 months	1.5 month	5 days

Table 4.5 Parameter estimates for the Target subsystem

Parameter	Engineering Phase		
	System Engineering	Engineering for Procurement	Area Engineering
Initial Internal Deadline	187 days	187 days	187 days
Maximum Internal Deadline Extension Dates	40 days	40 days	40 days
Initial Project Deadline for the Phase	712 days	712 days	712 days
Maximum Project Deadline Extension Dates	0 days	0 days	0 days
Initial Quality Goal	0.9 Unitless	0.9 Unitless	0.9 Unitless
Experienced Employee Avg Hourly Pay Rate	650NOK	650NOK	650NOK
Transferred-In Company Employees Avg Hourly Pay Rate	500NOK	500NOK	500NOK
New Employees Avg Hourly Pay Rate	400NOK	400NOK	400NOK
Experienced Hired-In Externally Avg Hourly Pay Rate	800NOK	800NOK	800NOK
New Hired-In Externally Avg Hourly Pay Rate	500NOK	500NOK	500NOK
Avg Hourly Overtime Pay Rate	1000NOK	1000NOK	1000NOK

Once the model had been parameterized, it was run to simulate the DolWin Beta project. The figures below portray the models output (in blue) compared to the DolWin Beta engineering process actual behavior (in red).

Figures 4.9(A-D) portray the comparison between the simulated (blue) and actual (red) work progress of the three engineering activities and the total Engineering.

During most of the development period of the project, the model replicates the actual work progress in both the individual engineering phases and the overall engineering.

Although the overall fit between the simulated and the actual engineering work progress in all the engineering phase is acceptable, there are some points that need explanation. For example,

on the 167th project day additional engineering works are added to the scope of the phase, hence reducing the overall progress of the phases with a relatively larger drop correspondingly in system engineering, around 6%, and a smaller drop in area engineering, around 1%.

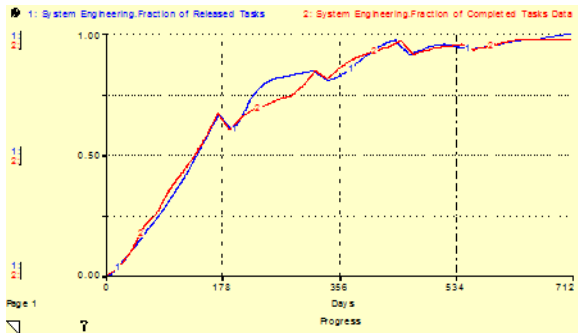


Figure 4.9(A) Work progress in System Engineering phase

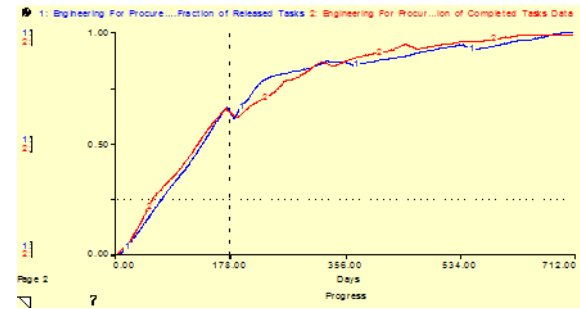


Figure 4.9(B) Work progress in Engineering for Procurement phase

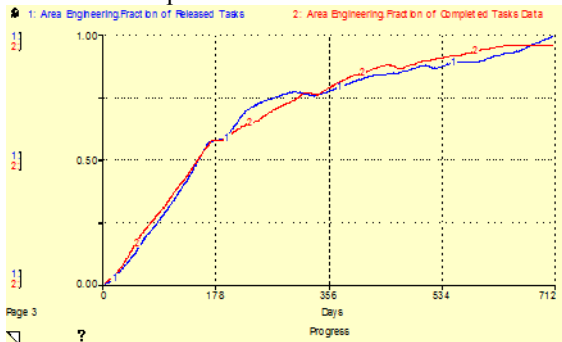


Figure 4.9(C) Work progress in Area Engineering phase

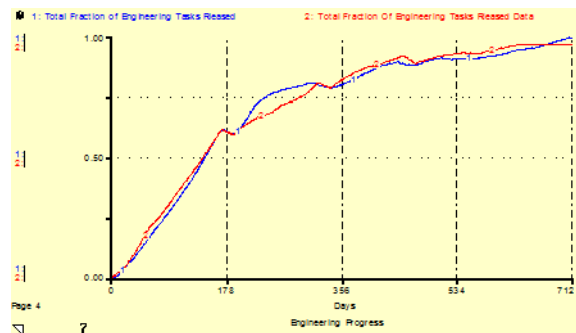


Figure 4.9(D) Work progress in Overall Engineering

The additional scope of work came to picture at the time when the phases approached their internal deadline, initially set to the 187th project day. The additional scope of the work, together with the motive for complying with the internal deadlines, forced engineering to recruit more labor force, as can be seen in Figures 4.10 (A-D).

One noticeable difference between the simulated and the actual labor force shown in the figures below is, in the historical labor force curve the additional labor force had started to join the phases one month earlier than the additional scope of work is introduced. This implies that the managers were primed to expect a change in scope much earlier. However, the model only recognizes the change in scope, when it actually is introduced, and hence, the simulated labor force lags behind the actual labor force.

Another point that needs explanation is the deviation of the simulated curve from the actual progress in Figures 4.9, specifically, starting from the 220th project day. This is, of course, due to the presence of a relatively larger labor force in the phases after the internal deadline.

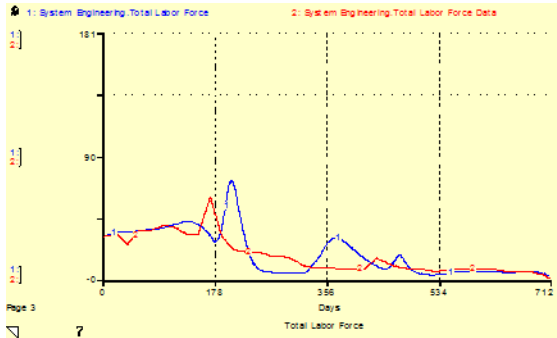


Figure 4.10 (A) Total labor force in System Engineering phase

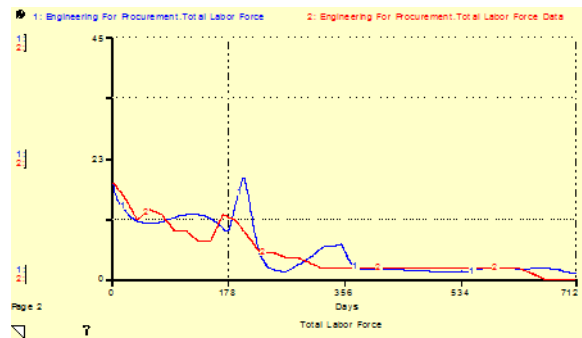


Figure 4.10(B) Total labor force in Engineering for Procurement phase

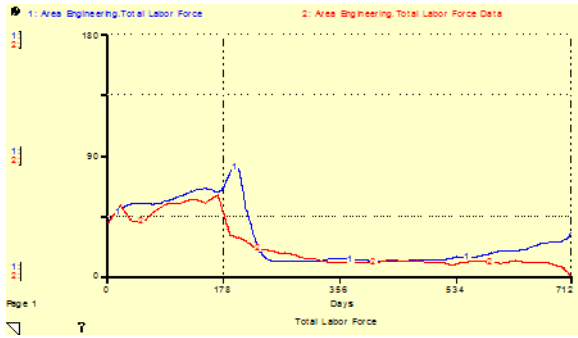


Figure 4.10(C) Total labor force in Area Engineering

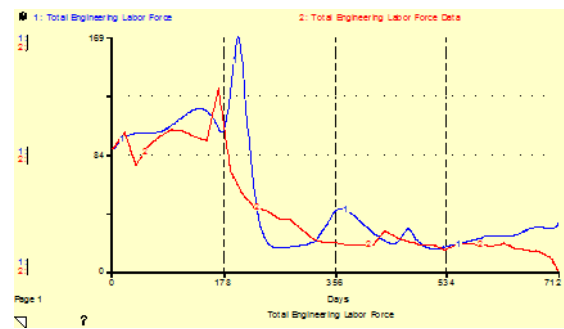


Figure 4.10(D) Total Engineering labor force

In the formulation of the model, we assumed that it takes some time before the managers adjust the labor force affected by the initial internal deadline to the new deadline. We also assumed that the labor force cannot sit idle as long as there are available engineering tasks to handle. Hence, this has resulted a slight increase in the progress of the engineering phases.

The third model output compared with the DolWin Beta historical behavior is the cumulative man-hours expended.

But, before we run this comparison, we have been warned by two managers of the company (Interviewee 1; Interviewee 2) from paying more emphasis against the cumulative expended man-hour records. This is because the labor force, which actually did the engineering job, is the one who records the expended man-hours and, often, the man-hours could be recorded much later in the project.

For example, a labor force could record all his/her man-hours at the end of the month. However, man-hour reports are generated every week and the man-hours done by the labor force, in our example, will be missed from the three prior weeks reports and will be presented in the last report as if they are done in that reporting week.

The second reason is the man-hours could be recorded against a wrong engineering phase or to a wrong project phase. For example man-hours done against system engineering could be recorded against area engineering or engineering for procurement, and some time even outside of the engineering phases, say to the construction or testing phases of the project. There are departments that redistribute wrongly recoded man-hours to the appropriate engineering phases but such activity usually takes a very long time (Interviewee 2).

With this ground, we run the model and the outputs are portrayed in Figures 4.11(A-D). The comparison between the simulated (blue) and actual (red) cumulative expended man-hours in the three engineering activities and in the entire engineering process shows that the model replicated the actual expended man-hours in most of the development periods.

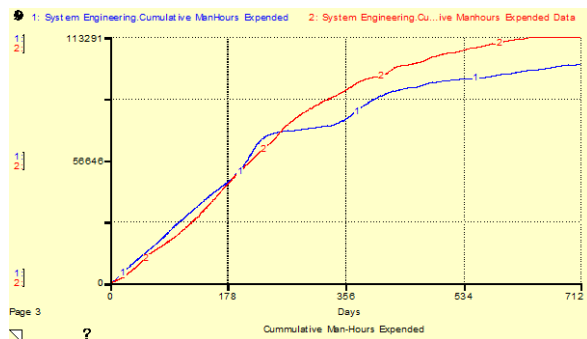


Figure 4.11(A) Cumulative Expanded Man-Hour in System Engineering phase

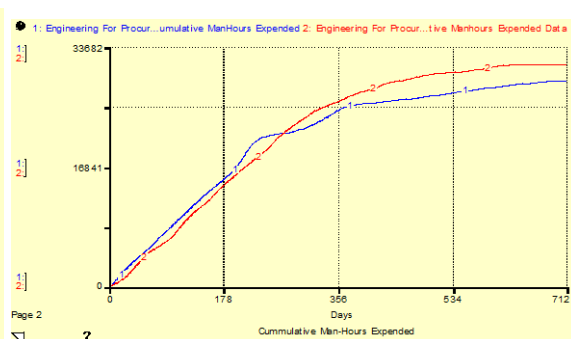


Figure 4.11(B) Cumulative Expanded Man-Hour in Engineering for Procurement phase

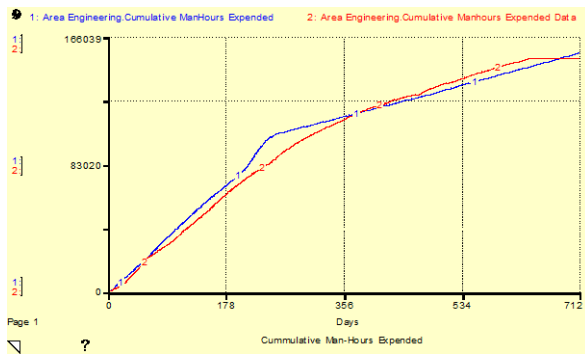


Figure 4.11(C) Cumulative Expanded Man-Hour in Area Engineering phase

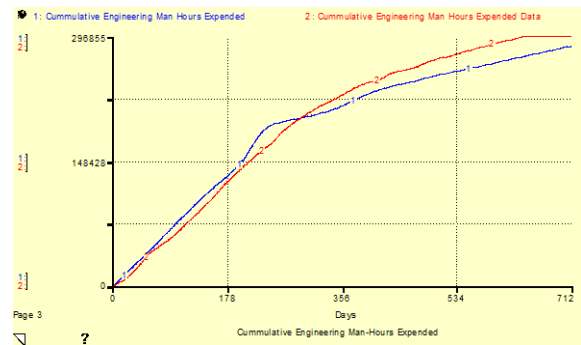


Figure 4.11(D) Cumulative Expanded Man-Hour in the entire Engineering

Given the above-mentioned fact about the possible wrong recordings of the cumulative man-hours recorded, we believe that the model has replicated the cumulative expended man-hours with an acceptable fit.

Despite, the near to perfect fit in the work progress (Figure 4.1) and labor force (Figure 4.2) curves of the system engineering and engineering for procurement phases, particularly in the later periods of the project, the small gaps seen between the simulated and the actual cumulative expended man-hours and a relatively good fit in the entire engineering process could clearly support the claims made by the two managers.

4.2.2 Sensitivity Analysis

Sensitivity analysis is made to ascertain whether or not plausible shifts in the model parameters can cause a model to fail behavior test previously passed (Forrester & Senge, 1979). Specially, sensitivity analysis is conducted, on parameter values that are estimated based on statistical data and expert knowledge, or parameter values resulting from other research. Besides examining how sensitive the model is to the parameter, the purpose of sensitivity analysis is also to examine whether the real system would exhibit similar high sensitivity to the corresponding parameter (Barlas, 1994).

We have tested sensitivity by observing the models performance across a range of values in the three engineering phases of the DolWin Beta project. We have carried out the sensitivity analysis based on selected parameters from three subsystems of an engineering phase, work

process subsystem, human resource subsystem and target subsystem. The selected parameters and their values are listed in Table 4.6. The values in Table 4.6 are taken from the system engineering; however, the same procedure is applied in the other two engineering phases too.

We took the parametric values that replicated the historical value as a reference and carried out a sensitivity analysis by adding and subtracting 50% of the reference parameter values. We considered the parametric values above the reference values as “Pessimistic” values and those below the reference as “Optimistic” values. The reference values are referred as “Baseline” values. Exceptions to our plus or minus 50% consideration are the work precedence parameters. In the work precedence parameters, we considered hyperbolic, “S” shaped, linear and open (unconstrained) relations.

Table 4.6 Parameters for Sensitivity analysis

Subsystem	Parameter	Sensitivity test scenario		
		Optimistic (-50%)	Baseline scenario	Pessimistic (+50%)
Work Process	Minimum Regular Processing Duration per Task	0.5 days	1 days	1.5 days
	Minimum QA Duration per Task	0.065 days	0.13 days	0.195 days
	Minimum Rework Duration per Task Discovered in the Phase	0.065 days	0.13 days	0.195 days
	Minimum Rework Duration per Task Discovered outside the phase	0.25 days	0.5 days	0.75 days
	Time to Release Tasks	2.5 days	5 days	7.5 days
	Internal Precedence	Open	Hyperbola	Linear
	External precedence - System Eng. on Eng. for Procurement	Open	Linear	“S” shaped
	External precedence - Eng. For Procurement on Area Eng.	Open	Hyperbola	Linear
Human Resource	Initial total work force	16	31	46
	Avg Assimilation Time of New Employees	30 days	60 days	90 days
	Avg Assimilation Time of Transferred-In Company Employees	10 days	20 days	30 days
	Avg Assimilation Time of New Hire-In Externally	10 days	20 days	30 days
	Demobilization delay	5 days	10 days	15 days
Target	Maximum Internal Deadline Extension Dates	20 days	40	60
	Max Time to Adjust Labor Force Affected by Internal Deadline	10	20	30
	Initial quality goal	0.8	0.9	1

Sensitivity is measured in the changes in the project performance due to change in parameter values. The three measures of project performance are cycle time, quality and cost. Cycle time is the time required for effectively all processed tasks to be released. Since the DoIWin Beta project has a fixed deadline, we measured the engineering process performance in terms of completing all the engineering works on or before the project deadline. Quality is measured in terms of the total number of unsuccessfully processed tasks released. Cost is the cumulative of all the payments made in an engineering phase to the labor for the service they provided in that engineering phase.

The baseline performance of the System Engineering Phase, for example, is: 712 project days (cycle time), 1.66 defects released and 65.55M NOK cost. The raw data for all the engineering phases is presented in Tables 4.7 to 4.9.

Model sensitivity is the percent loss or improvement of project performance compared to the performance of the baseline scenario due to changing a single parameter value from the baseline value (Ford, 1995, pp. 125).

As an example when the minimum regular processing duration per task increase from 1 day (baseline scenario) to 1.5 days (pessimistic scenario), the project cost in the system engineering phase increase from 65.55M NOK reduces to 63.4M NOK, on the other hand when the quality assurance duration in the same phase increases from 0.13 days (baseline scenario) to 0.195 days (pessimistic scenario), the phase's cost increases from its baseline value of 65.55M NOK to 69.35MNOK.

Table 4.7 Parameters Sensitivity in System Engineering Phase

Subsystem	Parameter	Cost Performance (Baseline = 65.55MNOK)		Quality Performance (Baseline =1.66 defects)	
		Optimistic scenario	Pessimistic scenario	Optimistic scenario	Pessimistic scenario
Work Process	Minimum Regular Processing Duration per Task	73.23	63.4	1.41	1.88
	Minimum QA Duration per Task	61.5	69.35	1.66	1.51
	Minimum Rework Duration per Task Discovered both inside and outside the phase	65.54	65.55	1.66	1.66
	Time to Release Tasks	65.3	65.53	1.45	1.67
	Internal Precedence	65.7	497.76	1.38	1.03
	External precedence	65.52	59.07	1.57	1.19
Human Resource	Initial total work force	65.45	64.29	1.94	1.44
	Avg Assimilation Time for all new project members	65.14	65.88	1.02	2.18
	Demobilization delay	65.74	65.27	1.75	1.57
Target	Maximum Internal Deadline Extension Dates	66.27	65.54	2.54	1.66
	Max Time to Adjust Labor Force Affected by Internal Deadline	65.56	65.54	1.66	1.66
	Initial quality goal	65.55	65.55	1.66	1.66

Table 4.8 Parameters Sensitivity in Engineering for Procurement Phase

Subsystem	Parameter	Cost Performance (Baseline = 18.62MNOK)		Quality Performance (Baseline =0.12 defects)	
		Optimistic scenario	Pessimistic scenario	Optimistic scenario	Pessimistic scenario
Work Process	Minimum Regular Processing Duration per Task	23	17.81	0.13	0.13
	Minimum QA Duration per Task	17.45	20.16	0.1	0.12
	Minimum Rework Duration per Task Discovered both inside and outside the phase	18.62	18.62	0.12	0.12
	Time to Release Tasks	18.54	19.23	0.12	0.12
	Internal Precedence	17.73	111.68	0.1	0.05
	External precedence	17.71	104.1	0.11	0.02
Human Resource	Initial total labor force	19.14	18.8	0.16	0.12
	Avg Assimilation Time for all new project members	18.7	18.55	0.09	0.15
	Demobilization delay	18.56	18.95	0.13	0.12
Target	Maximum Internal Deadline Extension Dates	18.22	18.62	0.13	0.12
	Max Time to Adjust Labor Force Affected by Internal Deadline	18.62	18.62	0.12	0.12
	Initial quality goal	18.62	18.62	0.12	0.12

Table 4.9 Parameters Sensitivity in Area Engineering Phase

Subsystem	Parameter	Cost Performance (Baseline =102.87MNOK)		Quality Performance (Baseline =0.77 defects)	
		Optimistic scenario	Pessimistic scenario	Optimistic scenario	Pessimistic scenario
Work Process	Minimum Regular Processing Duration per Task	85.34	100.23	0.86	0.79
	Minimum QA Duration per Task	164.26	119.57	0.81	0.84
	Minimum Rework Duration per Task Discovered both inside and outside the phase	102.86	102.87	0.77	0.77
	Time to Release Tasks	100.63	111.9	0.78	0.77
	Internal Precedence	17.73	111.68	0.1	0.05
	External precedence	17.71	104.1	0.11	0.02
Human Resource	Initial total labor force	103.66	109.38	1.18	0.59
	Avg Assimilation Time for all new project members	101.75	103.55	0.59	0.93
	Demobilization delay	103.24	104.6	0.81	0.76
Target	Maximum Internal Deadline Extension Dates	104.4	105.95	1	0.79
	Max Time to Adjust Labor Force Affected by Internal Deadline	102.79	105.79	0.77	0.77
	Initial quality goal	102.87	102.87	0.77	0.77

Tables 4.10 to 4.12 summarize the results of the sensitivity analysis carried out on the percent of performance change in cost and quality. The performances in cycle time are described with the help of time series graphs shown below.

Table 4.10 Parameters Sensitivity in System Engineering Phase

Subsystem	Parameter	% Change in Cost Performance		% Change in quality Performance	
		Optimistic scenario	Pessimistic scenario	Optimistic scenario	Pessimistic scenario
Work Process	Minimum Regular Processing Duration per Task	11.72	-3.28	-15.06	13.25
	Minimum QA Duration per Task	-6.18	5.80	0.00	-9.04
	Minimum Rework Duration per Task Discovered both inside and outside the phase	-0.02	0.00	0.00	0.00
	Time to Release Tasks	-0.38	-0.03	-12.65	0.60
	Internal Precedence	0.23	659.36	-16.87	-37.95
	External precedence	-0.05	-9.89	-5.42	-28.31
Human Resource	Initial total work force	-0.15	-1.92	16.87	-13.25
	Avg Assimilation Time for all new project members	-0.63	0.50	-38.55	31.33
	Demobilization delay	0.29	-0.43	5.42	-5.42
Target	Maximum Internal Deadline Extension Dates	1.11	0.00	53.01	0.00
	Max Time to Adjust Labor Force Affected by Internal Deadline	0.02	-0.02	0.00	0.00
	Initial quality goal	0.00	0.00	0.00	0.00

During the sensitivity testing we have tested some related variables at the same time, for example the three different average assimilation times of the new project members are tested at the same time. Hence, we only have one sensitivity test result for such parameters.

Table 4.11 Parameters Sensitivity in Engineering for Procurement Phase

Subsystem	Parameter	% Change in Cost Performance		% Change in quality Performance	
		Optimistic scenario	Pessimistic scenario	Optimistic scenario	Pessimistic scenario
Work Process	Minimum Regular Processing Duration per Task	23.52	-4.35	8.33	8.33
	Minimum QA Duration per Task	-6.28	8.27	-16.67	0.00
	Minimum Rework Duration per Task Discovered both inside and outside the phase	0.00	0.00	0.00	0.00
	Time to Release Tasks	-0.43	3.28	0.00	0.00
	Internal Precedence	-4.78	499.79	-16.67	-58.33
	External precedence	-4.89	459.08	-8.33	-83.33
Human Resource	Initial total labor force	2.79	0.97	33.33	0.00
	Avg Assimilation Time for all new project members	0.43	-0.38	-25.00	25.00
	Demobilization delay	-0.32	1.77	8.33	0.00
Target	Maximum Internal Deadline Extension Dates	-2.15	0.00	8.33	0.00
	Max Time to Adjust Labor Force Affected by Internal Deadline	0.00	0.00	0.00	0.00
	Initial quality goal	0.00	0.00	0.00	0.00

Table 4.12 Parameters Sensitivity in Area Engineering Phase

Subsystem	Parameter	% Change in Cost Performance		% Change in quality Performance	
		Optimistic scenario	Pessimistic scenario	Optimistic scenario	Pessimistic scenario
Work Process	Minimum Regular Processing Duration per Task	-17.04	-2.57	11.69	2.60
	Minimum QA Duration per Task	59.68	16.23	5.19	9.09
	Minimum Rework Duration per Task Discovered both inside and outside the phase	-0.01	0.00	0.00	0.00
	Time to Release Tasks	-2.18	8.78	1.30	0.00
	Internal Precedence	-20.99	277.85	-14.29	-31.17
	External precedence	-35.40	274.74	-12.99	-45.45
Human Resource	Initial total labor force	0.77	6.33	53.25	-23.38
	Avg Assimilation Time for all new project members	-1.09	0.66	-23.38	20.78
	Demobilization delay	0.36	1.68	5.19	-1.30
Target	Maximum Internal Deadline Extension Dates	1.49	2.99	29.87	2.60
	Max Time to Adjust Labor Force Affected by Internal Deadline	-0.08	2.84	0.00	0.00
	Initial quality goal	0.00	0.00	0.00	0.00

The sensitivity of the model behavior is the range of performance change (in the baseline performance) (Ford, 1995). These results are shown in Table 4.13 to 15. For example, the 3.28% reduction in cost of system engineering phase due to an increase in regular processing minimum duration per task (in the pessimistic scenario) and the 11.72% increase in cost in the optimistic scenario produces a 15% total sensitivity of the model's cost performance to the regular processing minimum duration per task parameter as shown in the first row of Table 4.13.

Table 4.13 Parameters Sensitivity in System Engineering Phase

Subsystem	Parameter	% Cost Performance Range	% Quality Performance Range
Work Process	Minimum Regular Processing Duration per Task	15	28.31
	Minimum QA Duration per Task	11.98	9.04
	Minimum Rework Duration per Task Discovered both inside and outside the phase	0.02	0
	Time to Release Tasks	0.35	13.25
	Internal Precedence	659.13	54.82
	External precedence	9.84	22.89
Human Resource	Initial total work force	1.77	30.12
	Avg Assimilation Time for all new project members	1.13	69.88
	Demobilization delay	0.72	10.84
Target	Maximum Internal Deadline Extension Dates	1.11	53.01
	Max Time to Adjust Labor Force Affected by Internal Deadline	0.04	0.00
	Initial quality goal	0.00	0.00

Table 4.14 Parameters Sensitivity in Engineering for Procurement Phase

Subsystem	Parameter	% Change in Cost Performance	% Change in quality Performance
Work Process	Minimum Regular Processing Duration per Task	27.87	0
	Minimum QA Duration per Task	14.54	16.67
	Minimum Rework Duration per Task Discovered both inside and outside the phase	0.00	0.00
	Time to Release Tasks	3.71	0.00
	Internal Precedence	503.78	41.66
	External precedence	463.89	0
Human Resource	Initial total labor force	1.82	33.33
	Avg Assimilation Time for all new project members	0.81	50
	Demobilization delay	1.99	8.33
Target	Maximum Internal Deadline Extension Dates	2.15	8.33
	Max Time to Adjust Labor Force Affected by Internal Deadline	0.00	0.00
	Initial quality goal	0.00	0.00

Table 4.15 Parameters Sensitivity in Area Engineering Phase

Subsystem	Parameter	% Change in Cost Performance	% Change in quality Performance
Work Process	Minimum Regular Processing Duration per Task	14.47	9.09
	Minimum QA Duration per Task	43.45	3.9
	Minimum Rework Duration per Task Discovered both inside and outside the phase	0.01	0.00
	Time to Release Tasks	10.96	1.30
	Internal Precedence	298.84	16.88
	External precedence	310.14	32.46
Human Resource	Initial total labor force	5.56	76.63
	Avg Assimilation Time for all new project members	1.75	44.16
	Demobilization delay	1.32	6.49
Target	Maximum Internal Deadline Extension Dates	1.5	27.27
	Max Time to Adjust Labor Force Affected by Internal Deadline	3.64	0.00
	Initial quality goal	0.00	0.00

Based on the range of performance changes in Tables 4.13-15, we can conclude that the two performance measures (cost and quality) are more sensitive to the internal and external precedence parameters. The minimum quality assurance duration is another parameter to which the cost and quality performance of the model are dependent across the three engineering phases.

From the above sensitivity analysis we can say that the model is insensitive to initial quality goal, and minimum rework duration and

The figures shown below also confirm that the cycle time performance of the model is more sensitive to the internal and external precedence of the model. As shown in Figures 4.12 A-F the project couldn't be completed within the deadline when the internal and external work precedencies are set to pessimistic (linear and "S"- shaped) relations.

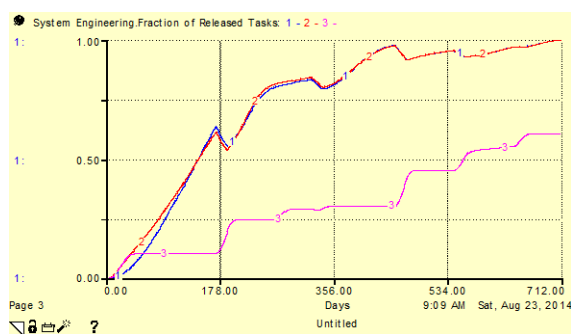


Figure 4.12(A) Progress of System Engineering phase under Internal precedence parameter

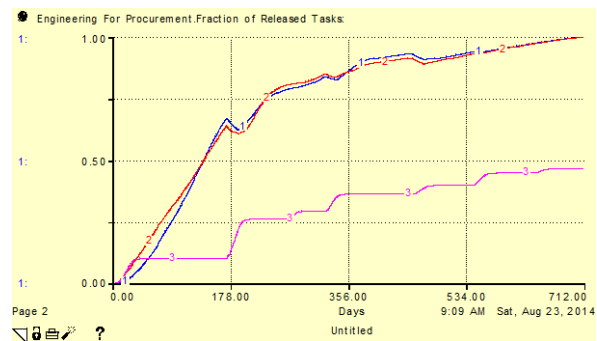


Figure 4.12(B) Progress of Engineering for Procurement phase under Internal precedence parameter

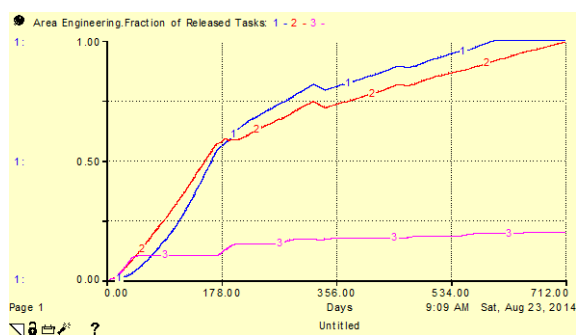


Figure 4.12(C) Progress of Area Engineering

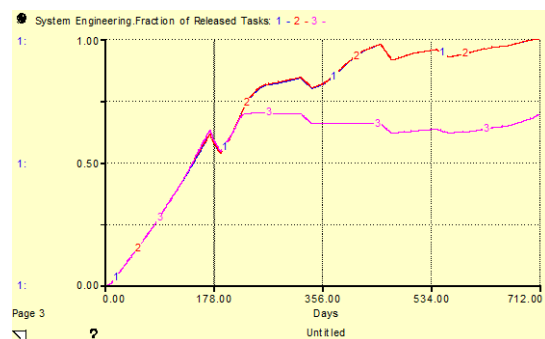
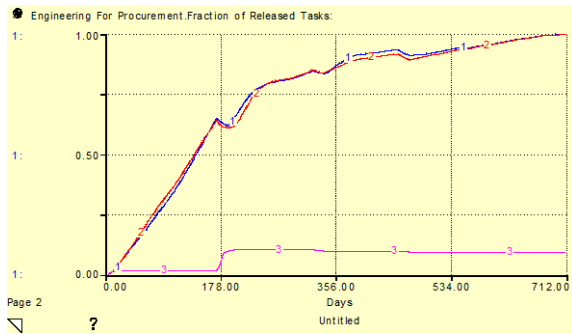


Figure 4.12(D) Progress of System Engineering

phase under Internal precedence parameter



phase under External precedence parameter

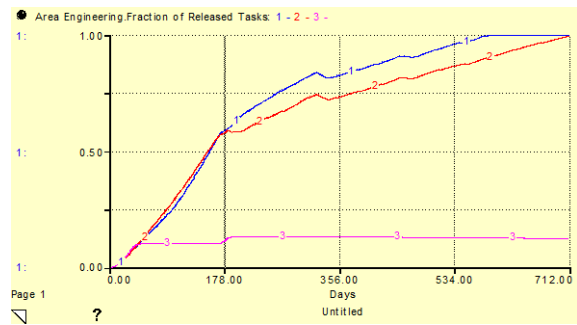


Figure 4.12(E) Progress of Engineering for Procurement phase under External precedence parameter

Figure 4.12(F) Progress of Area Engineering phase under External precedence parameter

Chapter 5

5 Policy Analysis

In this chapter, we will mainly focus on examining scenarios on selected variables, which could serve as future policies. As we have explained in the earlier chapters, the main objective of this research is to investigate the drivers for the high cost of construction with the help of system dynamics methodology. From the sensitivity analysis we made in chapter four, we have realized that the model is very sensitive to the work precedence relation parameters. However, these parameters are exogenous to our model and very specific to the work process of the company.

Hence, we opted on carrying out our scenario analysis on the internal deadline and project deadlines of the company and evaluate their performance on cost, cycle time and quality. As we have explained before, the company has two deadlines, internal and external. The internal deadline is set on the 187th project day with a possible extension of 40 project days, whereas the project deadline is set to the 712th project day, which is actually equal to the final project completion date of DolWin Beta project. The main objective of the internal deadline is to complete 70% of the engineering work as early as possible, so that construction activities can be started early in the project.

We have chosen seven different scenarios to assess how the internal and project deadlines react to these scenarios. The first scenario is the baseline or reference scenario. This scenario represents the reference condition and we use it to measure the other scenarios performance against it.

In our second scenario, we have considered a situation, where there is no internal deadline but a fixed project deadline that equals with the project's fixed deadline. In the third scenario, we tried to ignore both internal and external deadlines by setting a single deadline 400 workdays behind the current project deadline ($712 + 400 = 1112$ work days).

In the fourth and fifth scenario, we considered both internal and external deadlines, but this time the internal deadline is initially set 40 days below and above the references internal deadline. In the fourth scenario it was above the reference internal deadline (187+40) workdays and in the fifth below the reference internal deadline (187-40) workdays. The six and the seventh scenarios have exactly the same approach as the 4th and 5th, the only difference is we have added and subtracted 80 workdays instead 40 workdays from the internal deadline. (187-80) workdays in the sixth and (187+80) workdays on the seventh scenario. The result of the model run is displayed in Figure 5.1(A-D). The performance of the three engineering phases in the three performance indicators is also summarized in Table 5.1.

Table 5.1 Performance indicators for different scenarios

S.NO	Scenario	Cost Performance (in MNOK)				Unsuccessfully Processed Released Tasks (in # defects)				Cycle Time (in Workdays)	Early Construction starting day
		System Eng	Eng. for Proc	Area Eng	Total Eng	System Eng	Eng. for Proc	Area Eng	Total Eng	Total Eng	Total Eng
1	Baseline	65.90	18.51	107.74	192.15	1.40	0.13	1.14	2.67	742	212
2	With out Internal Deadline but with the fixed project deadline	81.88	23.17	350.25	455.30	12.57	0.24	2.41	15.22	742	554
3	With out Internal Deadline and Project deadline (+400)	64.10	18.85	189.50	272.45	1.21	0.04	0.65	1.90	850	597
4	New Internal Deadline (187+40)	72.27	19.76	174.69	266.72	2.72	0.28	4.15	7.15	770	261
5	New Internal Deadline (187-40)	71.57	20.15	167.09	258.81	2.26	0.21	3.54	6.01	737	169
6	New Internal Deadline (187-80)	69.97	21.71	160.04	251.72	2.13	0.28	4.04	6.45	736	127
7	New Internal Deadline (187+80)	71.55	20.13	186.06	277.74	3.65	0.37	3.81	7.83	736	309

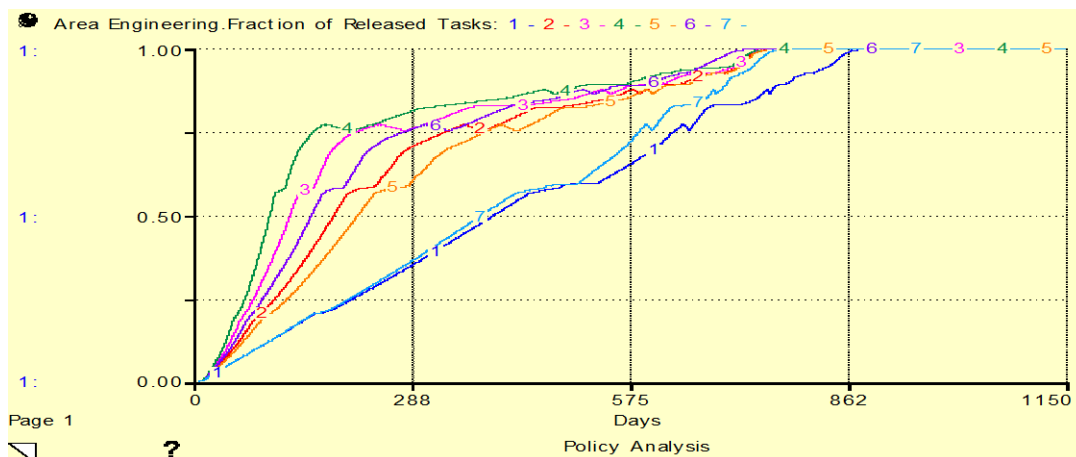


Figure 5.1 Scenario outputs

From Table 5.1 we can see that (notice the colored cells; green the lowest, orange the highest) the baseline scenario has the lowest aggregate cost (192.15 MNOK), whereas, the scenario number two, with out internal deadline and but with a fixed project deadline) has the highest cost (455.3MNOK, a relative increase of 1.37 from the baseline). This second scenario has also the highest number of flawed tasks released (15.22 defects, a relative increase of 4.7 from the baseline scenario). On the other hand, scenario three (which has no internal deadline a relatively relaxed project deadline) has the lowest flawed tasks released. But this scenario has the highest cycle time (project completion time) and it takes a minimum of 597 days (approximately 2.5 years) to start construction activities with this scenario. The minimum project completion time with the earliest construction starting date (127 workdays, a relative reduction of 0.4 from the baseline) can be achieved with scenario 6, which has an internal deadline of 80 workdays less that the reference. However, scenario 6 compared to the reference has a relative increase of 0.3 in cost and a 1.4 relative increase in defective tasks.

In general, from the scenario analysis we can conclude that internal deadlines are vital for the successful completion of an engineering work within its scheduled deadline and with a relatively reduced project cost. However, the decision about the better scenario lies on the trade off between cost, motive for early construction startup and on the number of defects generated. Since the construction activity is outside our boundary, our recommendation for the better scenario would be a bit limited. However, we believe that this scenario analysis could give a good insight for manager to make their decisions. Given the scenarios shown above and their analysis, we recommended Scenario 6, (with an early internal deadline of approximately 1/5 of the project deadline), should be considered in the engineering process.

Chapter 6

6 Conclusion and Recommendation

6.1 Conclusion

The reduction of project cost has become a high priority for many construction companies who are looking for ways to become more competitive and to accomplish more with given resources. Yet large, complex development projects often experience substantial cost overruns. Problems of cost overrun on projects have persisted for decades, in spite of numerous advances in the field of 'project management'. Project management techniques such as PERT and CPM have been enhancing project performances since the 1950, however, most project management concepts and tools view projects statically. But large-scale projects are extremely complex and highly dynamic involving multiple feedback processes and non-linear relationships, which are very difficult to understand with human mental models. However, the use of system dynamics tools can help managers identify the causes of cost overruns with the application of feedback control systems. This research investigates the impacts of dynamic project structure, particularly the engineering process, on the construction cost of HVDC offshore wind energy converter substation.

A dynamic simulation model of multiple engineering phases was built using the system dynamics methodology. The model integrates several previously developed and tested project structures. Simulations describe the behavior generated by the interaction of customized engineering phases and a project management structure. Each phase explicitly models the impacts of work process, resource capacity, scope, and targets on three engineering activities: regular processing, quality assurance, and rework.

Project performance is measured in cost, cycle time, and quality. The model was calibrated to the DolWin Beta project of Aibel AS for a three-phase engineering. Quantitative and qualitative data concerning the engineering process, and project was collected for parameter estimation through interviews, surveys and document analysis. Sensitivity tests indicate that two of performance measures (cost and quality) are most sensitive to work precedence relations

and minimum quality assurance parameters.

Project and phase behavior and performance data were collected and analyzed to generate reference modes. Testing revealed that when the model is appropriately parameterized the resulting simulated behavior closely resembles the actual historical behavior of the project. The similarity in behavior modes between the project behavior and model simulations supports the model's ability to simulate the dynamic engineering process.

The model was applied to the investigation of schedule completion date policies for improved project performance. Seven different schedule completion scenarios were tested. Model simulations indicate that internal deadlines are vital for the successful completion of engineering works and a project could be more benefited when internal deadlines are set around the 1/5 of the planned project deadline.

6.2 Limitations of the Research

In this research work there were three basic limitations which we have not accounted. The first is related to the model size. In order to provide a complete picture about the cost driver of a big construction project such as DolWin Beta, it needs a full understanding and representation of the entire project phase. However, due to time constraint and other practical reasons our research is only bounded to the engineering project phase. Hence, conclusion and recommendations deduced from such a narrow scope may not serve as explanation to the cost performance of the entire project.

The second is associated with the aggregation level of the model – In our model we have considered three engineering phases (System Engineering, Engineering for Procurement and Area Engineering) and we have aggregated all the activities in the engineering process under these three phases. We made this aggregation for a good reason of simplification. However, the engineering process can further be disaggregated to discipline levels. In the engineering processes of Aibel AS, there are up to 10 different engineering disciplines. Each discipline has its own specific specialization and carry out some specific task in a project. Some of the disciplines are Electrical Engineering, Mechanical Engineering, Structure Engineering ...

The third limitation is associated with data collection – Most of the parameters we used in the model are estimated by few managers of the company during the interviews. However, a better estimation of parameters could be found if more managers from other projects of the company were involved.

6.3 Recommendation for Future Research

The findings and limitations of this work point to potentially valuable extensions. They include:

- The investigation of the remaining phases of the DolWin Beta Project, Construction, procurement, Installation and testing
- Relaxing the model boundary assumptions to include multiple projects, market introduction and product performance, technological and organizational evolution, or market competitors.
- Add model structure to internalize currently exogenous inputs to the model such as resource availability, process descriptors and development activity priority.
- Dynamic impacts of project features and policies on important non-performance measures such as project manageability or developer moral.

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Appendix

Appendix A: Survey Questions to managers

1. How do you measure works (activities) in your department? For example in number of tasks (drawings, calculations...), in weight, in man-hours...
2. When you start a new project,
 - a. how many percent of the initially needed workforce level do you usually get?
 - b. how about the percentages of workforce mix at the start up, say the percentage among Experienced workforce, Hired-Ins and New employees (rookies)?
3. For a drawing that could take one full working day of an experienced engineer when it is done for the first time, how long on average does it take
 - a. for self check?
 - b. for interdisciplinary check?
 - c. for final review?
4. For a calculation that could take one full day of an experienced engineer when it is done for the first time, how long on average would it take
 - a. for self check?
 - b. for interdisciplinary check?
 - c. for final review?
5. For a drawing that could take one full working day of an experienced engineer when it is done for the first time, how long on average would it take to rework it if errors are found
 - a. during self check?
 - b. during interdisciplinary check?
 - c. during final review?
6. For a calculation that could take one full day of an experienced engineer when it is done for the first time, how long on average would it take to rework it if errors are found
 - a. during self check?

- b. during interdisciplinary check?
 - c. during final review?
7. When you assign workers on an already started project, how do you keep the proportion of workers? Say, how many New employees do you assign with an Experienced employee?
 8. For a project that has already been started, how many working days does it usually take until
 - a. personnel are mobilized and start actual work in the new project?
 - b. Hired-Ins are hired and start actual work in the project?
 - c. New employees are hired and start actual work in the project?
 9. To be fully productive, on average, how long does it take for
 - a. an employee who has been transferred from another project?
 - b. a newly hired Hired-In?
 - c. a newly hired rookie?
 10. When a project is over staffed, which work force do you demobilize first?
 11. In your department, how many working weeks (days) does it take to demobilize
 - a. an Experienced employee?
 - b. a Hired-In?
 - c. a New employee?
 12. For the last 12 months, what is the average turnover in your department?
 13. When your project is behind its schedule, what do you usually do first in your department? Say increasing the workload (work pressure), allow for overtime, transfer (hire) personnel...
 14. How often do you face conflict on resources (competition for the same personnel) from different projects?

Appendix B: Model Equations

System Engineering Phase Equations

$$\text{Avg_Schedule_Pressure}(t) = \text{Avg_Schedule_Pressure}(t - dt) + (\text{Change_in_Avg_SP}) * dt$$

$$\text{INIT Avg_Schedule_Pressure} = \text{Schedule_Pressure}$$

INFLOWS:

$$\text{Change_in_Avg_SP} = (\text{Schedule_Pressure} - \text{Avg_Schedule_Pressure}) / \text{Workload_Stress_Onset_time}$$

$$\begin{aligned} \text{Defective_Tasks_Discoverd_by_Downstream}(t) = \\ \text{Defective_Tasks_Discoverd_by_Downstream}(t - dt) + \\ (\text{Defective_Task_Discovery_Rate_from_Down_stream} - \\ \text{Rework_Rate_of_Downstream_Discovered_Defective_Tasks}) * dt \end{aligned}$$

$$\text{INIT Defective_Tasks_Discoverd_by_Downstream} = 0$$

INFLOWS:

$$\begin{aligned} \text{Defective_Task_Discovery_Rate_from_Down_stream} = \\ \text{Intraphase_Defective_Tasks_Coordinated_with_Downstream} \end{aligned}$$

OUTFLOWS:

$$\begin{aligned} \text{Rework_Rate_of_Downstream_Discovered_Defective_Tasks} = \\ (\text{Successful_Rework_Rate} + \text{Unsuccessful_Rework_Rate}) * \text{Fraction_of_Defective_Tasks_Dis} \\ \text{coverd_by_Downstream} \end{aligned}$$

$$\text{Internal_Deadline}(t) = \text{Internal_Deadline}(t - dt) + (\text{Change_to_Internal_Deadline}) * dt$$

$$\text{INIT Internal_Deadline} = \text{Initial_internal_Deadline}$$

INFLOWS:

$$\begin{aligned} \text{Change_to_Internal_Deadline} = \text{MIN}((\text{Maximum_Tolerable_Internal_Deadline} - \\ \text{Internal_Deadline}) / \text{Internal_Deadline_Adjustment_Time}, \\ ((\text{Indicated_Completion_date_for_70\%_of_Phase_Scope} - \\ \text{Internal_Deadline}) / \text{Internal_Deadline_Adjustment_Time})) \end{aligned}$$

$$\begin{aligned} \text{Perceived_Present_Condition_of_Labor_Force_Sought}(t) = \\ \text{Perceived_Present_Condition_of_Labor_Force_Sought}(t - dt) + \\ (\text{Change_in_Perceive_Present_Conditions}) * dt \end{aligned}$$

INIT Perceived_Present_Condition_of_Labor_Force_Sought = INIT(Labor_Force_Sought)/
 (1+Time_to_Perceive_Present_Conditions * Perceived_Trend_in_Labor_Force_Sought)
 {people}

INFLOWS:

Change_in_Perceive_Present_Conditions = (Labor_Force_Sought-
 Perceived_Present_Condition_of_Labor_Force_Sought)/
 Time_to_Perceive_Present_Conditions {people/days}

Perceived_Trend_in_Labor_Force_Sought(t) = Perceived_Trend_in_Labor_Force_Sought(t -
 dt) + (Change_in_TREND) * dt

INIT Perceived_Trend_in_Labor_Force_Sought = 0

INFLOWS:

Change_in_TREND = (Indicated_Trend_in_Labor_force_Sought -
 Perceived_Trend_in_Labor_Force_Sought)/ Time_to_Perceive_Trend
 Quality_Goal(t) = Quality_Goal(t - dt) + (Change_in_Quality_Goal) * dt

INIT Quality_Goal = 0.9

INFLOWS:

Change_in_Quality_Goal = Quality_Gap/Quality_Goal_Adjustment_Time
 Reference_Condition_of_Labor_Force_Sought(t) =
 Reference_Condition_of_Labor_Force_Sought(t - dt) + (Change_in_Reference_Condition) *
 dt

INIT Reference_Condition_of_Labor_Force_Sought = INIT(
 Perceived_Present_Condition_of_Labor_Force_Sought)/(1+
 Time_Horizon_for_Reference_Condition * Perceived_Trend_in_Labor_Force_Sought)

INFLOWS:

Change_in_Reference_Condition = (Perceived_Present_Condition_of_Labor_Force_Sought -
 Reference_Condition_of_Labor_Force_Sought)/ Time_Horizon_for_Reference_Condition
 Total_Defective_Tasks_Sent_to_Upstream(t) = Total_Defective_Tasks_Sent_to_Upstream(t -
 dt) + (Accum_Rate_of_Defective_Tasks_Sent_to_Upstream) * dt

INIT Total_Defective_Tasks_Sent_to_Upstream = 0

INFLOWS:

Accum_Rate_of_Defective_Tasks_Sent_to_Upstream =
 Upstream_Defective_Task_Discovery_Rate
 Total_Discovered_Unsuccessfully_Processed_Tasks(t) =
 Total_Discovered_Unsuccessfully_Processed_Tasks(t - dt) +
 (Accum_Rate_of__Discovered_Unsuccessfully_Processed_Tasks) * dt
 INIT Total_Discovered_Unsuccessfully_Processed_Tasks = 0

INFLOWS:

Accum_Rate_of__Discovered_Unsuccessfully_Processed_Tasks =
 Unsuccessfully_processed_Task_Dicoverry_Rate
 Total_Sucessfully_Processed_Tasks_Approved_to_be_Released(t) =
 Total_Sucessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +
 (Accum_Rate_of_Sucessfully_Processed_Tasks_Approved_to_be_Released) * dt
 INIT Total_Sucessfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Accum_Rate_of_Sucessfully_Processed_Tasks_Approved_to_be_Released =
 Approval_Rate_of_Sucessfully_Processed_Tasks
 Total_Sucessfully_Processed_Tasks_Released(t) =
 Total_Sucessfully_Processed_Tasks_Released(t - dt) +
 (Accum_Rate_of_Sucessfully_Processed_Tasks_Released) * dt
 INIT Total_Sucessfully_Processed_Tasks_Released = 0

INFLOWS:

Accum_Rate_of_Sucessfully_Processed_Tasks_Released =
 Sucessfully_Processed_Tasks_Release_Rate
 Total_Sucessfully__Processed_Tasks(t) = Total_Sucessfully__Processed_Tasks(t - dt) +
 (Accum_Rate_of_Sucessfully_Processed_Tasks) * dt
 INIT Total_Sucessfully__Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Sucessfully_Processed_Tasks =
 Successful__Rework_Rate+Successful_Processing_Rate

```

Total_Undiscoverd_Unsucessfully_Processed_Tasks(t) =
Total_Undiscoverd_Unsucessfully_Processed_Tasks(t - dt) +
(Accum_Rate_of_Undiscoverd__Unsucessfully_Processed_Tasks) * dt
INIT Total_Undiscoverd_Unsucessfully_Processed_Tasks = 0
INFLOWS:
Accum_Rate_of_Undiscoverd__Unsucessfully_Processed_Tasks =
Unsuccessful_Processing_Rate+Unsuccessful_Rework_Rate
Total_Unsucessesfully_Processed_Tasks_Released(t) =
Total_Unsucessesfully_Processed_Tasks_Released(t - dt) +
(Accum_Rate_of__Unsucessesfully_Processed_Tasks_Released) * dt
INIT Total_Unsucessesfully_Processed_Tasks_Released = 0
INFLOWS:
Accum_Rate_of__Unsucessesfully_Processed_Tasks_Released =
Unsuccessfully_Processed_Tasks_Release_Rate
Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released(t) =
Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +
(Accum_Rate_of_Unsucessfully_Processed_Tasks_Approved_to_be_Released) * dt
INIT Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released = 0
INFLOWS:
Accum_Rate_of_Unsucessfully_Processed_Tasks_Approved_to_be_Released =
Approval_Rate_of_Undiscovered_Unsucessfully_Processed_Tasks
Adjustment_Towards_the_30%_Phase_Scope_Deadline(t) =
Adjustment_Towards_the_30%_Phase_Scope_Deadline(t - dt) +
(Change_in_Phase_Deadline_Adjustment) * dt
INIT Adjustment_Towards_the_30%_Phase_Scope_Deadline = 10
INFLOWS:
Change_in_Phase_Deadline_Adjustment =
IF(Remaining_Tasks>Thirty_%_of__Phase_Scope)THEN(0)ELSE((Deadline_for_the_remai
ning_30%_Phase_Scope-
Adjustment_Towards_the_30%_Phase_Scope_Deadline)/Time_to_Adjust_new_Deadline)

```

Cumulative_Man_Days_Expended(t) = Cumulative_Man_Days_Expended(t - dt) +

(Total_Daily__Man_Days_Expended) * dt

INIT Cumulative_Man_Days_Expended = 0 {Unit-people*days}

INFLOWS:

Total_Daily__Man_Days_Expended =

Total_Labor_Force*Avg_Daily_Labor_Force_Per_Staff+ManDay_Equivalence_of_Overtime
_Hrs_worked_per_Day {Unit- people/days=people*days/days}

Cumulative_Man_Days_Expended_for_Engineering_Activities(t) =

Cumulative_Man_Days_Expended_for_Engineering_Activities(t - dt) +

(Daily_Labor_Force_for_Engineering_Activities) * dt

INIT Cumulative_Man_Days_Expended_for_Engineering_Activities = 0

INFLOWS:

Daily_Labor_Force_for_Engineering_Activities = Total_Daily__Man_Days_Expended-

Daily_Labor_Force__for_Training {Unit- people/days=people/days - people/days}

Cumulative_Training_MD(t) = Cumulative_Training_MD(t - dt) +

(Daily_Labor_Force__for_Training) * dt

INIT Cumulative_Training_MD = 0 {The cumulated number of training mandays unit -
people*days}

INFLOWS:

Daily_Labor_Force__for_Training =

(New_Employees+New_Hired_in_Externally+Transferred_in_Company_Employees)*Traine
rs_per_New_Labor_Force {unit - pepole/days = people*days/days}

Discovered_Unsuccessfully_Processed_Tasks(t) =

Discovered_Unsuccessfully_Processed_Tasks(t - dt) +

(Intraphase_Unsuccessfully_processed_Task_Discovery_Rate +

Intraphase_Defective_Tasks_Coordinated_with_Downstream - Successful__Rework_Rate -
Unsuccessful_Rework_Rate) * dt

INIT Discovered_Unsuccessfully_Processed_Tasks = 0

INFLOWS:

Intraphase_Unsuccessfully_processed_Task_Discovery_Rate =

Unsuccessfully_processed_Task_Dicoverery_Rate-Upstream_Defective_Task_Discovery_Rate

Intraphase_Defective_Tasks_Coordinated_with_Downstream =

Fraction_of_Coordinated_Tasks_from_Downstream

OUTFLOWS:

Successful__Rework_Rate =

Rework_Rate*Probability_of_Tasks_to_be_Successfully_Reworked

Unsuccessful_Rework_Rate = Rework_Rate-Successful__Rework_Rate

Exhaustion_Due_to_Overtime_Work(t) = Exhaustion_Due_to_Overtime_Work(t - dt) +

(Rate_of_Increase_in_Exhaustion_Level - Rate_of_Depletion_in_Exhaustion_Level) * dt

INIT Exhaustion_Due_to_Overtime_Work = 0 {exhaustion}

INFLOWS:

Rate_of_Increase_in_Exhaustion_Level =

GRAPH(Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF/Normal_Work_Hours_per_Day)

(1.00, 0.00), (1.03, 0.2), (1.07, 0.4), (1.10, 0.6), (1.13, 0.8), (1.17, 1.00), (1.20, 1.20), (1.23, 1.40), (1.27, 1.60)

OUTFLOWS:

Rate_of_Depletion_in_Exhaustion_Level = IF

(Perceived_Rate_of_Increase_in_Exhaustion_Level<=

0.01)THEN(Exhaustion_Due_to_Overtime_Work/Exhaustion_Depletion_Time)ELSE(0)

Experienced_Employees(t) = Experienced_Employees(t - dt) +

(Assimilation_Rate_of_New_Employees +

Assimilation_Rate_of__Transferred_in_Company_Employees -

Experienced_Employees_Quit_Rate - Experienced_Employees_Demobilization_Rate) * dt

INIT Experienced_Employees = Initial_Total_Labor_Force*0.8

INFLOWS:

Assimilation_Rate_of_New_Employees =

New_Employees/Avg_Assimilation_Time_of_New_Employees

Assimilation_Rate_of__Transferred_in_Company_Employees =

Transferred_in_Company_Employees/Avg_Assimilation_Time_of_Transferred_in_Company_Employees

OUTFLOWS:

$\text{Experienced_Employees_Quit_Rate} = \text{Experienced_Employees} * \text{Quit_Fraction}$
 $\text{Experienced_Employees_Demobilization_Rate} = \text{MIN}(\text{Experienced_Employees}/\text{DT},$
 $(\text{Demobilization_Rate} -$
 $(\text{New_Employees_Demobilization_Rate} + \text{Experienced_Hired_in_Demobilization_Rate} + \text{New_Hired_in_Demobilization_Rate} + \text{Transferred_in_Company_Employees_Demobilization_Rate}))$

$\text{Experienced_Employees_Costs_to_Date}(t) = \text{Experienced_Employees_Costs_to_Date}(t - dt)$
 $+ (\text{Regular_Daily_Salary_of_Experienced_Employees}) * dt$

INIT Experienced_Employees_Costs_to_Date = 0

INFLOWS:

$\text{Regular_Daily_Salary_of_Experienced_Employees} =$
 $\text{IF}(\text{Fraction_of_Released_Tasks} < 0.9999) \text{ THEN} (\text{Experienced_Employees} * \text{Experienced_Employee_Avg_Hourly_Pay_Rate} * \text{Avg_Daily_Labor_Force_Per_Staff} * \text{Normal_Work_Hours_per_Day}) \text{ ELSE} (0)$

$\text{Experienced_Hired_in_Externally}(t) = \text{Experienced_Hired_in_Externally}(t - dt) +$
 $(\text{Assimilation_Rate_of_New_Hire_in_Externally} - \text{Experienced_Hired_in_Demobilization_Rate} - \text{Experienced_Hired_in_Externally_Quit_Rate}) * dt$

INIT Experienced_Hired_in_Externally = Initial_Total_Labor_Force*0.2

INFLOWS:

$\text{Assimilation_Rate_of_New_Hire_in_Externally} =$
 $\text{New_Hired_in_Externally}/\text{Avg_Assimilation_Time_of_New_Hire_in_Externally}$

OUTFLOWS:

$\text{Experienced_Hired_in_Demobilization_Rate} =$
 $\text{MIN}(\text{Experienced_Hired_in_Externally}/\text{DT}, (\text{Demobilization_Rate} - \text{New_Hired_in_Demobilization_Rate}))$

$\text{Experienced_Hired_in_Externally_Quit_Rate} =$
 $\text{Experienced_Hired_in_Externally}/\text{Avg_Employment_Duration_of_Hire_In_Externally}$
 $\text{Experienced_Hired_in_Externally_Costs_to_Date}(t) =$
 $\text{Experienced_Hired_in_Externally_Costs_to_Date}(t - dt) +$
 $(\text{Regular_Daily_Salary_of_Experienced_Hired_in_Externally}) * dt$

INIT Experienced_Hired_in_Externally_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_Experienced_Hired_in_Externally =

IF(Fraction_of_Released_Tasks<0.9999)THEN(Experienced_Hired_in_Externally *

Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate *

Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day)ELSE(0)

New_Employees(t) = New_Employees(t - dt) + (Hiring_Rate_of__New_Employees -

Assimilation_Rate_of_New_Employees - New_Employees_Demobilization_Rate) * dt

INIT New_Employees = 0

INFLOWS:

Hiring_Rate_of__New_Employees = MAX(0,

Desired_New_Employees/Avg_Hiring_Time_of_New_Employees)

OUTFLOWS:

Assimilation_Rate_of_New_Employees =

New_Employees/Avg_Assimilation_Time_of_New_Employees

New_Employees_Demobilization_Rate = MIN(New_Employees/DT, (Demobilization_Rate-(New_Hired_in_Demobilization_Rate+Experienced_Hired_in_Demobilization_Rate+Transferred_in_Company_Employees_Demobilization_Rate)))

New_Employees_Costs_to_Date(t) = New_Employees_Costs_to_Date(t - dt) +

(Regular_Daily_Salary_of_New_Employees) * dt

INIT New_Employees_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_New_Employees =

IF(Fraction_of_Released_Tasks<0.9999)THEN(New_Employees*Normal_Work_Hours_per_Day*New_Employees_Avg_Hourly_Pay_Rate*Avg_Daily_Labor_Force_Per_Staff)ELSE(0)

New_Hired_in_Externally(t) = New_Hired_in_Externally(t - dt) +

(Hiring_Rate_of_New_Hired_in_Externally -

Assimilation_Rate_of_New_Hire_in_Externally - New_Hired_in_Demobilization_Rate) * dt

INIT New_Hired_in_Externally = 0

INFLOWS:

Hiring_Rate_of_New_Hired_in_Externally = MAX(0,

Desired_New_Hired_in_Externally/Avg_Hiring_Time_of_New_Hired_in_Externally)

OUTFLOWS:

Assimilation_Rate_of_New_Hire_in_Externally =

New_Hired_in_Externally/Avg_Assimilation_Time_of_New_Hire_in_Externally

New_Hired_in_Demobilization_Rate = MIN(Demobilization_Rate,

New_Hired_in_Externally/DT)

New_Hired_in_Externally_Costs_to_Date(t) = New_Hired_in_Externally_Costs_to_Date(t -

dt) + (Regular_Daily_Salary_of_New_Hired_in_Externally) * dt

INIT New_Hired_in_Externally_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_New_Hired_in_Externally =

IF(Fraction_of_Released_Tasks<0.9999)THEN(New_Hired_in_Externally *

New_Hired_in_Externally_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff *

Normal_Work_Hours_per_Day)ELSE(0)

Overtime_Costs_to_Date(t) = Overtime_Costs_to_Date(t - dt) + (Total_Daily_Overtime_Pay)

* dt

INIT Overtime_Costs_to_Date = 0

INFLOWS:

Total_Daily_Overtime_Pay =

IF(Fraction_of_Released_Tasks<0.9999)THEN(Avg_Hourly_Overtime_Pay_Rate *

Total_Overtime_Hrs_Worked_Per_Day)ELSE(0)

Perceived_Quality_Assurance_Productivity(t) = Perceived_Quality_Assurance_Productivity(t

- dt) + (Change_in_Perceived_Quality_Assurance_Productivity) * dt

INIT Perceived_Quality_Assurance_Productivity = Ref_Quality_Assurance_Productivity

INFLOWS:

Change_in_Perceived_Quality_Assurance_Productivity =

MAX(((Reported_Quality_Assurance_Productivity-

Perceived_Quality_Assurance_Productivity)/Time_to_adjust_Perceived_Quality_Assurance

Productivity),Perceived_Minimum_Quality_Assurance_Productivity-

Perceived_Quality_Assurance_Productivity)

Perceived_Regular_Processing_Productivity(t) =

Perceived_Regular_Processing_Productivity(t - dt) +

(Change_in_Perceived_Regular_Processing_Productivity) * dt

INIT Perceived_Regular_Processing_Productivity = Ref_Regular_Processing_Productivity

INFLOWS:

Change_in_Perceived_Regular_Processing_Productivity =

MAX(((Reported_Regular_Processing_Productivity-

Perceived_Regular_Processing_Productivity)/Time_to_adjust_Perceived_Regular_Processing_Productivity),Perceived_Minimum_Regular_Processing_Productivity-

Perceived_Regular_Processing_Productivity)

Perceived_Rework_Productivity(t) = Perceived_Rework_Productivity(t - dt) +

(Change_in_Perceived_Rework_Productivity) * dt

INIT Perceived_Rework_Productivity = Ref_Rework_Productivity

INFLOWS:

Change_in_Perceived_Rework_Productivity = MAX(((Reported_Rework_Productivity-

Perceived_Rework_Productivity)/Time_to_adjust_Perceived_Rework_Productivity),Perceived_Minimum_Rework_Productivity-Perceived_Rework_Productivity)

Project_Deadline_for_the_Phase(t) = Project_Deadline_for_the_Phase(t - dt) +

(Change_in_Project_Deadline) * dt

INIT Project_Deadline_for_the_Phase = Initial_Project_Deadline_for_the_Phase

INFLOWS:

Change_in_Project_Deadline = MIN((Maximum_Tolerable_Project_Completion_Date-

Project_Deadline_for_the_Phase)/Project_Deadline_Adjustment_Time,

(Indicated_Completion_Date_for_the_Phase-

Project_Deadline_for_the_Phase)/Project_Deadline_Adjustment_Time)

Reported_Quality_Assurance_Productivity(t) = Reported_Quality_Assurance_Productivity(t -

dt) + (Change_in_Reported_Quality_Assurance_Productivity) * dt

INIT Reported_Quality_Assurance_Productivity = Ref_Quality_Assurance_Productivity

INFLOWS:

Change_in_Reported_Quality_Assurance_Productivity =
 (Current_Quality_Assurance_Productivity-
 Reported_Quality_Assurance_Productivity)/Quality_Assurance_Productivity_Report_Time
 Reported_Regular_Processing_Productivity(t) =
 Reported_Regular_Processing_Productivity(t - dt) +
 (Change_in_Reported_Regular_Processing_Productivity) * dt

INIT Reported_Regular_Processing_Productivity = Ref_Regular_Processing_Productivity

INFLOWS:

Change_in_Reported_Regular_Processing_Productivity =
 (Current_Regular_Processing_Productivity-
 Reported_Regular_Processing_Productivity)/Regular_Processing_Productivity_Report_Time
 Reported_Rework_Productivity(t) = Reported_Rework_Productivity(t - dt) +
 (Change_in_Reported_Rework_Productivity) * dt

INIT Reported_Rework_Productivity = Ref_Rework_Productivity

INFLOWS:

Change_in_Reported_Rework_Productivity = (Current_Rework_Productivity-
 Reported_Rework_Productivity)/Rework_Productivity_Report_Time
 Successfully_Processed_Tasks(t) = Successfully_Processed_Tasks(t - dt) +
 (Successful_Processing_Rate + Successful__Rework_Rate -
 Approval_Rate_of_Successfully_Processed_Tasks) * dt

INIT Successfully_Processed_Tasks = 0

INFLOWS:

Successful_Processing_Rate = Regular_Processing_Rate*(1-
 Fraction_of_Inherited_Unsuccessfully_Processed_Tasks)*(1-
 Probability_to_be_Defective_Task)

Successful__Rework_Rate =
 Rework_Rate*Probability_of_Tasks_to_be_Successfully_Reworked

OUTFLOWS:

Approval_Rate_of_Successfully_Processed_Tasks = Quality_Assurance_Rate_2

Successfully_Processed_Tasks_Approved_to_be_Released(t) =
 Successfully_Processed_Tasks_Approved_to_be_Released(t - dt) +

(Approval_Rate_of_Successfully_Processed_Tasks -
 Successfully_Processed_Tasks_Release_Rate) * dt

INIT Successfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Approval_Rate_of_Successfully_Processed_Tasks = Quality_Assurance_Rate_2

OUTFLOWS:

Successfully_Processed_Tasks_Release_Rate =

Successfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

Successfully_Processed_Tasks_Released(t) = Successfully_Processed_Tasks_Released(t - dt) +
 (Successfully_Processed_Tasks_Release_Rate) * dt

INIT Successfully_Processed_Tasks_Released = 0

INFLOWS:

Successfully_Processed_Tasks_Release_Rate =

Successfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

Tasks_Identified_to_be_Processed(t) = Tasks_Identified_to_be_Processed(t - dt) +

(Return_Rate_of_Coord_Tasks_Sent_to_Upstream + Rate_of_Change_in_Scope -
 Successful_Processing_Rate - Unsuccessful_Processing_Rate) * dt

INIT Tasks_Identified_to_be_Processed = 8186

INFLOWS:

Return_Rate_of_Coord_Tasks_Sent_to_Upstream =

Upstream_Defective_Task_Discovery_Rate

Rate_of_Change_in_Scope = Scope_Change

OUTFLOWS:

Successful_Processing_Rate = Regular_Processing_Rate*(1-
 Fraction_of_Inherited_Unsuccessfully_Processed_Tasks)*(1-
 Probability_to_be_Defective_Task)

Unsuccessful_Processing_Rate = Regular_Processing_Rate-Successful_Processing_Rate

Time_from_Last_Exhaustion_Break(t) = Time_from_Last_Exhaustion_Break(t - dt) +
 (Overtime_Work_Break_Setter) * dt

INIT Time_from_Last_Exhaustion_Break = -1 {Unitless}

INFLOWS:

Overtime_Work_Break_Setter = (MAX(Time_from_Last_Exhaustion_Break,
Overtime_Work_Break_Indicator)-Time_from_Last_Exhaustion_Break)/DT

Time_To_Recover(t) = Time_To_Recover(t - dt) + (Change_in_Time_To_Recover) * dt

INIT Time_To_Recover = 0 {Unitless}

INFLOWS:

Change_in_Time_To_Recover = IF

(Exhaustion_Due_to_Overtime_Work/Maximum_Tolerable_Exhaustion_Level>=0.1)

THEN(1)ELSE(-Time_To_Recover/DT) {Unitless/day}

Transferred_in_Company_Employees(t) = Transferred_in_Company_Employees(t - dt) +

(Rate_of_Mobilization_of_Company_Employees -

Assimilation_Rate_of__Transferred_in_Company_Employees -

Transferred_in_Company_Employees_Demobilization_Rate) * dt

INIT Transferred_in_Company_Employees = 0

INFLOWS:

Rate_of_Mobilization_of_Company_Employees = MAX(0,

(Desired_Company_Employee_Transferee_in / Mobilization_Delay))

OUTFLOWS:

Assimilation_Rate_of__Transferred_in_Company_Employees =

Transferred_in_Company_Employees/Avg_Assimilation_Time_of_Transferred_in_Company
_Employees

Transferred_in_Company_Employees_Demobilization_Rate =

MIN(Transferred_in_Company_Employees/DT, (Demobilization_Rate-

(New_Hired_in_Demobilization_Rate+Experienced_Hired_in_Demobilization_Rate)))

Transferred_in_Company_Employees_Costs_to_Date(t) =

Transferred_in_Company_Employees_Costs_to_Date(t - dt) +

(Regular_Daily_Salary_of_Transferred_in_Company_Employees) * dt

INIT Transferred_in_Company_Employees_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_Transferred_in_Company_Employees =

IF(Fraction_of_Released_Tasks<0.9999)THEN(Transferred_in_Company_Employees *

Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate *

Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day)ELSE(0)

Undiscovered__Unsuccessfully__Processed_Tasks(t) =

Undiscovered__Unsuccessfully__Processed_Tasks(t - dt) + (Unsuccessful_Processing_Rate +
Unsuccessful_Rework_Rate - Intraphase_Unsuccessfully_processed_Task_Discovery_Rate -
Approval_Rate_of_Undiscovered_Unsuccessfully_Processed_Tasks -
Upstream_Defective_Task_Discovery_Rate) * dt

INIT Undiscovered__Unsuccessfully__Processed_Tasks = 0

INFLOWS:

Unsuccessful_Processing_Rate = Regular_Processing_Rate-Successful_Processing_Rate

Unsuccessful_Rework_Rate = Rework_Rate-Successful__Rework_Rate

OUTFLOWS:

Intraphase_Unsuccessfully_processed_Task_Discovery_Rate =

Unsuccessfully_processed_Task_Dicoverry_Rate-Upstream_Defective_Task_Discovery_Rate

Approval_Rate_of_Undiscovered_Unsuccessfully_Processed_Tasks =

Quality__Assurance_Rate_1-Unsuccessfully_processed_Task_Dicoverry_Rate

Upstream_Defective_Task_Discovery_Rate =

Fraction_of_Inherited_Unsuccessfully_Processed_Tasks*Unsuccessfully_processed_Task_Di
covery_Rate

Unsuccessfully_Processed_Tasks_Approved_to_be_Released(t) =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +

(Approval_Rate_of_Undiscovered_Unsuccessfully_Processed_Tasks -
Unsuccessfully_Processed_Tasks_Release_Rate) * dt

INIT Unsuccessfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Approval_Rate_of_Undiscovered_Unsuccessfully_Processed_Tasks =

Quality__Assurance_Rate_1-Unsuccessfully_processed_Task_Dicoverry_Rate

OUTFLOWS:

Unsuccessfully_Processed_Tasks_Release_Rate =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

Unsuccessfully_Processed_Tasks_Released(t) = Unsuccessfully_Processed_Tasks_Released(t - dt) + (Unsuccessfully_Processed_Tasks_Release_Rate -

Intraphase_Defective_Tasks_Coordinated_with_Downstream) * dt

INIT Unsuccessfully_Processed_Tasks_Released = 0

INFLOWS:

Unsuccessfully_Processed_Tasks_Release_Rate =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

OUTFLOWS:

Intraphase_Defective_Tasks_Coordinated_with_Downstream =

Fraction_of_Coordinated_Tasks_from_Downstream

Actual_Labor_Force_Required =

Perceived_Present_Condition_of_Labor_Force_Sought+Perceived_Present_Condition_of_Labor_Force_Sought*Perceived_Trend_in_Labor_Force_Sought*Time_to_Perceive_Trend

Actual_Productivity = Total_Released_Tasks/(Cumulative_Man_Days_Expended+1)

Average_Nominal_Potential_Productivity =

Fraction_of_Experienced_Employees*Reference_Potential_Productivity_of_Experienced_Employees+Fraction_of_New_Employees*Reference_Potential_Productivity_of_New_Employees+Reference_Potential_Productivity_of_Experienced_Hire_in*Fraction_of_Experienced_Hire_in+Reference_Potential_Productivity_of__New_Hire_in*Fraction_of_New_Hire_in+Reference_Potential_Productivity_of_Transferredin_Company_Employees*Fraction_of_Transferred_in_Company_Employees

Avg_Assimilation_&_Hiring_Time_of_New_Employees =

Avg_Hiring_Time_of_New_Employees+Avg_Assimilation_Time_of_New_Employees

Avg_Assimilation_&_Hiring_Time_of_New_Hired_in =

Avg_Hiring_Time_of_New_Hired_in_Externally+Avg_Assimilation_Time_of_New_Hire_in_Externally

Avg_Assimilation_Time_of_New_Employees = 60

Avg_Assimilation_Time_of_New_Hire_in_Externally = 20

Avg_Assimilation_Time_of_Transferred_in_Company_Employees = 20

Avg_Daily_Labor_Force_Per_Staff = 1 {Unit- Unitless=days/days}

Avg_Employment_Duration_of_Hire_In_Externally = 220

Avg_Hiring_Time_of_New_Employees = 40

Avg_Hiring_Time_of_New_Hired_in_Externally = 14

Avg_Hourly_Overtime_Pay_Rate = 1000

Budget_Status = -0.5

Ceiling_on_Fraction_of_Hired_in_Externally = 0.3

Ceiling_on_New_Hired_in_Externally = MAX(0,(Perceived_Layoff_in_Hired_in_Externally + Ceiling_on__Hired_in_Externally -Experienced_Hired_in_Externally - New_Hired_in_Externally))

Ceiling_on_New_Labor_Force =

Full_Time_Equivalent_of_Experienced_Labor_Force*Max_New_Recruit_Per_Full_Time_Experienced_Labor_Force

Ceiling_on_Total_Labor_Force = Ceiling_on_New_Labor_Force+Experienced_Labor_Force

Ceiling_on__Hired_in_Externally =

Total_Labor_Force*Ceiling_on_Fraction_of_Hired_in_Externally

Converter_45 = Tasks_Perceived__Completed/(Cumulative_Man_Days_Expended+0.1)

Converter_50 = GRAPH(TIME)

(0.00, 86.0), (19.0, 100), (37.0, 75.0), (56.0, 90.0), (75.0, 98.0), (94.0, 101), (112, 101), (131, 94.0), (150, 88.0), (169, 133), (187, 71.0), (206, 57.0), (225, 43.0), (244, 38.0), (262, 37.0), (281, 30.0), (300, 21.0), (319, 20.0), (337, 20.0), (356, 19.0), (375, 19.0), (394, 19.0), (412, 19.0), (431, 19.0), (450, 19.0), (469, 19.0), (487, 18.0), (506, 14.0), (525, 17.0), (543, 17.0), (562, 17.0), (581, 16.0), (600, 17.0), (618, 17.0), (637, 16.0)

Converter_52 = Total_Released_Tasks/Total_number_of_Tasks

Converter_53 = Total_Tasks_in_the_Phase_at_Any_Time-Current_Scope

Converter_54 = Fraction_of_Completed_Tasks_Data*Phase_Scope_Data

Coordinated_Tasks_to_be_Sent_to_Upstream =

Upstream_Defective_Task_Discovery_Rate*Upstream_Phase_Scope/Current_Scope

Cost_Effect_on_Regular_Processing_Importance = GRAPH(Budget_Status)

(-1.00, 1.87), (-0.9, 1.58), (-0.8, 1.35), (-0.7, 1.17), (-0.6, 1.06), (-0.5, 1.00), (-0.4, 0.98), (-0.3, 0.95), (-0.2, 0.89), (-0.1, 0.81), (0.00, 0.65)

Cummulative_Engineering_Man_Hours_Expended =

Cumulative_ManHours_Expended+Area_Engineering.Cumulative_ManHours_Expended+Engineering_For_Procurement.Cumulative_ManHours_Expended

Cummulative_Engineering_Man_Hours_Expended_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 8206), (37.0, 22017), (56.0, 39003), (75.0, 49285), (94.0, 59865), (112, 73497), (131, 87345), (150, 101598), (169, 117892), (187, 131643), (206, 145033), (225, 157717), (244, 168793), (262, 183607), (281, 195070), (300, 204541), (319, 213186), (337, 219978), (356, 227402), (375, 235901), (394, 241923), (412, 244940), (431, 253253), (450, 256844), (469, 259840), (487, 266397), (506, 271016), (525, 274095), (543, 278512), (562, 282458), (581, 286254), (600, 290459), (618, 293239), (637, 296855)

Cumulative_ManHours_Expended = Cumulative_Man_Days_Expended*7.5

Cumulative_Manhours_Expended_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 2712), (37.0, 7355), (56.0, 13028), (75.0, 16700), (94.0, 20559), (112, 25202), (131, 30459), (150, 36716), (169, 43255), (187, 49133), (206, 54745), (225, 60437), (244, 65274), (262, 71638), (281, 76413), (300, 80057), (319, 83280), (337, 85865), (356, 88826), (375, 92663), (394, 94763), (412, 95409), (431, 99496), (450, 100642), (469, 101723), (487, 104181), (506, 105678), (525, 106617), (543, 107972), (562, 109059), (581, 110307), (600, 111493), (618, 112273), (637, 113291)

Current_Quality = 1-

(Discovered_Unsuccessfully_Processed_Tasks/(Total_Released_Tasks+Successfully_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks_Approved_to_be_Released+Undiscovered__Unsuccessfully__Processed_Tasks+Successfully_Processed_Tasks+0.000001))

Current_Quality_Assurance_Productivity =

(Quality_Assurance_Rate_1+Quality_Assurance_Rate_2)/(Daily_Labor_Force_to_Quality_Assurance+0.00001)

Current_Regular_Processing_Productivity =

Regular_Processing_Rate/(Daily_Labor_Force_to_Regular__Processing+0.00001)

Current_Rework_Productivity = Rework_Rate/(Daily_Labor_Force_to_Rework+0.00001)

Current_Scope = Scope_of_work

Daily_Labor_Force_to_Quality_Assurance =

Daily_Labor_Force_for_Engineering_Activities*Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog+0*Labor_Fraction_to_Quality_Assurance

Daily_Labor_Force_to_Regular_Processing =

Daily_Labor_Force_for_Engineering_Activities*Labor_Force_Fraction_to_Regular_Processing_due_to_backlog+0*Labor_Fraction_to_Regular_Processing {People-day/day=People*(day/day)}

Daily_Labor_Force_to_Rework =

Daily_Labor_Force_for_Engineering_Activities*Labor_Force_Fraction_to_Rework_due_to_backlog+0*Labor_Fraction_to_Rework

Daily_QA_Labor_Force_for_Unsuccessfully_Processed_Tasks =

Daily_Labor_Force_to_Quality_Assurance*(Undiscovered_Unsuccessfully_Processed_Tasks/Total_Tasks_to_QA)

Daily_QA_Labor_force_to_Successfully_Processed_Tasks =

Daily_Labor_Force_to_Quality_Assurance*(Successfully_Processed_Tasks/Total_Tasks_to_QA)

Deadline_for_the_Remaining_30%_Phase_Scope =

0.70*Initial_Project_Deadline_for_the_Phase

Demobilization_Delay = 10

Demobilization_Rate = MAX(0,-Labor_Force_Gap/Demobilization_Delay)

Desired_Company_Employee_Transferee_in = Labor_Force_Gap -

(Desired_New_Hired_in_Externally + Desired_New_Employees)

Desired_Labor_Force_for_Quality_Assurance =

(Quality_Assurance_Processing_Limit_from_Task_Availability_1+Quality_Assurance_Processing_Limit_from_Task_Availability_2)/(Perceived_Quality_Assurance_Productivity+0.000001)

Desired_Labor_Force_for_Regular_Processing =

Regular_Processing_Limit_from_Task_Availability/(Perceived_Regular_Processing_Productivity+0.1)

Desired_Labor_Force_for_Rework =

Rework_Processing_Limit_from_Task_Availability/(Perceived_Rework_Productivity+0.1)

$Desired_New_Employees = Labor_Force_Gap * New_Employees_Hiring_Fraction$
 $Desired_New_Hired_in_Externally =$
 $MIN(Ceiling_on_New_Hired_in_Externally, Labor_Force_Gap * New_Hired_in_Externally_Hiring_Fraction)$
 $Desired_Productivity = Remaining_Tasks / (Total_Available_Man_Days + 0.00001)$
 $Desire_for_LF_Stability_Effect_on_WCLF = GRAPH((Project_Deadline_for_the_Phase - TIME) /$
 $(Avg_Assimilation_Time_of_Transferred_in_Company_Employees + Mobilization_Delay))$
 $(0.00, 0.00), (0.3, 0.1), (0.6, 0.4), (0.9, 0.85), (1.20, 1.00), (1.50, 1.00), (1.80, 1.00), (2.10,$
 $1.00), (2.40, 1.00), (2.70, 1.00), (3.00, 1.00)$
 $Desire_for_Schedule_Stability_Effect_on_WCLF =$
 $GRAPH(Project_Deadline_for_the_Phase / (Maximum_Tolerable_Project_Completion_Date))$
 $(0.86, 0.00), (0.88, 0.1), (0.9, 0.2), (0.92, 0.35), (0.94, 0.6), (0.96, 0.7), (0.98, 0.77), (1.00,$
 $0.89), (1.05, 1.00)$
 $Dummy_Variable = 1$ {Invalid number only used to allow the model run}
 $Effect_of_Exhaustion_Level_on_Overtime_Duration =$
 $GRAPH(Exhaustion_Due_to_Overtime_Work / Maximum_Tolerable_Exhaustion_Level$
 $\{Unitless = exhaustion/exhaustion\})$
 $(0.00, 1.00), (0.1, 0.9), (0.2, 0.8), (0.3, 0.7), (0.4, 0.6), (0.5, 0.5), (0.6, 0.4), (0.7, 0.3), (0.8,$
 $0.2), (0.9, 0.1), (1.00, 0.00)$
 $Effect_of_Experience_on_QoP = GRAPH(Fraction_of_Experienced_Labor_Force)$
 $(0.00, 0.5), (0.2, 0.6), (0.4, 0.7), (0.6, 0.8), (0.8, 0.9), (1.00, 1.00)$
 $Effect_of_Fatigue_on_QoP = GRAPH(Exhaustion_Due_to_Overtime_Work)$
 $(0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9), (20.0, 0.89)$
 $Effect_of_Labor_Size_on_Productivity = 1$ {Invalid number only used to allow the model run}
 $Effect_of_Learning_on_Potential_Productivity =$
 $GRAPH(Percent_of_Tasks_Actually_Completed)$
 $(0.00, 1.00), (0.1, 1.01), (0.2, 1.03), (0.3, 1.05), (0.4, 1.10), (0.5, 1.15), (0.6, 1.22), (0.7, 1.26),$
 $(0.8, 1.29), (0.9, 1.30), (1.00, 1.30)$

Effect_of_Schedule_Pressure_on_Labor_Force_Productivity =
Positive_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity*Negative_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity
Effect_of_Schedule_Pressure_on_QoP = GRAPH(Schedule_Pressure)
(0.00, 1.00), (0.5, 1.00), (1.00, 1.00), (1.50, 0.94), (2.00, 0.9), (2.50, 0.85), (3.00, 0.79), (3.50, 0.72), (4.00, 0.64), (4.50, 0.55), (5.00, 0.45)
Effect_of_Schedule_Pressure_on_Regular_Processing_Importance = 1 {Invalid number only used to allow the model run}
Effect_of_Fatigue_on_Labor_Force_Productivity =
GRAPH(Exhaustion_Due_to_Overtime_Work)
(0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9), (20.0, 0.89)
Exhaustion_Depletion_Time = 10 {Days}
Expected_Average_Productivity = Planned_Productivity*Weight_to_Planned_Productivity + (1-Weight_to_Planned_Productivity)*Actual_Productivity
Experienced_Employee_Avg_Hourly_Pay_Rate = 650
Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate = 800
Experienced_Labor_Force = Experienced_Employees+Experienced_Hired_in_Externally
External_Precedence_from_Down_stream =
GRAPH(Fraction_of_Released_Tasks_from_Downstream)
(0.475, 0.7), (0.6, 0.85), (0.7, 1.00)
External_Precedence_from_Up_stream = 1
External_Precedence_Relation =
MIN(External_Precedence_from_Down_stream,External_Precedence_from_Up_stream)
Fraction_of_Completed_Tasks_Data = GRAPH(TIME)
(0.00, 0.00), (19.0, 0.039), (37.0, 0.107), (56.0, 0.205), (75.0, 0.258), (94.0, 0.353), (112, 0.419), (131, 0.488), (150, 0.572), (169, 0.671), (187, 0.603), (206, 0.658), (225, 0.689), (244, 0.706), (262, 0.73), (281, 0.744), (300, 0.786), (319, 0.848), (337, 0.814), (356, 0.859), (375, 0.894), (394, 0.916), (412, 0.932), (431, 0.947), (450, 0.974), (469, 0.917), (487, 0.932), (506, 0.945), (525, 0.95), (543, 0.96), (562, 0.936), (581, 0.946), (600, 0.96), (618, 0.971), (637, 0.982)

$$\text{Fraction_of_Defective_Tasks_Discoverd_by_Downstream} = \frac{\text{Defective_Tasks_Discoverd_by_Downstream}}{(\text{Discovered_Unsuccessfully_Processed_Tasks} + 0.00001)}$$

$$\text{Fraction_of_Experienced_Employees} = \frac{\text{Experienced_Employees}}{(\text{Total_Labor_Force} + 0.000000001)}$$

$$\text{Fraction_of_Experienced_Hire_in} = \frac{\text{Experienced_Hired_in_Externally}}{(\text{Total_Labor_Force} + 0.000000001)}$$

$$\text{Fraction_of_Experienced_Labor_Force} = \frac{\text{Experienced_Labor_Force}}{(\text{Total_Labor_Force} + 0.000000001)}$$

$$\text{Fraction_of_Inherited_Unsuccessfully_Processed_Tasks} = 0$$

$$\text{Fraction_of_New_Employees} = \frac{\text{New_Employees}}{(\text{Total_Labor_Force} + 0.000000001)}$$

$$\text{Fraction_of_New_Hire_in} = \frac{\text{New_Hired_in_Externally}}{(\text{Total_Labor_Force} + 0.000000001)}$$

$$\text{Fraction_of_Released_Tasks} = \frac{\text{Total_Released_Tasks}}{\text{Current_Scope}}$$

$$\text{Fraction_of_Tasks_Perceived_Completed} = \frac{\text{Tasks_Perceived_Completed}}{\text{Current_Scope}}$$

$$\text{Fraction_of_Transferred_in_Company_Employees} = \frac{\text{Transferred_in_Company_Employees}}{(\text{Total_Labor_Force} + 0.000000001)}$$

$$\text{Fraction_of_Unsuccessfully_Processed_Tasks_Released} = \frac{\text{Unsuccessfully_Processed_Tasks_Released}}{(\text{Total_Released_Tasks} + 0.000001)}$$

$$\text{Full_Time_Equivalent_Labor_Force} = \text{Avg_Daily_Labor_Force_Per_Staff} * \text{Total_Labor_Force} \quad \{\text{People} = \text{People} * (\text{Days} / \text{Days})\}$$

$$\text{Full_Time_Equivalent_of_Experienced_Labor_Force} = \text{Experienced_Labor_Force} * \text{Avg_Daily_Labor_Force_Per_Staff}$$

$$\text{Hours_to_ManDays_Convertor} = 1 / 7.5 \quad \{\text{People-Day} / \text{Hour}\}$$

$$\text{Indicated_Completion_date_for_70\%_of_Phase_Scope} = \text{IF} (\text{Remaining_Tasks} > \text{Thirty_ \%_of_Phase_Scope}) \text{ THEN} (\text{TIME} + \text{Perceived_Project_Completion_Time_Still_Required}) \text{ ELSE} (0)$$

$$\text{Indicated_Completion_Date_for_the_Phase} = \text{TIME} + \text{Perceived_Project_Completion_Time_Still_Required} \quad \{\text{Days} = \text{Days} + \text{Days}\}$$

$$\text{Indicated_Labor_Force} = (\text{IF} (\text{TIME} > 320 \text{ and } \text{TIME} < 470) \text{ THEN} (5 * (\text{Total_Man_Days_Perceived_Still_Needed} / (\text{Time_Remaining_to_Deadline} + 1))) / \text{Avg_Daily_Labor_Force_Per_Staff})$$

$$\text{ELSE}(\text{Total_Man_Days_Perceived_Still_Needed}/(\text{Time_Remaining_to_Deadline})/\text{Avg_Daily_Labor_Force_Per_Staff}) * 0 + (\text{Total_Man_Days_Perceived_Still_Needed}/(\text{Time_Remaining_to_Deadline})/\text{Avg_Daily_Labor_Force_Per_Staff})$$

$$\text{Indicated_Trend_in_Labor_force_Sought} = ((\text{Perceived_Present_Condition_of_Labor_Force_Sought} - \text{Reference_Condition_of_Labor_Force_Sought}) / (1 + \text{Reference_Condition_of_Labor_Force_Sought})) / \text{Time_Horizon_for_Reference_Condition}$$

$$\text{Initial_internal_Deadline} = 187$$

$$\text{Initial_Project_Deadline_for_the_Phase} = 712$$

$$\text{Initial_Total_Labor_Force} = 31$$

$$\text{Internal_Deadline_Adjustment_Time} = 5$$

$$\text{Internal_Precedence_Relation} = \text{GRAPH}(\text{Fraction_of_Tasks_Perceived_Completed})$$

(0.00, 0.026), (0.1, 0.17), (0.2, 0.376), (0.3, 0.573), (0.4, 0.658), (0.5, 0.796), (0.6, 0.868), (0.7, 0.91), (0.8, 0.953), (0.9, 0.986), (1.00, 1.00)

$$\text{Inverse_of_SP_Tolerance_Time} = \text{GRAPH}(\text{Schedule_Pressure})$$

(1.00, 0.00), (1.10, 0.0055), (1.15, 0.0083), (1.20, 0.03), (1.30, 0.2)

$$\text{Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog} = \text{Desired_Labor_Force_for_Quality_Assurance} / (\text{Total_Desired_Labor_Force} + 0.00001)$$

$$\text{Labor_Force_Fraction_to_Regular_Processing_due_to_backlog} = \text{Desired_Labor_Force_for_Regular_Processing} / (\text{Total_Desired_Labor_Force} + 0.00001)$$

$$\text{Labor_Force_Fraction_to_Rework_due_to_backlog} = \text{Desired_Labor_Force_for_Rework} / (\text{Total_Desired_Labor_Force} + 0.00001)$$

$$\text{Labor_Force_Gap} = \text{Actual_Labor_Force_Required} - \text{Total_Labor_Force}$$

$$\text{Labor_Force_Needed} = (\text{MIN}((\text{Willingness_to_Change_Labor_Force_Level} * \text{Indicated_Labor_Force} + (1 - \text{Willingness_to_Change_Labor_Force_Level}) * \text{Total_Labor_Force}), \text{Indicated_Labor_Force}))$$

$$\text{Labor_Force_Productivity} = \text{Potential_Productivity} * \text{Total_Effect_on_Labor_Force_Productivity} \{ \text{Tasks/People-day} \}$$

$$\text{Labor_Force_Sought} = \text{MIN}(\text{Labor_Force_Needed}, \text{Ceiling_on_Total_Labor_Force})$$

{people}

Labor_Fraction_to_Quality_Assurance =

Pressure_for_Quality_Assurance/Total_Pressure_for_Activities*0+0.1 { This number is used to help the model run }

Labor_Fraction_to_Regular_Processing =

Pressure_for_Regular_Processing/Total_Pressure_for_Activities*0+0.7 { This number is used to help the model run }

Labor_Fraction_to_Rework = Pressure_for_Rework/Total_Pressure_for_Activities*0+0.1

{ This number is used to help the model run }

Managerial_Effect_on_Productivity = 1 { Invalid number only used to allow the model run }

ManDay_Equivalence_of_Overtime_Hrs_Worked_per_Day =

Total_Overtime_Hrs_Worked_Per_Day*Hours_to_ManDays_Convertor { People-Day/Day }

Maximum_Allowed_Overtime_Hours_Per_Day_per_Full_Time_Employee = 2

{ hours/People-Days }

Maximum_Internal_Deadline_Extension_Dates = 40

Maximum_Overtime_Hours_that_Can_be_Worked =

Overtime_Duration_Threshold*Full_Time_Equivalent_Labor_Force*Maximum_Allowed_Overtime_Hours_Per_Day_per_Full_Time_Employee*Willingness_To_Work_Overtime
{ hours=Days*People*(hours/People-Days)*Unitless }

Maximum_Project_Deadline_Extention_Dates = 0

Maximum_Tolerable_Exhaustion_Level = 20 { exhaustion }

Maximum_Tolerable_Internal_Deadline =

Initial_internal_Deadline+Maximum_Internal_Deadline_Extension_Dates

Maximum_Tolerable_Project_Completion_Date =

initial_Project_Deadline_for_the_Phase+Maximum_Project_Deadline_Extention_Dates

Max_New_Recruit_Per_Full_Time_Experienced_Labor_Force = 2

Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline = 20

Minimum_QA_Duration_per_Task = 0.13

Minimum_Regular_Processing_Duration_per_Task = 1

Minimum_Rework_Duration_per_Task =

Minimum_Rework_Duration_per_Task_Discovered_in_the_Phase*(1-

Fraction_of_Defective_Tasks_Discoverd_by_Downstream)+Minimum_Rework_Duration_pe

r_Task_Discovered_outside_the_phase*Fraction_of_Defective_Tasks_Discovered_by_Downs
 team

Minimum_Rework_Duration_per_Task_Discovered_in_the_Phase = 0.133 {0.133 days =
 1hrs/7.5 hrs/day}

Minimum_Rework_Duration_per_Task_Discovered_outside_the_phase = 0.5 {days}

Mobilization_Delay = 10

Negative_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity =

GRAPH(Avg_Schedule_Pressure)

(0.7, 1.00), (0.8, 1.00), (0.9, 1.00), (1.00, 1.00), (1.10, 0.98), (1.20, 0.95), (1.30, 0.9), (1.40,
 0.8), (1.50, 0.68), (1.60, 0.55), (1.70, 0.45), (1.80, 0.4)

New_Employees_Avg_Hourly_Pay_Rate = 400

New_Employees__Hiring_Fraction =

GRAPH(Time_to_Project_Deadline/Avg_Assimilation_&_Hiring_Time_of_New_Employee
 s)

(0.00, 0.00), (0.3, 0.00), (0.6, 0.00), (0.9, 0.00), (1.20, 0.01), (1.50, 0.04), (1.80, 0.08), (2.10,
 0.15), (2.40, 0.25), (2.70, 0.33), (3.00, 0.33)

New_Hired_in_Externally_Avg_Hourly_Pay_Rate = 500

New_Hired_in_Externally_Hiring_Fraction =

GRAPH(Time_to_Project_Deadline/Avg_Assimilation_&_Hiring_Time_of_New_Hired_in)

(0.00, 0.5), (0.5, 0.5), (1.00, 0.35), (1.50, 0.3), (2.00, 0.25), (2.50, 0.17), (3.00, 0.1), (3.50,
 0.03), (4.00, 0.03)

Nominal_Overtime_Duration_Threshold = GRAPH(Time_Remaining_to_Deadline {Days})

(0.00, 0.00), (5.00, 5.00), (10.0, 10.0), (15.0, 15.0), (20.0, 20.0)

Normal_Work_Hours_per_Day = 7.5 {hours/People-Days}

Overall_Expected_Engineering_Productivity =

(Expected_Average_Productivity+Area_Engineering.Expected_Average_Productivity+Engin
 eering_For_Procurement.Expected_Average_Productivity)/3

Overall_Expected_Engineering_Productivity_Data = GRAPH(TIME)

(0.00, 0.92), (19.0, 0.93), (37.0, 0.95), (56.0, 0.96), (75.0, 1.00), (94.0, 0.98), (112, 0.96),
 (131, 0.96), (150, 0.95), (169, 0.95), (187, 0.92), (206, 0.89), (225, 0.85), (244, 0.82), (262,
 0.8), (281, 0.8), (300, 0.81), (319, 0.81), (337, 0.82), (356, 0.81), (375, 0.81), (394, 0.82),

(412, 0.8), (431, 0.81), (450, 0.81), (469, 0.8), (487, 0.8), (506, 0.8), (525, 0.79), (543, 0.79), (562, 0.79), (581, 0.79), (600, 0.79), (618, 0.78), (637, 0.78)

Overtime_Duration_Threshold =

Effect_of_Exhaustion_Level_on_Overtime_Duration*Nominal_Overtime_Duration_Threshold {Days=Days*Unitless}

Overtime_Worked_per_Day_per_FullTime_Equivalent_LF =

Total_Overtime_Hours_that_will_be_Handled/(Full_Time_Equivalent_Labor_Force*Overtime_Duration_Threshold+0.000001) {hours/ People-Day}

Overtime_Work_Break_Indicator =

IF(Overtime_Duration_Threshold=0)THEN(TIME+DT)ELSE(0) {days}

Perceived_Layoff_in_Hired_in_Externally =

SMTH1((Experienced_Hired_in_Demobilization_Rate+New_Hired_in_Demobilization_Rate), 10)

Perceived_Minimum_Quality_Assurance_Productivity = 0.1

Perceived_Minimum_Regular_Processing_Productivity = 0.1

Perceived_Minimum_Rework_Productivity = 0.1

Perceived_Net_Shortage_in_Man_Days = Total_Man_Days_Perceived_Still_Needed-

Total_Available_Man_Days {People-Days=(People-Days)-(People-Days)}

Perceived_Project_Completion_Time_Needed = (IF(Remaining_Tasks-

Thirty_%_of_Phase_Scope>0)THEN((Remaining_Tasks-Thirty_%_of_Phase_Scope)/

(Expected_Average_Productivity*Actual_Labor_Force_Required*Avg_Daily_Labor_Force_Per_Staff))ELSE((Remaining_Tasks)/

(Expected_Average_Productivity*Actual_Labor_Force_Required*Avg_Daily_Labor_Force_Per_Staff))*0+(Remaining_Tasks/(Expected_Average_Productivity*Actual_Labor_Force_Required/Avg_Daily_Labor_Force_Per_Staff))

Perceived_Project_Completion_Time_Still_Required =

Perceived_Project_Completion_Time_Needed-

Perceived_Work_Days_to_be_Recovered_Via_Overtime

Perceived_Rate_of_Increase_in_Exhaustion_Level =

SMTH1(Rate_of_Increase_in_Exhaustion_Level, 1)

Perceived_Shortage_in_Man_Days = Perceived_Net_Shortage_in_Man_Days

Perceived_Shortage_in_Man_Hours =

Perceived_Shortage_in_Man_Days*Normal_Work_Hours_per_Day {hours=(People-Days)*(hours/(People-Days))}

Perceived_Work_Days_to_be_Recovered_Via_Overtime =

Perceived_Man_Days_to_be_handled_via_Overtime/(Full_Time_Equivalent_Labor_Force+0.99999) {Days= People-Days/People}

Percent_of_Tasks_Actually_Completed = (Total_Tasks_Actually_Completed/Current_Scope)

Perceived_Man_Days_to_be_Handled_via_Overtime =

Total_Overtime_Hours_that_will_be_Handled/Normal_Work_Hours_per_Day {People-Days= hours/(hours/People-Days)}

Phase_Scope_Data = GRAPH(TIME)

(0.00, 8186), (19.0, 8186), (37.0, 8186), (56.0, 8186), (75.0, 8186), (94.0, 8186), (112, 8186), (131, 8186), (150, 8186), (169, 8186), (187, 10356), (206, 10356), (225, 10356), (244, 10356), (262, 10356), (281, 10410), (300, 10410), (319, 10410), (337, 11076), (356, 11076), (375, 11076), (394, 11076), (412, 11076), (431, 11076), (450, 11076), (469, 11915), (487, 11915), (506, 11915), (525, 11915), (543, 11915), (562, 12345), (581, 12345), (600, 12345), (618, 12345), (637, 12345), (656, 12436), (675, 12436), (693, 12436), (712, 12436)

Planned_Productivity = GRAPH(TIME)

(0.00, 0.88), (19.0, 0.9), (37.0, 0.96), (56.0, 0.95), (75.0, 1.05), (94.0, 1.02), (112, 0.98), (131, 0.96), (150, 0.95), (169, 0.95)

Positive_Effect_of_Schedule_Pressure_on_Labor_Force_Productivity =

GRAPH(Schedule_Pressure)

(0.4, 0.8), (0.5, 0.8), (0.6, 0.8), (0.7, 0.82), (0.8, 0.88), (0.9, 0.95), (1.00, 1.00), (1.10, 1.08), (1.20, 1.15), (1.30, 1.21), (1.40, 1.27), (1.50, 1.30), (1.60, 1.30)

Potential_Productivity =

Effect_of_Learning_on_Potential_Productivity*Average_Nominal_Potential_Productivity

Pressure_for_Quality_Assurance =

EXP(Required_Labor_Force_for_Quality_Assurance*Quality_Gap_Effect_on_RW&QA_Importance*Quality_Assurance_Priority/Dummy_Variable)

Pressure_for_Rework =

EXP(Required_Labor_Force_for_Rework*Rework_Priority*Quality_Gap_Effect_on_RW& QA_Importance/Dummy_Variable)

Pressure_for_Regular_Processing =

EXP(Required_Labor_for_Regular_Processing*Regular_Processing_Priority*Effect_of_Schedule_Pressure_on_Regular_Processing_Importance*Cost_Effect_on_Regular_Processing_Importance/Dummy_Variable)

Previous_Scope = HISTORY(Current_Scope, TIME-1)

Probability_of_Tasks_to_be_Successfully_Reworked = (1-

Probability_to_be_Defective_Rework_from_Quality_of_Practice)

Probability_to_be_Defective_from_Quality_of_Practice =

GRAPH(Quality_of_Practice_in_Regular_Processing/Reference_Quality_of_Practice_in_Regular_Processing)

(0.00, 0.5), (0.1, 0.45), (0.2, 0.36), (0.3, 0.28), (0.4, 0.21), (0.5, 0.15), (0.6, 0.1), (0.7, 0.06), (0.8, 0.03), (0.9, 0.01), (1.00, 0.00)

Probability_to_be_Defective_Rework_from_Quality_of_Practice =

GRAPH(Quality_of_Practice_in_Rework/Reference_Quality_of_Practice_in_Rework)

(0.00, 0.5), (0.1, 0.45), (0.2, 0.36), (0.3, 0.28), (0.4, 0.21), (0.5, 0.15), (0.6, 0.1), (0.7, 0.06), (0.8, 0.03), (0.9, 0.01), (1.00, 0.00)

Probability_to_be_Defective_Task =

(Probability_to_be_Defective_from_Inherent_Task_Complexity*Probability_to_be_Defective_from_Quality_of_Practice)

Probability_to_be_Defective_from_Inherent_Task_Complexity = 0.2

Probability_to_Discover_Unsuccessfully_Processed_Tasks =

GRAPH(Quality_of_Practice_in_QA/Reference_Quality_of_Practice_in_QA)

(0.00, 0.00), (0.1, 0.3), (0.2, 0.4), (0.3, 0.6), (0.4, 0.75), (0.5, 0.8), (0.6, 0.85), (0.7, 0.9), (0.8, 0.92), (0.9, 0.95), (1.00, 1.00)

Productivity_Data = GRAPH(TIME)

(0.00, 0.88), (19.0, 0.9), (37.0, 0.96), (56.0, 0.95), (75.0, 1.05), (94.0, 1.02), (112, 0.98), (131, 0.96), (150, 0.95), (169, 0.95), (187, 0.93), (206, 0.89), (225, 0.84), (244, 0.79), (262, 0.76), (281, 0.77), (300, 0.8), (319, 0.79), (337, 0.8), (356, 0.8), (375, 0.8), (394, 0.81), (412, 0.79),

(431, 0.8), (450, 0.81), (469, 0.8), (487, 0.8), (506, 0.8), (525, 0.79), (543, 0.79), (562, 0.79),
 (581, 0.8), (600, 0.8), (618, 0.8), (637, 0.81)

Productivity_in_Quality_Assurance =

Labor_Force_Productivity*QA_Productivity_Multiplier

Productivity_in_Rework = Labor_Force_Productivity*Rework_Productivity_Multiplier

Project_Deadline_Adjustment_Time = 5

QA_Productivity_Multiplier =

Minimum_Regular_Processing_Duration_per_Task/Minimum_QA_Duration_per_Task

Quality_Assurance_Priority = 1 {Invalid number only used to allow the model run}

Quality_Assurance_Processing_Limit =

(Quality_Assurance_Processing_Limit_from_Task_Availability_1+Quality_Assurance_Proce
 ssing_Limit_from_Task_Availability_2)

Quality_Assurance_Processing_Limit_from_Resources_1 =

Daily_QA_Labor_Force_for_Unsuccessfully_Processed_Tasks*Productivity_in_Quality_Ass
 urance

Quality_Assurance_Processing_Limit_from_Resources_2 =

Daily_QA_Labor_force_to_Successfully_Processed_Tasks*Productivity_in_Quality_Assuran
 ce

Quality_Assurance_Processing_Limit_from_Task_Availability_1 =

(Undiscoverd__Unsuccessfully__Processed_Tasks/Minimum_QA_Duration_per_Task)

Quality_Assurance_Processing_Limit_from_Task_Availability_2 =

(Successfully_Processed_Tasks/Minimum_QA_Duration_per_Task)

Quality_Assurance_Productivity_Report_Time = 5

Quality_Assurance_Rate_2 =

MIN(Quality_Assurance_Processing_Limit_from_Task_Availability_2,Quality_Assurance_Pr
 ocessing_Limit_from_Resources_2)

Quality_Gap = Current_Quality-Quality_Goal

Quality_Gap_Effect_on_RW&QA_Importance = GRAPH(Quality_Gap)

(-1.00, 2.20), (-0.9, 2.14), (-0.8, 2.07), (-0.7, 1.99), (-0.6, 1.90), (-0.5, 1.80), (-0.4, 1.68), (-0.3,
 1.54), (-0.2, 1.38), (-0.1, 1.20), (0.00, 1.00)

Quality_Goal_Adjustment_Time = 20

Quality_of_Practice =
 Effect_of_Fatigue_on_QoP*Effect_of_Experience_on_QoP*Effect_of_Schedule_Pressure_o
 n_QoP
 Quality_of_Practice_in_QA = Quality_of_Practice*Reference_Quality_of_Practice_in_QA
 Quality_of_Practice_in_Regular_Processing =
 Quality_of_Practice*Reference_Quality_of_Practice_in_Regular_Processing
 Quality_of_Practice_in_Rework =
 Quality_of_Practice*Reference_Quality_of_Practice_in_Rework
 Quality_Assurance_Rate_1 =
 MIN(Quality_Assurance_Processing_Limit_from_Resources_1,
 Quality_Assurance_Processing_Limit_from_Task_Availablity_1)
 Quit_Fraction = 0.05/240
 Reference_Quality_of_Practice_in_Regular_Processing = 0.8
 Reference_Potential_Productivity_of_Experienced_Employees = 1
 Reference_Potential_Productivity_of_Experienced_Hire_in = 1
 Reference_Potential_Productivity_of_New_Employees = 0.5
 Reference_Potential_Productivity_of_Transferredin_Company_Employees = 0.8
 Reference_Potential_Productivity_of__New_Hire_in = 0.8
 Reference_Quality_of_Practice_in_QA = 0.9
 Reference_Quality_of_Practice_in_Rework = 0.9
 Ref_Quality_Assurance_Productivity = 10
 Ref_Regular_Processing_Productivity = 0.88
 Ref_Rework_Productivity = 1.5
 Regular_Processing_Limit_from_Resources =
 Daily_Labor_Force_to_Regular__Processing*Labor_Force_Productivity {Tasks/day=
 (People-day/day)*(Tasks/People-day)}
 Regular_Processing_Limit_from_Task_Availability =
 Tasks_Available_for_Regular_Processing/Minimum_Regular_Processing_Duration_per_Tas
 k
 Regular_Processing_Priority = 1 {Invalid number only used to allow the model run}
 Regular_Processing_Productivity_Report_Time = 5

Regular_Processing_Rate =
MIN(Regular_Processing_Limit_from_Task_Availability,Regular_Processing_Limit_from_Resources)
Release_Package_Size = 0.015*Current_Scope
Release_Trigger =
IF(Total_Tasks_to_be_Released>=Release_Package_Size)THEN(1)ELSE(0)
Remaining_Tasks = Current_Scope-Total_Released_Tasks
Required_Labor_Force_for_Quality_Assurance =
(Quality_Assurance_Processing_Limit/(Productivity_in_Quality_Assurance*0+1))*0+1
Required_Labor_Force_for_Rework =
(Rework_Processing_Limit_from_Task_Availability/(Productivity_in_Rework*0+1))*0+1
Required_Labor_for_Regular_Processing =
(Regular_Processing_Limit_from_Task_Availability/(Labor_Force_Productivity*0+1))*0+1
Rework_Priority = 1 {Invalid number only used to allow the model run}
Rework_Processing_Limit_from_Resources =
Daily_Labor_Force_to_Rework*Productivity_in_Rework
Rework_Processing_Limit_from_Task_Availability =
Discovered_Unsuccessfully_Processed_Tasks/(Minimum_Rework_Duration_per_Task+0.00001)
Rework_Productivity_Multiplier =
Minimum_Regular_Processing_Duration_per_Task/Minimum_Rework_Duration_per_Task
Rework_Productivity_Report_Time = 5
Rework_Rate =
MIN(Rework_Processing_Limit_from_Task_Availability,Rework_Processing_Limit_from_Resources)
Schedule_Pressure =
(Total_Man_Days_Perceived_Still_Needed)/(Total_Available_Man_Days+1)
Scope_Change = (IF(Current_Scope - Previous_Scope>0) THEN(STEP(Current_Scope-Previous_Scope, TIME)) ELSE(0))
Scope_Change_1 = PULSE(2170,167,0)+PULSE(54,262,0)+PULSE(666,319,0)+
PULSE(839,450,0)+PULSE(433,543,0)+PULSE(88,637,0)

Scope_of_work = GRAPH(Total_Released_Tasks/Total_number_of_Tasks)
 (0.00, 8186), (0.44, 8186), (0.5, 10356), (0.61, 10356), (0.62, 10410), (0.71, 10410), (0.72,
 11076), (0.87, 11076), (0.88, 11915), (0.92, 11915), (0.93, 12345), (0.97, 12345), (0.98,
 12436), (1.00, 12436)
 Tasks_Available_for_Regular_Processing = (MAX(0, Total_Tasks_Available-
 (Current_Scope-Tasks_Identified_to_be_Processed)))
 Tasks_Perceived__Completed =
 Successfully_Processed_Tasks+Undiscoverd__Unsuccessfully__Processed_Tasks+Successfu
 lly_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks_Approve
 d_to_be_Released+Sucessfully_Processed_Tasks_Released+Unsuccessfully_Processed_Task
 s_Released
 Thirty_%_of__Phase_Scope = Current_Scope*0.3
 Time_Horizon_for_Reference_Condition = 10
 Time_Remaining_to_Complete_70%_of_the_Phase_Scope =
 IF(Internal_Deadline>(13+TIME))THEN(Internal_Deadline-TIME)ELSE(13)
 Time_Remaining_to_Deadline =
 (IF((Internal_Deadline+Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline)
 >TIME) THEN(Time_Remaining_to_Internal_Deadline) ELSE(
 MAX(Project_Deadline_for_the_Phase-TIME,
 1))) * 0 + (MAX(Project_Deadline_for_the_Phase-TIME, 1)) {Days}
 Time_Remaining_to_Internal_Deadline = IF(Remaining_Tasks-
 Thirty_%_of__Phase_Scope>0)
 THEN(Time_Remaining_to_Complete_70%_of_the_Phase_Scope)ELSE(IF(Remaining_Tas
 ks-Thirty_%_of__Phase_Scope < 0 and
 (Internal_Deadline+Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline)>TI
 ME)THEN(Adjustment_Towards_the_30%_Phase_Scope_Deadline)ELSE(0))
 Time_to_Adjust_New_Deadline = 5
 Time_to_adjust_Perceived_Quality_Assurance_Productivity = 10
 Time_to_adjust_Perceived_Regular_Processing_Productivity = 10
 Time_to_adjust_Perceived_Rework_Productivity = 10
 Time_to_Perceive_an_Increase_in_SP = 1/(Inverse_of_SP_Tolerance_Time+0.00001)

Time_to_Perceive_a_Decrease_in_SP = GRAPH(Avg_Schedule_Pressure)

(1.00, 1e-06), (1.10, 5.00), (1.15, 20.9), (1.20, 63.3), (1.30, 180)

Time_to_Perceive_Present_Conditions = 5 {days}

Time_to_Perceive_Trend = 5

Time_to_Project_Deadline = 712-TIME

Time_to_Release_Tasks = 5

Total_Available_Man_Days =

Actual_Labor_Force_Required*Avg_Daily_Labor_Force_Per_Staff*Time_Remaining_to_Deadline

Total_Cost =

(Experienced_Employees_Costs_to_Date+Transferred_in_Company_Employees_Costs_to_Date+New_Employees_Costs_to_Date+Overtime_Costs_to_Date+New_Hired_in_Externally_Costs_to_Date+Experienced_Hired_in_Externally_Costs_to_Date)

Total_Desired_Labor_Force =

Desired_Labor_Force_for_Regular_Processing+Desired_Labor_Force_for_Rework+Desired_Labor_Force_for_Quality_Assurance

Total_Effect_on_Labor_Force_Productivity =

Managerial_Effect_on_Productivity*Effect_of_Schedule_Pressure_on_Labor_Force_Productivity*Effect_of_Fatigue_on_Labor_Force_Productivity*Effect_of_Labor_Size_on_Productivity

Total_Engineering_Labor_Force =

Total_Labor_Force+Area_Engineering.Total_Labor_Force+Engineering_For_Procurement.Total_Labor_Force

Total_Engineering_Labor_Force_Data =

Total_Labor_Force_Data+Area_Engineering.Total_Labor_Force_Data+Engineering_For_Procurement.Total_Labor_Force_Data

Total_Engineering_Scope =

Current_Scope+Area_Engineering.Current_Scope+Engineering_For_Procurement.Current_Scope

Total_Engineering_Tasks_Released =

Total_Released_Tasks+Engineering_For_Procurement.Total_Released_Tasks+Area_Engineering.Total_Released_Tasks

Total_Fraction_of_Engineering_Tasks_Released =

Total_Engineering_Tasks_Released/Total_Engineering_Scope

Total_Fraction_Of_Engineering_Tasks_Released_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 0.042), (37.0, 0.112), (56.0, 0.203), (75.0, 0.26), (94.0, 0.329), (112, 0.396), (131, 0.463), (150, 0.538), (169, 0.616), (187, 0.592), (206, 0.634), (225, 0.665), (244, 0.682), (262, 0.715), (281, 0.735), (300, 0.764), (319, 0.81), (337, 0.788), (356, 0.823), (375, 0.852), (394, 0.873), (412, 0.886), (431, 0.903), (450, 0.922), (469, 0.89), (487, 0.905), (506, 0.92), (525, 0.927), (543, 0.936), (562, 0.929), (581, 0.939), (600, 0.952), (618, 0.961), (637, 0.971)

Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF =

Overtime_Worked_per_Day_per_FullTime_Equivalent_LF+Normal_Work_Hours_per_Day {hours/People-Days}

Total_Labor_Force =

(New_Employees+Experienced_Employees+Transferred_in_Company_Employees+New_Hired_in_Externally+Experienced_Hired_in_Externally)

Total_Labor_Force_Data = GRAPH(TIME)

(0.00, 31.0), (19.0, 33.0), (37.0, 25.0), (56.0, 36.0), (75.0, 36.0), (94.0, 39.0), (112, 38.0), (131, 33.0), (150, 33.0), (169, 60.0), (188, 31.0), (207, 21.0), (226, 20.0), (245, 20.0), (264, 17.0), (283, 17.0), (302, 14.0), (321, 9.00), (340, 8.00), (359, 8.00), (378, 7.00), (397, 7.00), (416, 7.00), (435, 15.0), (454, 11.0), (473, 8.00), (492, 7.00), (511, 7.00), (530, 5.00), (549, 7.00), (568, 7.00), (587, 7.00), (606, 7.00), (625, 7.00), (644, 5.00), (663, 5.00), (682, 5.00), (701, 3.00), (712, 0.00)

Total_Man_Days_Perceived_Still_Needed = (IF(Remaining_Tasks-

Thirty_%_of__Phase_Scope>0)THEN((Remaining_Tasks-

Thirty_%_of__Phase_Scope)/Expected_Average_Productivity)ELSE(Remaining_Tasks/Expected_Average_Productivity))*0+(Remaining_Tasks/Expected_Average_Productivity)

$$\text{Total_Man_Days_Still_Required} = \text{Perceived_Net_Shortage_in_Man_Days} -$$

$$\text{Perceived_Man_Days_to_be_handled_via_Overtime} \quad \{\text{People-Days} = (\text{People-Days}) - (\text{People-Days})\}$$

$$\text{Total_number_of_Tasks} = 12435$$

$$\text{Total_Overtime_Hours_that_will_be_Handled} =$$

$$\text{MAX}(\text{MIN}(\text{Maximum_Overtime_Hours_that_Can_be_worked}, \text{Perceived_Shortage_in_Man_Hours}), 0) \quad \{\text{hours} = (\text{hours}, \text{hours})\}$$

$$\text{Total_Overtime_Hrs_Worked_Per_Day} =$$

$$\text{Overtime_Worked_per_Day_per_FullTime_Equivalent_LF} * \text{Total_Labor_Force}$$

$$\{\text{Hours/Day}\}$$

$$\text{Total_Pressure_for_Activities} =$$

$$\text{Pressure_for_Rework} + \text{Pressure_for_Quality_Assurance} + \text{Pressure_for_Regular_Processing}$$

$$\text{Total_Released_Tasks} =$$

$$\text{Successfully_Processed_Tasks_Released} + \text{Unsuccessfully_Processed_Tasks_Released}$$

$$\text{Total_Tasks_Available} =$$

$$\text{Current_Scope} * \text{MIN}(\text{Internal_Precedence_Relation}, \text{External_Precedence_Relation})$$

$$\text{Total_Tasks_to_be_Released} =$$

$$\text{Successfully_Processed_Tasks_Approved_to_be_Released} + \text{Unsuccessfully_Processed_Tasks}$$

$$\text{_Approved_to_be_Released} + 0.0000009$$

$$\text{Total_Tasks_to_QA} =$$

$$\text{Successfully_Processed_Tasks} + \text{Undiscovered_Unsuccessfully_Processed_Tasks} + 0.00001$$

$$\{\text{This small number is used to avoid division by zero}\}$$

$$\text{Trainers_per_New_Labor_Force} = 0.2 \quad \{\text{On average each new labor force consumes in}$$

$$\text{training overhead the equivalent of 20\% of an experienced labor force's daily working time}$$

$$\text{for the duration of the training or assimilation period. Unit - Unitless} = \text{days/days}\}$$

$$\text{Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate} = 500$$

$$\text{Unsuccessfully_processed_Task_Discovery_Rate} =$$

$$\text{Quality_Assurance_Rate}_1 * \text{Probability_to_Discover_Unsuccessfully_Processed_Tasks}$$

$$\text{Upstream_Phase_Scope} = 0$$

$$\text{Weight_to_Planned_Productivity} = \text{GRAPH}(\text{Fraction_of_Released_Tasks})$$

(0.00, 1.00), (0.1, 0.9), (0.2, 0.7), (0.3, 0.5), (0.4, 0.3), (0.5, 0.1), (0.6, 0.00), (0.7, 0.00), (0.8, 0.00), (0.9, 0.00), (1.00, 0.00)

Willingness_to_Change_Labor_Force_Level =

MAX(Desire_for_Schedule_Stability_Effect_on_WCLF, Desire_for_LF_Stability_Effect_on_WCLF)

Willingness_To_Work_Overtime =

IF(TIME >= Time_To_Recover + Time_from_Last_Exhaustion_Break) THEN (1) ELSE (0)

{Unitless = Unitless + Unitless}

Workload_Stress_Onset_time = IF Schedule_Pressure > Avg_Schedule_Pressure THEN

Time_to_Perceive_an_Increase_in_SP ELSE Time_to_Perceive_a_Decrease_in_SP

Total_Tasks_Actually_Completed =

Successfully_Processed_Tasks_Approved_to_be_Released +

Successfully_Processed_Tasks_Released + Unsuccessfully_Processed_Tasks_Released +

Unsuccessfully_Processed_Tasks_Approved_to_be_Released

Total_Tasks_in_the_Phase_at_Any_Time = Discovered_Unsuccessfully_Processed_Tasks +

Successfully_Processed_Tasks_Approved_to_be_Released +

Successfully_Processed_Tasks_Released + Successfully_Processed_Tasks +

Tasks_Identified_to_be_Processed + Undiscovered_Unsuccessfully_Processed_Tasks +

Unsuccessfully_Processed_Tasks_Released +

Unsuccessfully_Processed_Tasks_Approved_to_be_Released

Engineering for Procurement Phase Equations

$$\text{Avg_Schedule_Pressure}(t) = \text{Avg_Schedule_Pressure}(t - dt) + (\text{Change_in_Avg_SP}) * dt$$

$$\text{INIT Avg_Schedule_Pressure} = \text{Schedule_Pressure}$$

INFLOWS:

$$\text{Change_in_Avg_SP} = (\text{Schedule_Pressure} - \text{Avg_Schedule_Pressure}) / \text{Workload_Stress_Onset_time}$$

$$\begin{aligned} \text{Defective_Tasks_Discoverd_by_Downstream}(t) = \\ \text{Defective_Tasks_Discoverd_by_Downstream}(t - dt) + \\ (\text{Defective_Task_Discovery_Rate_from_Down_stream} - \\ \text{Rework_Rate_of_Downstream_Discovered_Defective_Tasks}) * dt \end{aligned}$$

$$\text{INIT Defective_Tasks_Discoverd_by_Downstream} = 0$$

INFLOWS:

$$\begin{aligned} \text{Defective_Task_Discovery_Rate_from_Down_stream} = \\ \text{Intraphase_Defective_Tasks_Coordinated_with_Downstream} \end{aligned}$$

OUTFLOWS:

$$\begin{aligned} \text{Rework_Rate_of_Downstream_Discovered_Defective_Tasks} = \\ (\text{Sucessful_Rework_Rate} + \text{Uncessesful_Rework_Rate}) * \text{Fraction_of_Defective_Tasks_Disc} \\ \text{overd_by_Downstream} \end{aligned}$$

$$\begin{aligned} \text{Experienced_Hired_in_Externally}(t) = \text{Experienced_Hired_in_Externally}(t - dt) + \\ (\text{Assimilation_Rate_of_New_Hire_in} - \text{Experienced_Hire_in_Demobilization_Rate} - \\ \text{Experienced_Hire_in_Quit_Rate}) * dt \end{aligned}$$

$$\text{INIT Experienced_Hired_in_Externally} = \text{Initial_Total_Labor_Force} * 0.2$$

INFLOWS:

$$\begin{aligned} \text{Assimilation_Rate_of_New_Hire_in} = \\ \text{New_Hire_in} / \text{Avg_Assimilation_Time_of_NewHire_in} \end{aligned}$$

OUTFLOWS:

$$\begin{aligned} \text{Experienced_Hire_in_Demobilization_Rate} = \\ \text{MIN}(\text{Experienced_Hired_in_Externally} / \text{DT}, (\text{Demobilization_Rate} - \\ \text{New_Hire_in_Demobilization_Rate})) \end{aligned}$$

$$\begin{aligned} \text{Experienced_Hire_in_Quit_Rate} = \\ \text{Experienced_Hired_in_Externally} / \text{Avg_Employment_Duration_of_Hire_In_Externally} \end{aligned}$$

Experienced_Hired_in_Externally_2(t) = Experienced_Hired_in_Externally_2(t - dt)

INIT Experienced_Hired_in_Externally_2 = Initial_Total_Labor_Force*0.2

Internal_Deadline(t) = Internal_Deadline(t - dt) + (Change_to_Internal_Deadline) * dt

INIT Internal_Deadline = Initial_internal_Deadline

INFLOWS:

Change_to_Internal_Deadline = MIN((Maximum_Tolerable_Internal_Deadline-
Internal_Deadline)/Internal_Deadline_Adjustment_Time,

((Indicated_Completion_date_for_70%_of_Phase_Scope-
Internal_Deadline)/Internal_Deadline_Adjustment_Time))

Perceived_Present_Condition_PPC(t) = Perceived_Present_Condition_PPC(t - dt) +
(Change_in_PPC) * dt

INIT Perceived_Present_Condition_PPC =

INIT(Input)/(1+Time_to_Perceive_Present_Conditions_TPPC*Perceived_Trend_TREND)

INFLOWS:

Change_in_PPC = (Input-Perceived_Present_Condition_PPC)/

Time_to_Perceive_Present_Conditions_TPPC

Perceived_Trend_TREND(t) = Perceived_Trend_TREND(t - dt) + (Change_in_TREND) * dt

INIT Perceived_Trend_TREND = 0.15

INFLOWS:

Change_in_TREND = (Indicated_Trend_ITREND -Perceived_Trend_TREND)/

Time_to_Perceive_Trend_TPT

Quality_Goal(t) = Quality_Goal(t - dt) + (Change_in_Quality_Goal) * dt

INIT Quality_Goal = 0.9

INFLOWS:

Change_in_Quality_Goal = Quality_Gap/Quality_Goal_Adjustment_Time

Reference_Condition_RC(t) = Reference_Condition_RC(t - dt) + (Change_in_RC) * dt

INIT Reference_Condition_RC = INIT(Perceived_Present_Condition_PPC)/(1+

Time_Horizon_for_Reference_Condition_THRC * Perceived_Trend_TREND)

INFLOWS:

Change_in_RC = (Perceived_Present_Condition_PPC -Reference_Condition_RC)/

Time_Horizon_for_Reference_Condition_THRC

Total_Defective_Tasks_Sent_to_Upstream(t) = Total_Defective_Tasks_Sent_to_Upstream(t - dt) + (Accum_Rate_of_Defective_Tasks_Sent_to_Upstream) * dt

INIT Total_Defective_Tasks_Sent_to_Upstream = 0

INFLOWS:

Accum_Rate_of_Defective_Tasks_Sent_to_Upstream =

Upstream_Defective_Task_Discovery_Rate

Total_Discovered_Unsuccessfully_Processed_Tasks(t) =

Total_Discovered_Unsuccessfully_Processed_Tasks(t - dt) +

(Accum_Rate_of_Discovered_Unsuccessfully_Processed_Tasks) * dt

INIT Total_Discovered_Unsuccessfully_Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Discovered_Unsuccessfully_Processed_Tasks =

Unsuccessfully_processed_Task_Discovery_Rate

Total_Successfully_Processed_Tasks_Approved_to_be_Released(t) =

Total_Successfully_Processed_Tasks_Approved_to_be_Released(t - dt) +

(Accum_Rate_of_Successfully_Processed_Tasks_Approved_to_be_Released) * dt

INIT Total_Successfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Accum_Rate_of_Successfully_Processed_Tasks_Approved_to_be_Released =

Approval_Rate_of_Successfully_Processed_Tasks

Total_Successfully_Processed_Tasks_Released(t) =

Total_Successfully_Processed_Tasks_Released(t - dt) +

(Accum_Rate_of_Successfully_Processed_Tasks_Released) * dt

INIT Total_Successfully_Processed_Tasks_Released = 0

INFLOWS:

Accum_Rate_of_Successfully_Processed_Tasks_Released =

Successfully_Processed_Tasks_Release_Rate

Total_Successfully_Processed_Tasks(t) = Total_Successfully_Processed_Tasks(t - dt) +

(Accum_Rate_of_Successfully_Processed_Tasks) * dt

INIT Total_Successfully_Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Sucessfully_Processed_Tasks =
 Successful__Rework_Rate+Successful_Processing_Rate
 Total_Undiscoverd_Unsucessfully_Processed_Tasks(t) =
 Total_Undiscoverd_Unsucessfully_Processed_Tasks(t - dt) +
 (Accum_Rate_of_Undiscoverd__Unsucessfully_Processed_Tasks) * dt
 INIT Total_Undiscoverd_Unsucessfully_Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Undiscoverd__Unsucessfully_Processed_Tasks =
 Unsucessful__Processing_Rate+Uncessesful__Rework_Rate
 Total_Unsucessesfully_Processed_Tasks_Released(t) =
 Total_Unsucessesfully_Processed_Tasks_Released(t - dt) +
 (Accum_Rate_of__Unsucessesfully_Processed_Tasks_Released) * dt
 INIT Total_Unsucessesfully_Processed_Tasks_Released = 0

INFLOWS:

Accum_Rate_of__Unsucessesfully_Processed_Tasks_Released =
 Unsucessfully_Processed_Tasks_Release_Rate
 Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released(t) =
 Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +
 (Accum_Rate_of_Unsucessfully_Processed_Tasks_Approved_to_be_Released) * dt
 INIT Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Accum_Rate_of_Unsucessfully_Processed_Tasks_Approved_to_be_Released =
 Approval_Rate_of_Undiscoverd_Unsucessfully_Processed_Tasks
 Adjustment_Towards_the_30%_Phase_Scope_Deadline(t) =
 Adjustment_Towards_the_30%_Phase_Scope_Deadline(t - dt) +
 (Change_in_Phase_Deadline_Adjustment) * dt
 INIT Adjustment_Towards_the_30%_Phase_Scope_Deadline = 10

INFLOWS:

Change_in_Phase_Deadline_Adjustment =
 IF(Remaining_Tasks>Thirty_%_of__Phase_Scope)THEN(0)ELSE((Deadline_for_the_Remai

ning_30%_Phase_Scope-

Adjustment_Towards_the_30%_Phase_Scope_Deadline)/Time_to_Adjust_New_Deadline)

Cumulative_Man_Days_Expended(t) = Cumulative_Man_Days_Expended(t - dt) +

(Total_Daily_Labor_Force_Expended) * dt

INIT Cumulative_Man_Days_Expended = 0 {Unit-people*days}

INFLOWS:

Total_Daily_Labor_Force_Expended =

Total_Labor_Force*Avg_Daily_Labor_Force_Per_Staff+ManDay_Equivalence_of_Overtime

_Hrs_worked_per_Day {Unit- people/days=people*days/days}

Cumulative_Man_Days_Expended_for_Development_Activities(t) =

Cumulative_Man_Days_Expended_for_Development_Activities(t - dt) +

(Daily_Labor_Force_for_Development_Activities) * dt

INIT Cumulative_Man_Days_Expended_for_Development_Activities = 0

INFLOWS:

Daily_Labor_Force_for_Development_Activities = (Total_Daily_Labor_Force_Expended-

Daily_Labor_Force__for_Training) {Unit- people/days=people/days - people/days}

Cumulative_Training_MD(t) = Cumulative_Training_MD(t - dt) +

(Daily_Labor_Force__for_Training) * dt

INIT Cumulative_Training_MD = 0 {The cumulated number of training mandays unit -

people*days}

INFLOWS:

Daily_Labor_Force__for_Training =

(New_Employees+New_Hire_in+Transferred_in_Company_Employees)*Trainers_per_New

_Labor_Force {unit - pepole/days = people*days/days}

Discovered_Unsuccessfully_Processed_Tasks(t) =

Discovered_Unsuccessfully_Processed_Tasks(t - dt) +

(Intraphase_Unccessfully_processed_Task_Discovery_Rate +

Intraphase_Defective_Tasks_Coordinated_with_Downstream - Sucessful__Rework_Rate -

Uncessesful__Rework_Rate) * dt

INIT Discovered_Unsuccessfully_Processed_Tasks = 0

INFLOWS:

Intraphase_Unsuccessfully_processed_Task_Discovery_Rate =
 UnSuccessfully_processed_Task_Discovery_Rate-Upstream_Defective_Task_Discovery_Rate
 Intraphase_Defective_Tasks_Coordinated_with_Downstream =
 Area_Engineering.Coordinated_Tasks_to_be_Sent_to_Upstream

OUTFLOWS:

Successful__Rework_Rate =
 Rework_Rate*Probability_of_Tasks_to_be_Successfully_Reworked
 Unsuccessful__Rework_Rate = Rework_Rate-Successful__Rework_Rate
 Exhaustion_Due_to_Overtime_Work(t) = Exhaustion_Due_to_Overtime_Work(t - dt) +
 (Rate_of_Increase_in_Exhaustion_Level - Rate_of_Depletion_in_Exhaustion_Level) * dt
 INIT Exhaustion_Due_to_Overtime_Work = 0 {exhaustion}

INFLOWS:

Rate_of_Increase_in_Exhaustion_Level =
 GRAPH(Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF/Normal_Work_Ho
 urs_per_Day)
 (1.00, 0.00), (1.03, 0.2), (1.07, 0.4), (1.10, 0.6), (1.13, 0.8), (1.17, 1.00), (1.20, 1.20), (1.23,
 1.40), (1.27, 1.60)

OUTFLOWS:

Rate_of_Depletion_in_Exhaustion_Level = IF
 (Perceived_Rate_of_Increase_in_Exhaustion_Level<=
 0.01)THEN(Exhaustion_Due_to_Overtime_Work/Exhaustion_Depletion_Time)ELSE(0)
 Experienced_Employees(t) = Experienced_Employees(t - dt) +
 (Assimilation_Rate_of_New_Employees +
 Assimilation_Rate_of__Transferred_in_Company_Employees -
 Experienced_Employees_Quit_Rate - Experienced_Employees_Demobilization_Rate) * dt
 INIT Experienced_Employees = Initial_Total_Labor_Force*0.8

INFLOWS:

Assimilation_Rate_of_New_Employees =
 New_Employees/Avg_Assimilation_Time_of_New_Employees

Assimilation_Rate_of__Transferred_in_Company_Employees =
 Transferred_in_Company_Employees/Avg_Assimilation_Time_of_Transferred_in_Company
 _Employees

OUTFLOWS:

Experienced_Employees_Quit_Rate = Experienced_Employees*Quit_Fraction

Experienced_Employees_Demobilization_Rate = MIN(Experienced_Employees/DT,
 (Demobilization_Rate-

(New_Hire_in_Demobilization_Rate+Experienced_Hire_in_Demobilization_Rate+Transferred_in_Company_Employees_Demobilization_Rate+New_Employees_Demobilization_Rate))
)

Experienced_Employees_1(t) = Experienced_Employees_1(t - dt)

INIT Experienced_Employees_1 = Initial_Total_Labor_Force*0.8

Experienced_Employees_2(t) = Experienced_Employees_2(t - dt)

INIT Experienced_Employees_2 = Initial_Total_Labor_Force*0.8

Experienced_Employees_Costs_to_Date(t) = Experienced_Employees_Costs_to_Date(t - dt)
 + (Regular_Daily_Salary_of_Experienced_Employees) * dt

INIT Experienced_Employees_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_Experienced_Employees =

IF(Fraction_of_Released_Tasks<0.9999)THEN(Experienced_Employees *
 Experienced_Employee_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff *
 Normal_Work_Hours_per_Day)ELSE(0)

Experienced_Hired_in_Externally_Costs_to_Date(t) =

Experienced_Hired_in_Externally_Costs_to_Date(t - dt) +
 (Regular_Daily_Salary_of_Experienced_Hired_in_Externally) * dt

INIT Experienced_Hired_in_Externally_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_Experienced_Hired_in_Externally =

IF(Fraction_of_Released_Tasks<0.9999)THEN(Experienced_Hired_in_Externally *
 Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate *
 Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day)ELSE(0)

New_Employees(t) = New_Employees(t - dt) + (Hiring_Rate_of__New_Employees - Assimilation_Rate_of_New_Employees - New_Employees_Demobilization_Rate) * dt

INIT New_Employees = 0

INFLOWS:

Hiring_Rate_of__New_Employees = MAX(0,

Desired_No_New_Employees_to_be_Hired/Avg_Hiring_Time_of_New_Employees)

OUTFLOWS:

Assimilation_Rate_of_New_Employees =

New_Employees/Avg_Assimilation_Time_of_New_Employees

New_Employees_Demobilization_Rate = MIN(New_Employees/DT, (Demobilization_Rate - (New_Hire_in_Demobilization_Rate + Experienced_Hire_in_Demobilization_Rate + Transferred_in_Company_Employees_Demobilization_Rate)))

New_Employees_Costs_to_Date(t) = New_Employees_Costs_to_Date(t - dt) + (Regular_Daily_Salary_of_New_Employees) * dt

INIT New_Employees_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_New_Employees =

IF(Fraction_of_Released_Tasks < 0.9999) THEN (New_Employees * Normal_Work_Hours_per_Day * New_Employees_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff) ELSE (0)

New_Hired_in_Externally(t) = New_Hired_in_Externally(t - dt)

INIT New_Hired_in_Externally = 0

New_Hired_in_Externally_Costs_to_Date(t) = New_Hired_in_Externally_Costs_to_Date(t - dt) + (Regular_Daily_Salary_of_New_Hired_in_Externally) * dt

INIT New_Hired_in_Externally_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_New_Hired_in_Externally =

IF(Fraction_of_Released_Tasks < 0.9999) THEN (New_Hired_in_Externally * New_Hired_in_Externally_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day) ELSE (0)

$New_Hire_in(t) = New_Hire_in(t - dt) + (Hiring_Rate_of_New_Hire_in -$
 $Assimilation_Rate_of_New_Hire_in - New_Hire_in_Demobilization_Rate) * dt$

INIT $New_Hire_in = 0$

INFLOWS:

$Hiring_Rate_of_New_Hire_in = MAX(0,$

$Desired_No_New_Consultants_to_be_Hired/Avg_Hiring_Time_of_New_Hire_in)$

OUTFLOWS:

$Assimilation_Rate_of_New_Hire_in =$

$New_Hire_in/Avg_Assimilation_Time_of_NewHire_in$

$New_Hire_in_Demobilization_Rate = MIN(Demobilization_Rate, New_Hire_in/DT)$

$Overtime_Costs_to_Date(t) = Overtime_Costs_to_Date(t - dt) + (Total_Daily_Overtime_Pay)$
 $* dt$

INIT $Overtime_Costs_to_Date = 0$

INFLOWS:

$Total_Daily_Overtime_Pay =$

$IF(Fraction_of_Released_Tasks < 0.9999) THEN (Avg_Hourly_Overtime_Pay_Rate * Total_Overtime_Hrs_Worked_Per_Day) ELSE (0)$

$Perceived_Quality_Assurance_Productivity(t) = Perceived_Quality_Assurance_Productivity(t - dt) + (Change_in_Perceived_Quality_Assurance_Productivity) * dt$

INIT $Perceived_Quality_Assurance_Productivity = Ref_Quality_Assurance_Productivity$

INFLOWS:

$Change_in_Perceived_Quality_Assurance_Productivity =$

$MAX(((Reported_Quality_Assurance_Productivity - Perceived_Quality_Assurance_Productivity)/Time_to_adjust_Perceived_Quality_Assurance_Productivity), Perceived_Minimum_Quality_Assurance_Productivity - Perceived_Quality_Assurance_Productivity)$

$Perceived_Regular_Processing_Productivity(t) =$

$Perceived_Regular_Processing_Productivity(t - dt) + (Change_in_Perceived_Regular_Processing_Productivity) * dt$

INIT $Perceived_Regular_Processing_Productivity = Ref_Regular_Processing_Productivity$

INFLOWS:

Change_in_Perceived_Regular_Processing_Productivity =
 MAX(((Reported_Regular_Processing_Productivity-
 Perceived_Regular_Processing_Productivity)/Time_to_adjust_Perceived_Regular_Processing
 _Productivity),Perceived_Minimum_Regular_Processing_Productivity-
 Perceived_Regular_Processing_Productivity)

Perceived_Rework_Productivity(t) = Perceived_Rework_Productivity(t - dt) +
 (Change_in_Perceived_Rework_Productivity) * dt

INIT Perceived_Rework_Productivity = Ref_Rework_Productivity

INFLOWS:

Change_in_Perceived_Rework_Productivity = MAX(((Reported_Rework_Productivity-
 Perceived_Rework_Productivity)/Time_to_adjust_Perceived_Rework_Productivity),Perceive
 d_Minimum_Rework_Productivity-Perceived_Rework_Productivity)

Project_Deadline_for_the_Phase(t) = Project_Deadline_for_the_Phase(t - dt) +
 (Change_in_Project_Deadline) * dt

INIT Project_Deadline_for_the_Phase = initial_Project_Deadline_for_the_Phase

INFLOWS:

Change_in_Project_Deadline = MIN((Maximum_Tolerable_Project_Completion_Date-
 Project_Deadline_for_the_Phase)/Project_Deadline_Adjustment_Time,

(Indicated_Completion_Date_for_the_Phase-

Project_Deadline_for_the_Phase)/Project_Deadline_Adjustment_Time)

Reported_Quality_Assurance_Productivity(t) = Reported_Quality_Assurance_Productivity(t -
 dt) + (Change_in_Reported_Quality_Assurance_Productivity) * dt

INIT Reported_Quality_Assurance_Productivity = Ref_Quality_Assurance_Productivity

INFLOWS:

Change_in_Reported_Quality_Assurance_Productivity =

(Current_Quality_Assurance_Productivity-

Reported_Quality_Assurance_Productivity)/Quality_Assurance_Productivity_Report_Time

Reported_Regular_Processing_Productivity(t) =

Reported_Regular_Processing_Productivity(t - dt) +

(Change_in_Reported_Regular_Processing_Productivity) * dt

INIT Reported_Regular_Processing_Productivity = Ref_Regular_Processing_Productivity

INFLOWS:

Change_in_Reported_Regular_Processing_Productivity =
 (Current_Regular_Processing_Productivity -
 Reported_Regular_Processing_Productivity)/Regular_Processing_Productivity_Report_Time
 Reported_Rework_Productivity(t) = Reported_Rework_Productivity(t - dt) +
 (Change_in_Reported_Rework_Productivity) * dt

INIT Reported_Rework_Productivity = Ref_Rework_Productivity

INFLOWS:

Change_in_Reported_Rework_Productivity = (Current_Rework_Productivity -
 Reported_Rework_Productivity)/Rework_Productivity_Report_Time
 Successfully_Processed_Tasks_Approved_to_be_Released(t) =
 Successfully_Processed_Tasks_Approved_to_be_Released(t - dt) +
 (Approval_Rate_of_Successfully_Processed_Tasks -
 Successfully_Processed_Tasks_Release_Rate) * dt

INIT Successfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Approval_Rate_of_Successfully_Processed_Tasks = Quality_Assurance_Rate_2

OUTFLOWS:

Successfully_Processed_Tasks_Release_Rate =
 Successfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks
 Successfully_Processed_Tasks_Released(t) = Successfully_Processed_Tasks_Released(t - dt)
 + (Successfully_Processed_Tasks_Release_Rate) * dt

INIT Successfully_Processed_Tasks_Released = 0

INFLOWS:

Successfully_Processed_Tasks_Release_Rate =
 Successfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks
 Successfully__Processed_Tasks(t) = Successfully__Processed_Tasks(t - dt) +
 (Successful_Processing_Rate + Successful__Rework_Rate -
 Approval_Rate_of_Successfully_Processed_Tasks) * dt

INIT Successfully__Processed_Tasks = 0

INFLOWS:

Successful_Processing_Rate = Regular__Processing_Rate*(1-
 Fraction_of_Inherited_Unsuccessfully_Processed_Tasks)*(1-
 Probability_to_be_Defective_Task)

Successful__Rework_Rate =
 Rework_Rate*Probability_of_Tasks_to_be_Successfully_Reworked

OUTFLOWS:

Approval_Rate_of_Successfully_Processed_Tasks = Quality_Assurance_Rate_2
 Tasks_Identified__to_be_Processed(t) = Tasks_Identified__to_be_Processed(t - dt) +
 (Return_Rate_of_Coord_Tasks_Sent_to_Upstream + Rate_of_Change_in_Scope -
 Successful_Processing_Rate - Unsuccessful__Processing_Rate) * dt

INIT Tasks_Identified__to_be_Processed = 2651

INFLOWS:

Return_Rate_of_Coord_Tasks_Sent_to_Upstream =
 Upstream_Defective_Task_Discovery_Rate
 Rate_of_Change_in_Scope = Scope_Change

OUTFLOWS:

Successful_Processing_Rate = Regular__Processing_Rate*(1-
 Fraction_of_Inherited_Unsuccessfully_Processed_Tasks)*(1-
 Probability_to_be_Defective_Task)
 Unsuccessful__Processing_Rate = Regular__Processing_Rate-Successful_Processing_Rate
 Time_from_Last_Exhaustion_Break(t) = Time_from_Last_Exhaustion_Break(t - dt) +
 (Overtime_Work_Break_Setter) * dt

INIT Time_from_Last_Exhaustion_Break = -1 {Unitless}

INFLOWS:

Overtime_Work_Break_Setter = (MAX(Time_from_Last_Exhaustion_Break,
 Overtime_Work_Break_Indicator)-Time_from_Last_Exhaustion_Break)/DT
 Time_To_Recover(t) = Time_To_Recover(t - dt) + (Change_in_Time_To_Recover) * dt

INIT Time_To_Recover = 0 {Unitless}

INFLOWS:


```

Change_in_Time_To_Recover = IF
(Exhaustion_Due_to_Overtime_Work/Maximum_Tolerable_Exhaustion_Level>=0.1)
THEN(1)ELSE(-Time_To_Recover/DT) {Unitless/day}
Transferred_in_Company_Employees(t) = Transferred_in_Company_Employees(t - dt) +
(Rate_of_Mobilization_of_Company_Employees -
Assimilation_Rate_of__Transferred_in_Company_Employees -
Transferred_in_Company_Employees_Demobilization_Rate) * dt
INIT Transferred_in_Company_Employees = 0
INFLOWS:
Rate_of_Mobilization_of_Company_Employees = MAX(0, (Labor__Force_Gap-
Desired_No_New_Consultants_to_be_Hired-
Desired_No_New_Employees_to_be_Hired)/Mobilization_Delay)
OUTFLOWS:
Assimilation_Rate_of__Transferred_in_Company_Employees =
Transferred_in_Company_Employees/Avg_Assimilation_Time_of_Transferred_in_Company
_Employees
Transferred_in_Company_Employees_Demobilization_Rate =
MIN(Transferred_in_Company_Employees/DT, (Demobilization_Rate-
(New_Hire_in_Demobilization_Rate+Experienced_Hire_in_Demobilizationt_Rate)))
Transferred_in_Company_Employees_1(t) = Transferred_in_Company_Employees_1(t - dt)
INIT Transferred_in_Company_Employees_1 = 0
Transferred_in_Company_Employees_Costs_to_Date(t) =
Transferred_in_Company_Employees_Costs_to_Date(t - dt) +
(Regular_Daily_Salary_of_Transferred_in_Company_Employees) * dt
INIT Transferred_in_Company_Employees_Costs_to_Date = 0
INFLOWS:
Regular_Daily_Salary_of_Transferred_in_Company_Employees =
IF(Fraction_of_Released_Tasks<0.9999)THEN(Transferred_in_Company_Employees *
Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate *
Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day)ELSE(0)

```

Undiscoverd__Unsuccessfully__Processed_Tasks(t) =

Undiscoverd__Unsuccessfully__Processed_Tasks(t - dt) + (Unsuccessful__Processing_Rate +
Uncessesful__Rework_Rate - Intraphase_Unccessfully_processed_Task_Discovery_Rate -
Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks -
Upstream_Defective_Task_Discovery_Rate) * dt

INIT Undiscoverd__Unsuccessfully__Processed_Tasks = 0

INFLOWS:

Unsuccessful__Processing_Rate = Regular__Processing_Rate-Successful__Processing_Rate

Uncessesful__Rework_Rate = Rework_Rate-Sucessful__Rework_Rate

OUTFLOWS:

Intraphase_Unccessfully_processed_Task_Discovery_Rate =

UnSuccessfully_processed_Task_Dicoverry_Rate-Upstream_Defective_Task_Discovery_Rate

Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks =

Quality__Assurance_Rate_1-UnSuccessfully_processed_Task_Dicoverry_Rate

Upstream_Defective_Task_Discovery_Rate =

Fraction_of_Inherited_Unsuccessfully_Processed_Tasks*UnSuccessfully_processed_Task_D
icoverry_Rate

Unsuccessfully_Processed_Tasks_Approved_to_be_Released(t) =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +

(Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks -

Unsuccessfully_Processed_Tasks_Release_Rate) * dt

INIT Unsuccessfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks =

Quality__Assurance_Rate_1-UnSuccessfully_processed_Task_Dicoverry_Rate

OUTFLOWS:

Unsuccessfully_Processed_Tasks_Release_Rate =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

Unsuccessfully_Processed_Tasks_Released(t) = Unsuccessfully_Processed_Tasks_Released(t
- dt) + (Unsuccessfully_Processed_Tasks_Release_Rate -

Intraphase_Defective_Tasks_Coordinated_with_Downstream) * dt

INIT Unsuccessfully_Processed_Tasks_Released = 0

INFLOWS:

Unsuccessfully_Processed_Tasks_Release_Rate =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

OUTFLOWS:

Intraphase_Defective_Tasks_Coordinated_with_Downstream =

Area_Engineering.Coordinated_Tasks_to_be_Sent_to_Upstream

Actual_Labor_Force_Required =

Perceived_Present_Condition_PPC+Perceived_Present_Condition_PPC*Output*Time_to_Perceive_Trend_TPT

Actual_Productivity = Total_Released_Tasks/(Cumulative_Man_Days_Expended+1)

Average_Nominal_Potential_Productivity =

Fraction_of_Experienced_Employees*Reference_Potential_Productivity_of_Experienced_Employees+

Fraction_of_New_Employees*Reference_Potential_Productivity_of_New_Employees+

Reference_Potential_Productivity_of_Experienced_Hire_in*Fraction_of_Experienced_Hire_in+

Reference_Potential_Productivity_of__New_Hire_in*Fraction_of_New_Hire_in+Reference_Potential_Productivity_of_Transferred_in_Company_Employees*Fraction_of_Transferred_in_Company_Employees

Avg_Assimilation_&_Hiring_Time_of_New_Employees =

Avg_Hiring_Time_of_New_Employees+Avg_Assimilation_Time_of_New_Employees

Avg_Assimilation_&_Hiring_Time_of_New_Hire_in =

Avg_Hiring_Time_of_New_Hire_in+Avg_Assimilation_Time_of_NewHire_in

Avg_Assimilation_Time_of_NewHire_in = 20

Avg_Hiring_Time_of_New_Hire_in+Avg_Assimilation_Time_of_NewHire_in

Avg_Assimilation_Time_of_NewHire_in = 20

Avg_Assimilation_Time_of_New_Employees = 60

Avg_Assimilation_Time_of_Transferred_in_Company_Employees = 20

Avg_Daily_Labor_Force_Per_Staff = 1 {Unit- Unitless=days/days}

Avg_Employment_Duration_of_Hire_In_Externally = 220

Avg_Hiring_Time_of_New_Employees = 40

Avg_Hiring_Time_of_New_Hire_in = 14

Avg_Hourly_Overtime_Pay_Rate = 1000

Budget_Status = -0.5

Ceiling_on_New_Labor_Force =

Full_Time_Equivalent_of_Experienced_Labor_Force*Max_NewHires_Per_Full_Time_Experienced_Labor_Force

Ceiling_on_Total_Labor_Force = Ceiling_on_New_Labor_Force+Experienced_Labor_Force

Converter_12 = GRAPH(TIME)

(0.00, 10.0), (19.0, 12.0), (37.0, 14.0), (56.0, 7.00), (75.0, 8.00), (94.0, 14.0), (112, 13.0), (131, 9.00), (150, 13.0), (169, 10.0), (187, 11.0), (206, 9.00), (225, 10.0), (244, 12.0), (262, 10.0), (281, 8.00), (300, 9.00), (319, 5.00), (337, 4.00), (356, 6.00), (375, 4.00), (394, 3.00), (412, 6.00), (431, 2.00), (450, 2.00), (469, 3.00), (487, 2.00), (506, 1.00), (525, 1.00), (543, 1.00), (562, 2.00), (581, 2.00), (600, 2.00), (618, 1.00)

Converter_4 = Cumulative_Man_Days_Expended_for_Development_Activities*7.5

Coordinated_Tasks_to_be_Sent_to_Upstream =

Upstream_Defective_Task_Discovery_Rate*Upstream_Phase_Scope/Current_Scope

Cost_Effect_on_Regular_Processing_Importance = GRAPH(Budget_Status)

(-1.00, 1.87), (-0.9, 1.58), (-0.8, 1.35), (-0.7, 1.17), (-0.6, 1.06), (-0.5, 1.00), (-0.4, 0.98), (-0.3, 0.95), (-0.2, 0.89), (-0.1, 0.81), (0.00, 0.65)

Cumulative_ManHours_Expended = Cumulative_Man_Days_Expended*7.5

Cumulative_Manhours_Expended_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 987), (37.0, 2637), (56.0, 4598), (75.0, 5628), (94.0, 6796), (112, 8782), (131, 10545), (150, 11827), (169, 13712), (187, 15073), (206, 16608), (225, 17932), (244, 19344), (262, 21058), (281, 22399), (300, 23543), (319, 24750), (337, 25459), (356, 26088), (375, 26887), (394, 27512), (412, 27880), (431, 28665), (450, 28967), (469, 29287), (487, 29716), (506, 29949), (525, 30055), (543, 30200), (562, 30403), (581, 30688), (600, 30959), (618, 31199), (637, 31349)

Current_Quality = 1-

(Discovered_Unsuccessfully_Processed_Tasks/(Total_Released_Tasks+Successfully_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks_Approved_to_be_Released+Undiscovered__Unsuccessfully__Processed_Tasks+Successfully__Processed_Tasks+0.000001))

Current_Quality_Assurance_Productivity =

$(\text{Quality_Assurance_Rate_1} + \text{Quality_Assurance_Rate_2}) / (\text{Daily_Labor_Force_to_Quality_Assurance} + 0.00001)$

Current_Regular_Processing_Productivity =

$\text{Regular_Processing_Rate} / (\text{Daily_Labor_Force_to_Regular_Processing} + 0.00001)$

Current_Rework_Productivity = $\text{Rework_Rate} / (\text{Daily_Labor_Force_to_Rework} + 0.00001)$

Current_Scope = Scope_of_work

Daily_Labor_Force_to_Quality_Assurance =

$\text{Daily_Labor_Force_for_Development_Activities} * \text{Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog} + 0 * \text{Labor_Force_Fraction_to_Quality_Assurance}$

Daily_Labor_Force_to_Regular_Processing =

$\text{Daily_Labor_Force_for_Development_Activities} * \text{Labor_Force_Fraction_to_Regular_Processing_due_to_backlog} + 0 * \text{Labor_Force_Fraction_to_Regular_Processing}$ {People-day/day=People*(day/day)}

Daily_Labor_Force_to_Rework =

$\text{Daily_Labor_Force_for_Development_Activities} * \text{Labor_Force_Fraction_to_Rework_due_to_backlog} + 0 * \text{Labor_Force_Fraction_to_Rework}$

Daily_QA_Labor_Force_for_Unsuccessfully_Processed_Tasks =

$\text{Daily_Labor_Force_to_Quality_Assurance} * (\text{Undiscovered_Unsuccessfully_Processed_Tasks} / \text{Total_Tasks_to_QA})$

Daily_QA_Labor_force_to_Successfully_Processed_Tasks =

$\text{Daily_Labor_Force_to_Quality_Assurance} * (\text{Successfully_Processed_Tasks} / \text{Total_Tasks_to_QA})$

Deadline_for_the_Remaining_30%_Phase_Scope =

$0.7 * \text{Initial_Project_Deadline_for_the_Phase}$

Demobilization_Delay = 10

Demobilization_Rate = $\text{MAX}(0, -\text{Labor_Force_Gap} / \text{Demobilization_Delay})$

Desired_Labor_Force_for_Quality_Assurance =

$(\text{Quality_Assurance_Processing_Limit_from_Task_Availability_1} + \text{Quality_Assurance_Processing_Limit_from_Task_Availability_2}) / (\text{Perceived_Quality_Assurance_Productivity} + 0.1)$

$\text{Desired_Labor_Force_for_Regular_Processing} =$
 $\text{Regular_Processing_Limit_from_Task_Availability}/(\text{Perceived_Regular_Processing_Productivity}+0.1)$
 $\text{Desired_Labor_Force_for_Rework} =$
 $\text{Rework_Processing_Limit_from_Task_Availability}/(\text{Perceived_Rework_Productivity}+0.1)$
 $\text{Desired_No_New_Consultants_to_be_Hired} =$
 $\text{MIN}(\text{Max_No_New_Hire_inthat_could_be_Hired}, \text{Labor_Force_Gap} * \text{New_Hire_in_Hiring_Fraction})$
 $\text{Desired_No_New_Employees_to_be_Hired} =$
 $\text{Labor_Force_Gap} * \text{New_Employees_Hiring_Fraction}$
 $\text{Desired_Productivity} = \text{Remaining_Tasks}/(\text{Total_Available_Man_Days}+0.00001)$
 $\text{Desire_for_LF_Stability_Effect_on_WCLF} = \text{GRAPH}((\text{Project_Deadline_for_the_Phase-Time}) /$
 $(\text{Avg_Assimilation_Time_of_Transferred_in_Company_Employees}+\text{Mobilization_Delay}))$
 $(0.00, 0.00), (0.3, 0.00), (0.6, 0.1), (0.9, 0.4), (1.20, 0.85), (1.50, 1.00), (1.80, 1.00), (2.10,$
 $1.00), (2.40, 1.00), (2.70, 1.00), (3.00, 1.00)$
 $\text{Desire_for_Schedule_Stability_Effect_on_WCLF} =$
 $\text{GRAPH}(\text{Project_Deadline_for_the_Phase}/(\text{Maximum_Tolerable_Project_Completion_Date}))$
 $(0.86, 0.00), (0.88, 0.1), (0.9, 0.2), (0.92, 0.35), (0.94, 0.6), (0.96, 0.7), (0.98, 0.77), (1.00,$
 $0.89), (1.05, 1.00)$
 $\text{Dummy_Variable} = 1$ {Invalid number only used to allow the model run}
 $\text{Effect_of_Experience_on_QoP} = \text{GRAPH}(\text{Fraction_of_Experienced_Labor_Force})$
 $(0.00, 0.5), (0.2, 0.6), (0.4, 0.7), (0.6, 0.8), (0.8, 0.9), (1.00, 1.00)$
 $\text{Effect_of_Fatigue_on_QoP} = \text{GRAPH}(\text{Exhaustion_Due_to_Overtime_Work})$
 $(0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9), (20.0, 0.89)$
 $\text{Effect_of_Schedule_Pressure_on_QoP} = \text{GRAPH}(\text{Schedule_Pressure})$
 $(0.00, 1.00), (0.5, 0.99), (1.00, 0.97), (1.50, 0.94), (2.00, 0.9), (2.50, 0.85), (3.00, 0.79), (3.50,$
 $0.72), (4.00, 0.64), (4.50, 0.55), (5.00, 0.45)$
 $\text{Effect_of_Schedule_Pressure_on_Regular_Processing_Importance} = 1$ {Invalid number only
 used to allow the model run}
 $\text{Exhaustion_Depletion_Time} = 10$ {Days}

Exhaustion_Level_Effect_on_Overtime_Duration =

GRAPH(Exhaustion_Due_to_Overtime_Work/Maximum_Tolerable_Exhaustion_Level
{Unitless =exhaustion/exhaustion})

(0.00, 1.00), (0.1, 0.9), (0.2, 0.8), (0.3, 0.7), (0.4, 0.6), (0.5, 0.5), (0.6, 0.4), (0.7, 0.3), (0.8,
0.2), (0.9, 0.1), (1.00, 0.00)

Expected_Average_Productivity = Planned_Productivity*Weight_to_Planned_Productivity +
(1-Weight_to_Planned_Productivity)*Actual_Productivity

Experienced_Employee_Avg_Hourly_Pay_Rate = 650

Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate = 800

Experienced_Labor_Force = Experienced_Employees+Experienced_Hired_in_Externally

External_Precedence_from_Down_stream =

GRAPH(Fraction_of_Released_Tasks_from_Downstream)

(0.15, 0.475), (0.7, 1.00)

External_Precedence_from_Up_stream =

GRAPH(System_Engineering.Fraction_of_Released_Tasks)

(0.2, 0.254), (0.376, 0.457), (0.573, 0.628), (0.658, 0.753), (0.796, 0.846), (0.868, 0.904),
(0.91, 0.94), (0.953, 0.972), (0.986, 0.994), (1.00, 1.00)

External_Precedence_Relation = MIN(External_Precedence_from_Down_stream,
External_Precedence_from_Up_stream)

Fatigue_Effect_on_Labor_Force_Productivity =

GRAPH(Exhaustion_Due_to_Overtime_Work)

(0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9), (20.0, 0.89)

Fraction_of_Completed_Tasks_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 0.054), (37.0, 0.144), (56.0, 0.253), (75.0, 0.312), (94.0, 0.368), (112,
0.436), (131, 0.519), (150, 0.592), (169, 0.655), (187, 0.613), (206, 0.664), (225, 0.695), (244,
0.726), (262, 0.78), (281, 0.793), (300, 0.829), (319, 0.868), (337, 0.844), (356, 0.868), (375,
0.886), (394, 0.899), (412, 0.907), (431, 0.919), (450, 0.946), (469, 0.921), (487, 0.932), (506,
0.943), (525, 0.95), (543, 0.957), (562, 0.955), (581, 0.963), (600, 0.973), (618, 0.98), (637,
0.987)

$$\text{Fraction_of_Defective_Tasks_Discoverd_by_Downstream} = \frac{\text{Defective_Tasks_Discoverd_by_Downstream}}{(\text{Discovered_Unsuccessfully_Processed_Tasks} + 0.00001)}$$

$$\text{Fraction_of_Experienced_Employees} = \frac{\text{Experienced_Employees}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_Experienced_Hire_in} = \frac{\text{Experienced_Hired_in_Externally}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_Experienced_Labor_Force} = \frac{\text{Experienced_Labor_Force}}{(\text{Total_Labor_Force} + 0.00000001)}$$

$$\text{Fraction_of_Inherited_Unsuccessfully_Processed_Tasks} = \text{System_Engineering.Fraction_of_Unsuccessfully_Processed_Tasks_Released}$$

$$\text{Fraction_of_New_Employees} = \frac{\text{New_Employees}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_New_Hire_in} = \frac{\text{New_Hire_in}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_Released_Tasks} = \frac{\text{Total_Released_Tasks}}{\text{Current_Scope}}$$

$$\text{Fraction_of_Tasks_Perceived_Completed} = \frac{\text{Tasks_Perceived_Completed}}{\text{Current_Scope}}$$

$$\text{Fraction_of_Transferred_in_Company_Employees} = \frac{\text{Transferred_in_Company_Employees}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_Unsuccessfully_Processed_Tasks_Released} = \frac{\text{Unsuccessfully_Processed_Tasks_Released}}{(\text{Total_Released_Tasks} + 0.000001)}$$

$$\text{Full_Time_Equivalent_Labor_Force} = \text{Avg_Daily_Labor_Force_Per_Staff} * \text{Total_Labor_Force} \quad \{\text{People} = \text{People} * (\text{Days} / \text{Days})\}$$

$$\text{Full_Time_Equivalent_of_Experienced_Labor_Force} = \text{Experienced_Labor_Force} * \text{Avg_Daily_Labor_Force_Per_Staff}$$

$$\text{Hours_to_ManDays_Convertor} = 1 / 7.5 \quad \{\text{People-Day/Hour}\}$$

$$\text{Indicated_Completion_date_for_70\%_of_Phase_Scope} = \text{IF} (\text{Remaining_Tasks} - \text{Thirty_ \%_of_Phase_Scope} > 0) \text{ THEN} (\text{TIME} + \text{Percieved_Project_Completion_Time_Still_Required}) \text{ ELSE} (0)$$

$$\text{Indicated_Completion_Date_for_the_Phase} = \text{TIME} + \text{Percieved_Project_Completion_Time_Still_Required} \quad \{\text{Days} = \text{Days} + \text{Days}\}$$

$$\text{Indicated_Labor_Force} = (\text{IF} (\text{TIME} > 265 \text{ and } \text{TIME} < 350) \text{ THEN} (5 * (\text{Total_Man_Days_Perceived_Still_Needed} / (\text{Time_Remaining_to_Deadline} + 1))) / \text{Av}$$

g_Daily_Labor_Force_Per_Staff)

ELSE((Total_Man_Days_Perceived_Still_Needed/Time_Remaining_to_Deadline)/Avg_Daily_Labor_Force_Per_Staff))*0+(

Total_Man_Days_Perceived_Still_Needed/(Time_Remaining_to_Deadline)/Avg_Daily_Labor_Force_Per_Staff)

Indicated_Trend_ITREND = ((Perceived_Present_Condition_PPC-Reference_Condition_RC)/(1+Reference_Condition_RC))/Time_Horizon_for_Reference_Condition_THRC

Initial_internal_Deadline = 187

initial_Project_Deadline_for_the_Phase = 712

Initial_Total_Labor_Force = 18

Input = Labor_Force_Sought

Internal_Deadline_Adjustment_Time = 5

Internal_Precedence_Relation = GRAPH(Fraction_of_Tasks_Perceived_Completed)
(0.00, 0.042), (0.1, 0.241), (0.2, 0.457), (0.3, 0.628), (0.4, 0.753), (0.5, 0.846), (0.6, 0.904),
(0.7, 0.94), (0.8, 0.972), (0.9, 0.994), (1.00, 1.00)

Inverse_of_SP_Tolerance_time = GRAPH(Schedule_Pressure)
(1.00, 0.00), (1.10, 0.03), (1.15, 0.04), (1.20, 0.16), (1.30, 1.00)

Inverse_of_SP_Tolerance_Time_1 = GRAPH(Schedule_Pressure)
(1.00, 0.00), (1.10, 0.0055), (1.15, 0.0083), (1.20, 0.03), (1.30, 0.2)

Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog =
Desired_Labor_Force_for_Quality_Assurance/(Total_Desired_Labor_Force_for_Engineering_Activities+0.00001)

Labor_Force_Fraction_to_Regular_Processing_due_to_backlog =
Desired_Labor_Force_for_Regular_Processing/(Total_Desired_Labor_Force_for_Engineering_Activities+0.00001)

Labor_Force_Fraction_to_Rework_due_to_backlog =
Desired_Labor_Force_for_Rework/(Total_Desired_Labor_Force_for_Engineering_Activities+0.00001)

Labor_Force_Needed =

$\text{MIN}((\text{Willingness_to_Change_Labor_Force_Level} * \text{Indicated_Labor_Force} + (1 - \text{Willingness_to_Change_Labor_Force_Level}) * \text{Total_Labor_Force}), \text{Indicated_Labor_Force})$

Labor_Force_Productivity =

$\text{Potential_Productivity} * \text{Total_Effect_on_Labor_Force_Productivity}$ {Tasks/People-day}

Labor_Force_Sought = $\text{MIN}(\text{Labor_Force_Needed}, \text{Ceiling_on_Total_Labor_Force})$

Labor_Fraction_to_Quality_Assurance =

$\text{Pressure_for_Quality_Assurance} / \text{Total_Pressure_for_Activities} * 0 + 0.1$ {This number is used to help the model run}

Labor_Fraction_to_Regular_Processing =

$\text{Pressure_for_Regular_Processing} / \text{Total_Pressure_for_Activities} * 0 + 0.7$ {This number is used to help the model run}

Labor_Fraction_to_Rework = $\text{Pressure_for_Rework} / \text{Total_Pressure_for_Activities} * 0 + 0.1$
{This number is used to help the model run}

Labor_Size_Effect_on_Productivity = 1 {Invalid number only used to allow the model run}

Labor_Force_Gap = $\text{Labor_Force_Sought} * 0 + \text{Actual_Labor_Force_Required} - \text{Total_Labor_Force}$

Learning_Effect_on_Potential_Productivity =

$\text{GRAPH}(\text{Percent_of_Tasks_Actually_Completed})$

(0.00, 1.00), (0.1, 1.01), (0.2, 1.03), (0.3, 1.05), (0.4, 1.10), (0.5, 1.15), (0.6, 1.22), (0.7, 1.26), (0.8, 1.29), (0.9, 1.30), (1.00, 1.30)

Managerial_Effect_on_Productivity = 1 {Invalid number only used to allow the model run}

ManDay_Equivalence_of_Overtime_Hrs_worked_per_Day =

$\text{Total_Overtime_Hrs_Worked_Per_Day} * \text{Hours_to_ManDays_Convertor}$ {People-Day/Day}

Maximum_Allowed_Overtime_Hours_Per_Day_per_Employee = 2 {hours/People-Days}

Maximum_Internal_Deadline_Extention = 40

Maximum_Overtime_Hours_that_Can_be_worked =

$\text{Overtime_Duration_Threshold} * \text{Full_Time_Equivalent_Labor_Force} * \text{Maximum_Allowed_Overtime_Hours_Per_Day_per_Employee} * \text{Willingness_To_Work_Overtime}$
{hours=Days*People*(hours/People-Days)*Unitless}

Maximum_Tolerable_Exhaustion_Level = 20 {exhaustion}

Maximum_Tolerable_Internal_Deadline =
 Initial_internal_Deadline+Maximum_Internal_Deadline_Extention
 Maximum_Tolerable_Project_Completion_Date =
 initial_Project_Deadline_for_the_Phase+Max_Scheduled_Completion_Extention_Dates
 Max_Hire_in_Fraction_Allowed = 0.3
 Max_NewHires_Per_Full_Time_Experienced_Labor_Force = 1
 Max_No_New_Hire_inthat_could_be_Hired = MAX(0,(Perceived_Layoff_in_Hire_in +
 Max_No__Hire_in_Allowed -Experienced_Hired_in_Externally -New_Hire_in))
 Max_No__Hire_in_Allowed = Total_Labor_Force*Max_Hire_in_Fraction_Allowed
 Max_Scheduled_Completion_Extention_Dates = 0
 Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline = 20
 Minimum_QA_Duration_per_Task = 0.13
 Minimum_Regular_Processing_Duration_per_Task = 1
 Minimum_Rework_Duration_per_Task =
 Minimum_Rework_Duration_per_Task_Discovered_in_the_Phase*(1-
 Fraction_of_Defective_Tasks_Discoverd_by_Downstream)+Minimum_Rework_Duration_pe
 r_Task_Discovered_Outside_the_Phase*Fraction_of_Defective_Tasks_Discoverd_by_Down
 stream
 Minimum_Rework_Duration_per_Task_Discovered_in_the_Phase = 0.133 {0.133 days =
 1hrs/7.5 hrs/day}
 Minimum_Rework_Duration_per_Task_Discovered_Outside_the_Phase = 0.5 {days}
 Mobilization_Delay = 10
 Negative_Schedule_Pressure_Effect_on_Labor_Force_Productivity =
 GRAPH(Avg_Schedule_Pressure)
 (0.7, 1.00), (0.8, 1.00), (0.9, 1.00), (1.00, 1.00), (1.10, 0.98), (1.20, 0.95), (1.30, 0.9), (1.40,
 0.8), (1.50, 0.68), (1.60, 0.55), (1.70, 0.45), (1.80, 0.4)
 New_Employees_Avg_Hourly_Pay_Rate = 400
 New_Employees__Hiring_Fraction =
 GRAPH(Time_to_Project_Deadline/Avg_Assimilation_&_Hiring_Time_of_New_Employee
 s)

(0.00, 0.00), (0.3, 0.00), (0.6, 0.00), (0.9, 0.00), (1.20, 0.01), (1.50, 0.04), (1.80, 0.08), (2.10, 0.15), (2.40, 0.25), (2.70, 0.33), (3.00, 0.33)

New_Hired_in_Externally_Avg_Hourly_Pay_Rate = 500

New_Hire_in_Hiring_Fraction =

GRAPH(Time_to_Project_Deadline/Avg_Assimilation_&_Hiring_Time_of_New_Hire_in)
 (0.00, 0.5), (0.5, 0.5), (1.00, 0.35), (1.50, 0.3), (2.00, 0.25), (2.50, 0.17), (3.00, 0.1), (3.50, 0.03), (4.00, 0.03)

Nominal_Overtime_Duration_Threshold = GRAPH(Time_Remaining_to_Deadline {Days})
 (0.00, 0.00), (5.00, 5.00), (10.0, 10.0), (15.0, 15.0), (20.0, 20.0)

Normal_Work_Hours_per_Day = 7.5 {hours/People-Days}

Normal_Work_Hours_per_Day_1 = 7.5 {hours/People-Days}

Output = Perceived_Trend_TREND

Overtime_Duration_Threshold =

Exhaustion_Level_Effect_on_Overtime_Duration*Nominal_Overtime_Duration_Threshold
 {Days=Days*Unitless}

Overtime_Worked_per_Day_per_FullTime_Equivalent_LF =

Total_Overtime_Hours_that_will_be_Handled/(Full_Time_Equivalent_Labor_Force*Overtime_Duration_Threshold+0.0001)

Overtime_Work_Break_Indicator =

IF(Overtime_Duration_Threshold=0)THEN(TIME+DT)ELSE(0) {days}

Perceived_Layoff_in_Hire_in =

SMTH1((Experienced_Hire_in_Demobilization_Rate+New_Hire_in_Demobilization_Rate),
 10)

Perceived_Minimum_Quality_Assurance_Productivity = 0.1

Perceived_Minimum_Regular_Processing_Productivity = 0.1

Perceived_Minimum_Rework_Productivity = 0.1

Perceived_Net_Shortage_in_Man_Days = Total_Man_Days_Perceived_Still_Needed-

Total_Available_Man_Days {People-Days=(People-Days)-(People-Days)}

Perceived_Rate_of_Increase_in_Exhaustion_Level =

SMTH1(Rate_of_Increase_in_Exhaustion_Level, 1)

Perceived_Shortage_in_Man_Days = Perceived_Net_Shortage_in_Man_Days

Perceived_Shortage_in_Man_Hours =

Perceived_Shortage_in_Man_Days*Normal_Work_Hours_per_Day {hours=(People-Days)*(hours/(People-Days))}

Percent_of_Tasks_Actually_Completed = (Total_Tasks_Actually_Completed/Current_Scope)

Perceived_Man_Days_to_be_Handled_via_Overtime =

Total_Overtime_Hours_that_will_be_Handled/Normal_Work_Hours_per_Day {People-Days= hours/(hours/People-Days)}

Perceived_Project_Completion_Time_Needed = (IF(Remaining_Tasks-

Thirty_%_of_Phase_Scope>0)THEN((Remaining_Tasks-Thirty_%_of_Phase_Scope)/

(Expected_Average_Productivity*Actual_Labor_Force_Required*Avg_Daily_Labor_Force_Per_Staff))ELSE((Remaining_Tasks)/

(Expected_Average_Productivity*Actual_Labor_Force_Required*Avg_Daily_Labor_Force_Per_Staff))

*0+(Remaining_Tasks/(Expected_Average_Productivity*Actual_Labor_Force_Required/Avg_Daily_Labor_Force_Per_Staff))

Perceived_Project_Completion_Time_Still_Required =

Perceived_Project_Completion_Time_Needed-

Perceived_Work_Days_to_be_Recovered_Via_Overtime

Perceived_Work_Days_to_be_Recovered_Via_Overtime =

Perceived_Man_Days_to_be_handled_via_Overtime/(Full_Time_Equivalent_Labor_Force+0.99999) {Days= People-Days/People}

Phase_Scope_Data = GRAPH(TIME)

(0.00, 2651), (19.0, 2651), (37.0, 2651), (56.0, 2651), (75.0, 2651), (94.0, 2651), (112, 2651),

(131, 2651), (150, 2651), (169, 2651), (187, 3106), (206, 3106), (225, 3106), (244, 3106),

(262, 3106), (281, 3118), (300, 3118), (319, 3118), (337, 3279), (356, 3279), (375, 3279),

(394, 3279), (412, 3279), (431, 3279), (450, 3279), (469, 3396), (487, 3396), (506, 3396),

(525, 3396), (543, 3396), (562, 3427), (581, 3427), (600, 3427), (618, 3427), (637, 3427),

(656, 3433), (675, 3433), (693, 3433), (712, 3433)

Planned_Productivity = GRAPH(TIME)

(0.00, 1.08), (19.0, 1.09), (37.0, 1.08), (56.0, 1.10), (75.0, 0.99), (94.0, 0.92), (112, 0.97),

(131, 1.00), (150, 1.01), (169, 1.01)

Positive_Schedule_Pressure_Effect_on_Labor_Force_Productivity =

GRAPH(Schedule_Pressure)

(0.4, 0.8), (0.5, 0.8), (0.6, 0.8), (0.7, 0.82), (0.8, 0.88), (0.9, 0.95), (1.00, 1.00), (1.10, 1.08),
(1.20, 1.15), (1.30, 1.21), (1.40, 1.27), (1.50, 1.30), (1.60, 1.30)

Potential_Productivity =

Learning_Effect_on_Potential_Productivity*Average_Nominal_Potential_Productivity

Pressure_for_Quality_Assurance =

EXP(Required_Labor_Force_for_Quality_Assurance*Quality_Gap_Effect_on_RW&QA_Im
portance*Quality_Assurance_Priority/Dummy_Variable)

Pressure_for_Rework =

EXP(Required_Labor_Force_for_Rework*Rework_Priority*Quality_Gap_Effect_on_RW&
QA_Importance/Dummy_Variable)

Pressure_for_Regular_Processing =

EXP(Required_Labor_for_Regular_Processing*Regular_Processing_Priority*Effect_of_Sche
dule_Pressure_on_Regular_Processing_Importance*Cost_Effect_on_Regular_Processing_Im
portance/Dummy_Variable)

Previous_Scope = HISTORY(Current_Scope, TIME-1)

Probability_of_Tasks_to_be_Sucessfully_Reworked = 1-

Probability_to_be_Defective_Rework_from_Quality_of_Practice

Probability_to_be_Defective_from_Quality_of_Practice =

GRAPH(Quality_of_Practice_in_Regular_Processing/Referance_Quality_of_Practice_in_Re
gular_Processing)

(0.00, 0.5), (0.1, 0.45), (0.2, 0.36), (0.3, 0.28), (0.4, 0.21), (0.5, 0.15), (0.6, 0.1), (0.7, 0.06),
(0.8, 0.03), (0.9, 0.01), (1.00, 0.00)

Probability_to_be_Defective_Rework_from_Quality_of_Practice =

GRAPH(Quality_of_Practice_in_Rework/Reference_Quality_of_Practice_in_Rework)

(0.00, 0.5), (0.1, 0.45), (0.2, 0.36), (0.3, 0.28), (0.4, 0.21), (0.5, 0.15), (0.6, 0.1), (0.7, 0.06),
(0.8, 0.03), (0.9, 0.01), (1.00, 0.00)

Probability_to_be_Defective_Task =

Probabilty_to_be_Defective_from_Inherent_Task_Complexity*Probability_to_be_Defective_
from_Quality_of_Practice + 0*0.05

Probabilty_to_be_Defective_from_Inherent_Task_Complexity = 0.05

Probablity_to_Discover_Unsuccessfully_Processed_Tasks =

GRAPH(Quality_of_Practice_in_QA/Reference_Quality_of_Practice_in_QA)

(0.00, 0.00), (0.1, 0.3), (0.2, 0.4), (0.3, 0.6), (0.4, 0.75), (0.5, 0.8), (0.6, 0.85), (0.7, 0.9), (0.8, 0.92), (0.9, 0.95), (1.00, 1.00)

Productivity_Data = GRAPH(TIME)

(0.00, 1.08), (19.0, 1.09), (37.0, 1.09), (56.0, 1.10), (75.0, 1.08), (94.0, 0.99), (112, 0.98), (131, 1.00), (150, 0.95), (169, 0.95), (187, 0.93), (206, 0.9), (225, 0.87), (244, 0.86), (262, 0.83), (281, 0.82), (300, 0.82), (319, 0.82), (337, 0.82), (356, 0.81), (375, 0.8), (394, 0.8), (412, 0.79), (431, 0.8), (450, 0.8), (469, 0.8), (487, 0.8), (506, 0.81), (525, 0.81), (543, 0.81), (562, 0.81), (581, 0.81), (600, 0.81), (618, 0.81), (637, 0.81)

Productivity_in_Quality_Assurance =

Labor_Force_Productivity*QA_Productivity_Multiplier

Productivity__in_Rework = Labor_Force_Productivity*Rework_Productivity_Multiplier

Project_Deadline_Adjustment_Time = 5

QA_Productivity_Multiplier =

Minimum_Regular_Processing_Duration_per_Task/Minimum_QA_Duration_per_Task

Quality_Assurance_Priority = 1 {Invalid number only used to allow the model run}

Quality_Assurance_Processing_Limit =

(Quality_Assurance_Processing_Limit_from_Task_Availablity_1+Quality_Assurance_Proce
ssing_Limit_from_Task_Availablity_2)

Quality_Assurance_Processing_Limit_from_Resources_1 =

Daily_QA_Labor_Force_for_Unsuccessfully_Processed_Tasks*Productivity_in_Quality_Ass
urance

Quality_Assurance_Processing_Limit_from_Resources_2 =

Daily_QA_Labor_force_to_Successfully_Processed_Tasks*Productivity_in_Quality_Assuran
ce

Quality_Assurance_Processing_Limit_from_Task_Availablity_1 =

(Undiscoverd__Unsuccessfully__Processed_Tasks/Minimum_QA_Duration_per_Task)

Quality_Assurance_Processing_Limit_from_Task_Availablity_2 =

(Successfully__Processed_Tasks/Minimum_QA_Duration_per_Task)

Quality_Assurance_Productivity_Report_Time = 5

Quality_Assurance_Rate_2 =

MIN(Quality_Assurance_Processing_Limit_from_Task_Availablity_2,Quality_Assurance_Processing_Limit_from_Resources_2)

Quality_Gap = Current_Quality-Quality_Goal

Quality_Gap_Effect_on_RW&QA_Importance = GRAPH(Quality_Gap)

(-1.00, 2.20), (-0.9, 2.14), (-0.8, 2.07), (-0.7, 1.99), (-0.6, 1.90), (-0.5, 1.80), (-0.4, 1.68), (-0.3, 1.54), (-0.2, 1.38), (-0.1, 1.20), (0.00, 1.00)

Quality_Goal_Adjustment_Time = 30

Quality_of_Practice =

Effect_of_Fatigue_on_QoP*Effect_of_Experience_on_QoP*Effect_of_Schedule_Pressure_on_QoP

Quality_of_Practice_in_QA = Quality_of_Practice*Reference_Quality_of_Practice_in_QA

Quality_of_Practice_in_Regular_Processing =

Quality_of_Practice*Referance_Quality_of_Practice_in_Regular_Processing

Quality_of_Practice_in_Rework =

Quality_of_Practice*Reference_Quality_of_Practice_in_Rework

Quality_Assurance_Rate_1 =

MIN(Quality_Assurance_Processing_Limit_from_Resources_1,

Quality_Assurance_Processing_Limit_from_Task_Availablity_1)

Quit_Fraction = 0.05/240

Referance_Quality_of_Practice_in_Regular_Processing = 1

Reference_Potential_Productivity_of_Experienced_Employees = 1

Reference_Potential_Productivity_of_Experienced_Hire_in = 1

Reference_Potential_Productivity_of_New_Employees = 0.5

Reference_Potential_Productivity_of_Transferredin_Company_Employees = 0.8

Reference_Potential_Productivity_of__New_Hire_in = 0.8

Reference_Quality_of_Practice_in_QA = 0.9

Reference_Quality_of_Practice_in_Rework = 0.9

Ref_Quality_Assurance_Productivity = 10

Ref_Regular_Processing_Productivity = 0.8

Ref_Rework_Productivity = 1.5

Regular_Processing_Limit_from_Resources =

Daily_Labor_Force_to_Regular__Processing*Labor_Force_Productivity {Tasks/day=
(People-day/day)*(Tasks/People-day)}

Regular_Processing_Limit_from_Task_Availability =

Tasks_Available_for_Regular_Processing/Minimum_Regular_Processing_Duration_per_Task

Regular_Processing_Priority = 1 {Invalid number only used to allow the model run}

Regular_Processing_Productivity_Report_Time = 5

Regular__Processing_Rate =

MIN(Regular_Processing_Limit_from_Task_Availability,Regular_Processing_Limit_from_Resources)

Remaining_Tasks = Current_Scope-Total_Released_Tasks

Required_Labor_Force_for_Quality_Assurance =

Quality_Assurance_Processing_Limit/Productivity_in_Quality_Assurance

Required_Labor_Force_for_Rework =

Rework_Processing_Limit_from_Task_Availability/Productivity__in_Rework

Required_Labor_for_Regular_Processing =

(Regular_Processing_Limit_from_Task_Availability/Labor_Force_Productivity)*0+1

Rework_Priority = 1 {Invalid number only used to allow the model run}

Rework_Processing_Limit_from_Resources =

Daily_Labor_Force_to_Rework*Productivity__in_Rework

Rework_Processing_Limit_from_Task_Availability =

Discovered_Unsuccessfully_Processed_Tasks/(Minimum_Rework_Duration_per_Task+0.00001)

Rework_Productivity_Multiplier =

Minimum_Regular_Processing_Duration_per_Task/Minimum_Rework_Duration_per_Task

Rework_Productivity_Report_Time = 5

Rework_Rate =

MIN(Rework_Processing_Limit_from_Task_Availability,Rework_Processing_Limit_from_Resources)

```

Schedule_Pressure =
(Total_Man_Days_Perceived_Still_Needed)/(Total_Available_Man_Days+0.9999)
Schedule_Pressure_Effect_on_Labor_Force_Productivity =
Positive_Schedule_Pressure_Effect_on_Labor_Force_Productivity*Negative_Schedule_Pressure_Effect_on_Labor_Force_Productivity
Scope_Change = (IF(Current_Scope - Previous_Scope>0) THEN(STEP(Current_Scope-Previous_Scope, TIME)) ELSE(0))
Scope_Change_Data = PULSE(455,167,0)+PULSE(12,262,0)+PULSE(161,319,0)+PULSE(117,450,0)+PULSE(31,543,0)+PULSE(6,637,0)
Scope_of_work = GRAPH(Total_Released_Tasks/Total_number_of_Tasks)
(0.00, 2651), (0.51, 2651), (0.55, 3106), (0.71, 3106), (0.71, 3107), (0.72, 3118), (0.79, 3118),
(0.81, 3279), (0.9, 3279), (0.91, 3396), (0.95, 3396), (0.96, 3427), (0.99, 3428), (1.00, 3433)
Tasks_Available_for_Regular_Processing = (MAX(0, Total_Tasks_Available-(Current_Scope-Tasks_Identified__to_be_Processed)))
Tasks_Perceived__Completed =
Successfully__Processed_Tasks+Undiscoverd__Unsuccessfully__Processed_Tasks+Successfully_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks_Approved_to_be_Released+Successfully_Processed_Tasks_Released+Unsuccessfully_Processed_Tasks_Released
Thirty_%_of__Phase_Scope = Current_Scope*0.3
Time_Horizon_for_Reference_Condition_THRC = 10
Time_Remaining_to_Complete_70%_of_the_Phase_Scope =
IF(Internal_Deadline>(5+TIME))THEN(Internal_Deadline-TIME)ELSE(5)
Time_Remaining_to_Deadline =
(IF((Internal_Deadline+Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline)>TIME) THEN(Time_Remaining_to_Internal_Deadline)ELSE(
MAX(Project_Deadline_for_the_Phase-TIME,
1)))*0+(MAX(Project_Deadline_for_the_Phase-TIME, 1)) {Days}
Time_Remaining_to_Internal_Deadline = IF(Remaining_Tasks-
Thirty_%_of__Phase_Scope>0)
THEN(Time_Remaining_to_Complete_70%_of_the_Phase_Scope)ELSE(IF(Remaining_Tas

```

$ks\text{-Thirty_}\% \text{ of_Phase_Scope} < 0$ and
 $(\text{Internal_Deadline} + \text{Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline}) > \text{TIME}$
 THEN(Adjustment_Towards_the_30%_Phase_Scope_Deadline) ELSE(0)
 $\text{Time_to_Adjust_New_Deadline} = 5$
 $\text{Time_to_adjust_Perceived_Quality_Assurance_Productivity} = 20$
 $\text{Time_to_adjust_Perceived_Regular_Processing_Productivity} = 20$
 $\text{Time_to_adjust_Perceived_Rework_Productivity} = 20$
 $\text{Time_to_Perceive_an_Increase_in_SP} =$
 $1/(\text{Inverse_of_SP_Tolerance_time} + 0 * \text{Inverse_Of_SP_Tolerance_time} + 0.00001)$
 $\text{Time_to_Perceive_a_Decrease_in_SP} = \text{GRAPH}(\text{Avg_Schedule_Pressure})$
 $(1.00, 1e-06), (1.10, 5.00), (1.15, 20.9), (1.20, 63.3), (1.30, 180)$
 $\text{Time_to_Perceive_Present_Conditions_TPPC} = 5$
 $\text{Time_to_Perceive_Trend_TPT} = 5$
 $\text{Time_to_Project_Deadline} = 712 - \text{TIME}$
 $\text{Time_to_Release_Tasks} = 5$
 $\text{Total_Available_Man_Days} =$
 $\text{Actual_Labor_Force_Required} * \text{Avg_Daily_Labor_Force_Per_Staff} * \text{Time_Remaining_to_Deadline}$
 $\text{Total_Cost} =$
 $\text{Experienced_Employees_Costs_to_Date} + \text{Transferred_in_Company_Employees_Costs_to_Date}$
 $+ \text{New_Employees_Costs_to_Date} + \text{Overtime_Costs_to_Date} + \text{New_Hired_in_Externally_Costs_to_Date}$
 $+ \text{Experienced_Hired_in_Externally_Costs_to_Date}$
 $\text{Total_Desired_Labor_Force_for_Engineering_Activities} =$
 $\text{Desired_Labor_Force_for_Regular_Processing} + \text{Desired_Labor_Force_for_Rework} + \text{Desired_Labor_Force_for_Quality_Assurance}$
 $\text{Total_Effect_on_Labor_Force_Productivity} =$
 $\text{Managerial_Effect_on_Productivity} * \text{Schedule_Pressure_Effect_on_Labor_Force_Productivity}$
 $* \text{Fatigue_Effect_on_Labor_Force_Productivity} * \text{Labor_Size_Effect_on_Productivity}$
 $\text{Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF} =$
 $\text{Overtime_Worked_per_Day_per_FullTime_Equivalent_LF} + \text{Normal_Work_Hours_per_Day}$
 {hours/People-Days}

Total_Labor_Force =

New_Employees+Experienced_Employees+Transferred_in_Company_Employees+New_Hire_in+Experienced_Hired_in_Externally

Total_Labor_Force_Data = GRAPH(TIME)

(0.00, 18.0), (19.0, 15.0), (37.0, 11.0), (56.0, 13.0), (75.0, 12.0), (94.0, 9.00), (112, 9.00), (131, 7.00), (150, 7.00), (169, 12.0), (188, 11.0), (207, 8.00), (226, 5.00), (245, 5.00), (264, 4.00), (283, 4.00), (302, 3.00), (321, 2.00), (340, 2.00), (359, 2.00), (378, 2.00), (397, 2.00), (416, 2.00), (435, 2.00), (454, 2.00), (473, 2.00), (492, 2.00), (511, 2.00), (530, 2.00), (549, 2.00), (568, 2.00), (587, 2.00), (606, 2.00), (625, 2.00), (644, 1.00), (663, 0.00), (682, 0.00), (701, 0.00), (712, 0.00)

Total_Man_Days_Perceived_Still_Needed = (IF(Remaining_Tasks-Thirty_%_of_Phase_Scope>0)THEN((Remaining_Tasks-Thirty_%_of_Phase_Scope)/Expected_Average_Productivity)ELSE(Remaining_Tasks/Expected_Average_Productivity))*0+ (Remaining_Tasks/Expected_Average_Productivity)

Total_Man_Days_Still_Required = Perceived_Net_Shortage_in_Man_Days-

Perceived_Man_Days_to_be_handled_via_Overtime {People-Days= (People-Days)-(People-Days)}

Total_number_of_Tasks = 3433

Total_Overtime_Hours_that_will_be_Handled =

MAX(MIN(Maximum_Overtime_Hours_that_Can_be_worked,Perceived_Shortage_in_Man_Hours), 0) {hours=(hours, hours)}

Total_Overtime_Hrs_Worked_Per_Day =

Overtime_Worked_per_Day_per_FullTime_Equivalent_LF*Total_Labor_Force {Hours/Day}

Total_Pressure_for_Activities =

Pressure_for_Rework+Pressure_for_Quality_Assurance+Pressure_for_Regular_Processing

Total_Released_Tasks =

Successfully_Processed_Tasks_Released+Unsuccessfully_Processed_Tasks_Released

Total_Tasks_Available =

Current_Scope*MIN(Internal_Precedence_Relation,External_Precedence_Relation)

Total_Tasks_to_be_Released =
 Successfully_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks
 _Approved_to_be_Released+0.0000009

Total_Tasks_to_QA =
 Successfully__Processed_Tasks+Undiscoverd__Unsuccessfully__Processed_Tasks+0.00001
 {This small number is used to avoid division by zero}

Trainers_per_New_Labor_Force = 0.2 {On average each new labor force consumes in
 training overhead the equivalent of 20% of an experienced labor force's daily working time
 for the duration of the training or assimilation period. Unit - Unitless = days/days}

Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate = 500

Unsuccessfully_processed_Task_Dicovery_Rate =
 Quality__Assurance_Rate_1*Probablity_to_Discover_Unsuccessfully_Processed_Tasks
 Weight_to_Planned_Productivity = GRAPH(Fraction_of_Released_Tasks)
 (0.00, 1.00), (0.1, 0.9), (0.2, 0.7), (0.3, 0.5), (0.4, 0.3), (0.5, 0.1), (0.6, 0.00), (0.7, 0.00), (0.8,
 0.00), (0.9, 0.00), (1.00, 0.00)

Willingness_to_Change_Labor_Force_Level =
 MAX(Desire_for_Schedule_Stability_Effect_on_WCLF,Desire_for_LF_Stability_Effect_on_
 WCLF)

Willingness_To_Work_Overtime =
 IF(TIME>=Time_To_Recover+Time_from_Last_Exhaustion_Break)THEN(1)ELSE(0)
 {Unitless =Unitless+Unitless}

Workload_Stress_Onset_time = IF Schedule_Pressure>Avg_Schedule_Pressure THEN
 Time_to_Perceive_an_Increase_in_SP ELSE Time_to_Perceive_a_Decrease_in_SP

Total_Tasks_Actually_Completed =
 Successfully_Processed_Tasks_Approved_to_be_Released +
 Successfully_Processed_Tasks_Released + Unsuccessfully_Processed_Tasks_Released +
 Unsuccessfully_Processed_Tasks_Approved_to_be_Released

Total_Tasks_in_the_Phase_at_Any_Time = Discovered_Unsuccessfully_Processed_Tasks +
 Successfully_Processed_Tasks_Approved_to_be_Released +
 Successfully_Processed_Tasks_Released + Successfully__Processed_Tasks +
 Tasks_Identified__to_be_Processed + Undiscoverd__Unsuccessfully__Processed_Tasks +

Unsuccessfully_Processed_Tasks_Released +
Unsuccessfully_Processed_Tasks_Approved_to_be_Released

Area Engineering Phase Equations

$$\text{Avg_Schedule_Pressure}(t) = \text{Avg_Schedule_Pressure}(t - dt) + (\text{Change_in_Avg_SP}) * dt$$

$$\text{INIT Avg_Schedule_Pressure} = \text{Schedule_Pressure}$$

INFLOWS:

$$\text{Change_in_Avg_SP} = (\text{Schedule_Pressure} - \text{Avg_Schedule_Pressure}) / \text{Workload_Stress_Onset_time}$$

$$\text{Defective_Tasks_Discoverd_by_Downstream}(t) =$$

$$\text{Defective_Tasks_Discoverd_by_Downstream}(t - dt) +$$

$$(\text{Defective_Task_Discovery_Rate_from_Down_stream} -$$

$$\text{Rework_Rate_of_Downstream_Discovered_Defective_Tasks}) * dt$$

$$\text{INIT Defective_Tasks_Discoverd_by_Downstream} = 0$$

INFLOWS:

$$\text{Defective_Task_Discovery_Rate_from_Down_stream} =$$

$$\text{Intraphase_Defective_Tasks_Coordinated_with_Downstream}$$

OUTFLOWS:

$$\text{Rework_Rate_of_Downstream_Discovered_Defective_Tasks} =$$

$$(\text{Sucessful_Rework_Rate} + \text{Uncessesful_Rework_Rate}) * \text{Fraction_of_Defective_Tasks_Discoverd_by_Downstream}$$

$$\text{Experienced_Hired_in_Externally}(t) = \text{Experienced_Hired_in_Externally}(t - dt) +$$

$$(\text{Assimilation_Rate_of_New_Hire_in} - \text{Experienced_Hire_in_Demobilization_Rate} -$$

$$\text{Experienced_Hire_in_Quit_Rate}) * dt$$

$$\text{INIT Experienced_Hired_in_Externally} = \text{Initial_Total_Labor_Force} * 0.2$$

INFLOWS:

$$\text{Assimilation_Rate_of_New_Hire_in} =$$

$$\text{New_Hire_in} / \text{Avg_Assimilation_Time_of_New_Hire_in}$$

OUTFLOWS:

$$\text{Experienced_Hire_in_Demobilization_Rate} =$$

$$\text{MIN}(\text{Experienced_Hired_in_Externally} / \text{DT}, (\text{Demobilization_Rate} - \text{New_Hire_in_Demobilization_Rate}))$$

$$\text{Experienced_Hire_in_Quit_Rate} =$$

$$\text{Experienced_Hired_in_Externally} / \text{Avg_Employment_Duration_of_Hire_In_Externally}$$

Internal_Deadline(t) = Internal_Deadline(t - dt) + (Change_to_Internal_Deadline) * dt

INIT Internal_Deadline = Initial_internal_Deadline

INFLOWS:

Change_to_Internal_Deadline = MIN((Maximum_Tolerable_Internal_Deadline-
Internal_Deadline)/Internal_Deadline_Adjustment_Time ,
(Indicated_Completion_date_for_65%_of_Phase_Scope-
Internal_Deadline)/Internal_Deadline_Adjustment_Time)

Perceived_Present_Condition_PPC(t) = Perceived_Present_Condition_PPC(t - dt) +
(Change_in_PPC) * dt

INIT Perceived_Present_Condition_PPC =

INIT(Input)/(1+Time_to_Perceive_Present_Conditions_TPPC*Perceived_Trend_TREND)

INFLOWS:

Change_in_PPC = (Input-Perceived_Present_Condition_PPC)/

Time_to_Perceive_Present_Conditions_TPPC

Perceived_Trend_TREND(t) = Perceived_Trend_TREND(t - dt) + (Change_in_TREND) * dt

INIT Perceived_Trend_TREND = 0

INFLOWS:

Change_in_TREND = (Indicated_Trend_ITREND -Perceived_Trend_TREND)/

Time_to_Perceive_Trend_TPT

Quality_Goal(t) = Quality_Goal(t - dt) + (Change_in_Quality_Goal) * dt

INIT Quality_Goal = 0.9

INFLOWS:

Change_in_Quality_Goal = Quality_Gap/Quality_Goal_Adjustment_Time

Reference_Condition_RC(t) = Reference_Condition_RC(t - dt) + (Change_in_RC) * dt

INIT Reference_Condition_RC = INIT(Perceived_Present_Condition_PPC)/(1+
Time_Horizon_for_Reference_Condition_THRC * Perceived_Trend_TREND)

INFLOWS:

Change_in_RC = (Perceived_Present_Condition_PPC -Reference_Condition_RC)/

Time_Horizon_for_Reference_Condition_THRC

Total_Defective_Tasks_Sent_to_Upstream(t) = Total_Defective_Tasks_Sent_to_Upstream(t -
dt) + (Accum_Rate_of_Defective_Tasks_Sent_to_Upstream) * dt

INIT Total_Defective_Tasks_Sent_to_Upstream = 0

INFLOWS:

Accum_Rate_of_Defective_Tasks_Sent_to_Upstream =

Upstream_Defective_Task_Discovery_Rate

Total_Discovered_Unsuccessfully_Processed_Tasks(t) =

Total_Discovered_Unsuccessfully_Processed_Tasks(t - dt) +

(Accum_Rate_of_Discovered_Unsuccessfully_Processed_Tasks) * dt

INIT Total_Discovered_Unsuccessfully_Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Discovered_Unsuccessfully_Processed_Tasks =

Unsuccessfully_processed_Task_Discovery_Rate

Total_Successfully_Processed_Tasks_Approved_to_be_Released(t) =

Total_Successfully_Processed_Tasks_Approved_to_be_Released(t - dt) +

(Accum_Rate_of_Successfully_Processed_Tasks_Approved_to_be_Released) * dt

INIT Total_Successfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Accum_Rate_of_Successfully_Processed_Tasks_Approved_to_be_Released =

Approval_Rate_of_Successfully_Processed_Tasks

Total_Successfully_Processed_Tasks_Released(t) =

Total_Successfully_Processed_Tasks_Released(t - dt) +

(Accum_Rate_of_Successfully_Processed_Tasks_Released) * dt

INIT Total_Successfully_Processed_Tasks_Released = 0

INFLOWS:

Accum_Rate_of_Successfully_Processed_Tasks_Released =

Successfully_Processed_Tasks_Release_Rate

Total_Successfully__Processed_Tasks(t) = Total_Successfully__Processed_Tasks(t - dt) +

(Accum_Rate_of_Successfully_Processed_Tasks) * dt

INIT Total_Successfully__Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Successfully_Processed_Tasks =

Successful__Rework_Rate+Successful_Processing_Rate

Total_Undiscoverd_Unsucessfully_Processed_Tasks(t) =
 Total_Undiscoverd_Unsucessfully_Processed_Tasks(t - dt) +
 (Accum_Rate_of_Undiscoverd__Unsucessfully_Processed_Tasks) * dt

INIT Total_Undiscoverd_Unsucessfully_Processed_Tasks = 0

INFLOWS:

Accum_Rate_of_Undiscoverd__Unsucessfully_Processed_Tasks =
 Unsucessful__Processing_Rate+Uncessesful__Rework_Rate

Total_Unsucessesfully_Processed_Tasks_Released(t) =
 Total_Unsucessesfully_Processed_Tasks_Released(t - dt) +
 (Accum_Rate_of__Unsucessesfully_Processed_Tasks_Released) * dt

INIT Total_Unsucessesfully_Processed_Tasks_Released = 0

INFLOWS:

Accum_Rate_of__Unsucessesfully_Processed_Tasks_Released =
 Unsucessfully_Processed_Tasks_Release_Rate

Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released(t) =
 Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +
 (Accum_Rate_of_Unsucessfully_Processed_Tasks_Approved_to_be_Released) * dt

INIT Total_Unsucessfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Accum_Rate_of_Unsucessfully_Processed_Tasks_Approved_to_be_Released =
 Approval_Rate_of_Undiscoverd_Unsucessfully_Processed_Tasks

Adjustment_Towards_the_35%_Phase_Scope_Deadline(t) =
 Adjustment_Towards_the_35%_Phase_Scope_Deadline(t - dt) +
 (Change_in_Phase_Deadline_Adjustment) * dt

INIT Adjustment_Towards_the_35%_Phase_Scope_Deadline = 20

INFLOWS:

Change_in_Phase_Deadline_Adjustment =
 IF(Remaining_Tasks>Thirty_five_%_of__Phase_Scope)THEN(0)ELSE((Deadline_for_the_
 Remaining_30%_Phase_Scope-
 Adjustment_Towards_the_35%_Phase_Scope_Deadline)/Time_to_Adjust_New_Deadline)

Cumulative_Man_Days_Expended(t) = Cumulative_Man_Days_Expended(t - dt) +
(Total_Daily_Labor_Force_Expended) * dt

INIT Cumulative_Man_Days_Expended = 0 {Unit-people*days}

INFLOWS:

Total_Daily_Labor_Force_Expended =

Total_Labor_Force*Avg_Daily_Labor_Force_Per_Staff+ManDay_Equivalence_of_Overtime
_Hrs_worked_per_Day {Unit- people/days=people*days/days}

Cumulative_Man_Days_Expended_for_Development_Activities(t) =

Cumulative_Man_Days_Expended_for_Development_Activities(t - dt) +
(Daily_Labor_Force_for_Development_Activities) * dt

INIT Cumulative_Man_Days_Expended_for_Development_Activities = 0

INFLOWS:

Daily_Labor_Force_for_Development_Activities = (Total_Daily_Labor_Force_Expended-
Daily_Labor_Force__for_Training) {Unit- people/days=people/days - people/days}

Cumulative_Training_MD(t) = Cumulative_Training_MD(t - dt) +
(Daily_Labor_Force__for_Training) * dt

INIT Cumulative_Training_MD = 0 {The cumulated number of training mandays unit -
People*Days}

INFLOWS:

Daily_Labor_Force__for_Training =

(New_Employees+New_Hire_in+Transferred_in_Company_Employees)*Trainers_per_New
_Labor_Force {unit - pepole/days = people*days/days}

Discovered_Unsuccessfully_Processed_Tasks(t) =

Discovered_Unsuccessfully_Processed_Tasks(t - dt) +
(Intraphase_Unsuccessfully_processed_Task_Discovery_Rate +
Intraphase_Defective_Tasks_Coordinated_with_Downstream - Sucessful__Rework_Rate -
Uncessesful__Rework_Rate) * dt

INIT Discovered_Unsuccessfully_Processed_Tasks = 0

INFLOWS:

Intraphase_Unsuccessfully_processed_Task_Discovery_Rate =

Unsuccessfully_processed_Task_Dicoverery_Rate-Upstream_Defective_Task_Discovery_Rate

Intraphase_Defective_Tasks_Coordinated_with_Downstream =

Fraction_of_Coordinated_Tasks_from_Downstream

OUTFLOWS:

Successful__Rework_Rate =

Rework_Rate*Probability_of_Tasks_to_be_Successfully_Reworked

Unsuccessful__Rework_Rate = Rework_Rate-Successful__Rework_Rate

Exhaustion_Due_to_Overtime_Work(t) = Exhaustion_Due_to_Overtime_Work(t - dt) +

(Rate_of_Increase_in_Exhaustion_Level - Rate_of_Depletion_in_Exhaustion_Level) * dt

INIT Exhaustion_Due_to_Overtime_Work = 0 {exhaustion}

INFLOWS:

Rate_of_Increase_in_Exhaustion_Level =

GRAPH(Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF/Normal_Work_Hours_per_Day)

(1.00, 0.00), (1.03, 0.2), (1.07, 0.4), (1.10, 0.6), (1.13, 0.8), (1.17, 1.00), (1.20, 1.20), (1.23, 1.40), (1.27, 1.60)

OUTFLOWS:

Rate_of_Depletion_in_Exhaustion_Level = IF

(Perceived_Rate_of_Increase_in_Exhaustion_Level <=

0.01) THEN (Exhaustion_Due_to_Overtime_Work/Exhaustion_Depletion_Time) ELSE (0)

Experienced_Employees(t) = Experienced_Employees(t - dt) +

(Assimilation_Rate_of_New_Employees +

Assimilation_Rate_of_Transferred_in_Company_Employees -

Experienced_Employees_Quit_Rate - Experienced_Employees_Demobilization_Rate) * dt

INIT Experienced_Employees = Initial_Total_Labor_Force*0.8

INFLOWS:

Assimilation_Rate_of_New_Employees =

New_Employees/Avg_Assimilation_Time_of_New_Employees

Assimilation_Rate_of_Transferred_in_Company_Employees =

Transferred_in_Company_Employees/Avg_Assimilation_Time_of_Transferred_in_Company_Employees

OUTFLOWS:

$Experienced_Employees_Quit_Rate =$
 $Experienced_Employees * Experienced_Employee_Quit_Fraction$
 $Experienced_Employees_Demobilization_Rate =$
 $MIN(Experienced_Employees/DT, (Demobilization_Rate -$
 $(New_Hire_in_Demobilization_Rate + Experienced_Hire_in_Demobilization_Rate + Transferred_in_Company_Employees_Demobilization_Rate + New_Employees_Demobilization_Rate)))$
 $)$
 $Experienced_Employees_1(t) = Experienced_Employees_1(t - dt)$
 $INIT Experienced_Employees_1 = Initial_Total_Labor_Force * 0.8$
 $Experienced_Employees_Costs_to_Date(t) = Experienced_Employees_Costs_to_Date(t - dt)$
 $+ (Regular_Daily_Salary_of_Experienced_Employees) * dt$
 $INIT Experienced_Employees_Costs_to_Date = 0$
INFLOWS:
 $Regular_Daily_Salary_of_Experienced_Employees =$
 $IF(Fraction_of_Released_Tasks < 0.9999) THEN (Experienced_Employees * Experienced_Employee_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day) ELSE (0)$
 $Experienced_Hired_in_Externally_Costs_to_Date(t) =$
 $Experienced_Hired_in_Externally_Costs_to_Date(t - dt) +$
 $(Regular_Daily_Salary_of_Experienced_Hired_in_Externally) * dt$
 $INIT Experienced_Hired_in_Externally_Costs_to_Date = 0$
INFLOWS:
 $Regular_Daily_Salary_of_Experienced_Hired_in_Externally =$
 $IF(Fraction_of_Released_Tasks < 0.9999) THEN (Experienced_Hired_in_Externally * Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day) ELSE (0)$
 $New_Employees(t) = New_Employees(t - dt) + (Hiring_Rate_of_New_Employees - Assimilation_Rate_of_New_Employees - New_Employees_Demobilization_Rate) * dt$
 $INIT New_Employees = 0 \{People\}$
INFLOWS:

Hiring_Rate_of__New_Employees = MAX(0,
Desired_No_New_Employees_to_be_Hired/Avg_Hiring_Time_of_New_Employees)

OUTFLOWS:

Assimilation_Rate_of_New_Employees =
New_Employees/Avg_Assimilation_Time_of_New_Employees
New_Employees_Demobilization_Rate = MIN(New_Employees/DT, (Demobilization_Rate-
(New_Hire_in_Demobilization_Rate+Experienced_Hire_in_Demobilization_Rate+Transferr
ed_in_Company_Employees_Demobilization_Rate)))

New_Employees_1(t) = New_Employees_1(t - dt)

INIT New_Employees_1 = 0

New_Employees_Costs_to_Date(t) = New_Employees_Costs_to_Date(t - dt) +
(Regular_Daily_Salary_of_New_Employees) * dt

INIT New_Employees_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_New_Employees =
IF(Fraction_of_Released_Tasks<0.9999)THEN(New_Employees*Normal_Work_Hours_per
_Day*New_Employees_Avg_Hourly_Pay_Rate*Avg_Daily_Labor_Force_Per_Staff)ELSE(
0)

New_Hired_in_Externally(t) = New_Hired_in_Externally(t - dt)

INIT New_Hired_in_Externally = 0

New_Hired_in_Externally_Costs_to_Date(t) = New_Hired_in_Externally_Costs_to_Date(t -
dt) + (Regular_Daily_Salary_of_New_Hired_in_Externally) * dt

INIT New_Hired_in_Externally_Costs_to_Date = 0

INFLOWS:

Regular_Daily_Salary_of_New_Hired_in_Externally =
IF(Fraction_of_Released_Tasks<0.9999)THEN(New_Hired_in_Externally *
New_Hired_in_Externally_Avg_Hourly_Pay_Rate * Avg_Daily_Labor_Force_Per_Staff *
Normal_Work_Hours_per_Day)ELSE(0)

New_Hire_in(t) = New_Hire_in(t - dt) + (Hiring_Rate_of_New_Hire_in -
Assimilation_Rate_of_New_Hire_in - New_Hire_in_Demobilization_Rate) * dt

INIT New_Hire_in = 0

INFLOWS:

Hiring_Rate_of_New_Hire_in = MAX(0,

Desired_No_New_Hire_in_to_be_Hired/Avg_Hiring_Time_of_New_Hire_in)

OUTFLOWS:

Assimilation_Rate_of_New_Hire_in =

New_Hire_in/Avg_Assimilation_Time_of_New_Hire_in

New_Hire_in_Demobilization_Rate = MIN(Demobilization_Rate,New_Hire_in/DT)

Overtime_Costs_to_Date(t) = Overtime_Costs_to_Date(t - dt) + (Total_Daily_Overtime_Pay)

* dt

INIT Overtime_Costs_to_Date = 0

INFLOWS:

Total_Daily_Overtime_Pay =

IF(Fraction_of_Released_Tasks<0.9999)THEN(Avg_Hourly_Overtime_Pay_Rate *

Total_Overtime_Hrs_Worked_Per_Day)ELSE(0)

Perceived_Quality_Assurance_Productivity(t) = Perceived_Quality_Assurance_Productivity(t - dt) + (Change_in_Perceived_Quality_Assurance_Productivity) * dt

INIT Perceived_Quality_Assurance_Productivity = Ref_Quality_Assurance_Productivity

INFLOWS:

Change_in_Perceived_Quality_Assurance_Productivity =

MAX(((Reported_Quality_Assurance_Productivity-

Perceived_Quality_Assurance_Productivity)/Time_to_adjust_Perceived_Quality_Assurance_

Productivity),Perceived_Minimum_Quality_Assurance_Productivity-

Perceived_Quality_Assurance_Productivity)

Perceived_Regular_Processing_Productivity(t) =

Perceived_Regular_Processing_Productivity(t - dt) +

(Change_in_Perceived_Regular_Processing_Productivity) * dt

INIT Perceived_Regular_Processing_Productivity = Ref_Regular_Processing_Productivity

INFLOWS:

Change_in_Perceived_Regular_Processing_Productivity =

MAX(((Reported_Regular_Processing_Productivity-

Perceived_Regular_Processing_Productivity)/Time_to_adjust_Perceived_Regular_Processing

_Productivity), Perceived_Minimum_Regular_Processing_Productivity-
Perceived_Regular_Processing_Productivity)

Perceived_Rework_Productivity(t) = Perceived_Rework_Productivity(t - dt) +
(Change_in_Perceived_Rework_Productivity) * dt

INIT Perceived_Rework_Productivity = Ref_Rework_Productivity

INFLOWS:

Change_in_Perceived_Rework_Productivity = MAX(((Reported_Rework_Productivity-
Perceived_Rework_Productivity)/Time_to_adjust_Perceived_Rework_Productivity), Perceive
d_Minimum_Rework_Productivity-Perceived_Rework_Productivity)

Project_Deadline_for_the_Phase(t) = Project_Deadline_for_the_Phase(t - dt) +
(Change_in_Project_Deadline) * dt

INIT Project_Deadline_for_the_Phase = initial_Project_Deadline_for_the_Phase

INFLOWS:

Change_in_Project_Deadline = MIN((Maximum_Tolerable_Project_Completion_Date-
Project_Deadline_for_the_Phase)/Project_Deadline_Adjustment_Time,
(Indicated_Completion_Date_for_the_Phase-

Project_Deadline_for_the_Phase)/Project_Deadline_Adjustment_Time)

Reported_Quality_Assurance_Productivity(t) = Reported_Quality_Assurance_Productivity(t -
dt) + (Change_in_Reported_Quality_Assurance_Productivity) * dt

INIT Reported_Quality_Assurance_Productivity = Ref_Quality_Assurance_Productivity

INFLOWS:

Change_in_Reported_Quality_Assurance_Productivity =
(Current_Quality_Assurance_Productivity-
Reported_Quality_Assurance_Productivity)/Quality_Assurance_Productivity_Report_Time

Reported_Regular_Processing_Productivity(t) =
Reported_Regular_Processing_Productivity(t - dt) +
(Change_in_Reported_Regular_Processing_Productivity) * dt

INIT Reported_Regular_Processing_Productivity = Ref_Regular_Processing_Productivity

INFLOWS:

Change_in_Reported_Regular_Processing_Productivity =
 (Current_Regular_Processing_Productivity -
 Reported_Regular_Processing_Productivity)/Regular_Processing_Productivity_Report_Time
 Reported_Rework_Productivity(t) = Reported_Rework_Productivity(t - dt) +
 (Change_in_Reported_Rework_Productivity) * dt

INIT Reported_Rework_Productivity = Ref_Rework_Productivity

INFLOWS:

Change_in_Reported_Rework_Productivity = (Current_Rework_Productivity -
 Reported_Rework_Productivity)/Rework_Productivity_Report_Time

Successfully_Processed_Tasks_Approved_to_be_Released(t) =
 Successfully_Processed_Tasks_Approved_to_be_Released(t - dt) +
 (Approval_Rate_of_Successfully_Processed_Tasks -
 Successfully_Processed_Tasks_Release_Rate) * dt

INIT Successfully_Processed_Tasks_Approved_to_be_Released = 0 {Tasks}

INFLOWS:

Approval_Rate_of_Successfully_Processed_Tasks = Quality_Assurance_Rate_2

OUTFLOWS:

Successfully_Processed_Tasks_Release_Rate =
 Successfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks
 Successfully_Processed_Tasks_Released(t) = Successfully_Processed_Tasks_Released(t - dt)
 + (Successfully_Processed_Tasks_Release_Rate) * dt

INIT Successfully_Processed_Tasks_Released = 0 {Tasks}

INFLOWS:

Successfully_Processed_Tasks_Release_Rate =
 Successfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks
 Successfully__Processed_Tasks(t) = Successfully__Processed_Tasks(t - dt) +
 (Successful_Processing_Rate + Successful__Rework_Rate -
 Approval_Rate_of_Successfully_Processed_Tasks) * dt

INIT Successfully__Processed_Tasks = 0 {Tasks}

INFLOWS:

Successful_Processing_Rate = Regular__Processing_Rate*(1-
 Fraction_of_Inherited_Unsuccessfully_Processed_Tasks)*(1-
 Probability_to_be_Defective_Task) {Tasks/Days}

Successful__Rework_Rate =
 Rework_Rate*Probability_of_Tasks_to_be_Sucessfully_Reworked

OUTFLOWS:

Approval_Rate_of_Successfully_Processed_Tasks = Quality_Assurance_Rate_2
 Tasks_Identified_to_be_Processed(t) = Tasks_Identified_to_be_Processed(t - dt) +
 (Return_Rate_of_Coord_Tasks_Sent_to_Upstream + Rate_of__Change_in_Scope -
 Successful_Processing_Rate - Unsucessful__Processing_Rate) * dt

INIT Tasks_Identified_to_be_Processed = 13439 {Tasks}

INFLOWS:

Return_Rate_of_Coord_Tasks_Sent_to_Upstream =
 Upstream_Defective_Task_Discovery_Rate
 Rate_of__Change_in_Scope = Scope_Change

OUTFLOWS:

Successful_Processing_Rate = Regular__Processing_Rate*(1-
 Fraction_of_Inherited_Unsuccessfully_Processed_Tasks)*(1-
 Probability_to_be_Defective_Task) {Tasks/Days}
 Unsucessful__Processing_Rate = Regular__Processing_Rate-Successful_Processing_Rate
 Time_from_Last_Exhaustion_Break(t) = Time_from_Last_Exhaustion_Break(t - dt) +
 (Overtime_Work_Break_Setter) * dt

INIT Time_from_Last_Exhaustion_Break = -1 {Unitless}

INFLOWS:

Overtime_Work_Break_Setter = (MAX(Time_from_Last_Exhaustion_Break,
 Overtime_Work_Break_Indicator)-Time_from_Last_Exhaustion_Break)/DT
 Time_To_Recover(t) = Time_To_Recover(t - dt) + (Change_in_Time_To_Recover) * dt

INIT Time_To_Recover = 0 {Unitless}

INFLOWS:

$Change_in_Time_To_Recover = IF$
 $(Exhaustion_Due_to_Overtime_Work/Maximum_Tolerable_Exhaustion_Level \geq 0.1)$
 $THEN(1)ELSE(-Time_To_Recover/DT) \{Unitless/day\}$
 $Transferred_in_Company_Employees(t) = Transferred_in_Company_Employees(t - dt) +$
 $(Rate_of_Mobilization_of_Company_Employees -$
 $Assimilation_Rate_of_Transferred_in_Company_Employees -$
 $Transferred_in_Company_Employees_Demobilization_Rate) * dt$
 $INIT Transferred_in_Company_Employees = 0$
INFLOWS:
 $Rate_of_Mobilization_of_Company_Employees = MAX(0, (Labor_Force_Gap -$
 $Desired_No_New_Hire_in_to_be_Hired -$
 $Desired_No_New_Employees_to_be_Hired)/Mobilization_Delay)$
OUTFLOWS:
 $Assimilation_Rate_of_Transferred_in_Company_Employees =$
 $Transferred_in_Company_Employees/Avg_Assimilation_Time_of_Transferred_in_Company$
 $_Employees$
 $Transferred_in_Company_Employees_Demobilization_Rate =$
 $MIN(Transferred_in_Company_Employees/DT, (Demobilization_Rate -$
 $(New_Hire_in_Demobilization_Rate + Experienced_Hire_in_Demobilization_Rate)))$
 $Transferred_in_Company_Employees_1(t) = Transferred_in_Company_Employees_1(t - dt)$
 $INIT Transferred_in_Company_Employees_1 = 0$
 $Transferred_in_Company_Employees_Costs_to_Date(t) =$
 $Transferred_in_Company_Employees_Costs_to_Date(t - dt) +$
 $(Regular_Daily_Salary_of_Transferred_in_Company_Employees) * dt$
 $INIT Transferred_in_Company_Employees_Costs_to_Date = 0$
INFLOWS:
 $Regular_Daily_Salary_of_Transferred_in_Company_Employees =$
 $IF(Fraction_of_Released_Tasks < 0.9999)THEN(Transferred_in_Company_Employees *$
 $Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate *$
 $Avg_Daily_Labor_Force_Per_Staff * Normal_Work_Hours_per_Day)ELSE(0)$

Undiscoverd__Unsuccessfully__Processed_Tasks(t) =

Undiscoverd__Unsuccessfully__Processed_Tasks(t - dt) + (Unsuccessful__Processing_Rate +
Uncessesful__Rework_Rate - Intraphase_Unsuccessfully_processed_Task_Discovery_Rate -
Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks -
Upstream_Defective_Task_Discovery_Rate) * dt

INIT Undiscoverd__Unsuccessfully__Processed_Tasks = 0 {Tasks}

INFLOWS:

Unsuccessful__Processing_Rate = Regular__Processing_Rate-Successful__Processing_Rate

Uncessesful__Rework_Rate = Rework_Rate-Sucessful__Rework_Rate

OUTFLOWS:

Intraphase_Unsuccessfully_processed_Task_Discovery_Rate =

Unsuccessfully_processed_Task_Dicoverry_Rate-Upstream_Defective_Task_Discovery_Rate

Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks =

Quality__Assurance_Rate_1-Unsuccessfully_processed_Task_Dicoverry_Rate {Tasks/Days}

Upstream_Defective_Task_Discovery_Rate =

Fraction_of_Inherited_Unsuccessfully_Processed_Tasks*Unsuccessfully_processed_Task_Di
covery_Rate

Unsuccessfully_Processed_Tasks_Approved_to_be_Released(t) =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released(t - dt) +

(Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks -

Unsuccessfully_Processed_Tasks_Release_Rate) * dt

INIT Unsuccessfully_Processed_Tasks_Approved_to_be_Released = 0

INFLOWS:

Approval_Rate_of_Undiscoverd_Unsuccessfully_Processed_Tasks =

Quality__Assurance_Rate_1-Unsuccessfully_processed_Task_Dicoverry_Rate {Tasks/Days}

OUTFLOWS:

Unsuccessfully_Processed_Tasks_Release_Rate =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

Unsuccessfully_Processed_Tasks_Released(t) = Unsuccessfully_Processed_Tasks_Released(t
- dt) + (Unsuccessfully_Processed_Tasks_Release_Rate -

Intraphase_Defective_Tasks_Coordinated_with_Downstream) * dt

INIT Unsuccessfully_Processed_Tasks_Released = 0

INFLOWS:

Unsuccessfully_Processed_Tasks_Release_Rate =

Unsuccessfully_Processed_Tasks_Approved_to_be_Released/Time_to_Release_Tasks

OUTFLOWS:

Intraphase_Defective_Tasks_Coordinated_with_Downstream =

Fraction_of_Coordinated_Tasks_from_Downstream

Actual_Labor_Force_Required =

Perceived_Present_Condition_PPC+Perceived_Present_Condition_PPC*Output*Time_to_Perceive_Trend_TPT

Actual_Productivity = Total_Released_Tasks/(Cumulative_Man_Days_Expended+1)

Average_Nominal_Potential_Productivity =

Fraction_of_Experienced_Employees*Reference_Potential_Productivity_of_Experienced_Employees+

Fraction_of_New_Employees*Reference_Potential_Productivity_of_New_Employees+

Reference_Potential_Productivity_of_Experienced_Hire_in*Fraction_of_Experienced_Hire_in+

Reference_Potential_Productivity_of__NewHire_in*Fraction_of_New_Hire_in+Reference_Potential_Productivity_of_Transferredin_Company_Employees*Fraction_of_Transferred_in_Company_Employees

Avg_Assimilation_&_Hiring_Time_of_New_Employees =

Avg_Hiring_Time_of_New_Employees+Avg_Assimilation_Time_of_New_Employees

Avg_Assimilation_&_Hiring_Time_of_New_Hire_in =

Avg_Hiring_Time_of_New_Hire_in+Avg_Assimilation_Time_of_New_Hire_in

Avg_Assimilation_Time_of_New_Employees = 60

Avg_Assimilation_Time_of_New_Hire_in = 20

Avg_Assimilation_Time_of_Transferred_in_Company_Employees = 20

Avg_Daily_Labor_Force_Per_Staff = 1 {Unit- Unitless=days/days}

Avg_Employment_Duration_of_Hire_In_Externally = 220

Avg_Hiring_Time_of_New_Employees = 40

Avg_Hiring_Time_of_New_Hire_in = 14

Avg_Hourly_Overtime_Pay_Rate = 1000

Budget_Status = -0.5

Ceiling_on_New_Labor_Force =

Full_Time_Equivalent_of_Experienced_Labor_Force*Max_New_Hires_Per_Full_Time_Experienced_Labor_Force

Ceiling_on_Total_Labor_Force = Ceiling_on_New_Labor_Force+Experienced_Labor_Force

Converter_13 = Fraction_of_Completed_Tasks_Data*Phase_Scope_Data

Converter_3 = Cumulative_Man_Days_Expended_for_Development_Activities*7.5

Coordinated_Tasks_to_be_Sent_to_Upstream =

Upstream_Defective_Task_Discovery_Rate*Upstream_Phase_Scope/Current_Scope

Cost_Effect_on_Regular_Processing_Importance = GRAPH(Budget_Status)

(-1.00, 1.87), (-0.9, 1.58), (-0.8, 1.35), (-0.7, 1.17), (-0.6, 1.06), (-0.5, 1.00), (-0.4, 0.98), (-0.3, 0.95), (-0.2, 0.89), (-0.1, 0.81), (0.00, 0.65)

Cumulative_ManHours_Expended = Cumulative_Man_Days_Expended*7.5

Cumulative_Manhours_Expended_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 4507), (37.0, 12024), (56.0, 21377), (75.0, 26957), (94.0, 32510), (112, 39513), (131, 46341), (150, 53055), (169, 60925), (187, 67437), (206, 73680), (225, 79348), (244, 84175), (262, 90910), (281, 96257), (300, 100940), (319, 105155), (337, 108653), (356, 112487), (375, 116351), (394, 119648), (412, 121651), (431, 125092), (450, 127235), (469, 128831), (487, 132501), (506, 135390), (525, 137423), (543, 140341), (562, 142996), (581, 145259), (600, 148007), (618, 149767), (637, 152215)

Current_Quality = 1-

(Discovered_Unsuccessfully_Processed_Tasks/(Total_Released_Tasks+Successfully_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks_Approved_to_be_Released+Undiscovered_Unsuccessfully_Processed_Tasks+Successfully_Processed_Tasks+0.00001))

Current_Quality_Assurance_Productivity =

(Quality_Assurance_Rate_1+Quality_Assurance_Rate_2)/(Daily_Labor_Force_to_Quality_Assurance+0.00001)

Current_Regular_Processing_Productivity =

Regular_Processing_Rate/(Daily_Labor_Force_to_Regular_Processing+0.00001)

Current_Rework_Productivity = Rework_Rate/(Daily_Labor_Force_to_Rework+0.00001)

Current_Scope = Scope_of_work

Daily_Labor_Force_to_Quality_Assurance =

Daily_Labor_Force_for_Development_Activities*Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog+0*Labor_Fraction_to_Quality_Assurance

Daily_Labor_Force_to_Regular_Processing =

Daily_Labor_Force_for_Development_Activities*Labor_Force_Fraction_to_Regular_Processing_due_to_backlog+0*Labor_Fraction_to_Regular_Processing {People-day/day=People*(day/day)}

Daily_Labor_Force_to_Rework =

Daily_Labor_Force_for_Development_Activities*Labor_Force_Fraction_to_Rework_due_to_backlog+0*Labor_Fraction_to_Rework

Daily_QA_Labor_Force_for_UnSuccessfully_Processed_Tasks =

Daily_Labor_Force_to_Quality_Assurance*(Undiscovered_Unsuccessfully_Processed_Tasks/Total_Tasks_to_QA)

Daily_QA_Labor_force_to_Successfully_Processed_Tasks =

Daily_Labor_Force_to_Quality_Assurance*(Successfully_Processed_Tasks/Total_Tasks_to_QA)

Deadline_for_the_Remaining_30%_Phase_Scope =

0.7*Initial_Project_Deadline_for_the_Phase

Demobilization_Delay = 10

Demobilization_Rate = MAX(0,-Labor_Force_Gap/Demobilization_Delay)

Desired_Labor_Force_for_Quality_Assurance =

(Quality_Assurance_Processing_Limit_from_Task_Availability_1+Quality_Assurance_Processing_Limit_from_Task_Availability_2)/(Perceived_Quality_Assurance_Productivity+0.1)

Desired_Labor_Force_for_Regular_Processing =

Regular_Processing_Limit_from_Task_Availability/(Perceived_Regular_Processing_Productivity+0.1)

Desired_Labor_Force_for_Rework =

Rework_Processing_Limit_from_Task_Availability/(Perceived_Rework_Productivity+0.1)

Desired_No_New_Employees_to_be_Hired =

Labor_Force_Gap*New_Employees_Hiring_Fraction

Desired_No_New_Hire_in_to_be_Hired =

MIN(Max_No_New_Hire_in_that_could_be_Hired,Labor__Force_Gap*New_Hire_in_Hiring_Fraction)

Desired_Productivity = Remaining_Tasks/(Total_Available_Man_Days+0.00001)

Desire_for_LF_Stability_Effect_on_WCLF = GRAPH((Project_Deadline_for_the_Phase-Time)/

(Avg_Assimilation_Time_of_Transferred_in_Company_Employees+Mobilization_Delay))

(0.00, 0.00), (0.3, 0.00), (0.6, 0.1), (0.9, 0.4), (1.20, 0.85), (1.50, 1.00), (1.80, 1.00), (2.10, 1.00), (2.40, 1.00), (2.70, 1.00), (3.00, 1.00)

Desire_for_Schedule_Stability_Effect_on_WCLF =

GRAPH(Project_Deadline_for_the_Phase/(Maximum_Tolerable_Project_Completion_Date))

(0.86, 0.00), (0.88, 0.1), (0.9, 0.2), (0.92, 0.35), (0.94, 0.6), (0.96, 0.7), (0.98, 0.77), (1.00, 0.89), (1.05, 1.00)

Dummy_Variable = 1 {Invalid number only used to allow the model run}

Effect_of_Experience_on_QoP = GRAPH(Fraction_of_Experienced_Labor_Force)

(0.00, 0.5), (0.2, 0.6), (0.4, 0.7), (0.6, 0.8), (0.8, 0.9), (1.00, 1.00)

Effect_of_Fatigue_on_QoP = GRAPH(Exhaustion_Due_to_Overtime_Work)

(0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9), (20.0, 0.89)

Effect_of_Schedule_Pressure_on_QoP = GRAPH(Schedule_Pressure)

(0.00, 1.00), (0.5, 0.99), (1.00, 0.97), (1.50, 0.94), (2.00, 0.9), (2.50, 0.85), (3.00, 0.79), (3.50, 0.72), (4.00, 0.64), (4.50, 0.55), (5.00, 0.45)

Effect_of_Schedule_Pressure_on_Regular_Processing_Importance = 1 {Invalid number only used to allow the model run}

Exhaustion_Depletion_Time = 10 {Days}

Exhaustion_Level_Effect_on_Overtime_Duration =

GRAPH(Exhaustion_Due_to_Overtime_Work/Maximum_Tolerable_Exhaustion_Level {Unitless =exhaustion/exhaustion})

(0.00, 1.00), (0.1, 0.9), (0.2, 0.8), (0.3, 0.7), (0.4, 0.6), (0.5, 0.5), (0.6, 0.4), (0.7, 0.3), (0.8, 0.2), (0.9, 0.1), (1.00, 0.00)

Expected_Average_Productivity = Planned_Productivity*Weight_to_Planned_Productivity + (1-Weight_to_Planned_Productivity)*Actual_Productivity

Experienced_Employee_Avg_Hourly_Pay_Rate = 650

Experienced_Employee_Quit_Fraction = 0.05/240

Experienced_Hired_in_Externally_Avg_Hourly_Pay_Rate = 800

Experienced_Labor_Force = Experienced_Employees+Experienced_Hired_in_Externally

Experience_Effect_on_Quality_of_Practice = GRAPH(Fraction_of_Experienced_Employees)
(0.00, 2.00), (0.2, 1.80), (0.4, 1.60), (0.6, 1.40), (0.8, 1.20), (1.00, 1.00)

External_Precedence_from_Down_stream = Fraction_of_Released_Tasks_from_Downstream

External_Precedence_from_Up_stream =

GRAPH(Engineering_For_Procurement.Fraction_of_Released_Tasks)

(0.241, 0.208), (0.457, 0.421), (0.628, 0.583), (0.753, 0.7), (0.846, 0.82), (0.904, 0.852),
(0.94, 0.899), (0.972, 0.941), (0.994, 0.98), (1.00, 1.00)

External_Precedence_Relation = MIN(External_Precedence_from_Down_stream,

External_Precedence_from_Up_stream)

Fatigue_Effect_on_Labor_Force_Productivity =

GRAPH(Exhaustion_Due_to_Overtime_Work)

(0.00, 1.00), (5.00, 0.94), (10.0, 0.92), (15.0, 0.9), (20.0, 0.89)

Fraction_of_Completed_Tasks_Data = GRAPH(TIME)

(0.00, 0.00), (19.0, 0.041), (37.0, 0.109), (56.0, 0.192), (75.0, 0.25), (94.0, 0.308), (112,
0.373), (131, 0.436), (150, 0.507), (169, 0.575), (187, 0.58), (206, 0.612), (225, 0.642), (244,
0.656), (262, 0.69), (281, 0.716), (300, 0.736), (319, 0.771), (337, 0.758), (356, 0.788), (375,
0.814), (394, 0.837), (412, 0.85), (431, 0.868), (450, 0.881), (469, 0.864), (487, 0.88), (506,
0.896), (525, 0.904), (543, 0.913), (562, 0.918), (581, 0.929), (600, 0.942), (618, 0.949), (637,
0.958)

Fraction_of_Coordinated_Tasks_from_Downstream = 0

Fraction_of_Defective_Tasks_Discoverd_by_Downstream =

Defective_Tasks_Discoverd_by_Downstream/(Discovered_Unsucessfully_Processed_Tasks+
0.00001)

Fraction_of_Experienced_Employees =

Experienced_Employees/(Total_Labor_Force+0.00001)

Fraction_of_Experienced_Hire_in =

Experienced_Hired_in_Externally/(Total_Labor_Force+0.00001)

$$\text{Fraction_of_Experienced_Labor_Force} = \frac{\text{Experienced_Labor_Force}}{(\text{Total_Labor_Force} + 0.00000001)}$$

$$\text{Fraction_of_Inherited_Unsuccessfully_Processed_Tasks} = \text{Engineering_For_Procurement.Fraction_of_Unsuccessfully_Processed_Tasks_Released}$$

$$\text{Fraction_of_New_Employees} = \frac{\text{New_Employees}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_New_Hire_in} = \frac{\text{New_Hire_in}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_Released_Tasks} = \frac{\text{Total_Released_Tasks}}{\text{Current_Scope}}$$

$$\text{Fraction_of_Released_Tasks_from_Downstream} = 1$$

$$\text{Fraction_of_Tasks_Perceived_Completed} = \frac{\text{Tasks_Perceived_Completed}}{\text{Current_Scope}}$$

$$\text{Fraction_of_Transferred_in_Company_Employees} = \frac{\text{Transferred_in_Company_Employees}}{(\text{Total_Labor_Force} + 0.00001)}$$

$$\text{Fraction_of_Unsuccessfully_Processed_Tasks_Released} = \frac{\text{Unsuccessfully_Processed_Tasks_Released}}{(\text{Total_Released_Tasks} + 0.000001)}$$

$$\text{Full_Time_Equivalent_of_Experienced_Labor_Force} = \text{Experienced_Labor_Force} * \text{Avg_Daily_Labor_Force_Per_Staff}$$

$$\text{Full_Time_Equivalent_Labor_Force} = \text{Avg_Daily_Labor_Force_Per_Staff} * \text{Total_Labor_Force} \quad \{\text{People} = \text{People} * (\text{Days} / \text{Days})\}$$

$$\text{Hours_to_ManDays_Convertor} = 1 / 7.5 \quad \{\text{People-Day/Hour}\}$$

$$\text{Indicated_Completion_date_for_65\%_of_Phase_Scope} = \text{IF} \\ (\text{Remaining_Tasks} > \text{Thirty_five_ \%_of_Phase_Scope} > 0) \text{ THEN} \\ (\text{TIME} + \text{Perceived_Project_Completion_Time_Still_Required}) \text{ ELSE } (0)$$

$$\text{Indicated_Completion_Date_for_the_Phase} = \text{TIME} + \text{Perceived_Project_Completion_Time_Still_Required} \quad \{\text{Days} = \text{Days} + \text{Days}\}$$

$$\text{Indicated_Labor_Force} = \frac{(\text{Total_Man_Days_Perceived_Still_Needed} / \text{Time_Remaining_to_Deadline})}{\text{Avg_Daily_Labor_Force_Per_Staff}}$$

$$\text{Indicated_Trend_ITREND} = \frac{(\text{Perceived_Present_Condition_PPC} - \text{Reference_Condition_RC})}{(1 + \text{Reference_Condition_RC})} / \text{Time_Horizon_for_Reference_Condition_THRC}$$

$$\text{Initial_internal_Deadline} = 187$$

$$\text{initial_Project_Deadline_for_the_Phase} = 712$$

Initial_Total_Labor_Force = 39

Input = Labor_Force_Sought

Internal_Deadline_Adjustment_Time = 5

Internal_Precedence_Relation = GRAPH(Fraction_of_Tasks_Perceived_Completed)
 (0.00, 0.034), (0.1, 0.208), (0.2, 0.421), (0.3, 0.583), (0.4, 0.675), (0.5, 0.788), (0.6, 0.852),
 (0.7, 0.899), (0.8, 0.941), (0.9, 0.98), (1.00, 1.00)

Inverse_of_SP_Tolerance_time = GRAPH(Schedule_Pressure)
 (1.00, 0.00), (1.10, 0.03), (1.15, 0.04), (1.20, 0.16), (1.30, 1.00)

Inverse_of_SP_Tolerance_Time_1 = GRAPH(Schedule_Pressure)
 (1.00, 0.00), (1.10, 0.0055), (1.15, 0.0083), (1.20, 0.03), (1.30, 0.2)

Labor_Force_Fraction_to_Quality_Assurance_due_to_backlog =
 Desired_Labor_Force_for_Quality_Assurance/(Total_Desired_Labor_Force_for_Engineering
 _Activities+0.00001)

Labor_Force_Fraction_to_Regular_Processing_due_to_backlog =
 Desired_Labor_Force_for_Regular_Processing/(Total_Desired_Labor_Force_for_Engineerin
 g_Activities+0.00001)

Labor_Force_Fraction_to_Rework_due_to_backlog =
 Desired_Labor_Force_for_Rework/(Total_Desired_Labor_Force_for_Engineering_Activities
 +0.00001)

Labor_Force_Needed =
 MIN((Willingness_to_Change_Labor_Force_Level*Indicated_Labor_Force+(1-
 Willingness_to_Change_Labor_Force_Level)*Total_Labor_Force),Indicated_Labor_Force)

Labor_Force_Productivity =
 Potential_Productivity*Total_Effect_on_Labor_Force_Productivity {Tasks/People-day}

Labor_Force_Sought = MIN(Labor_Force_Needed,Ceiling_on_Total_Labor_Force)

Labor_Fraction_to_Quality_Assurance =
 Pressure_for_Quality_Assurance/Total_Pressure__for_Activities*0+0.1 {This number is used
 to help the model run}

Labor_Fraction_to_Regular_Processing =
 Pressure_for__Regular_Processing/Total_Pressure__for_Activities*0+0.7 {This number is
 used to help the model run}

$Labor_Fraction_to_Rework = Pressure_for_Rework/Total_Pressure_for_Activities*0+0.1$
 {This number is used to help the model run}
 $Labor_Size_Effect_on_Productivity = 1$ {Invalid number only used to allow the model run}
 $Labor_Force_Gap = Labor_Force_Sought*0+Actual_Labor_Force_Required-$
 $Total_Labor_Force$
 $Learning_Effect_on_Potential_Productivity =$
 $GRAPH(Percent_of_Tasks_Actually_Completed)$
 (0.00, 1.00), (0.1, 1.01), (0.2, 1.03), (0.3, 1.05), (0.4, 1.10), (0.5, 1.15), (0.6, 1.22), (0.7, 1.26),
 (0.8, 1.29), (0.9, 1.30), (1.00, 1.30)
 $Managerial_Effect_on_Productivity = 1$ {Invalid number only used to allow the model run}
 $ManDay_Equivalence_of_Overtime_Hrs_worked_per_Day =$
 $Total_Overtime_Hrs_Worked_Per_Day*Hours_to_ManDays_Convertor$ {People-Day/Day}
 $Maximum_Allowed_Overtime_Hours_Per_Day_per_Employee = 2$ {hours/People-Days}
 $Maximum_Internal_Deadline_Extention = 40$
 $Maximum_Overtime_Hours_that_Can_be_worked =$
 $Overtime_Duration_Threshold*Full_Time_Equivalent_Labor_Force*Maximum_Allowed_Overtime_Hours_Per_Day_per_Employee*Willingness_To_Work_Overtime$
 {hours=Days*People*(hours/People-Days)*Unitless}
 $Maximum_Tolerable_Exhaustion_Level = 20$ {exhaustion}
 $Maximum_Tolerable_Internal_Deadline =$
 $Initial_internal_Deadline+Maximum_Internal_Deadline_Extention$
 $Maximum_Tolerable_Project_Completion_Date =$
 $initial_Project_Deadline_for_the_Phase+Max_Scheduled_Completion_Extention_Dates$
 $Max_Hire_in_Fraction_Allowed = 0.3$
 $Max_New_Hires_Per_Full_Time_Experienced_Labor_Force = 2$
 $Max_No_New_Hire_in_that_could_be_Hired = MAX(0,(Perceived_Layoff_in_Hire_in +$
 $Max_No_Hire_in_Allowed -Experienced_Hired_in_Externally -New_Hire_in))$
 $Max_No_Hire_in_Allowed = Total_Labor_Force*Max_Hire_in_Fraction_Allowed$
 $Max_Scheduled_Completion_Extention_Dates = 0$
 $Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline = 20$
 $Minimum_QA_Duration_per_Task = 0.13$

Minimum_Regular_Processing_Duration_per_Task = 1

Minimum_Rework_Duration_per_Task =

Minimum_Rework_Duration_per_Task_Discovered_in_the_Phase*(1-
 Fraction_of_Defective_Tasks_Discovered_by_Downstream)+Minimum_Rework_Duration_per_Task_Discovered_outside_the_phase*Fraction_of_Defective_Tasks_Discovered_by_Downstream

Minimum_Rework_Duration_per_Task_Discovered_in_the_Phase = 0.133 {0.133 days = 1hrs/7.5 hrs/day}

Minimum_Rework_Duration_per_Task_Discovered_outside_the_phase = 0.5 {days}

Mobilization_Delay = 10

Negative_Schedule_Pressure_Effect_on_Labor_Force_Productivity =

GRAPH(Avg_Schedule_Pressure)

(0.7, 1.00), (0.8, 1.00), (0.9, 1.00), (1.00, 1.00), (1.10, 0.98), (1.20, 0.95), (1.30, 0.9), (1.40, 0.8), (1.50, 0.68), (1.60, 0.55), (1.70, 0.45), (1.80, 0.4)

New_Employees_Avg_Hourly_Pay_Rate = 400

New_Employees__Hiring_Fraction =

GRAPH(Time_to_Project_Deadline/Avg_Assimilation_&_Hiring_Time_of_New_Employees)

(0.00, 0.00), (0.3, 0.00), (0.6, 0.00), (0.9, 0.00), (1.20, 0.01), (1.50, 0.04), (1.80, 0.08), (2.10, 0.15), (2.40, 0.25), (2.70, 0.33), (3.00, 0.33)

New_Hired_in_Externally_Avg_Hourly_Pay_Rate = 500

New_Hire_in_Hiring_Fraction =

GRAPH(Time_to_Project_Deadline/Avg_Assimilation_&_Hiring_Time_of_New_Hire_in)

(0.00, 0.5), (0.5, 0.5), (1.00, 0.35), (1.50, 0.3), (2.00, 0.25), (2.50, 0.17), (3.00, 0.1), (3.50, 0.03), (4.00, 0.03)

Nominal_Overtime_Duration_Threshold = GRAPH(Time_Remaining_to_Deadline {Days})

(0.00, 0.00), (5.00, 5.00), (10.0, 10.0), (15.0, 15.0), (20.0, 20.0)

Normal_Work_Hours_per_Day = 7.5 {hours/People-Days}

Normal_Work_Hours_per_Day_1 = 7.5 {hours/People-Days}

Output = Perceived_Trend_TREND

Overtime_Duration_Threshold =
 Exhaustion_Level_Effect_on_Overtime_Duration*Nominal_Overtime_Duration_Threshold
 {Days=Days*Unitless}

Overtime_Worked_per_Day_per_Full_Time_Equivalent_LF =
 Total_Overtime_Hours_that_will_be_Handled/(Full_Time__Equivalent_Labor_Force*Overti
 me_Duration_Threshold+0.0001)

Overtime_Work_Break_Indicator =
 IF(Overtime_Duration_Threshold=0)THEN(TIME+DT)ELSE(0) {days}

Perceived_Layoff_in_Hire_in =
 SMTH1((Experienced_Hire_in_Demobilization_Rate+New_Hire_in_Demobilization_Rate),
 10)

Perceived_Minimum_Quality_Assurance_Productivity = 0.1
 Perceived_Minimum_Regular_Processing_Productivity = 0.1
 Perceived_Minimum_Rework_Productivity = 0.1

Perceived_Net_Shortage_in_Man_Days = Total_Man_Days_Perceived_Still_Needed-
 Total_Available_Man_Days {People-Days=(People-Days)-(People-Days)}

Perceived_Rate_of_Increase_in_Exhaustion_Level =
 SMTH1(Rate_of_Increase_in_Exhaustion_Level, 1)

Perceived_Shortage_in_Man_Days = Perceived_Net_Shortage_in_Man_Days
 Perceived_Shortage_in_Man_Hours =
 Perceived_Shortage_in_Man_Days*Normal_Work_Hours_per_Day {hours=(People-
 Days)*(hours/(People-Days))}

Percent_of_Tasks_Actually_Completed = (Total_Tasks_Actually_Completed/Current_Scope)

Perceived_Man_Days_to_be_Handled_via_Overtime =
 Total_Overtime_Hours_that_will_be_Handled/Normal_Work_Hours_per_Day {People-
 Days= hours/(hours/People-Days)}

Perceived_Project_Completion_Time_Needed = (IF(Remaining_Tasks-
 Thirty_five_%_of__Phase_Scope>0)THEN((Remaining_Tasks-
 Thirty_five_%_of__Phase_Scope)/
 (Expected_Average_Productivity*Actual_Labor_Force_Required*Avg_Daily_Labor_Force_
 Per_Staff))ELSE((Remaining_Tasks)/

$(\text{Expected_Average_Productivity} * \text{Actual_Labor_Force_Required} * \text{Avg_Daily_Labor_Force_Per_Staff})) * 0 + (\text{Remaining_Tasks} / (\text{Expected_Average_Productivity} * \text{Actual_Labor_Force_Required} / \text{Avg_Daily_Labor_Force_Per_Staff}))$

Percieved_Project_Completion_Time_Still_Required =

Percieved_Project_Completion_Time_Needed-

Percieved_Work_Days_to_be_Recovered_Via_Overtime

Percieved_Work_Days_to_be_Recovered_Via_Overtime =

$\text{Percieved_Man_Days_to_be_handled_via_Overtime} / (\text{Full_Time_Equivalent_Labor_Force} + 0.99999)$ {Days= People-Days/People}

Phase_Scope_Data = GRAPH(TIME)

(0.00, 13439), (19.0, 13439), (37.0, 13439), (56.0, 13439), (75.0, 13439), (94.0, 13439), (112, 13439), (131, 13439), (150, 13439), (169, 13439), (187, 14715), (206, 14715), (225, 14715), (244, 14715), (262, 14715), (281, 14865), (300, 14865), (319, 14865), (337, 15674), (356, 15674), (375, 15674), (394, 15674), (412, 15674), (431, 15674), (450, 15674), (469, 16117), (487, 16117), (506, 16117), (525, 16117), (543, 16117), (562, 16182), (581, 16182), (600, 16182), (618, 16182), (637, 16182), (656, 16202), (675, 16202), (693, 16202), (712, 16202)

Planned_Productivity = GRAPH(TIME)

(0.00, 0.91), (19.0, 0.91), (37.0, 0.95), (56.0, 1.02), (75.0, 1.03), (94.0, 1.04), (112, 1.04), (131, 1.05), (150, 1.05), (169, 1.04)

Positive_Schedule_Pressure_Effect_on_Labor_Force_Productivity =

GRAPH(Schedule_Pressure)

(0.4, 0.8), (0.5, 0.8), (0.6, 0.8), (0.7, 0.82), (0.8, 0.88), (0.9, 0.95), (1.00, 1.00), (1.10, 1.08), (1.20, 1.15), (1.30, 1.21), (1.40, 1.27), (1.50, 1.30), (1.60, 1.30)

Potential_Productivity =

Learning_Effect_on_Potential_Productivity * Average_Nominal_Potential_Productivity

Pressure_for_Quality_Assurance =

$\text{EXP}(0 * \text{Required_Labor_Force_for_Quality_Assurance} * \text{Quality_Gap_Effect_on_RW\&QA_Importance} * \text{Quality_Assurance_Priority} / \text{Dummy_Variable})$

Pressure_for_Rework =

$\text{EXP}(0 * \text{Required_Labor_Force_for_Rework} * \text{Rework_Priority} * \text{Quality_Gap_Effect_on_RW\&QA_Importance} / \text{Dummy_Variable})$

Pressure_for_Regular_Processing =

(EXP(0*Required_Labor_for_Regular_Processing*Regular_Processing_Priority*Effect_of_Schedule_Pressure_on_Regular_Processing_Importance*Cost_Effect_on_Regular_Processing_Importance/Dummy_Variable))*0+1

Previous_Scope = HISTORY(Current_Scope, TIME-1)

Probability_of_Tasks_to_be_Sucessfully_Reworked = 1-

Probability_to_be_Defective_Rework_from_Quality_of_Practice

Probability_to_be_Defective_from_Quality_of_Practice =

GRAPH(Quality_of_Practice_in_Regular_Processing/Referance_Quality_of_Practice_in_Regular_Processing)

(0.00, 0.5), (0.1, 0.45), (0.2, 0.36), (0.3, 0.28), (0.4, 0.21), (0.5, 0.15), (0.6, 0.1), (0.7, 0.06), (0.8, 0.03), (0.9, 0.01), (1.00, 0.00)

Probability_to_be_Defective_Rework_from_Quality_of_Practice =

GRAPH(Quality_of_Practice_in_Rework/Reference_Quality_of_Practice_in_Rework)

(0.00, 0.5), (0.1, 0.45), (0.2, 0.36), (0.3, 0.28), (0.4, 0.21), (0.5, 0.15), (0.6, 0.1), (0.7, 0.06), (0.8, 0.03), (0.9, 0.01), (1.00, 0.00)

Probability_to_be_Defective_Task =

Probabilty_to_be_Defective_from_Inherent_Task_Complexity*Probability_to_be_Defective_from_Quality_of_Practice

Probabilty_to_be_Defective_from_Inherent_Task_Complexity = 0.1

Probabilty_to_Discover_Unsuccessfully_Processed_Tasks =

GRAPH(Quality_of_Practice_in_QA/Reference_Quality_of_Practice_in_QA)

(0.00, 0.00), (0.1, 0.3), (0.2, 0.4), (0.3, 0.6), (0.4, 0.75), (0.5, 0.8), (0.6, 0.85), (0.7, 0.9), (0.8, 0.92), (0.9, 0.95), (1.00, 1.00)

Productivity_Data = GRAPH(TIME)

(0.00, 0.91), (19.0, 0.91), (37.0, 0.91), (56.0, 0.91), (75.0, 0.94), (94.0, 0.95), (112, 0.95), (131, 0.95), (150, 0.96), (169, 0.95), (187, 0.95), (206, 0.92), (225, 0.89), (244, 0.86), (262, 0.84), (281, 0.83), (300, 0.81), (319, 0.82), (337, 0.82), (356, 0.82), (375, 0.82), (394, 0.82), (412, 0.82), (431, 0.82), (450, 0.81), (469, 0.81), (487, 0.8), (506, 0.8), (525, 0.8), (543, 0.79), (562, 0.78), (581, 0.78), (600, 0.77), (618, 0.77), (637, 0.76)

Productivity_in_Quality_Assurance =

Labor_Force_Productivity*QA_Productivity_Multiplier

Productivity__in_Rework = Labor_Force_Productivity*Rework_Productivity_Multiplier

Project_Deadline_Adjustment_Time = 5

QA_Productivity_Multiplier =

Minimum_Regular_Processing_Duration_per_Task/Minimum_QA_Duration_per_Task

Quality_Assurance_Priority = 1 {Invalid number only used to allow the model run}

Quality_Assurance_Processing_Limit =

(Quality_Assurance_Processing_Limit_from_Task_Availablity_1+Quality_Assurance_Proce
ssing_Limit_from_Task_Availablity_2)

Quality_Assurance_Processing_Limit_from_Resources_1 =

Daily_QA_Labor_Force_for_UnSucessfully_Processed_Tasks*Productivity_in_Quality_Ass
urance

Quality_Assurance_Processing_Limit_from_Resources_2 =

Daily_QA_Labor_force_to_Successfully_Processed_Tasks*Productivity_in_Quality_Assuran
ce

Quality_Assurance_Processing_Limit_from_Task_Availablity_1 =

(Undiscoverd__Unsuccessfully__Processed_Tasks/Minimum_QA_Duration_per_Task)

Quality_Assurance_Processing_Limit_from_Task_Availablity_2 =

(Successfully__Processed_Tasks/Minimum_QA_Duration_per_Task)

Quality_Assurance_Productivity_Report_Time = 5

Quality_Assurance_Rate_2 =

MIN(Quality_Assurance_Processing_Limit_from_Task_Availablity_2,Quality_Assurance_Pr
ocessing_Limit_from_Resources_2)

Quality_Gap = Current_Quality-Quality_Goal

Quality_Gap_Effect_on_RW&QA_Importance = GRAPH(Quality_Gap)

(-1.00, 2.20), (-0.9, 2.14), (-0.8, 2.07), (-0.7, 1.99), (-0.6, 1.90), (-0.5, 1.80), (-0.4, 1.68), (-0.3,
1.54), (-0.2, 1.38), (-0.1, 1.20), (0.00, 1.00)

Quality_Goal_Adjustment_Time = 30

Quality_of_Practice =
 Effect_of_Fatigue_on_QoP*Effect_of_Experience_on_QoP*Effect_of_Schedule_Pressure_o
 n_QoP
 Quality_of_Practice_in_QA = Quality_of_Practice*Reference_Quality_of_Practice_in_QA
 Quality_of_Practice_in_Regular_Processing =
 Quality_of_Practice*Referance_Quality_of_Practice_in_Regular_Processing
 Quality_of_Practice_in_Rework =
 Quality_of_Practice*Reference_Quality_of_Practice_in_Rework
 Quality_Assurance_Rate_1 =
 MIN(Quality_Assurance_Processing_Limit_from_Resources_1,
 Quality_Assurance_Processing_Limit_from_Task_Availablity_1)
 Reference_Quality_of_Practice_in_Regular_Processing = 0.9
 Reference_Potential_Productivity_of_Experienced_Employees = 1
 Reference_Potential_Productivity_of_Experienced_Hire_in = 1
 Reference_Potential_Productivity_of_New_Employees = 0.5
 Reference_Potential_Productivity_of_Transferredin_Company_Employees = 0.8
 Reference_Potential_Productivity_of__NewHire_in = 0.8
 Reference_Quality_of_Practice_in_QA = 0.9
 Reference_Quality_of_Practice_in_Rework = 0.9
 Ref_Quality_Assurance_Productivity = 10
 Ref_Regular_Processing_Productivity = 0.88
 Ref_Rework_Productivity = 1.5
 Regular_Processing_Limit_from_Resources =
 Daily_Labor_Force_to_Regular__Processing*Labor_Force_Productivity {Tasks/day=
 (People-day/day)*(Tasks/People-day)}
 Regular_Processing_Limit_from_Task_Availability =
 Tasks_Available_for_Regular_Processing/Minimum_Regular_Processing_Duration_per_Tas
 k
 Regular_Processing_Priority = 1 {Invalid number only used to allow the model run}
 Regular_Processing_Productivity_Report_Time = 5

Regular__Processing_Rate =
MIN(Regular_Processing_Limit_from_Task_Availability,Regular_Processing_Limit_from_R
esources) {Tasks/Days}
Release_Package_Size = 0.015*Current_Scope
Release_Triger =
IF(Total_Tasks_to_be_Released>=Release_Package_Size)THEN(1)ELSE(0)
Remaining_Tasks = Current_Scope-Total_Released_Tasks
Required_Labor_Force_for_Quality_Assurance =
(Quality_Assurance_Processing_Limit/(Productivity_in_Quality_Assurance+1))+1
Required_Labor_Force_for_Rework =
(Rework_Processing_Limit_from_Task_Availablity/(Productivity__in_Rework+1))+1
Required_Labor_for_Regular_Processing =
(Regular_Processing_Limit_from_Task_Availability/(Labor_Force_Productivity+1))+1
Rework_Priority = 1 {Invalid number only used to allow the model run}
Rework_Processing_Limit_from_Resources =
Daily_Labor_Force_to_Rework*Productivity__in_Rework
Rework_Processing_Limit_from_Task_Availablity =
Discovered_Unsucessfully_Processed_Tasks/(Minimum_Rework_Duration_per_Task+0.000
01)
Rework_Productivity_Multiplier =
Minimum_Regular_Processing_Duration_per_Task/Minimum_Rework_Duration_per_Task
Rework_Productivity_Report_Time = 5
Rework_Rate =
MIN(Rework_Processing_Limit_from_Task_Availablity,Rework_Processing_Limit_from_R
esources)
Schedule_Pressure =
(Total_Man_Days_Perceived_Still_Needed)/(Total_Available_Man_Days+1)
Schedule_Pressure_Effect_on_Labor_Force_Productivity =
Positive_Schedule_Pressure_Effect_on_Labor_Force_Productivity*Negative_Schedule_Press
ure_Effect_on_Labor_Force_Productivity

$Scope_Change = (IF(Current_Scope - Previous_Scope > 0) THEN(STEP(Current_Scope - Previous_Scope, TIME)) ELSE(0))$
 $Scope_Change_Data = PULSE(1276,167,0)+PULSE(150,262,0)+PULSE(809,319,0)+$
 $PULSE(443,450,0)+PULSE(65,543,0)+PULSE(20,637,0)$
 $Scope_of_work = GRAPH(Total_Released_Tasks/Total_number_of_Tasks)$
 $(0.00, 13439), (0.47, 13439), (0.53, 14715), (0.63, 14715), (0.66, 14865), (0.71, 14865),$
 $(0.73, 15674), (0.85, 15674), (0.86, 16117), (0.91, 16117), (0.92, 16182), (0.96, 16182),$
 $(1.00, 16202)$
 $Tasks_Available_for_Regular_Processing = (MAX(0, Total_Tasks_Available -$
 $(Current_Scope - Tasks_Identified_to_be_Processed)))$
 $Tasks_Perceived_Completed =$
 $Successfully_Processed_Tasks + Undiscovered_Unsuccessfully_Processed_Tasks +$
 $Successfully_Processed_Tasks_Approved_to_be_Released + Unsuccessfully_Processed_Tasks_Approv$
 $ed_to_be_Released + Successfully_Processed_Tasks_Released + Unsuccessfully_Processed_Ta$
 $sks_Released$
 $Thirty_five_ \%_of_Phase_Scope = Current_Scope * 0.35$
 $Time_Horizon_for_Reference_Condition_THRC = 10$
 $Time_Remaining_to_Complete_75\%_of_the_Phase_Scope =$
 $(IF(Internal_Deadline > (15 + TIME)) THEN(Internal_Deadline - TIME) ELSE(15))$
 $Time_Remaining_to_Deadline =$
 $(IF((Internal_Deadline + Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline)$
 $> TIME) THEN(Time_Remaining_to_Internal_Deadline) ELSE($
 $MAX(Project_Deadline_for_the_Phase - TIME,$
 $1))) * 0 + (MAX(Project_Deadline_for_the_Phase - TIME, 1)) \{Days\}$
 $Time_Remaining_to_Internal_Deadline = IF(Remaining_Tasks -$
 $Thirty_five_ \%_of_Phase_Scope > 0)$
 $THEN(Time_Remaining_to_Complete_75\%_of_the_Phase_Scope) ELSE(IF(Remaining_Tas$
 $k - Thirty_five_ \%_of_Phase_Scope < 0 and$
 $(Internal_Deadline + Max_Time_to_Adjust_Labor_Force_Affected_by_Internal_Deadline) > TI$
 $ME) THEN(Adjustment_Towards_the_35\%_Phase_Scope_Deadline) ELSE(0))$
 $Time_to_Adjust_New_Deadline = 5$

$Time_to_adjust_Perceived_Quality_Assurance_Productivity = 20$
 $Time_to_adjust_Perceived_Regular_Processing_Productivity = 20$
 $Time_to_adjust_Perceived_Rework_Productivity = 20$
 $Time_to_Perceive_an_Increase_in_SP =$
 $1/(Inverse_of_SP_Tolerance_time_1+0*Inverse_Of_SP_Tolerance_time+0.00001)$
 $Time_to_Perceive_a_Decrease_in_SP = GRAPH(Avg_Schedule_Pressure)$
 $(1.00, 1e-06), (1.10, 5.00), (1.15, 20.9), (1.20, 63.3), (1.30, 180)$
 $Time_to_Perceive_Present_Conditions_TPPC = 5$
 $Time_to_Perceive_Trend_TPT = 5$
 $Time_to_Project_Deadline = 712-TIME$
 $Time_to_Release_Tasks = 5$
 $Total_Available_Man_Days =$
 $Actual_Labor_Force_Required*Avg_Daily_Labor_Force_Per_Staff*Time_Remaining_to_D$
 $eadline$
 $Total_Cost =$
 $Experienced_Employees_Costs_to_Date+Transferred_in_Company_Employees_Costs_to_D$
 $ate+New_Employees_Costs_to_Date+Overtime_Costs_to_Date+New_Hired_in_Externally_$
 $Costs_to_Date+Experienced_Hired_in_Externally_Costs_to_Date$
 $Total_Desired_Labor_Force_for_Engineering_Activities =$
 $Desired_Labor_Force_for_Regular_Processing+Desired_Labor_Force_for_Rework+Desired_$
 $Labor_Force_for_Quality_Assurance$
 $Total_Effect_on_Labor_Force_Productivity =$
 $Managerial_Effect_on_Productivity*Schedule_Pressure_Effect_on_Labor_Force_Productivit$
 $y*Fatigue_Effect_on_Labor_Force_Productivity*Labor_Size_Effect_on_Productivity$
 $Total_Hours_Worked_Per_Day_Per_Full_Time_Equivalent_LF =$
 $Overtime_Worked_per_Day_per_Full_Time_Equivalent_LF+Normal_Work_Hours_per_Day$
 $\{hours/People-Days\}$
 $Total_Labor_Force =$
 $New_Employees+Experienced_Employees+Transferred_in_Company_Employees+New_Hir$
 $e_in+Experienced_Hired_in_Externally$
 $Total_Labor_Force_Data = GRAPH(TIME)$

(0.00, 39.0), (19.0, 52.0), (37.0, 40.0), (56.0, 41.0), (75.0, 49.0), (94.0, 54.0), (112, 54.0),
 (131, 57.0), (150, 54.0), (169, 60.0), (188, 30.0), (207, 27.0), (226, 21.0), (245, 19.0), (264,
 17.0), (283, 16.0), (302, 13.0), (321, 12.0), (340, 10.0), (359, 10.0), (378, 10.0), (397, 10.0),
 (416, 10.0), (435, 12.0), (454, 11.0), (473, 11.0), (492, 10.0), (511, 10.0), (530, 8.00), (549,
 10.0), (568, 11.0), (587, 10.0), (606, 9.00), (625, 11.0), (644, 10.0), (663, 10.0), (682, 9.00),
 (701, 6.00), (712, 0.00)

Total_Man_Days_Perceived_Still_Needed = (IF(Remaining_Tasks-
 Thirty_five_%_of_Phase_Scope>0)THEN((Remaining_Tasks-
 Thirty_five_%_of_Phase_Scope)/Expected_Average_Productivity)ELSE(Remaining_Tasks/
 Expected_Average_Productivity))*0+ (Remaining_Tasks/Expected_Average_Productivity)

Total_Man_Days_Still_Required = Perceived_Net_Shortage_in_Man_Days-

Percieved_Man_Days_to_be_handled_via_Overtime {People-Days= (People-Days)-(People-
 Days)}

Total_number_of_Tasks = 16202

Total_Overtime_Hours_that_will_be_Handled =

MAX(MIN(Maximum_Overtime_Hours_that_Can_be_worked,Perceived_Shortage_in_Man_
 Hours), 0) {hours=(hours, hours)}

Total_Overtime_Hrs_Worked_Per_Day =

Overtime_Worked_per_Day_per_Full_Time_Equivalent_LF*Total_Labor_Force
 {Hours/Day}

Total_Pressure_for_Activities =

Pressure_for_Rework+Pressure_for_Quality_Assurance+Pressure_for_Regular_Processing

Total_Released_Tasks =

Successfully_Processed_Tasks_Released+Unsuccessfully_Processed_Tasks_Released

Total_Tasks_Available =

Current_Scope*MIN(Internal_Precedence_Relation,External_Precedence_Relation)

Total_Tasks_to_be_Released =

Successfully_Processed_Tasks_Approved_to_be_Released+Unsuccessfully_Processed_Tasks
 _Approved_to_be_Released+0.0000009

Total_Tasks_to_QA =

Successfully__Processed_Tasks+Undiscoverd__Unsuccessfully__Processed_Tasks+0.00001
 {This small number is used to avoid division by zero}

Trainers_per_New_Labor_Force = 0.2 {On average each new labor force consumes in training overhead the equivalent of 20% of an experienced labor force's daily working time for the duration of the training or assimilation period. Unit - Unitless = days/days}

Transferred_in_Company_Employees_Avg_Hourly_Pay_Rate = 500

Unsuccessfully_processed_Task_Discovery_Rate =

Quality__Assurance_Rate_1*Probablity_to_Discover_Unsuccessfully_Processed_Tasks

Weight_to_Planned_Productivity = GRAPH(Fraction_of_Released_Tasks)

(0.00, 1.00), (0.1, 0.9), (0.2, 0.7), (0.3, 0.5), (0.4, 0.3), (0.5, 0.1), (0.6, 0.00), (0.7, 0.00), (0.8, 0.00), (0.9, 0.00), (1.00, 0.00)

Willingness_to_Change_Labor_Force_Level =

MAX(Desire_for_Schedule_Stability_Effect_on_WCLF,Desire_for_LF_Stability_Effect_on_WCLF)

Willingness_To_Work_Overtime =

IF(TIME>=Time_To_Recover+Time_from_Last_Exhaustion_Break)THEN(1)ELSE(0)
 {Unitless =Unitless+Unitless}

Workload_Stress_Onset_time = IF Schedule_Pressure>Avg_Schedule_Pressure THEN

Time_to_Perceive_an_Increase_in_SP ELSE Time_to_Perceive_a_Decrease_in_SP

Total_Tasks_Actually_Completed =

Successfully_Processed_Tasks_Approved_to_be_Released +

Successfully_Processed_Tasks_Released + Unsuccessfully_Processed_Tasks_Released +

Unsuccessfully_Processed_Tasks_Approved_to_be_Released

Total_Tasks_in_the_Phase_at_Any_Time = Discovered_Unsuccessfully_Processed_Tasks +

Successfully_Processed_Tasks_Approved_to_be_Released +

Successfully_Processed_Tasks_Released + Successfully__Processed_Tasks +

Tasks_Identified_to_be_Processed + Undiscoverd__Unsuccessfully__Processed_Tasks +

Unsuccessfully_Processed_Tasks_Released +

Unsuccessfully_Processed_Tasks_Approved_to_be_Released

