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# Design Project Management Model with System Dynamics Approach

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**Abstract-** Projects are complex and dynamic systems, and their management requires dynamic and systems thinking. In this regard, the project managers do their best to achieve the goals desired by the stakeholders and prevent deviations in time, cost, quality, and resource allocation. However, non-considering the delays in a system approach causes errors that have already been created in the system to be discovered in the project's final steps. It will cause expensive rework, overtime, hiring additional workforce, re-allocation of resources, and deviation from the project schedule, resulting in reduced quality of the project and dissatisfaction among the stakeholders. In the present study, we will try to start the project by using the continuous systems simulation approach (system dynamics) with a simple but dynamic model and eliminate the model's shortcomings step by step through model simulation and with the help of Vensim software and complete the model with a systems perspective.

**Keywords-** Project management, System dynamics, Systems thinking, Team collaboration, System simulation, Error management, Delay management, Resource leveling.

**Introduction**

Project managers' problems become increasingly complex, and their solution requires systems thinking. Project managers often use a static view (discrete system simulation) to solve problems. It only hides the problem for a certain time [1, 2]. This discrete approach will cause non-solving problems and create bigger and more costly problems after a short period. The lack of a systems approach in project management has caused increased cost and time and failure to calculate delays and solve problems caused by delays in time. It ultimately will lead to project failure [3]. Static modeling approaches (discrete event simulation methods) in the best state determine how a change in the time required to complete a step may affect the total time to complete a project. However, the project manager can adjust the schedule by changing the time required for a few steps that have been directly affected to re-estimate and calculate the critical path and the required time re-allocation of resources to complete the project. However, the time required to perform other steps is assumed unchanged, meaning that all other interactions are ignored due to the lack of systems thinking [4].

Thus, many problems during the project are caused by unpredicted side effects of past performances and lack of calculating delays in time [5]. Additionally, most of these problem-solving policies in this approach will create temporary solutions that will not solve the problems and will create more problems in the future [6].

A project is a complex system that includes several interactive feedback processes [7]. Feedback processes are essential elements in system dynamics in project management. The traditional and static method of time and cost planning and resource allocation (discrete system simulation), such as critical path, does not receive feedback effects timely [8, 9]. Thus, the results of changes will often be incorrectly estimated if the project manager does not predict feedback and interactions and introduces changes manually without calculating delays. Generally, the classical approaches consider the project as a set of consecutive and parallel works that should be done at a specific cost and time. Therefore, they make detailed plans for all the steps and use different tools to implement and control the plans [1, 10].

In contrast, the system dynamics approach to project management provides a systemic and holistic view of the project. It tries to provide appropriate strategies in different situations by determining the role of each of the project variables and simulating their effects [11]. It is an object-oriented simulation method that helps to understand problems in complex and dynamic systems by modeling. The primary application of the system dynamics method is to find feedback processes that determine the system's dynamic behavior along with the stock and flow structures and time delays. The stocks and flows are the primary components of the system dynamics method, representing the effective interaction between variables in complex systems [2, 12].

The system dynamics (continuous event simulation method) looks more deeply at the interactions between system components. Hence, it can be used at strategic levels. This approach can show interactions qualitatively and is closely related to problem-solving structure and cause and effect graph. In this study, we are looking for an answer to the primary hypothesis that there is a relationship between systems thinking and problem-solving during the project. Then, an overview of the system dynamics models in project management will be presented. Then, using a simple model, we will continue the modeling process with the system dynamics approach. We will simulate and complete the model in each step using Vensim software [13].

**Literature review**

Jay Foster has taken a significant step in applying and developing systems thinking in practice by inventing the methodology of systems dynamics. Systems dynamics is a set of conceptual tools enabling us to understand the structure and dynamics of complex systems. Accordingly, we can design effective policies to achieve system goals by accurately modeling and simulating them [9, 14]. The most well-known application of system dynamics in project management is solving cost and schedule deviations. Studies in modeling changes and errors have focused on identifying factors affecting the success of change and error management processes]. One of the most recent studies focusing on change and error management has developed a methodology with a buffering approach to reduce uncertainty and a dynamic model. The system has been integrated into the construction and design to evaluate the effects of errors and changes on the performance of the project, simulation, and effectiveness of buffers [15, 16].

The structures used by system dynamics modelers to model projects can be divided into four groups. They include project characteristics, rework cycle, project control, and wave and sequential effects. The focal structure of system dynamics project models is a rework cycle that causes problematic behaviors developed during the project and causes many project management challenges. A significant issue in this area is the need to complete the order timely. Hence, delays in fulfilling the orders of customers, especially large customers, will lead to the loss of the organization's reputation and lag behind the competitors. Recent surveys suggest that more than 50% of large projects fail to achieve their goals in terms of cost and schedule [12]. In the system dynamics approach, strategic project management with the systems thinking approach leads to strategic decisions in the project design phase, directing operational decisions in that direction [8, 17].

The implementation of systems thinking in project management not only considers the relationships between different departments and the sequence of work in their field but also enables managers and analysts to check how a decision affects the entire performance of the project and make the appropriate and timely decision to change the goal if needed.The main difference between static project management (discrete event) and strategic project management (system dynamics and continuous event) is that it is impossible to change the goal . If project managers are faced with a lack of time and an accumulation of remaining tasks, The mental solution is to increase working hours or overtime, but in practice, problems arise that make the situation worse. Also, calculating errors and delays and their effects will be done dynamically. By doing this while removing the disadvantages of the model during implementation, we will prevent the accumulation of problems at the end of the project and, therefore, the need for a sudden increase in the hiring of people and the use of resources and expansion. We will not have time, and the project manager will achieve the desired goals and while fulfilling the wishes of the stakeholders, the possibility of project failure will be eliminated.

The significant difference between static project management (discrete event) and strategic project management (system dynamics and continuous event) is impossible to change the goal in a situation contingency. If project managers face a shortage of time and an accumulation of remaining work, they will increase working hours. However, some problems arise in practice, worsening the situation. However, in this study, by applying a strategic management approach (system dynamics approach), project scheduling, resource allocation and leveling, and calculation of errors and delays and their effects will be done dynamically. It will not only remove the shortcomings of the model during implementation but also prevent the accumulation of problems at the end of the project.

Hence, we will not need a sudden increase in the hiring of people, the use of resources, and the increase of time. Also, the project manager will achieve the desired goals. Accordingly, the wishes of the stakeholders will be fulfilled, and the possibility of project failure will be eliminated.

**Methodology**

The fundamental feature of any project is that the works or activities should be performed within a limited time. In other words, a project includes identifying works that need to be done, and their implementation is associated with a limited time and cost. In the simulation process in this study, we start with a simpler model and expand it according to the existing challenges and needs. In the proposed model, it is assumed that the project will be completed in 10 months. However, to ensure enough time to do the work, the project's duration is set to 24 months.

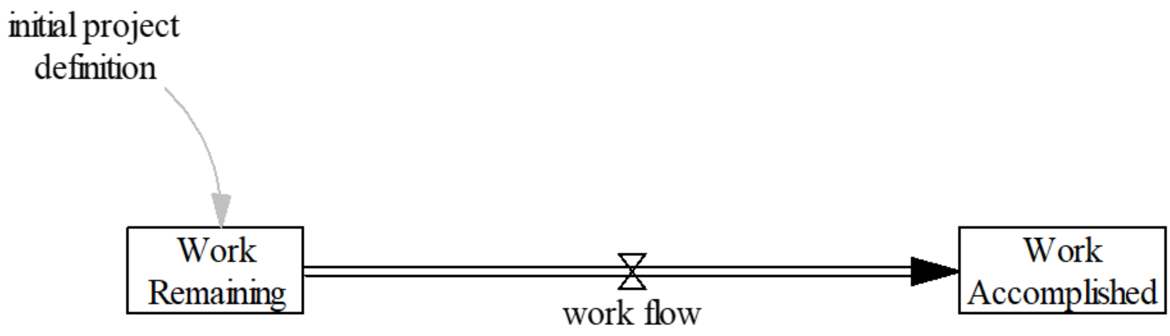
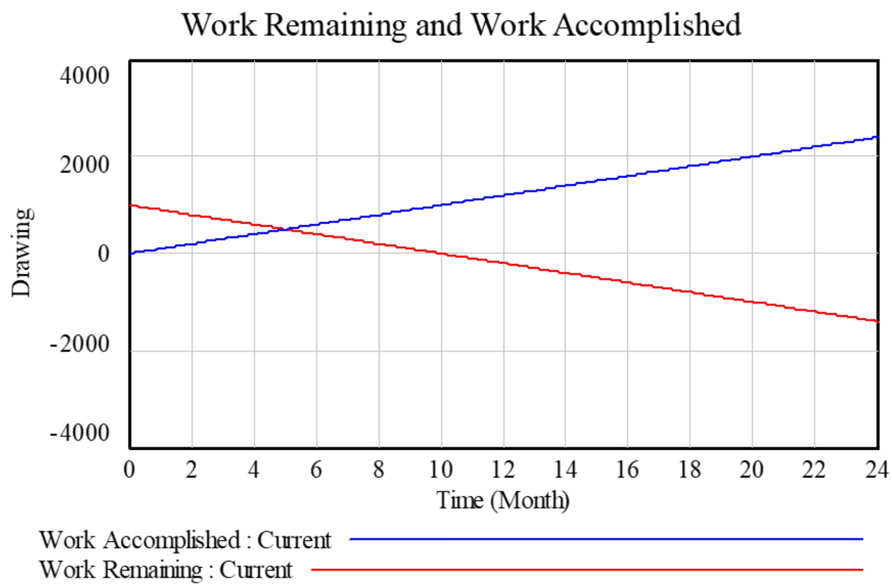



**Figure 1:** Initial workflow subsystem

The workflow in this project is 100 design units per month, meaning that 100 units of work are done every month.

Given what was stated above, we perform the simulation:




**Graph 1:** Work remaining and work accomplished under the initial workflow system

As shown in the red graph, the remaining work is zero after ten months, but work is still accomplished. In other words, there is no reason to close the project. It means that although the remaining work is zero, activities are ongoing, and work is being accomplished. It may be due to project parts that are completed over time. As a result, the project will continue without having any remaining work. There is a logical way to close the project model. The approach we choose here is to stop the activity at the end of the project. For this purpose, we add the concept "project is done" and create a connection from it to the workflow. The project's compliance with "project is done" instead of "work remaining" gives us a mechanism to reduce project scope if there are scheduling or budget problems. Here, we add the mentioned variable to the model:

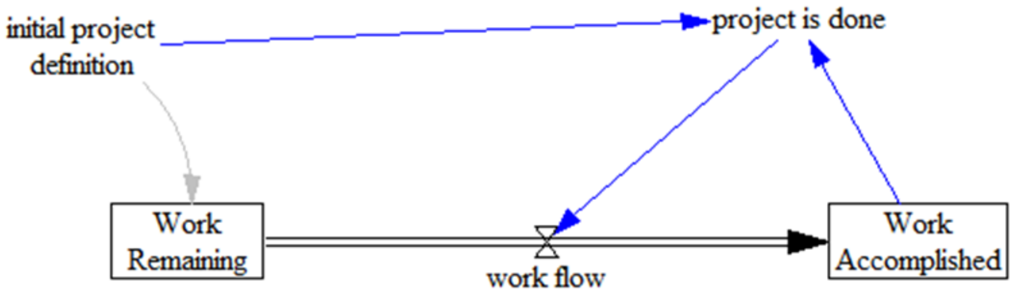
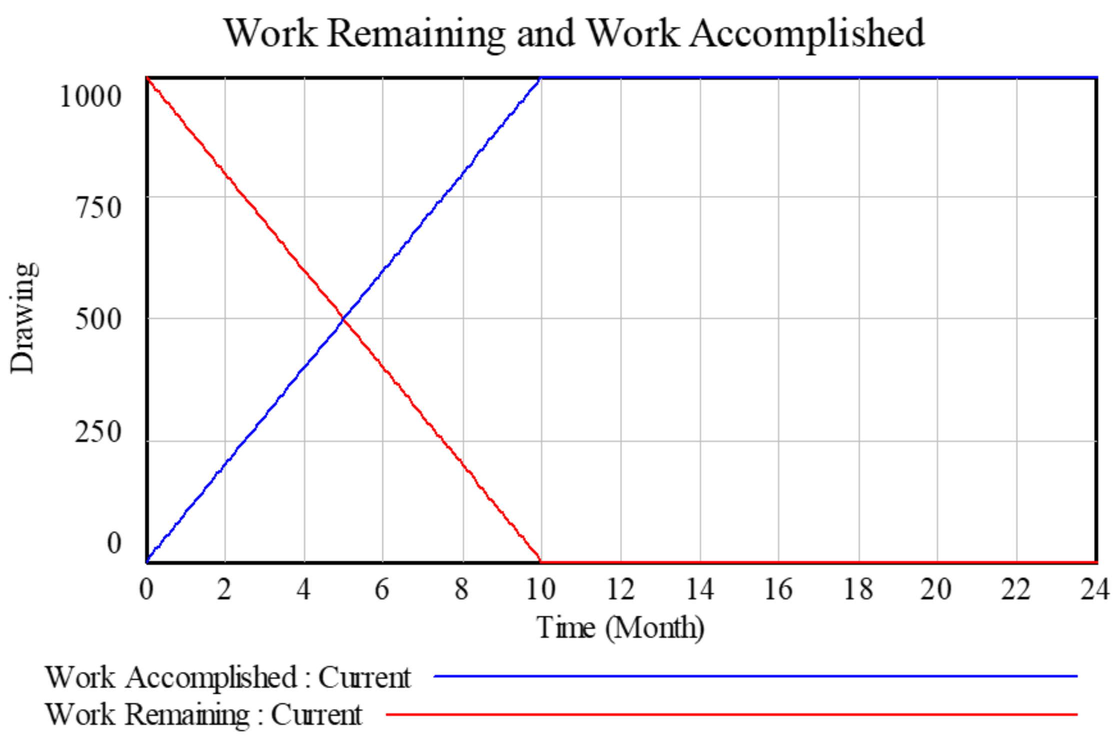



**Figure 2-** Subsystem of project's compliance with "project is done"

By applying the changes mentioned in the model equations and performing the simulation, we will have:




**Graph 2:** The work remaining and the work accomplished subsystem of project compliance with "project is done."

By applying these changes, the project is completed timely. The project completion means that all the activities have been done and the project is delivered timely. It indicates proper planning and control over the project schedule. Also, completing the project with a pre-determined budget means that financial resources have been used as expected and accurate financial planning. It indicates that the project was generally within the determined financial limits. In real projects, work is not always done without errors. Errors can occur due to various factors, such as a lack of proper communication between people, ignoring technical points, or simple mistakes. However, when errors occur, they are not detected at the moment of occurrence. In other words, errors remain hidden until a check or integration activity is performed and they are exposed.

Detection of errors is an essential part of the project management process. Errors may remain hidden until specific checks or integrations are performed. These activities act as checkpoints where errors are detected and exposed. During these checks or integrations, project entities can identify and react appropriately to any errors or mismatches that occur during the project. Management and eliminating errors effectively is a significant component of project management. It includes implementing quality control measures, conducting regular checks and inspections, facilitating effective communication between team members, and creating a culture of continuous improvement. Accordingly, project managers can reduce the impact of errors on the project and achieve successful work outcomes. The graph is drawn in a way to show the parallel flow of work with the accumulation of errors in "undiscovered rework" and the recursive flow from "work accomplished" to "work remaining ". By drawing the graph this way, we can visually show the impact of errors on the project. This approach addresses errors occurring throughout the workflow and may lead to undiscovered rework. Therefore, we expand the model as follows:

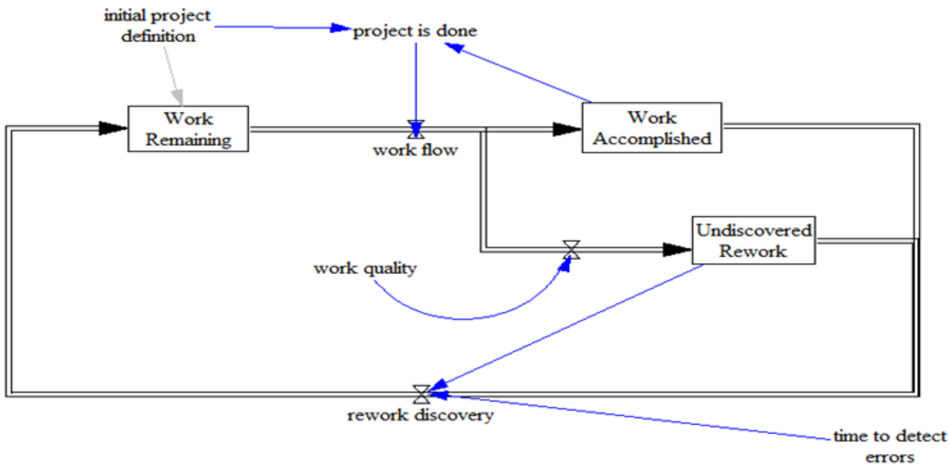
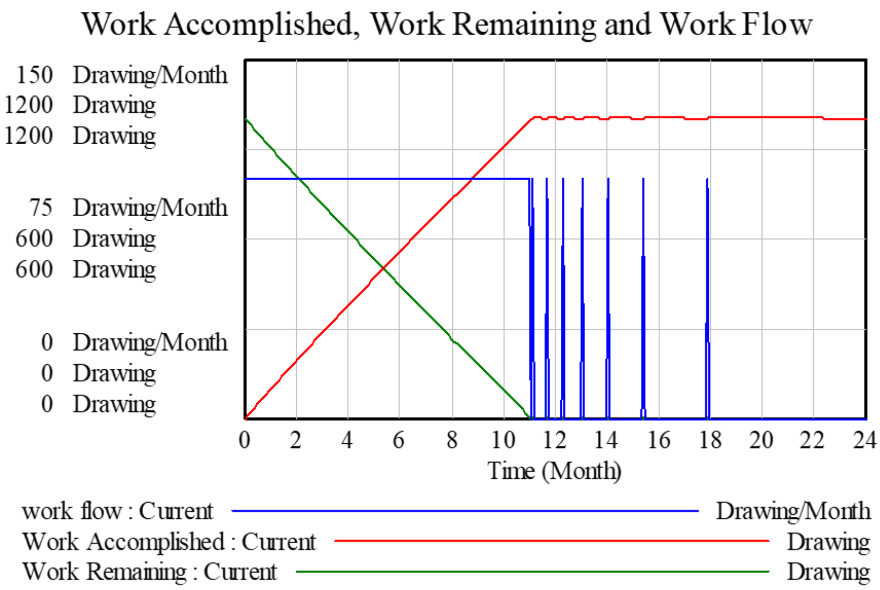



**Figure 3: The subsystem of dynamic application of the impact of errors on the project**

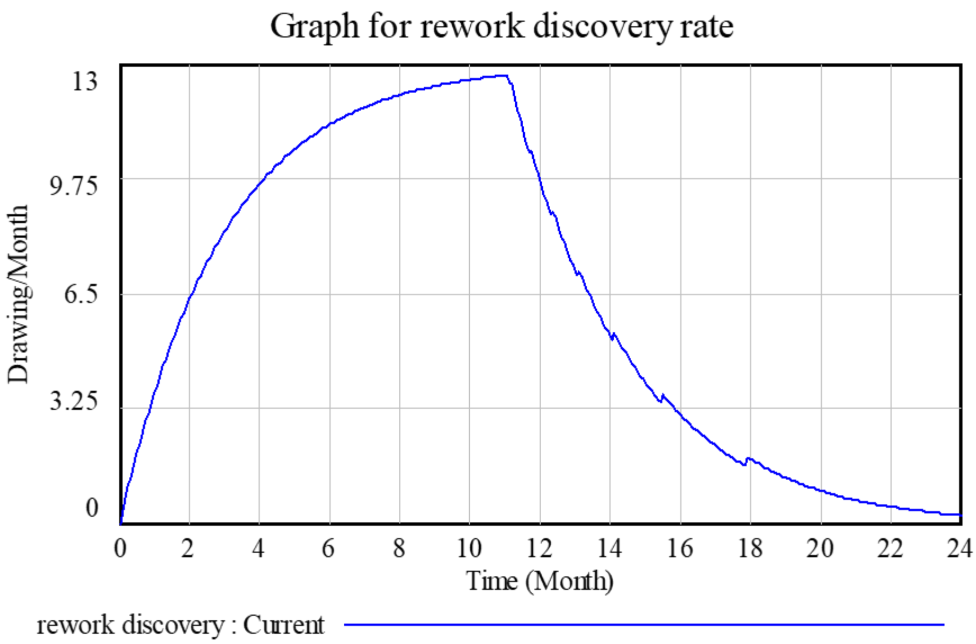
In this Figure, "undiscovered rework" indicates the accumulation of errors that have not yet been detected. As work progresses, errors can accumulate and will not be detected until check or integration activities are performed. A recursive flow from "work accomplished" to “work remaining" indicates that errors detected in the check or integration activities need additional work to be corrected. This flow shows the impact of errors on the overall progress of the project and the need to allocate resources and time to perform undiscovered rework. Setting time to detect the mistakes requires considering various factors. These factors include the types of errors that occur and those likely to find them. The dynamics of error detection will not be constant during the project, which should be addressed in the next step. Currently, an average time of 2 to 3 months seems reasonable. This value can be useful as a starting point. However, updating this value as the project progresses and more information is received is crucial. By regularly reviewing and updating the error detection time, we can ensure it is consistent with project needs and changes. Based on these interpretations, the following results will be obtained:




**Graph 3:** The subsystem of dynamic application of the impact of errors on the project

Based on the result of the above simulations, there are two significant points:

First, the project takes a little longer since work is not done correctly in the first period. Second, after the completion of the project, there are some repetitive activities since some works that need to be corrected are discovered later in the project and need to be redone. A glance at the "Undiscovered Rework" case indicates that this variable reaches its maximum value when the project is completed, which we see in the graph below.




**Graph 4:** Rework discovery rate

Although undiscovered rework is inherently invisible, there is a significant increase in the rework discovery rate in the late steps of a project. These steps are much like putting pieces of a puzzle together. As the project progresses and nears completion, it is revealed which pieces are missing or do not have the right shape. Similarly, in the later steps of a project, if there are problems with systems or planned components, these problems become more discoverable.

To reduce these problems, it is necessary to pay attention to detailed planning, effective communication, and coordination throughout the project. Regular inspections, reviews, and tests can help identify potential problems early and make corrections timely. A valid approach is to adjust the time of error detection based on the progress of the project. We can allocate more resources and make more effort to identify and solve problems in the final steps of the project. A simple representation of this approach can be seen below:

1. Initial steps: In the initial steps of a project, the focus is primarily on perception, planning, and design. However, it is necessary to pay attention to possible risks and challenges. The primary emphasis is on creating a solid foundation for the project.

2. Intermediate steps: More concrete components and systems are developed and integrated as the project progresses and reaches intermediate steps. In this step, any problems or discrepancies can be discovered by conducting reviews, inspections, and tests.

3. Final steps: In the final steps, when the project is to be completed, more effort can be made to review and validate all aspects of the project thoroughly. It includes comprehensive reviews, quality checks, functional tests, and simulations to ensure everything aligns with the design and desired requirements.

Given what was explained, we make changes in the model as follows:

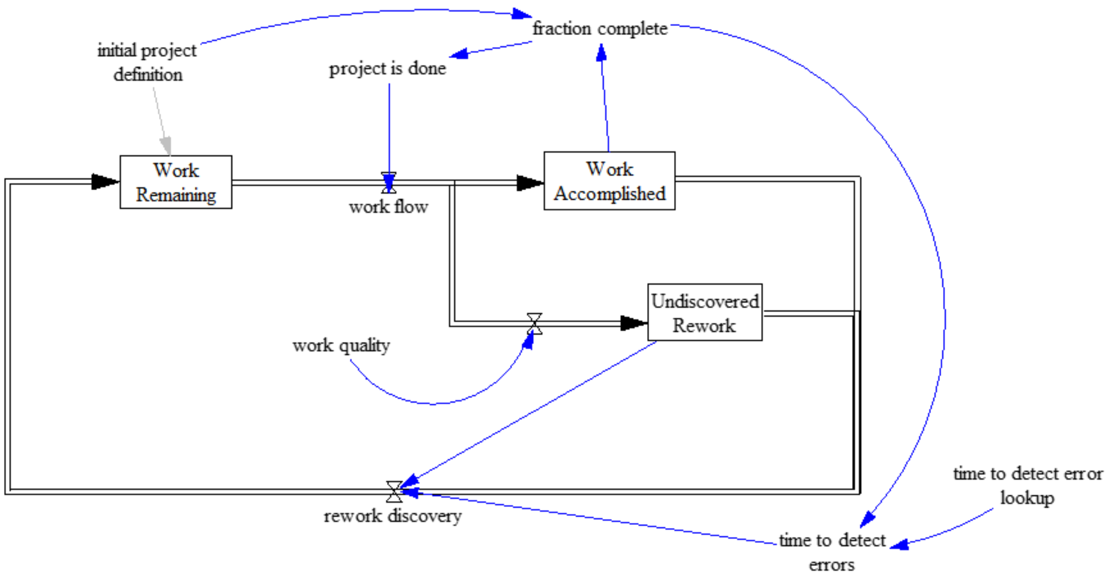
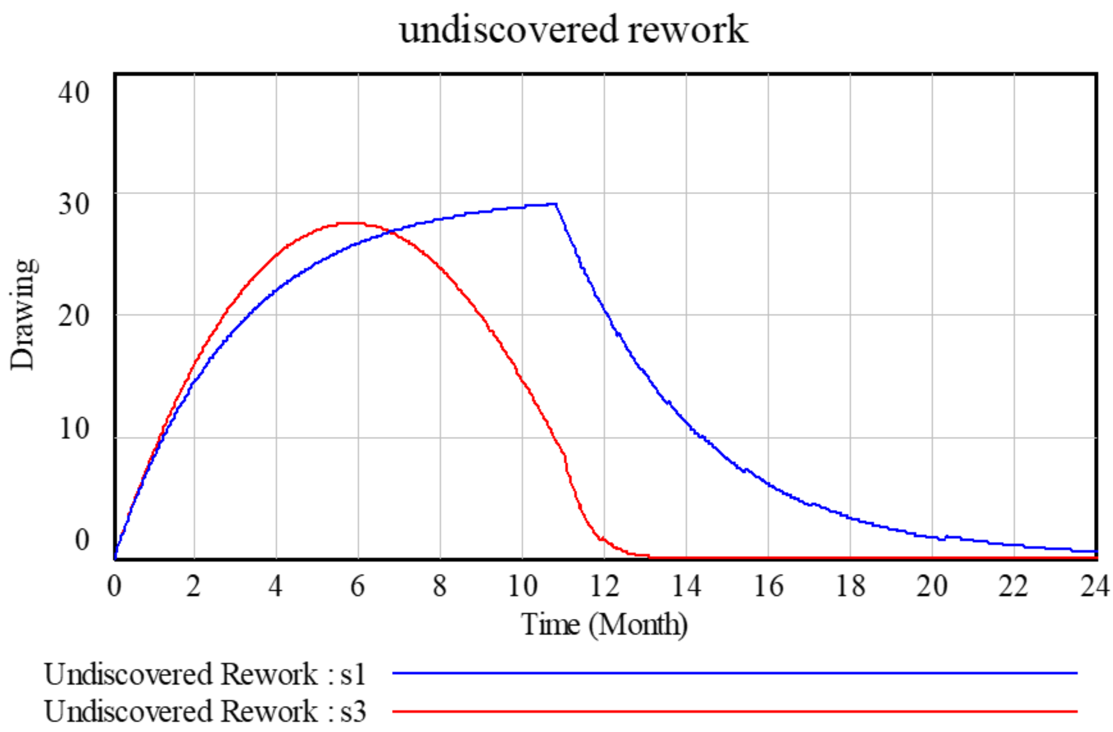



**Figure 4:** The subsystem of applying error detection

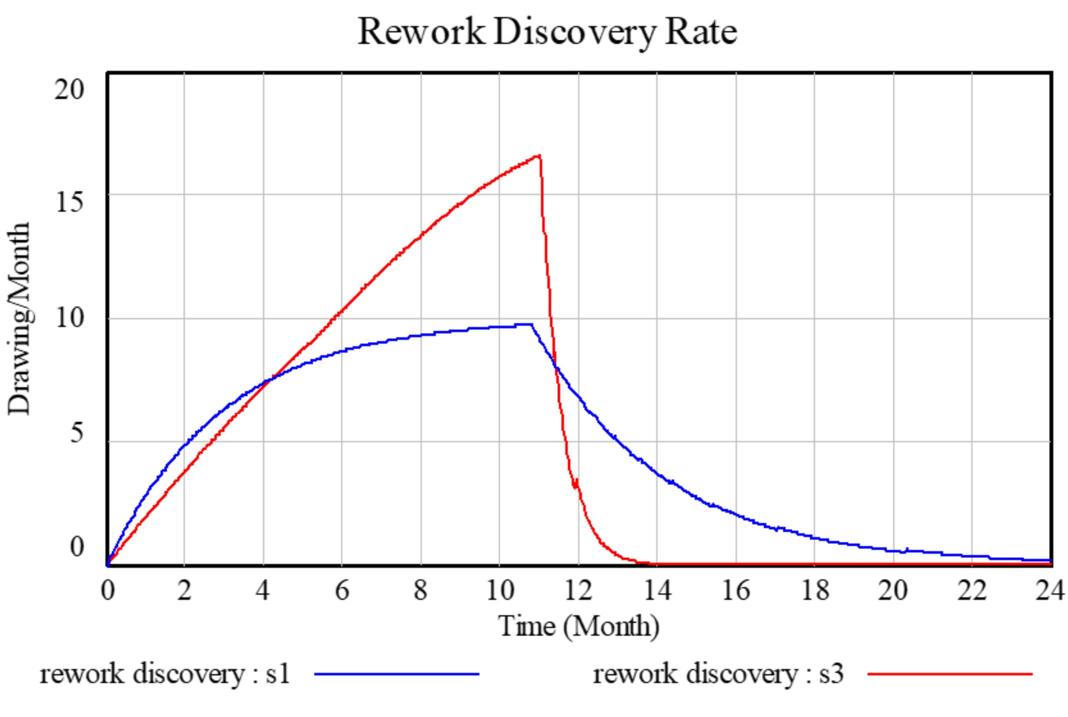
By adding the variable "fraction complete", the equations of the model can be completed. In this model, the error detection time can be calculated as a function of the "fraction complete".

If the "fraction complete" value is equal to or greater than the "specified threshold", we can dynamically adjust the time allocated to detect errors based on the project's progress. This approach allows the allocation of resources and ensures the detection of errors in the final steps of the project, and the model will be more comprehensive and logical than before.

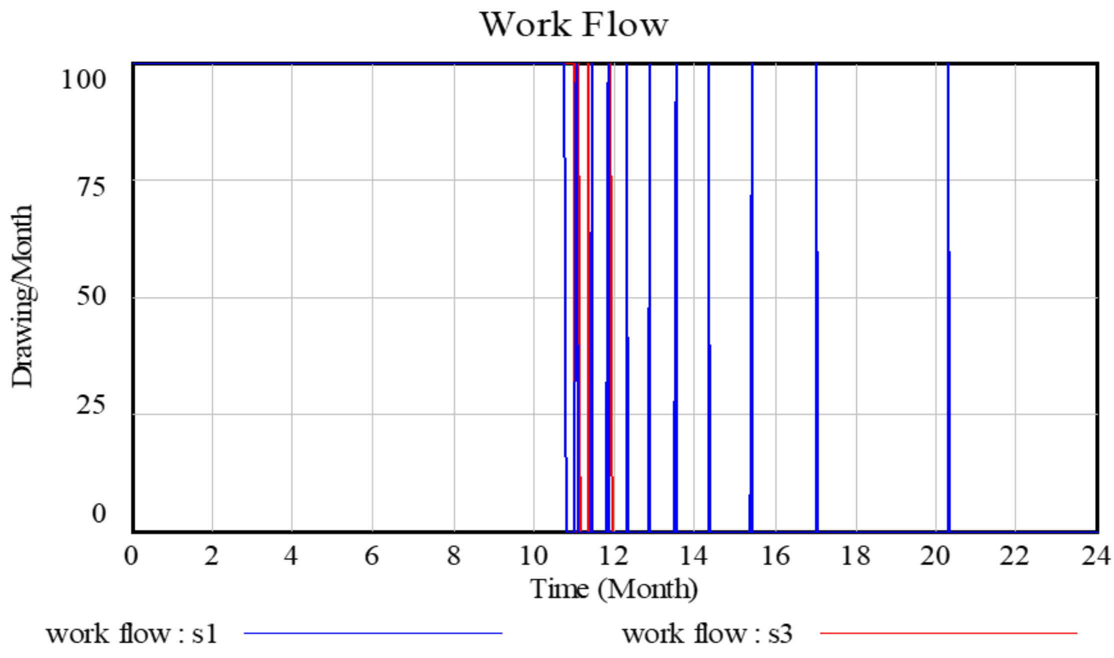
After adding the stated variables to the model and the new equations obtained, the simulation results will be as follows:




**Graph 5:** Undiscovered rework according to project status




**Graph 6:** rework discovery rate in $s_1$ and $s_3$




**Graph 7:** Comparison of the workflows of the first and third scenarios

Based on the above graphs, in the third scenario (s3), the project ends a little later than in the first scenario (s1). However, at the completion time, there is very little rework remaining.

Team Collaboration

To show the direct impact of team collaboration on undiscovered rework, we consider the following model:

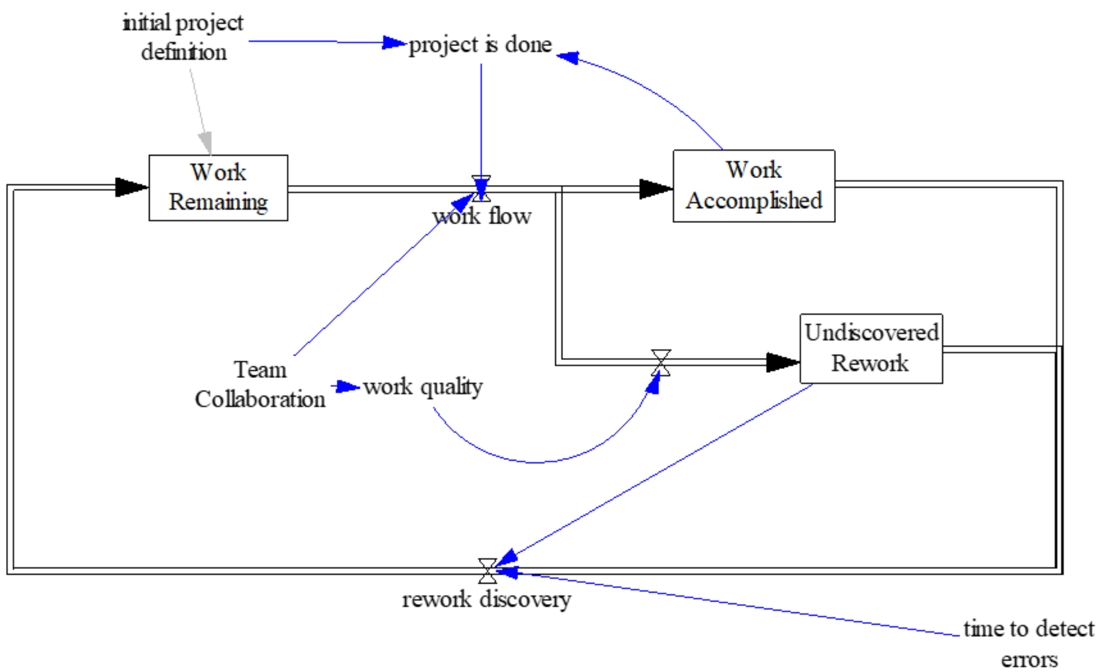
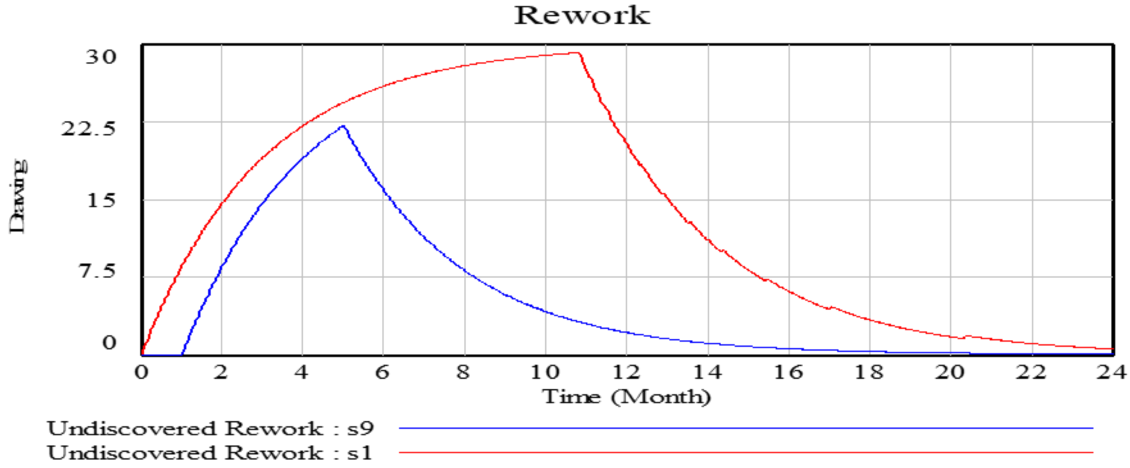



**Figure 5:** The subsystem of applying the effect of team collaboration on rework

We consider the team collaboration variable as a function of the pulse. By comparing this hypothetical scenario (s9) and the mentioned changes with the first scenario (s1), we see that if team collaboration is added, the rate of undiscovered rework decreases significantly, as shown in the figure below.




**Graph 8:** Comparison of discovered reworks in scenarios 1 and 9

We need to use the planned schedule and adjust the schedule by leveling the resources to manage the project and maintain its schedule. For this purpose, we can calculate the remaining time if we have a set end date. Considering the rate of work remaining, we can determine the speed we need to achieve the schedule. Thus, we add new variables to the structure as follows.

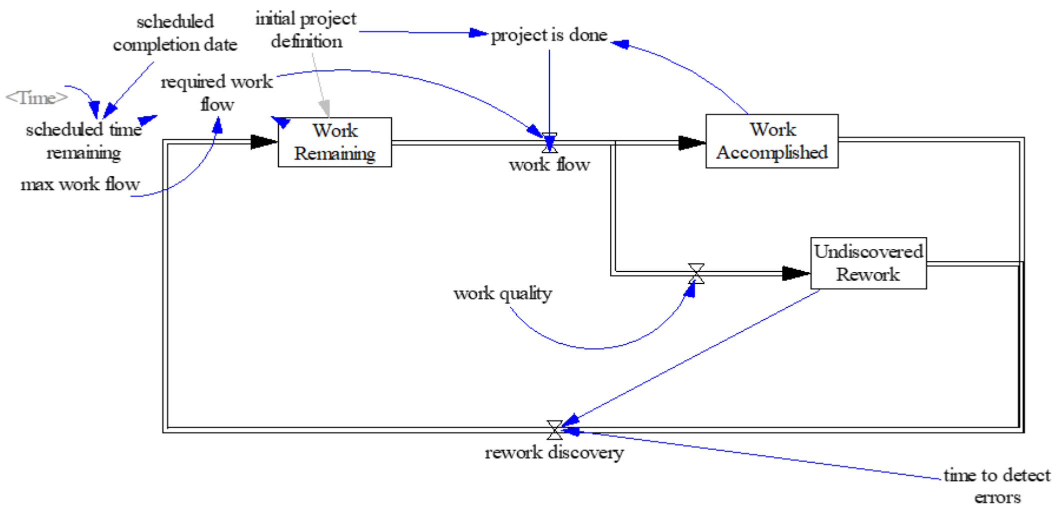
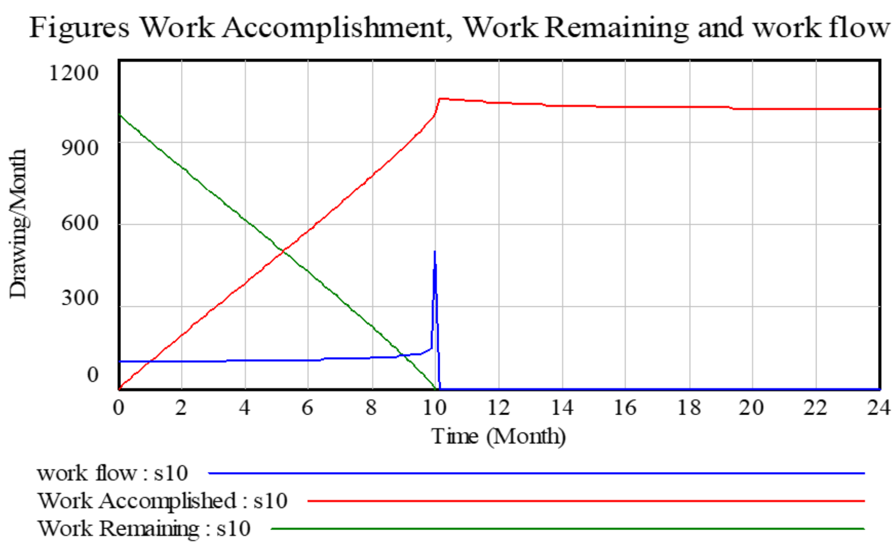



**Figure 6:** Project schedule management application subsystem




**Graph 9:** Comparison of workflow, work accomplished, and work remaining in project scheduling management.

As the project progresses, the workflow increases slowly and then suddenly increases at the last moment to complete the project timely. It indicates that there was flexibility in the project schedule that allowed for a gradual increase in the workflow. However, to observe the available time and the set time (deadline), there has been a sudden increase in the workflow at the last moment.

In the next section, we consider a model focusing on the workforce, which is considered the primary resource for doing work. The workforce can be people who are directly hired for the project, or those who exist within the organization and project tasks are assigned to them. In the most straightforward formulation, the required production rate is determined to be enough to complete the project on time. In other words, this value shows how many people there are and how much effort is needed to complete the project to observe the schedule and complete the project timely.

In this scenario, the project starts without any workforce, and then people are gradually hired to start and complete the work. In this view, the needs and supply of the workforce are considered directly and based on the project requirements.

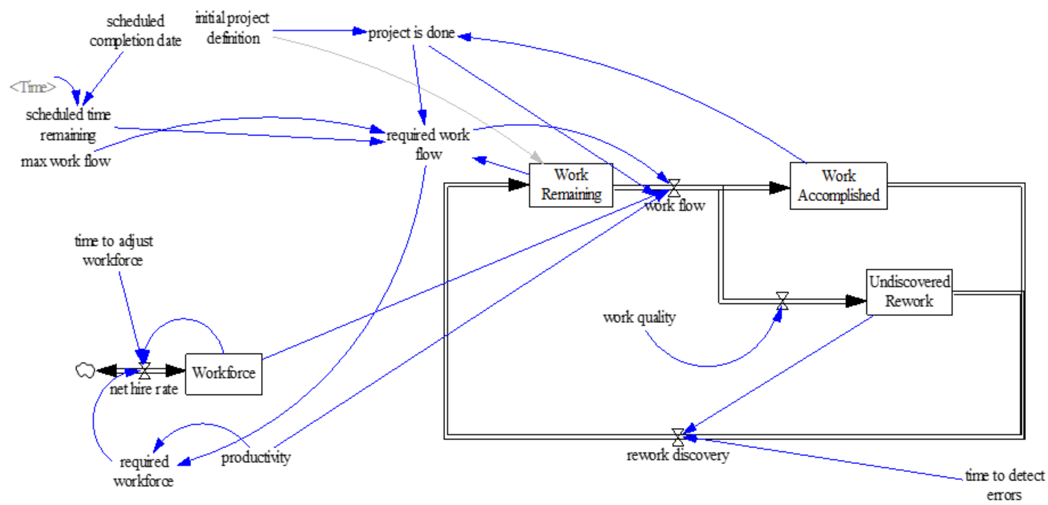
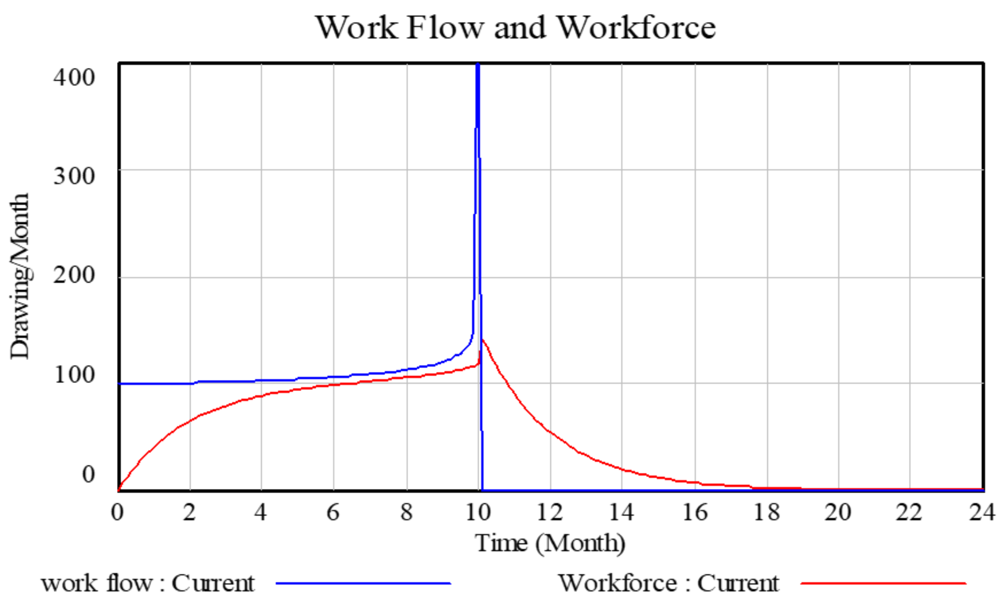



**Figure 7:** The subsystem of focusing on the project workforce




**Graph 10:** Work and workforce in the subsystem of focusing on the project workforce

The workforce quickly reaches 100 people, then slowly increases and begins to increase dramatically near the end of the project. Also, once the project is completed, the project activity is revived. We will try to correct these unrealistic behaviors in the next section. The shortcoming of the model was that as the project nears its completion, it is unlikely that more people will be added. As the project progresses, the team should be stabilized regarding positions and activities. In this problem, we add the willingness to change the workforce variable and several other variables with related equations to the model.

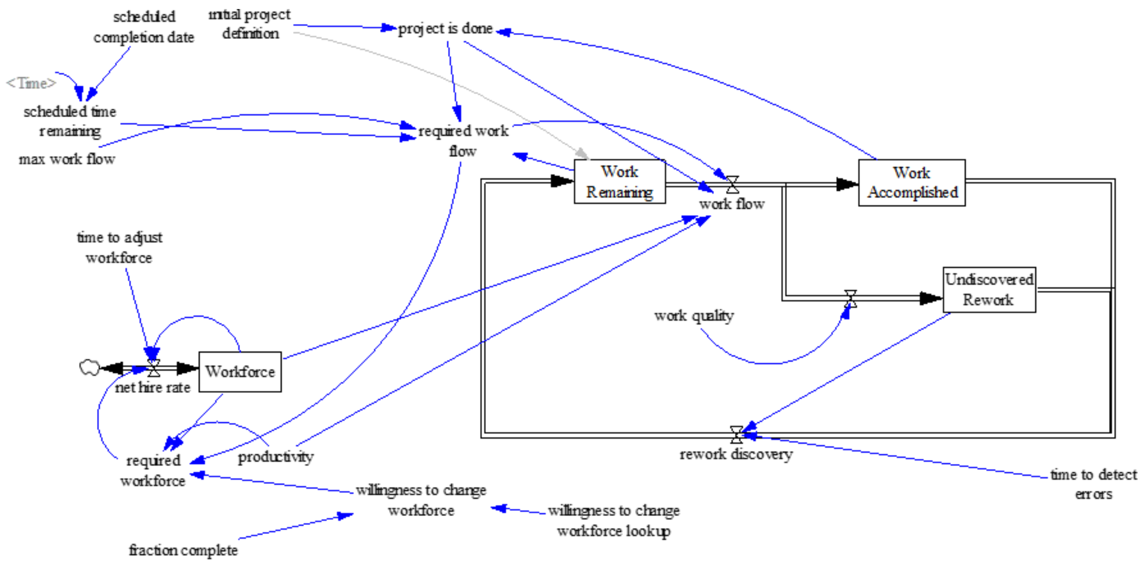
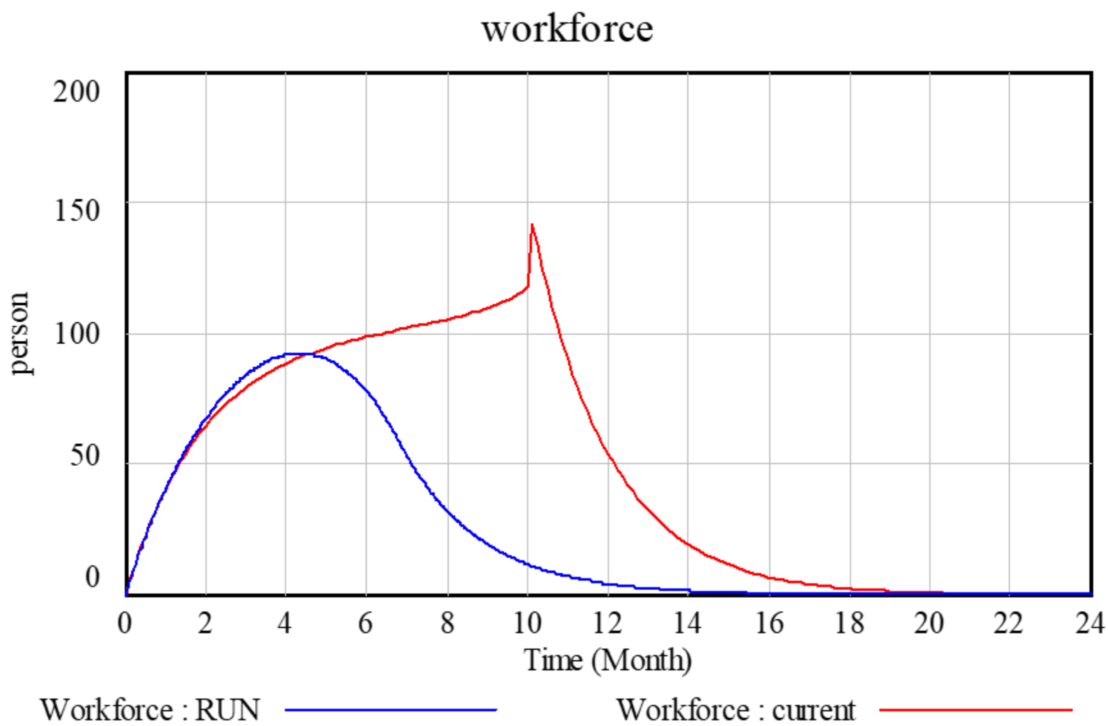
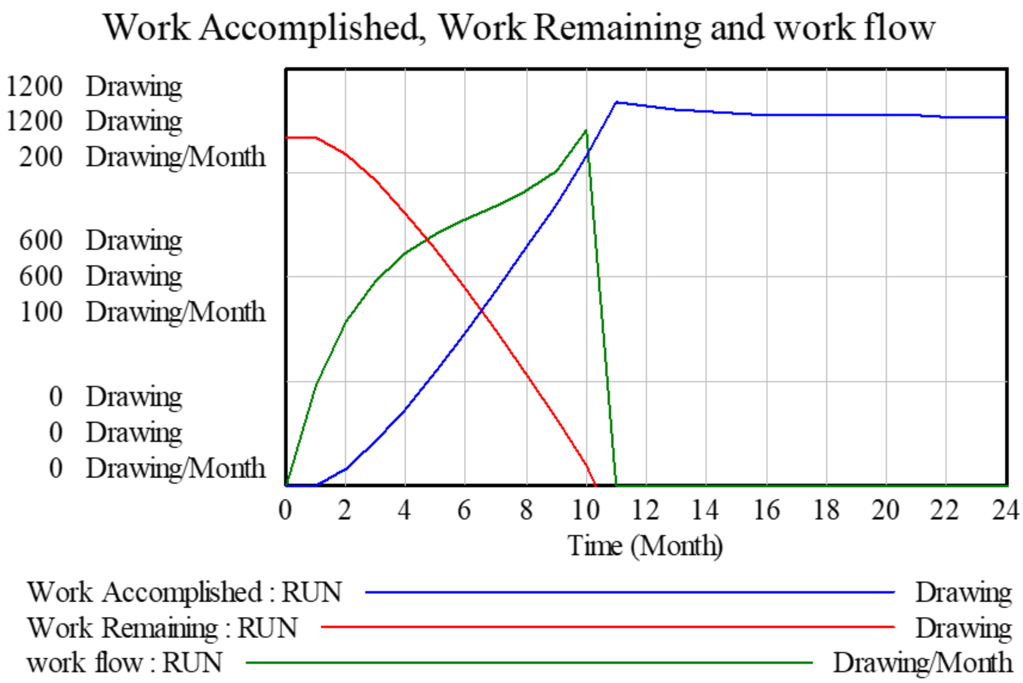



**Figure 8:** Subsystem for applying adjustment (correction) of demand for changes in the workforce at the end of the project




**Graph 11:** Adjustment (correction) of the demand for changes in the workforce at the end of the project

After simulating and solving this model, the workforce does not increase suddenly at the end of the project like before and is balanced.




**Graph 12:** work accomplished, work remaining, and workflow in the final completed model

This project ends a little later. However, it has the advantage that the activities at the end of it are stable, and resources do not increase suddenly.

**Conclusion**

Given the inefficient of project management approaches with a static and discrete event approach, this study presents a dynamic model with the principles of systems thinking (continuous event) in which the project behavior is simulated in the model. The analysis of the model outputs and the calculation of delays in each step prevents the accumulation of problems caused by the increase of critical factors of the project, such as time, cost, and resource allocation, by managing and controlling errors and delays during project implementation. It will ensure the achievement of the project goals. It also ensures that flexibility in adjusting goals when necessary, unlike static approaches, is achieved. This will lead to the satisfaction of the project's stakeholders and customers and increase competition's power in complex and competitive environments.

Projects are dynamic and complex systems, and a complete and comprehensive understanding of their behavior and improving their performance will not be achieved if dynamics, non-linear relationships, and feedback between factors are not considered. Thus, understanding the dynamics in the system and having a systems thinking view can ensure the project manager's success in achieving project goals with minimum deviation. Since projects are very complex systems that need to be managed using a dynamic and continuous approach and having systems thinking, it is necessary to use hybrid approaches for efficient and effective project management. Since using only one simulation method cannot consider different factors and categories in the competitive environment of project implementation, it is necessary to use a combination of two or more methods to solve the problem and model the systems. Increasing the complexity of a problem makes the need for a hybrid simulation method more necessary. Big projects are not an exception in this regard. Due to the complexities and environmental conditions, they need comprehensive and hybrid simulations. Thus, it is recommended that future studies combine the system dynamics method with other methods, such as expert systems and machine learning, artificial intelligence techniques, and soft operation research methods, so the results of system analysis and simulation are closer to reality. They are studied with a more comprehensive approach.

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