DYNAMIC PLANNING OF CONSTRUCTION ACTIVITIES USING HYBRID SIMULATION

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ABSTRACT

Traditional planning methods such as CPM and PERT have been useful tools to manage construction projects. However, the underlying model of these traditional methods often seems to fail to represent real projects as they tend to assume no interrelationship between project components. In reality, project components have complex dynamic feedback process that requires modeling of inherent uncertainty in the execution of these projects. Nevertheless, this dynamic nature and uncertainty have not been explicitly addressed by traditional planning methods. Project failure can be attributed to poor representation of the inner and outer aspects of operations that are responsible for project dynamics. Uncontrollable external forces are often cited but the real cause may be internal such as the feedback process among components of the project. An alternative perspective is offered in this paper through system dynamics (SD) that accounts for the feedback process and discrete event simulation (DES) for modeling the uncertainty. The proposed method utilizes SD method for modeling project dynamics and DES method coupled with CPM network for operational details and uncertainty, respectively. A case study that involves preparing engineering drawings in a design office is used to demonstrate the use of the developed method and to highlight its capabilities. Modeling the dynamic dimension is expected to enhance planning and scheduling of construction operations and to provide a better understanding of the impact of various internal and external factors on project schedule and productivity performance.

KEYWORDS

Dynamic Planning, Discrete Event Simulation, System Dynamic, Construction

INTRODUCTION

The increasing scale and complexity of modern construction projects make them vulnerable to poor outcomes due to the heterogeneous nature of project components. Therefore, there is a need to address the fragmented approach of dealing with issues of project planning and control. Traditional project management tools such as CPM-based network and PERT provide useful support to decision makers, and have been used since the mid-50's and early 60's. However, those methods suffer from critical limitations such as accounting for uncertainty in a dynamically changing project environment. The limitations associated with CPM have been addressed by McRimmon and Rayvec (1964) and Pritsker et al. (1989).These tradition methods focus on the details at the activity level (activity duration, resources, and cost) and neglect the interrelationships and dynamics among these activities. CPM-based network is constrained by the assumption that neglects the impacts of any surrounding factors on the project behavior and outcomes. The reality is that interrelationships among project influential elements are more complex than what have been suggested by the traditional methods.

There are two frequently reported observations on planning and execution of construction projects. The first has to do with uncertainty in time and cost of the components of construction projects. For instance, the estimation of duration and cost of activities is performed based on deterministic approach. However, in reality, those parameters are uncertain and more inclined to follow a probability distribution. In this context, simulation tool such as DES is effective for analyzing the stochastic nature of the parameters involved. DES, however, overlooks the modeling of the holistic behavior of these parameters and their impact on obtaining optimal results. The second is the existence of a complex dynamics among the construction project components. The feedback process is a resultant of the management decisions and polices, and their interaction with tactical level of the project. Failing to establish the links between management policies and the activity level can negatively influence project completion.

This paper presents a scheduling and planning method that utilizes a CPM-based network built on DES environment and integrated with SD mode that addresses management policies and decisions and their impact on project successful completion. The paper presents a background of the challenges, followed by a summary of comparison between characteristics of the traditional and SD methods. It also presents a case study to provide a proof of concept of the research presented in this paper.

BACKGROUND

Several techniques have been developed to help project managers to plan and schedule projects, and make informed decisions. Those techniques are developed on the assumptions that whereas a project may unique and not subjected to stochastic and dynamic behavior together. Commonly, the traditional techniques simply describe the project as top-to-bottom hierarchy through decomposition of project elements into smallest acceptable level where work packages could be described easily by activities. Thereafter, cost, duration, and resources are estimated, mainly from experience as deterministic numbers. Then the project`s job logic is described as a network of activities connected based on the work sequence and logic. The apparent and the purpose of this process is to describe the actual project behavior generated in reality, it is a predication scenario. One of the main concerns in such static and liner philosophy of addressing the issues of planning and controlling, lies in the ability of the restructured activities of the network from bottom-to-top to behave based on the assumed assumption at the project decomposition stage. Furthermore, management in reality is dynamic and responsive to new changes and information to keep project on track than adhering to the original plans. Those plans are targets or baselines of the management, when those targets are endangered, then actions are triggered to correct the derailing of project behavior from targets. Thus, traditional methods are used as baselines implemented within a dynamic environment of causal-effect feedback loops. Such challenges can be effectively addressed by alternative approach based on an integrative simulation environment that accounts for the project dynamics and details at activity level.

The SD method was introduced by Forrester (1961) as method for modeling and analyzing the complex system behavior in industrial management. The method has been used in different fields of social science where the holistic view and the feedback process are critical in understating the evolution of the system behavior (Abdel-Hamid, 1991; Lee et al. 2002; Park and Pena-Mora, 2003; Chahal, 2008). The SD model aims to capture the feedback processes responsible on the system behavior within a predefined boundary. The management practice to close gaps between project performance and targets is an application of one foundation of SD in project management and control (Lynesi and Ford, 2007). A common example of project control feedback loops generated in the planning and control cycle is demonstrated in Figure 1, (Rodrigues and Bowers, 1996). The Figure shows three loops that result from the management decisions and policies. The loops are called *balancing loops* of negative polarity (-), as emphasized by the “B”. The *balancing loops* (-) are responsible on making the system more stable while *reinforcing loops* (not shown in the figure) of positive polarity (+) try to drive system out of limits. The polarity of the loops is a resultant of the multiplication of the variables’ signs shown on the arrows. In loop “B1”, when project progress is behind the schedule, the management responds to perceived schedule slippage by either increasing the resources level or extending the project completion time. The decision of increasing the resources-level option should increase the productivity rate. As a result, perceived progress reduces the efforts remaining and eventually brings the forecasted completion date forward. Alternatively, in loop “B3”, the strategy to respond to schedule slippage is to adjust the project completion date. Balancing loops are desired in the project and establishing them is not easy task for manger, as there is continues adverse influences from external variables as emphasized by rectangular in Figure 1. For instance, increasing the workforce is expected to increase the progress rate. However, on one side, the decision of increasing the workforce is restricted by constrains such as budget limitation, availability of skilled workforce, space limitation, etc., and on the other side, the expected increase in productivity of the work force is constrained by factors such as motivation, training level, ability to work under high overtime. These kinds of mechanisms of causal and effect feedback loops are responsible on the real behavior of project, and efforts spent on understating loops evolution and their interaction mechanisms will enhance the understating of the management problems of construction projects.

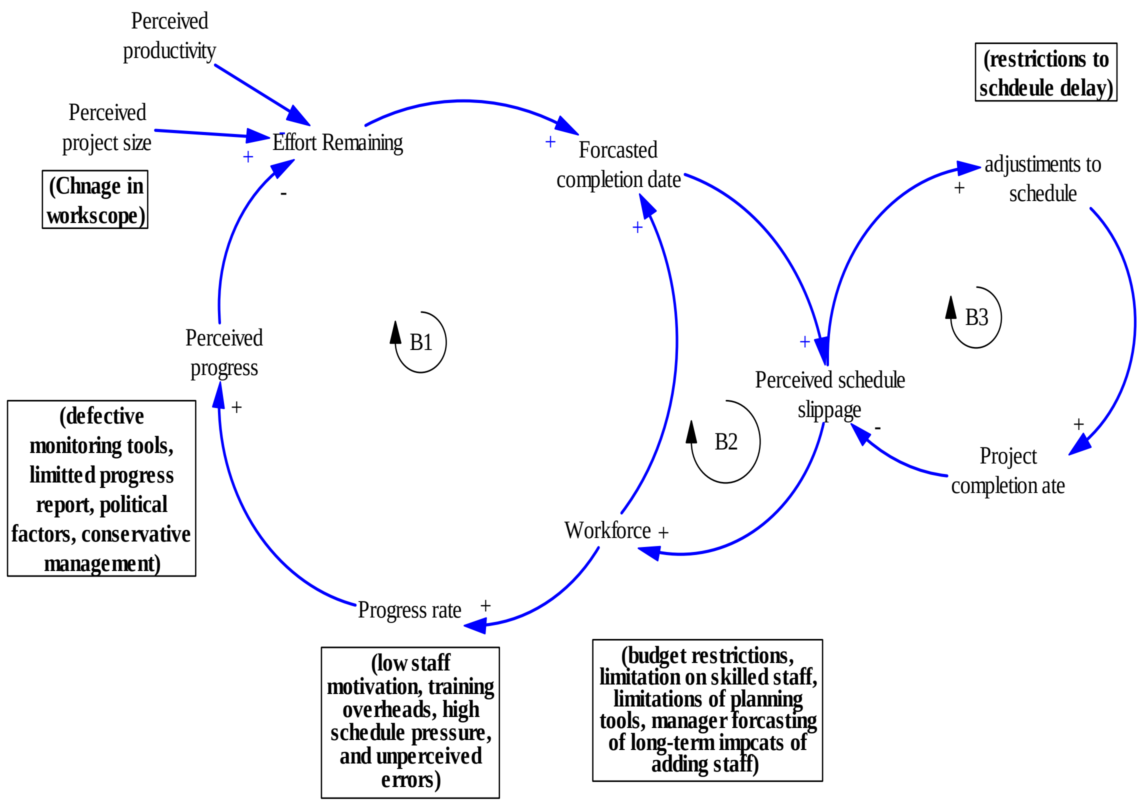


Figure 1- Feedback Process in Project Control Cycle

In order to address the concerns associated with planning methods, it is a good practice to summarize the main differences among them. The comparison is conducted between the methods of CPM-based network, DES, and SD from four perspectives as illustrated in Table 1. The study shows that CPM and DES methods address similar modeling issues except DES has the ability to account for the stochastic phenomenon witnessed in project at tactical level. SD method seems to be on the opposite side based on the characteristics perspective, while in reality it is complementary to the CPM and DES, as it addresses issues that are considered main limitations in CPM and DES.

Thus, as conclusion, the SD modeling and analysis offer different prospective of understanding system behavior and output from that offered by CPM and DES. This because SD model developer first understands the underlying influences that are responsible on the outcomes while developer of CPM tries to jump to the outcomes without considering the underlying influences. Rodrigues and Bowers (1996) had summarized the approaches that can be adopted to incorporate CPM-based network and SD:

1- A more sophisticated network model including the feedback processes and detailed mechanism for modeling activity durations and costs to reflect the underlying influences,

2- A more detailed and phased SD model, and

3- Adopting lessons learned from SD models in set of rules for use in making the estimation.

Table1-Comparison between the Traditional, DES, SD Planning Methods

Perspective	Traditional Method	DES Method	SD method
Focus	Activity	Operation	Holistic and Feedbacks
Level of Details	High Details	High Details	Little details
Behavior	Linear	Stochastic	Deterministic
Model type	Interrelated but distinct packages	Interrelated but distinct packages	Continuous flow

METHOD

The proposed planning method is implemented in a simulation environment. It utilizes SD model that models the policy management through capturing and quantifying their effects. The SD model creates a dynamic framework that exhibits the classic characteristics of project`s dynamic. However, such framework is considered incomplete unless it is coupled with CPM-based network to describe the job logic through activities sequence. The CPM network is developed using discrete simulation environment. This allows overcoming the deterministic nature of the tradition methods and accounts for randomness. The proposed implementation platform is demonstrated in Figure 2. The project scope is decomposed into smaller units to develop the work breakdown structure (WBS), from which activates are identified. Each activity duration and cost are inputted as probability distributions. The implementation platform used ProbSched as environment to develop the CPM network. The ProSched is a probabilistic scheduling package that uses Stroboscope as its engine and Microsoft Visio as its Graphical User Interface. ProbSched allows the definition of CPM networks where the cost and duration of each activity can be defined probabilistically. ProbSched produces graphical output to indicate the criticality of each activity and statistics of the early and late times and floats of each activity and the project (Ioannou and Martinez, 1998). The second component of the implementation involves developing SD model. The SD model is developed using Vensim Software Package from Ventana Systems, Inc.

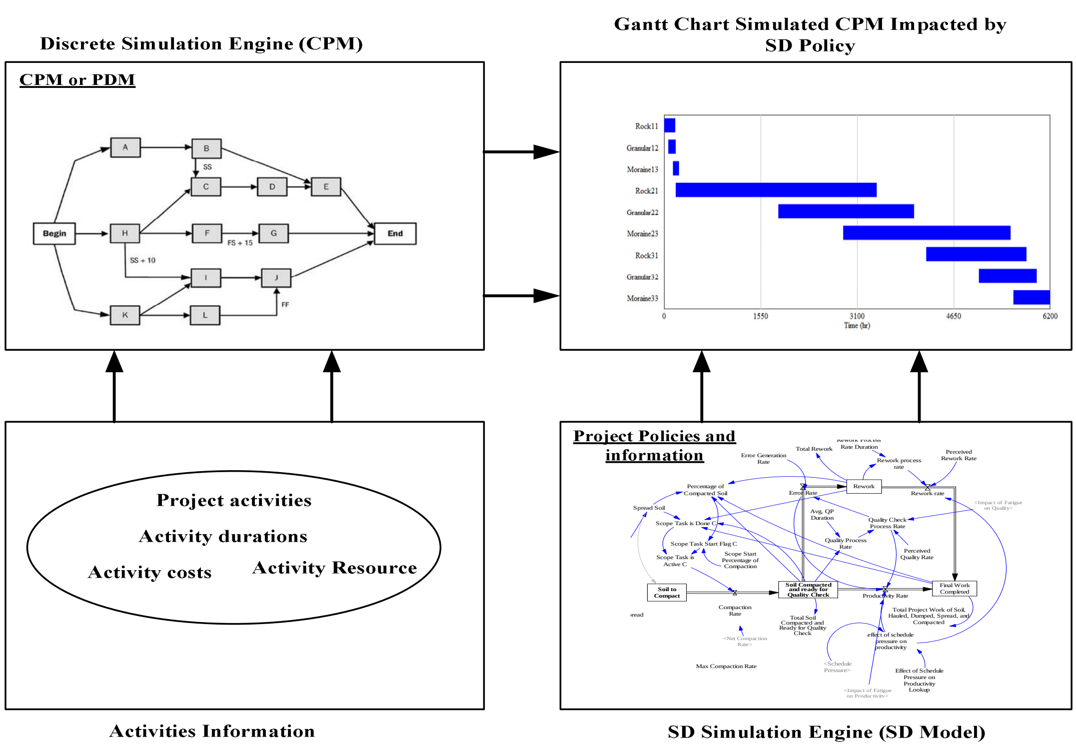


Figure 2- Architecture of the Proposed Planning System

RESULTS AND DISCUSSIONS

The method was tested using a real case study from a design firm that produces a verity of engineering drawings. The work involved preparing four types of engineering design drawings by different engineering offices in the same firm. In order to quantify and measure the drawings in a standard form, the firm developed units system that estimates drawings in term of work units (e.g.; one drawing equal to 2000 unit of work). The productivity of individuals is measured by number of drawing completed and checked per month. Table 2 demonstrates the characteristics of the case study used to implement the proposed method. The scope of the task is measured in term of units. The maximum available skilled workforce was 160 people. In column (2), the triangular probability distribution of task duration is estimated based on experience and from historical data. The start time for each task is shown in column (3). The duration distributions are inputted into the CPM-discrete simulation network. The model ran for 500 cycles and the average duration for each task was computed as shown column (4). Now, at this stage the CPM network computations are accomplished. The next stage involved developing SD model to represent the project dynamics. The developed SD model is composed of four modules (workflow, rework, quality, and labor). The purpose of the SD model is to study the effects of schedule pressure, fatigue, overtime, and rework cycle on quality and project duration. The planned profile of effort for each task shows ramp from 0 to 0.2 and ramp down from 0.8 to 1 as shown in Figure 3.

The SD model was simulated, and a sample of the results is shown in Figure 4. The project duration, estimated by the traditional method and discrete simulation had expanded from 70.9 months to 92 months, Figure 4.a. This represents an additional time of 32% in project duration. The work completed correctly shown in Figure 4.b represents the work checked and passed the quality test. Figure 4.c-d, shows the quality of work is degrading between 25 month and 45 month of the project duration as a result rework stock has increased to maximum between 30 month and 45 month. The cause of this behavior is due to the mounting schedule pressure, fatigue, and increased errors in work performed. The project has reach 50% of its duration while the actual productivity was not as perceived; this has triggered the loops to call for extra workforce that is beyond the maximum available limit (160 people). Therefore, the increase in the schedule pressure has triggered the need for overtime as policy to increase productivity, Figure 4.e; consequently, this has increased the errors rate in work performed, Figure 4.d. as a direct result of fatigue. The accumulation impact of those factors extended the project duration to 92 month. The accumulated quantity of work accomplished is shown in Figure 4.f d demonstrates S-curve behavior, this kind of curve is common and reflects the real accumulation of work execution.

Table 2- Case Study Data

Task Name	Task Scope in Units	Triangular probability Dist. of Task Length in Months	Start time for Tasks in Months	Simulated average Task Length in Months	Task Complet ion Time	Perquisite to Start Task	Productivity of individual engineer Drawing/ month
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Task1 (T1)	10000	20, 20.4, 20.9	0	20.5	20.5	0,0,0,0	20
Task2(T2)	50000	20, 20.2,20.6	20	20.35	40.35	T1,0,0,0	25
Task3(T3)	40000	10, 11.7, 12	40	11.4	51.4	T1,T2,0,0	15
Task4(T4)	20000	39.9, 40.5, 40.8	30	40.45	70.45	T1,T2,T3, 0	25
Project Duration (months)					70.45		

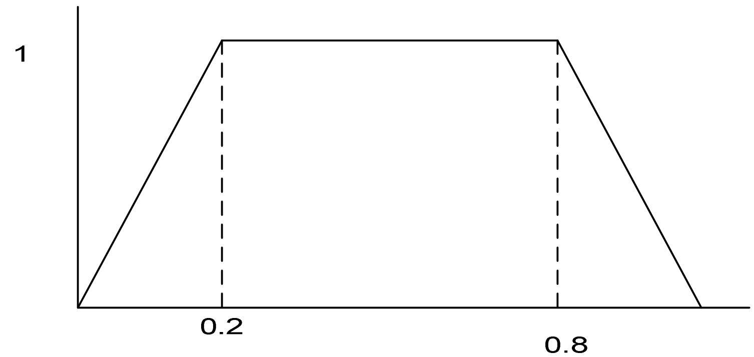
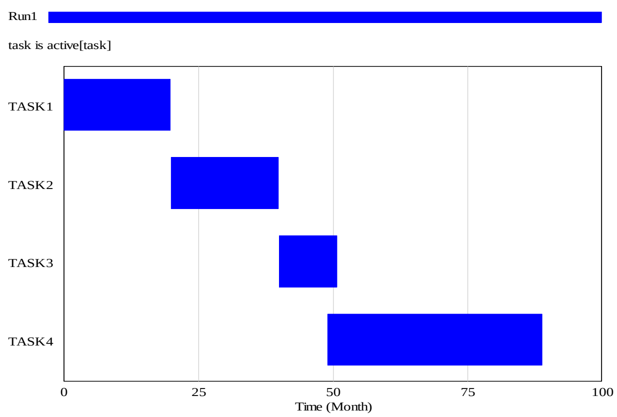
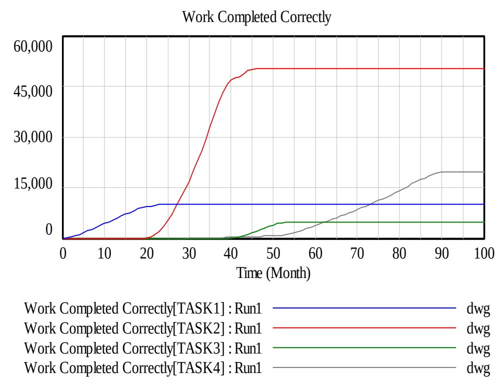


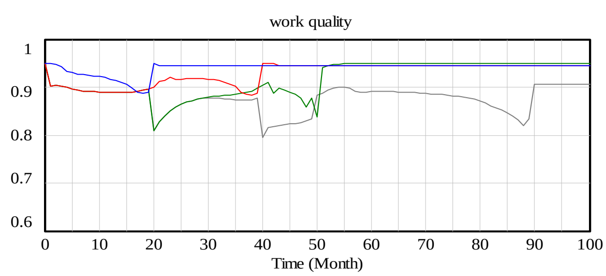
Figure 3-Planned work Profile



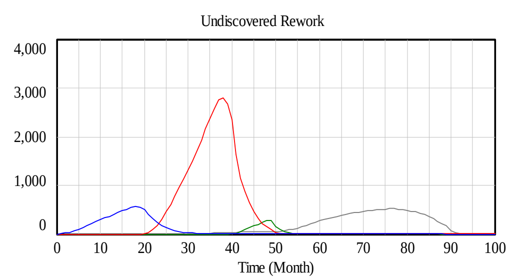
a) Gantt Chart of Completed Tasks



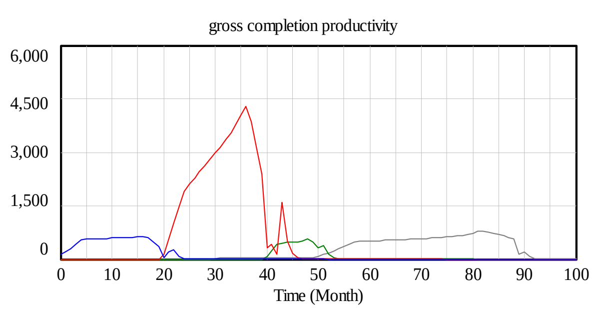
b) Tasks Completed Correctly



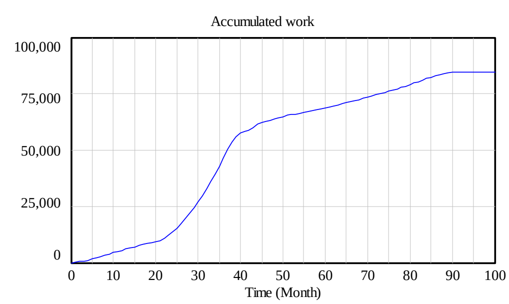
c) Fluctuation of Work Quality



d) Undiscovered Rework



e) Gross Completion Productivity



f) Accumulated Productivity

Figure 4-Sample of the Simulation Model Outputs

CONCLUSION

Traditional planning methods are based on decomposing a project into activities, and then establish the job logic among those activities. This results in addressing the construction problem in fragmented and linear fashion. The purpose of any project model whether it is a SD model or a CPM network is to strive to deliver unbiased model that capture likely behavior of project related parameters and their dynamic impact on project execution. This research indicates that SD is well suited to address the dynamic nature of the project interrelated parameters at the strategic level and traditional methods are well suited for modeling these parameters at the tactical level. Therefore, this paper has addressed those concerns by presetting an innovative method that integrated CPM-network developed in DES simulation environment with the SD model. The implementation infrastructure used discrete simulation engine, CPM network, and SD simulation engine.

The proposed method has been illustrated using a case study from the construction industry. The duration of the four tasks were estimated as probability distributions, and inputted into a model developed using discrete simulation to compute the average duration of the project. In the SD model, the average durations are used as initial inputs. The SD model was constructed to include four modules: workflow, rework, quality, and labor. The objective of the model was to study the effects of rework, fatigue, schedule pressure, and resource availability on project duration and quality of work performed. A significant difference in the outcomes has been observed between the static and the integrated models. The project duration increased by 32% from that planned originally in view of the dynamic impact of project related factors.

SD is still relatively not fully utilized in construction. The coupling of the traditional method with the SD is expected to provide valuable complementary information. Traditional techniques supply detailed information while the SD provides the impact of management policies and strategies on project execution. The method is expected to enhance current practice in project planning and modeling. Modeling of projects uncertainty and dynamics are main features of the developed methods.

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