An Improved Evaluation of Construction Project's Labor Need Based on Project Workflow

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***Abstract*—Nowadays, human resources are known as the most important source of construction projects whose management should be greatly considered. Therefore, there should be great consideration to human resource management of construction projects. One of the effective human resources management practices which directly associated with the performance of the project is obtaining project required labor. In this study, labor need and workflow of construction projects is considered in a closer look. Applying system dynamics, Causal Loop Diagram of project labor need based on project workflow is obtained. Next, a Stock-Flow model is developed to estimate exact labor need of construction projects. Finally, policies are proposed based on the simulation results. Presented model in this study is capable of accurate estimation of labor need in construction projects considering project dynamics. Applying this model, project managers and decision makers have the opportunity to plan for timely supplying of project labor.**

***Index Terms*—Human resource management, construction projects, system dynamics, labor need, project workflow.**

I. Introduction

Human resource management is regarded as a fundamental process to effective application of the labor for the desired performance of the project. In other words, it is referred to all proceedings related to the aspects of applying and managing individuals in the organization [1]. In fact, goals of the company or project are met only through human resources and success of the project relies on it [2]. To put it more clearly, success of any project depends on the function and availability of human resources. Since the success criteria of any project is based on the function of that project, thus we can say that human resources is the key factor in completion of the project with allocated budget, schedule, and desired quality. One of the effective human resources management factors in project performance is the formation of the required project team. When a new project begins, project team configurations must change. This creates a need for new processes such as allocation of labor to the project [3]. According to PMBOK:

Acquire Project Team is the process of confirming human resource availability and obtaining the team necessary to complete project activities. Failure to acquire the necessary human resources for the project may affect project schedules, budgets, customer satisfaction, quality, and risks. Insufficient human resources or capabilities decrease the probability of success and, in a worst case scenario, could result in project cancellation. A significant share of the economy of several industries in the world, however, is related to construction industry. HRM has the potential to release a significant amount of productive potential in the construction industry, which has remained untapped because of widespread ignorance of good practice in this area [4]. Construction industry is one of the many industries which widely uses human resources and depends on the sufficiency of labor [5]. To acquire the performance goals of the project, supply of the required project team is considered as a significant part of HRM practices. Failure in its provision to the right number and in the right time will result in the failure of the project. Since there is always excess or shortage in project labor [6], we can say that accurate estimation of labor need and its provision has a major impact on the progress and performance of project. In fact, it is vital to ensure the formation of project team and sufficiency of project labor in construction projects [7]. Construction projects have a dynamic nature. One of the dynamics is the change of the labor during the project [8]. Due to large changes in the labor pool, we will certainly face excess or shortage of labor without an effective planning [9]. Therefore, when there is an accurate estimation of labor fluctuations, we can improve project performance by appropriate and timely allocation of labor. Another available dynamics of construction projects is the project workflow. This dynamic may include changes in project scope, work completed, work remaining, rework cycle, ripple effects and knock-on-effects [8].

II. Literature Review

Human resources management emerged as a methodological style of management since the second half of the past century [2]. Supplying of required human resources as one of the main parts of human resources management is cited in PMBOK. Some models developed for estimating workforce such as regression, econometrics (based on key variables such as employment) and time series. [10] Presented a model for forecasting construction labor demand including economic variables such as manufacturing output, the price of materials, interest rates and labor productivity. In [6] a gray model with feasibility of accurate estimates of construction labor demand introduced in spite of limitation of data. [11] Used regression equations for estimating workforce of different works. Although above mentioned models of labor estimation are able to estimate the required labor of the project in long term, there are two major flaws in them: first, the variables considered in these models and their relation are limited. Actually, they lack a systematic perspective. The second flaw observed in these models is their inability to consider model variables dynamically and in the length of time. Regarding the fact that the nature of construction

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projects are dynamic and also include several effective variables, there is a need for a model to solve these problems. Therefore, the studies which investigate the dynamic modeling of project workflow and labor need can address this problem. System Dynamics tool presented by [12] provides this option to exactly evaluate the dynamics available in the project with regard to its effective factors. In 1995, [13] conducted studies on dynamics of project management and could model the structure of labor, rework, available labor, and quality and project scope more completely by using system dynamics (SD). In this study, subsystems of project scope and project workflow and resources were developed. In the subsystem of project workflow, amount of initial work is proportional to project scope and also the amount of work done and the work remaining along with rework are considered. Also the amount of labor need based on the whole work done, expected productivity and the time remaining to the end of project were calculated. In another study by [14], an SD model was presented to investigate the product development process in multiple-phase projects. [15] Explored strategic management of complicated projects by system dynamics. They noted the inefficiency of old tools as PERT and CPM in considering natural dynamics of the project. In their study, changes of project labor was investigated in several researches like the projects of software and shipbuilding. The project workflow and project labor need were modeled along with feedback processes as well. Labor need was defined based on the time remaining, project progress and available labor. In [16] different policies to improve cost and time performance of the project in a construction project examined. In the presented model, the project workflow includes project scope, rework, productivity and the rate of work accomplishment. A stock-flow model of the project workflow presented by [17] which includes more details compared to previous studies like the inclusion of changes of project scope and a more accurate examination of rework. Also in this study, the amount of desired labor and needed labor were obtained through work progress (completion rate), remaining time for completion and average productivity. In [18] the amount of labor needed obtained for performing a construction activity by system dynamics based on required construction rate and average productivity. In a research conducted by [8], the structure of system dynamics was stated in 4 categories of project characteristics, rework cycle, project control and the effects of policies (ripple, knock-on-effects) for project management. In the project progress subsystem of this study, productivity, and efforts applied, and errors had an effect on work progress. The amount of labor need was also calculated by comparing the time remaining and the time required to do the remaining work. In [19] the effect of organization dynamics on planning and construction performance studeid. In this study, desired resource adjustment was defined by productivity. Also project workflow included work to do, work rate, rework, and work completed. In [20] a stock-flow labor forecasting model presented for long term which can estimate the labor of construction industry for the next 10 years. This model is based on transition concept (input and output) and includes labor dynamics of construction industry while it lacks a systematic attitude. In [21] the workflow of construction projects modeled in 2 phases (design and construction) by SD. It concentrated on scope changes, rework and construction progress. Finally, in [22] 3 characteristics of the project studied that cause reinforcing loop. 3 main factors of this study include rework, schedule pressure, and ripple effect strength; where rework cycle was finally determined as the dominant cycle.

III. Model Description

In this section, for a better understanding, general structure of the model in form of its subsystems and sections as well as their relation with each other will be described. To follow, the causal loop diagram will be presented, and finally, subsystems of the research will be presented in a stock-flow diagram.

A. Subsystems and Sections of the Model

For a better description of the structure of the system dynamics model in this study, the model is divided to 2 subsystems and 2 sections including: labor subsystem, project workflow subsystem, project performance index section and policies section which will be explained below (Fig. 1).

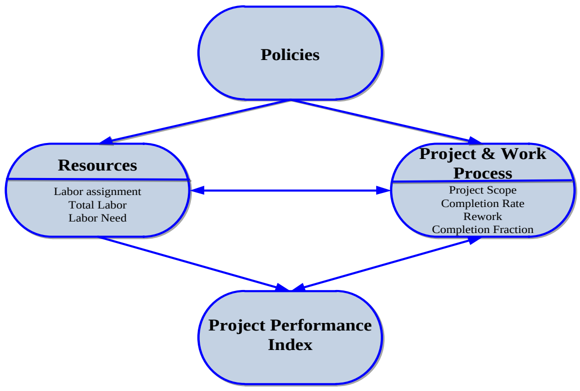

Fig. 1. Subsystems and section of the model.

Figure above shows subsystems, sections, and present important interactions among them. Subsystems and sections are associated by mutual variables. The way that subsystems of project workflow and labor relate to each other. Also these two subsystems are associated with project performance indexes with the difference that labor subsystem impacts only on performance index section and is not influenced by it; however, project performance indexes is associated with the project workflow subsystem. The effects of the policies applied on 2 subsystems of project workflow and project labor need will be investigated.

Project workflow subsystem: This subsystem includes factors such as project scope, work completion rate, rework, errors, and temporary and permanent termination of the project. These factors present the project workflow.

Labor subsystem: This subsystem includes variables such as labor allocation, labor need, and the total labor.

Performance index section: performance indexes will be investigated in this study.

Policies section: Policies include 1) use of labor with high productivity and 2) More hiring of the initial labor

B. Causal Loop Diagram

Feedback structure describes the complexities of environment-behavior during the time [23]. The present causal loop diagram has reinforcing and balancing loops. According to Fig. 2, with an increase in Work Planned to Do, the expected delays in the project completion increases. Consequently, labor shortfall and labor need increases. Following a raise New Labor Hiring, total labor go up. With an increase in amounts of total labor, Completion Rate which is influenced by the amount of labor productivity decreases and Work done and released increases. Subsequently, Unaccepted Work, which is influenced by errors, go up. Then, Reworks increases and affects project scope. Finally, work planned to do increases in a reinforcing loop (R1). Also, work planned to do increases similarly with R2 in a reinforcing loop R2, except the amount of work planned to do affects the work in progress and work done awaiting for acceptance. With an increase in labor shortfall, labor need increases which finally, results in more labor hiring. Consequently, total labor go up and labor shortfall declines in a balancing loop (B1). It should be noted that, new labor hired become familiar with the work over passage of time with a delay and increases total labor amount again (B2). In case work planned to do declines, Work in Progress and Work Done Awaiting for Acceptance gets down. Therefore, less work done and released and less work will be accepted. By accepting less work, work planned to do raises in the balancing loop (B3).

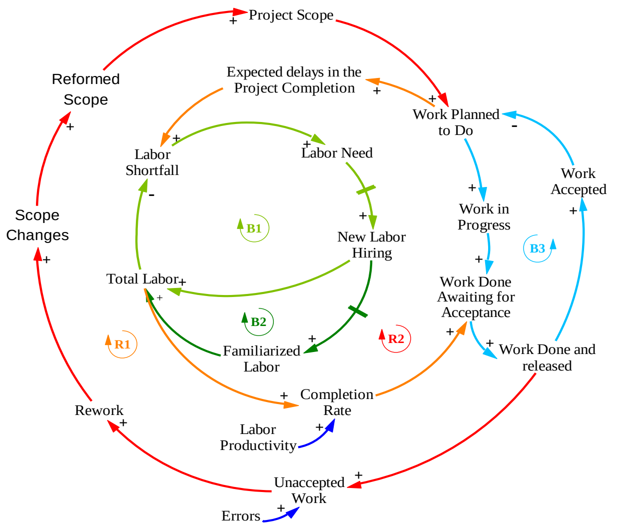

Fig. 2. Causal loop diagram.

C. Stock-Flow Diagram

As mentioned before, the model is divided to some subsystems and sections for a better understanding which includes subsystems of project workflow and project labor, and section of policies applied and project performance indexes. In this research, developed subsystems of project workflow and project labor are presented.

Fig. 3 shows the stock-flow model of project workflow. The developed model of the project workflow contains seven stocks of project scope, project scope to be planned, work planned to do, work in progress, and work done awaiting for acceptance, rework backlog, and work accepted. It is possible that project scope change due to several reasons such as changes in plans as well as changes according to the employer's request, for which the stock of project scope calculates this amount. After the confirmation of the scope, its planned amount will be identified by the stock of project scope to be planned. Then, this amount will be transferred to the stock of the work planned to do. Regarding the rate of the work availability, the work in progress will be calculated. After this stage, the work will be done according to the available labor in the project and their productivity. It is noteworthy that, in order to increase accuracy, work completion rate is considered by weight. Then, available work at stock of work done awaiting for acceptance, will be transferred to the stock of rework backlog with regard to error fraction and required rework. Also in case of final work confirmation, if there be not any hidden error fraction, it will be transferred to the stock of rework backlog again. After repeated completion of the work, the work will be investigated again and if error was detected, this cycle continues, otherwise, the work will go under final confirmation. The availability of error and rework during the project progress is due to the low quality of the work compared to the desired situation. It should be noted that the time remaining to do the rework during project has limitations, especially when the rework must be done late in the progress. This fact is considered in the model.

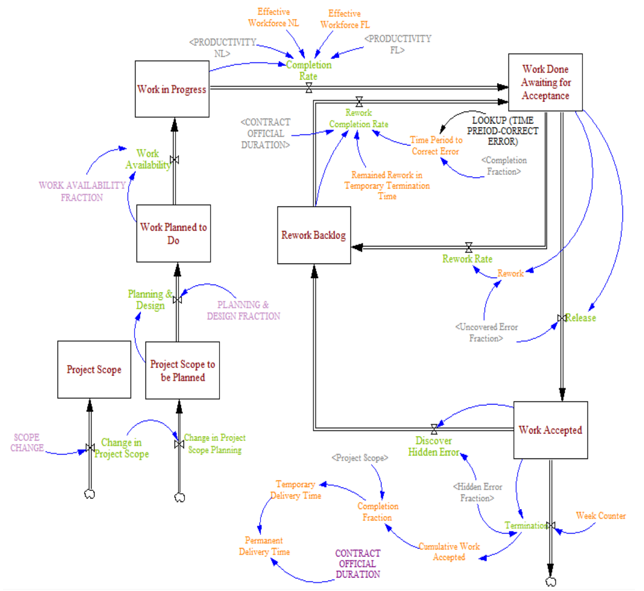

Fig. 3. Stock-flow model of project workflow.

Finally, when the work is confirmed, project is delivered to the employer. In the developed model of this study, temporary and permanent delivery of the project by the contractor to the employer is considered based on the completion fraction. Permanent delivery takes place when the project is temporarily delivered by the contractor to the employer.

Accurate and real-time estimation of the labor of the project has always been one of the main concerns of contractors and project owners which has not been studied completely. Therefore, this issue is the focus of the current study. The developed systematic dynamic model in the current study is able to estimate the labor in real-time and accurately with regard to dynamics of project workflow.

This model is also able to predict the changes and fluctuations of labor need.

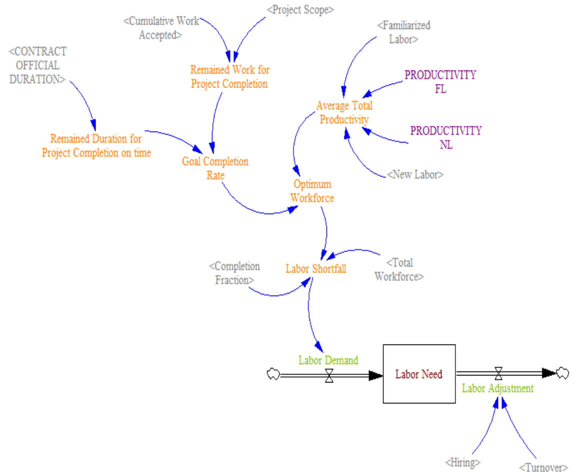

Fig. 4. Stock-flow model of labor need.

Considering Fig. 4, the amount of the remaining work will be obtained based on the project scope and accepted cumulative work. The time remaining for project completion will be calculated by the difference of the initial time of the contract and the time past from the project duration. After the calculation of the work and time remaining for work completion, the desired work rate will be obtained. The desired work rate as well as the total average total productivity determine the desired labor. This amount is calculated by weight for a more accurate computing of the total average total productivity. To continue, comparing the amount of the desired labor and total labor at the project, the amount of the labor need will be determined. This amount will be inserted to the stock of labor need as a rate. On the other hand, with regard to the amount of employment and turnover of the labor, the amount of labor need will be balanced. Due to the nature of a systematic dynamic model which consists of a combination of differential equations, it could be concluded that the developed model of labor need in current study not only has the ability of simulation and accurate estimation of project labor need, but also is able to detect the real-time fluctuations and changes of the labor of the project. In this research, labor hiring is considered as a policy to obtain the labor need of the project. This section includes three stocks of new labor, familiarized labor, and the total turnover (Fig. 5).

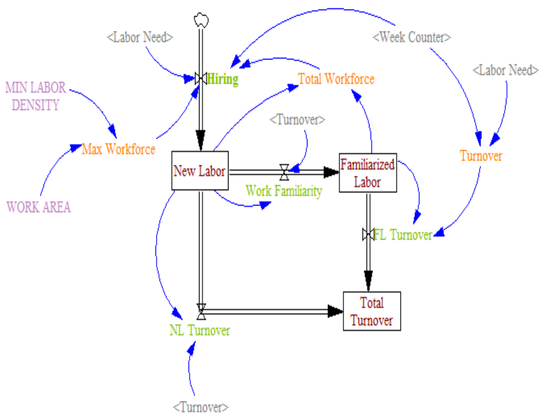

Fig. 5. Stock-flow model of labor hiring.

According to Fig. 5, labor hiring and turnover will occur based on the labor need of the project and the available labor. Indeed, hiring of the labor need of the project is limited. This limitation is identified based on work area and min labor density. As soon as the employment is done, recently employed new labor get familiar with the work after a while and become familiarized. It is critical to note that hiring and turnover are performed weekly. Generally, there are two main problems observed in accurate estimation of the project labor need:

1. Due to the inability of the contractor or the project manager in right and accurate estimation of the amount of the labor required for the project, there is generally a great tendency to apply constant labor. Therefore, the project will certainly be delayed. The reason is the presence of a factor such as an error due to low management quality. Presence of error results in rework, while it is usually ignored before the implementation of the project. Thus, it could be concluded that to avoid postponement in the project, required labor should be employed.

2. How and on what basis must the labor employment be? The contractor or the project manager, due to the presence of some facts and natural dynamics of the project such as error and rework, cannot have comprehensive knowledge of the application time and amount of project labor need.

To solve above problems, the presented dynamic model is able to accurately estimate labor need and labor employment weekly. To put it differently, exact estimation of labor need based on project workflow can result in right understanding of fluctuations and real-time changes of project labor at the beginning and during the execute of the project. In addition, labor hiring model is weekly and based on the realities of construction projects.

IV. Validation and the Results of Simulation

In this section, to evaluate the results of the presented model, simulation was used and by the simulation of the data from construction industry, the model was tested. The process of the validation of the model was performed for the reliability of in the results of simulation for the developed presented model. Also according to [24], the structure of the model was validated by standard testing methods of system dynamics models such as Boundary adequacy, structural assessment, dimensional consistency, parameter assessment, extreme conditions, and integration error. For clarity in analysis, the model was set for a simple construction activity.

A. *Model Application in a Sample Project*

To illustrate the efficiency and abilities of the presented model in the simulation and prediction of the amount of project labor need based on the workflow of the construction project, current model was applied to a sample project as a tiling project described below.

Initial work: 19320 wu
Productivity of New labor: 1.25 wu/ (man*Hour)
Contract official duration: 180 day
Familiarized labor productivity: 1.875 wu/ (man*Hour)
Initial new labor: 7 person
Quality: 90 %(0.9 Dmnl)

This activity will be compared as a base case to different policies in the policies implications section.

B. Base Case Simulation

A sample project used in this study is mentioned based on values which are simulated by presented SD model. Fig. 6-11 show the model behavior for the base case. The total amount of work to be done is set as the initial value of the project scope to be planned. Then, with the passage of time and due to the planning to prepare the work to do, this value changes to work planned to do. As illustrated in the Fig. 6, the amount of the planned work gets in the stock of work in progress and its amount is declined to zero. This stock must be regarded as the work available to be completed. Completion of the value of work in progress in day 175 means that if we want to take the project workflow simple and ignore its available complexities, the project must be completed in this day (175), while this fact is not in line with the real conditions of the project.

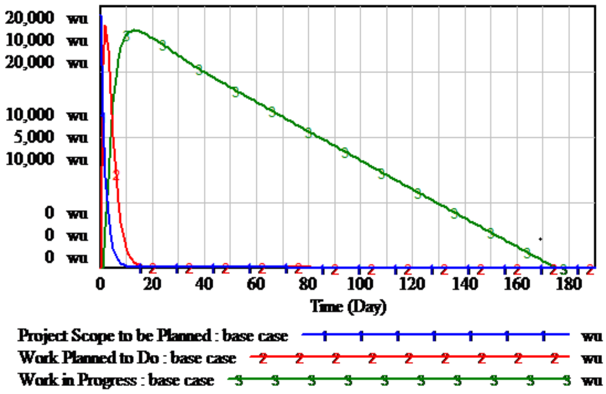

Fig. 6. Base case simulation of project scope to be planned, work planned to do and work in progress.

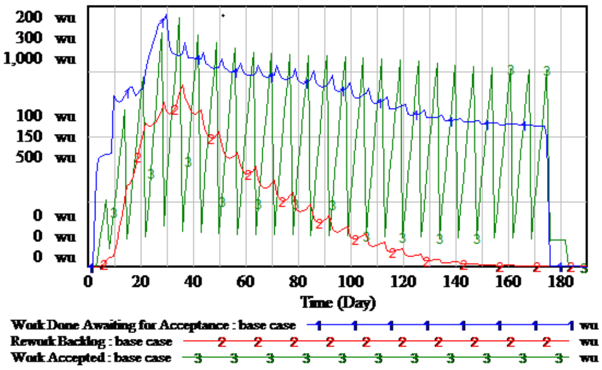

Fig. 7. Base case simulation of work done awaiting for acceptance, rework backlog and work accepted.

The amounts of the work available are performed with an identified completion rate. After that, the work done is waiting to be confirmed. Due to the supervision on the quality of the work done and the possibility of uncovered error, we observe rework. Discovering hidden errors at the final confirmation stage is also possible which causes rework. About the base case investigated in this study, the work quality is 90%. According to the Fig. 7, rework has reached its maximum in day 36 and then reduced gradually that is due to work accepted, work done awaiting for acceptance, and also the amount of errors. In day 189, the amount of the work accepted is ended. It is noteworthy that the reason of the Oscillatory behavior of the figure, especially work acceptance, is the weekly confirmation of the work.

Fig. 8 simulates the human resources status in the project for future. The initial workforce is 7 persons which are changed due to release of work, and consequently, identification of labor need. From the early stage of the project to a special time the amount of new labor generally increases and then decreases since the labor gets familiarized. Therefore, it can be concluded from the figure that from day 21 of the project, new labor started to lower and the amount of familiarized labor increased until day 26 and remained constant until the delivery day of the project. Finally, at the time of permanent delivery of the project, all of the labor is dismissed.

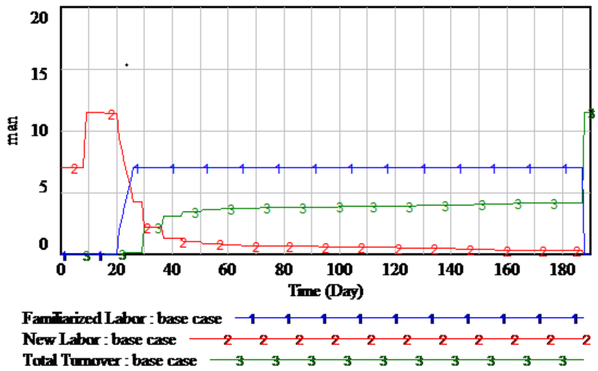

Fig. 8. Base case simulation of familiarized labor, new labor and total turnover.

However, exact and real-time estimation of project labor need is shown as the focus of the present study in Fig. 4. According to Fig. 9, amount of labor need differs during project execution. It means due to the presence of the dynamics of project workflow such as errors and reworks, the amount of the project labor need has changes and fluctuations. Fluctuations of labor need will be present until temporary delivery of the work which is day 169. It should be noted that positive numbers in labor need diagram represent labor hiring need, whereas negative numbers in labor need diagram represent excess of the labor and the necessity to dismiss them. The present systematic model, after accurate estimation of labor need, balances the labor of the project weekly.

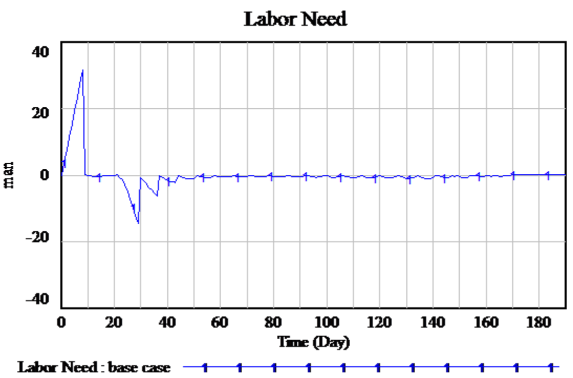

Fig. 9. Base case simulation of labor need.

Now it can be concluded from Fig. 10 that the temporary and permanent termination of the project will be days 169 and 187 respectively. Temporary termination will happen based on the completion of 95% of the total work and before the total completion which is 19320 square meter of tiling. The rationale for the development of this part of the model is the performance bond (completion bond) of the contractor. After the completion of the total work and the passage of a portion of contract official duration, the project will be terminated to the employer permanently.

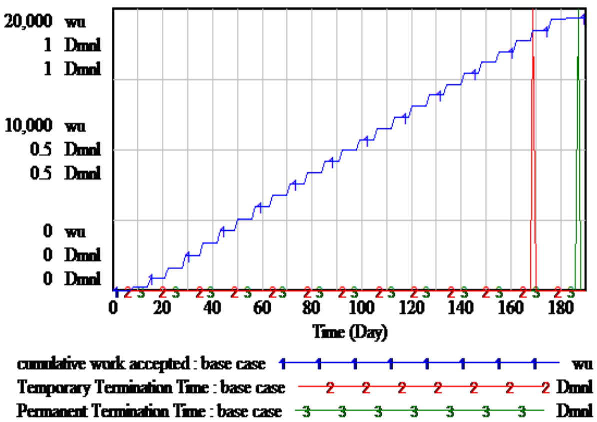

Fig. 10. Base case simulation of cumulative work accepted, temporary and permanent termination time.

As it was depicted in the simulation diagrams, exact estimation of labor need, hiring and turnover of the labor and generally, project completion with regard to the amount of labor need was possible. However, during the execution of the project, the contractor or project manager, due to lack of knowledge and inability to estimate the labor need, may decide to perform the project with constant workforce. Fig. 11 shows that in case of such decision, the project will be delivered to the employer with a 63 day delay which is the failure of the project.

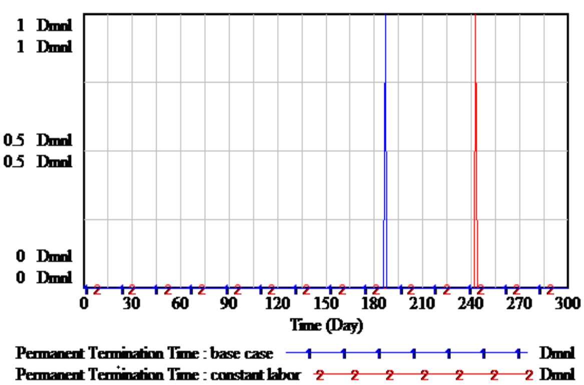

Fig. 11. Base case versus constant labor simulation.

V. Policy Implications

Since the provision of the project labor need based on the changes and fluctuations of labor need may cause the contractor a problem, it is necessary that some policies be investigated to facilitate this issue. In this section, 2 policies are presented to improve the model behavior and reduce the fluctuations of labor need. After its implementation, each policy is simulated and then compared to and evaluated by base case project.

A. Use of Labor with High Productivity

Low productivity of labors makes the completion of the project even more difficult. Thus, it is required to ensure the high productivity of the labor of the project. Different groups of labors have various productivities. Therefore, those with the highest productivity must be applied. In this research, except the productivity of base case labor, the productivity of another group of labor was also evaluated. Simulation results of implementing this policy show that in case labor with high productivity is used, labor and fluctuations of labor need could be reduced. Consequently, movement of the labors through hiring and turnover is reduced (Fig. 12). According to the figure, it is comprehended that applying labor with high productivity has a significant effect in reduction of fluctuations of labor need.

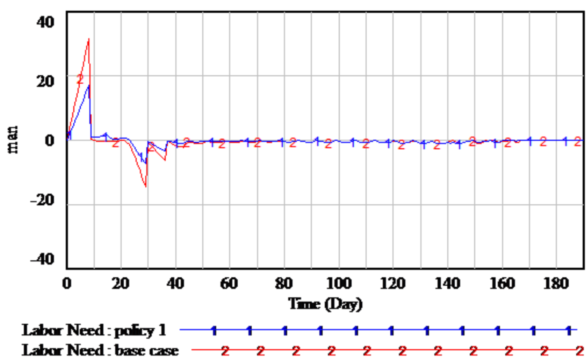

Fig. 12. Policy 1 simulation result.

B. More Hiring of the Initial Labor

If sufficient amount of initial labor is employed, fluctuations of project labor need and their movement will reduce. In this implemented policy, the number of initial applied labor was expanded from 7 in base case to 10 (Fig. 13). As the figure shows, an increase in the initial number of the labor improves the fluctuations of labor need.

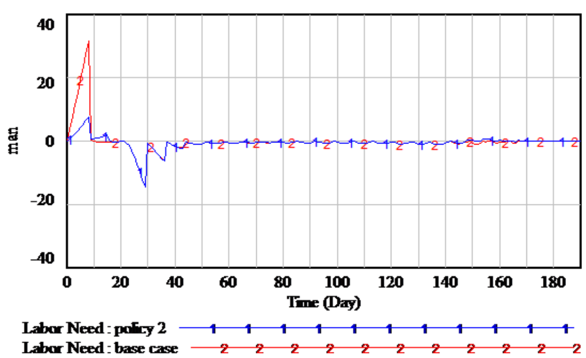

Fig. 13. Policy 2 simulation result.

VI. Conclusion

Obtaining project labor need, as one of the most important measures of human resource management, has always been a main concern of project managers and owners. Accurate and real-time estimation of the labor need, from the beginning of the project can give decision makers of the project the opportunity to make the necessary planning to obtain the project labor required before the execution of the project. On one hand, presented models of labor estimation in previous studies lack the ability to concern all effective factors in labor estimation as well as natural complexities and dynamics of construction projects. On the other hand, presented SD models of the past research deal with this fact in general terms. In this research, by using system dynamics method, a model is developed which is able to estimate the labor need of construction projects accurately and in real-time based on the project workflow the way that fills the gap of the previous research to a large amount.

For the modeling of labor need based on the workflow of construction projects, first, the dynamic nature of construction projects, labor need and project workflow were investigated. Then, by system dynamics method, the causal loop and stock-flow diagrams were presented. Current presented developed model is able to concern the dynamic nature of construction projects and simulate the exact amount of project labor need. By examining the results of the simulation results, it was identified that first, execution of the project using constant labor will postpone the project. Second, in case of labor hiring during project execution, we will observe fluctuations in labor need. Lastly, 2 policies of using labor with high productivity and more initial labor employment were presented to reduce the fluctuations of labor need in construction projects. Applying this model, decision makers of the project can both be completely aware of the amount of project labor need, and formulate necessary plan for obtaining the labor required before any action.To show the efficiency and capabilities of the presented model in simulating, it was performed on a building project. One of the advantages of the presented system dynamics model is its flexibility for applying in various projects.

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