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USING SYSTEM DYNAMICS SIMULATION TO UNDERSTAND THE FEEDBACK PROCESS IN A CONSTRUCTION PROJECT

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ABSTRACT

The fast changing, complex, and dynamic environment in the construction project nowadays has led to frequent occurrences of last minute changes and reworks. Such frequent occurrences can influence performance in terms of project completion time, which the completion time will result in delay and have an impact on the quality of the project. Usually, reworks occur because of last minute changes in order to fulfill the client's request or because of a decision made by the project manager. The Project Management Institute (PMI) has introduced the Project Management Body of Knowledge (PMBOK) as a standard guide that explains the different knowledge areas involved and needed to be taken into account when managing a project. As managing a construction project is complex and complicated, in addition to the project manager's lack of understanding on how different knowledge areas may influence other knowledge areas, the problem of project delay due to rework become inevitable. Therefore, the aim of this paper is to identify the interconnectivity and interrelationship between different knowledge areas in PMBOK using the System Dynamics (SD) simulation model. A construction project model of simulation was developed using Causal Loop Diagrams (CLD) as well as Stock and Flow Diagram (SFD). With the model, it is anticipated the project manager will be able to understand the feedback process of the project in order to prevent delays. The development of simulation model can be used to help and support the project manager in the process of planning and managing the construction project efficiently and making timely effective decision-making.

Keywords: Project Management, Construction Project Management, Simulation, System Dynamics.

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INTRODUCTION

The aim of this paper is to propose SD application to understand feedback (which involves cause and effect) in the processes taking place in construction projects. This is because any change in the project is related to the relationship between cause and effect. In addition, any other changes will also result in the changes of other things that are intertwined. The construction project usually involves a complex and dynamic behavior because it includes different relationships with the stakeholders, risks, uncertainties, and pressure (Miller, Radcliffe, & Isokangas, 2009). According to Ojugbele and Bodhanya (2015), a project that involves contact with different stakeholders in its processes is usually a complex project because each party has its own goals and the probability of changes occurring is high. For instance, when numerous changes occur this will cause the processes of managing and controlling the project to be more challenging. Consequently, the project will experience delays. Therefore, it is important for the project manager to clearly understand the relationship between cause and effect that will lead to changes in the project.

Project Management Institute (PMI) through the Project Management Body of Knowledge (PMBOK) has recommended ten knowledge areas of project management as a guide for project management. According to Maryman (2011) nowadays, PMBOK is currently accepted as best practices for the project management profession. PMBOK has also been recognized as the best project management practice as it fulfills the international standard set by ANSI/PMI 99-001-2008 and IEEE 1490-2011 (Maryman, 2011). The ten knowledge areas disclosed in PMBOK are project integration management, project time management, project cost management, project quality management, project scope management, project human resources management, project procurement management, project communication management, project risk management, and project stakeholder management (PMI, 2013).

Although PMBOK is acknowledged as the best practice project management and provides a detailed step-by-step process in every field of knowledge, Carton, Adam and Sammon (2008) have argued that PMBOK involves a discussion that is so broad which makes it difficult to understand the relationship between every field of knowledge. In addition, the process of identifying the relationships between various fields of knowledge of PMBOK from a broader perspective is very difficult. Therefore, some project managers tend to view the field of knowledge separately or one by one because too many knowledge areas are involved in the project. This situation has prevented the project manager from a fuller understanding of the

interconnectivity and interrelationship that exist between different areas of knowledge involved in the PMBOK of the project. Hence, this situation has also led the project manager to face with difficulties in understanding the changes that occur over time in a construction project.

As mentioned before, the aim of this study was to establish an understanding of the interconnectivity and interrelationships between different knowledge areas of PMBOK which are involved in the construction project. However, it would be easier if there was a better method that could be applied in dealing with a wide range of knowledge in the field of complex construction projects such as a system dynamics. As noted by Ambroz and Alda (2010), a powerful system dynamic is the appropriate methodology in dealing with a complex and dynamic system. The second objective of this study was to develop a system dynamics model that could be used to simulate the interconnectivity and interrelationship between different knowledge areas in this field.

REVIEW OF LITERATURE

Basic Concept of System Dynamics

Naturally, people think in linear form to solve problems instead of in multiple linearity. People define a problem and take an action to determine the expected results, and then believe that it is the end of the process (Forrester, 2009). This way of thinking applies to most areas in the public sector, in business, and in management. People rarely recognize or focus on understanding the reasons in order to clearly manage and resolve problems that constantly change over time with the hope that will not lead to an adverse changes on other things.

In dealing with most problems, it requires an act that could decide the outcome which will create another problem and action in the future. There is a loop which does not have a beginning and an end (Forrester, 2009) because we live in a complex behavioral response in which whatever happens must have a cause and effect connection. It was Professor Jay W. Forrester who introduced a methodology of System Dynamics (SD) in 1961 to model the complex systems and mental models with the feedback process of computer simulation methods (Sonawane, 2004). SD is a method that uses computer modeling and simulation software to analyze complex social behaviors that cannot be interpreted by the human mind (Forrester, Mass, & Ryan 1976). According to Sterman (2000), SD process can be divided into five phases as shown in Figure 1.

Figure 1: System Dynamics Process

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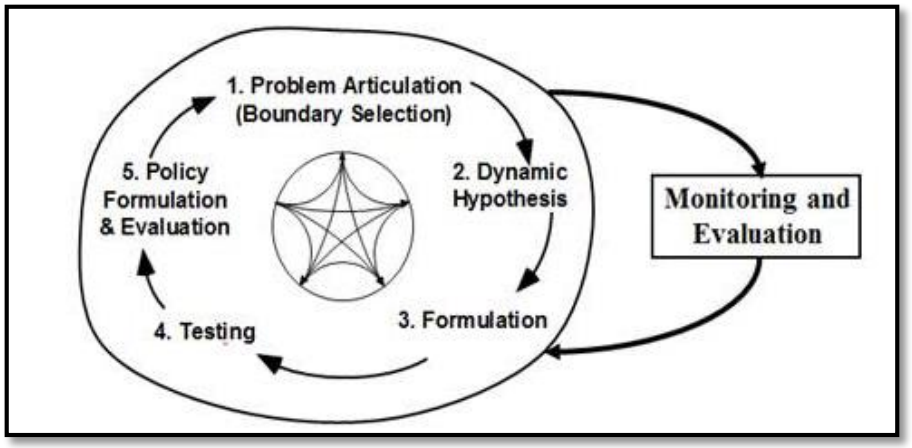

Source: Sterman, 2000

As shown in Figure 1, the SD process starts with the articulation of the problem in determining the problem that needs to be learned. Then, the process is continued by identifying the dynamic hypothesis. At the level of causal loop, diagrams will be used to understand the relationship among multiple variables, which will then be translated into the drafting of the stock and flow diagram. This is done by computing. Next, is the process is followed by testing the validity of the model with the actual behavior. The final phase involves the policy formulation and evaluation model. All these processes need to be monitored and evaluated in order to achieve a better result.

Project Management in Construction Project

In many areas, construction is known to be the required field which has contributed tremendously to development in every country. However, this area is not stranger to working with a dynamic and complex environment which makes the project construction management more challenging (Mawdesley & Al-Jubouri, 2009). The construction project is a temporary project activity which is necessary to achieve the project goals accordingly (Gustavsson & Gohary, 2012). According to Ojugbele and Bodhanya (2015), the construction project is necessary in dealing with the complex and dynamic situations, which always affect the existence of the frequent changes that lead to the delay of achieving the project goals.

Project management is important in order to achieve the objectives of a project. However, the task of management is unreasonable, demanding, and stressful. This leaves no choice for the

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project managers but to deal with the changes that occur in the project as fast as possible without deeply looking at the causes. Ahern, Leavy, and Byrne (2014) have asserted that if there is nobody who can understand the relationship between the activities of the entire project, this may suggest that uncertainty would somehow be inevitable. If this situation continues, it will increase errors in decision making due to the misunderstanding the causes of the changes.

SD in Construction Project

It is difficult to predict the changes in the behavior of the construction of a project because the changes mostly affect each and every phase of the construction project (Deniz & Zhu, 2016). Therefore, it is necessary to have a system that can monitor this project as a major project linking behavior with the project objectives (Deniz & Zhu, 2016). SD is suitable to be applied because it is a powerful method in understanding the dynamic environment especially the identification process feedback (Nabavi, Daniell, & Najafi, 2016).

The application of SD is very useful in order to understand the feedback process. SD has been used extensively used in construction project (Ebrahimy, AbouRizk, Fernando, & Mohamed, 2011). For example, Dangerfield, Green, and Austin (2010) used SD in their study to understand the construction competitiveness in order to improve the construction performance. Ebrahimy et al. (2011) applied SD to develop the supply chain of tunnel construction project at the planning stage enabling the planner to work in complex systems. Mawdesley and Al-Jubouri (2009) also used SD in their study to identify the variables that affect the productivity at the project site as well as to observe how all the variables interact with each other.

MODEL DEVELOPMENT

In the process of SD models developed, the purpose, scope, and boundaries of the study were defined prior to development of a Causal Loop Diagram (CLD), followed by the development of Stock and Flow Diagram (SFD). This study focused on the case study of the Pre-Construction Phase of a residential housing construction project in Kuantan, Pahang, in which the activities occurred before the Construction Phase. In the Pre-Construction Phase, there were three major processes involved – namely the Preliminary Process, Plan Approval Process, and Tender Process. However. The focus of this paper is only on the Preliminary Process because this was the first process involved in Pre-Construction Phase. Interview and observation data collection

techniques were used to collect all the information and data in order to answer the objectives of this study.

Causal Loop Diagram (CLD)

The first and important thing for project manager in developing the system dynamics model is identifying the problem and define the factors that could influence that problem. After that, the project manager also able to figuring out the causal relationship between those factors to building up a mental model in mind and then expresses it in a dynamic hypothesis of CLD.

The CLD can be represented as a map in understanding the feedback system in complex relationships. In an effort to help the construction process, it is necessary to understand the linkage within the feedback system during the construction. Every element in the CLD should be influenced by the direction of other elements as shown the examples in Figure 2. The positive or the negative sign at the arrow indicates the same (+) or opposite (-) influence of the earlier factor towards the afterward factor (Mehrjerdi, 2012).

The CLD is conducted to achieve the first objective of this study, which is to identify the interconnectivity and interrelationships between different knowledge areas. Figure 2 shows the causal loop diagram of activities involved in the Preliminary process in the Pre-Construction Phase. This CLD represents the relationship between all the activities occurred in the process. As the purpose of this study was to identify the interconnectivity and interrelationships between different knowledge areas in PMBOK, hence the diagram in Figure 2 is divided into different relevant knowledge areas of PMBOK namely, the Procurement Management and Scope Management. The numbers in the diagram represent the sequence of the loops of the activities in the project. All the loops are explained in the following section.

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Figure 2: CLD for Preliminary Process in Pre-Construction Phase

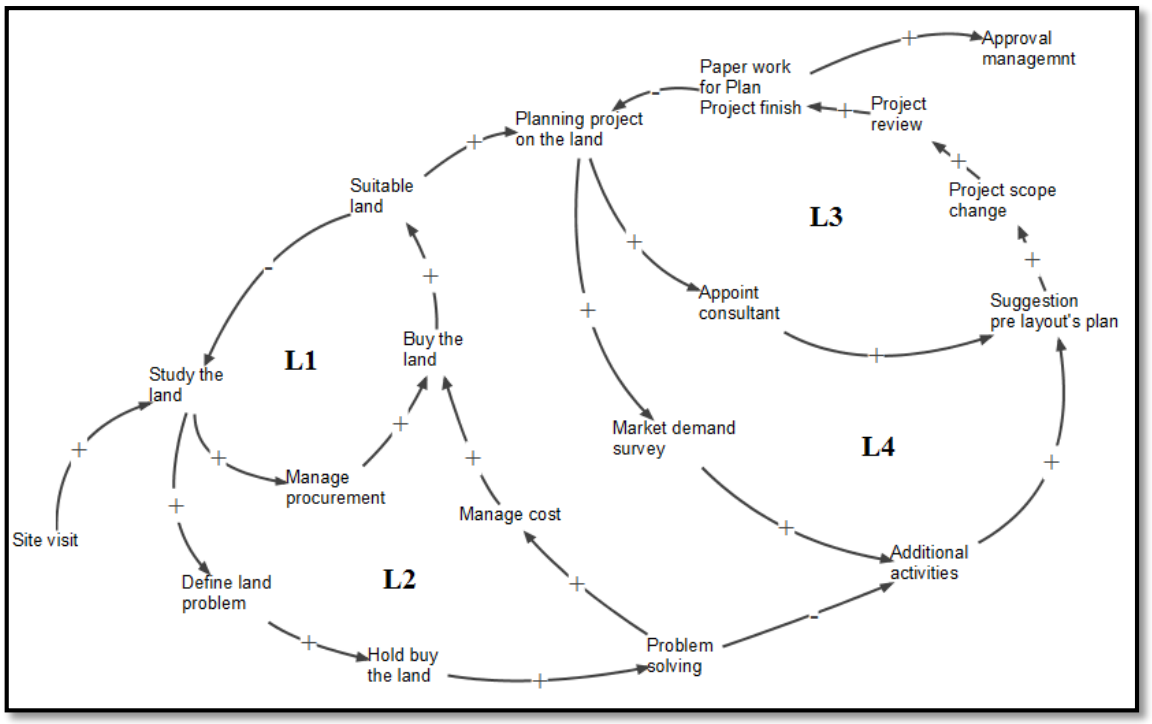

Figure 3 shows the loops for the activities that can be found in Procurement Management. This loop is named as Procurement Management because the aim of these activities is to buy the land. Procurement Management is related to the activities to buy or acquire service from outside the project team (PMI, 2013). This feedback process starts with Loop 1 (L1), which involves an increase in site visits, increase the study of the land, increase manage procurement, increase buy the land, and increases the suitability of the land. Then, its make study the land decrease. Loop 2 (L2) starts an increase in the study of the land, increase define the land problem, then cause increasing hold buy the land and increase in problem solving. For instance, when problem solving increases, manage cost increase, and buy the land also increase, which would later be followed by an increase the procurement of suitable land. An increase in the procurement of suitable land will result in the decrease in the need to study the land.

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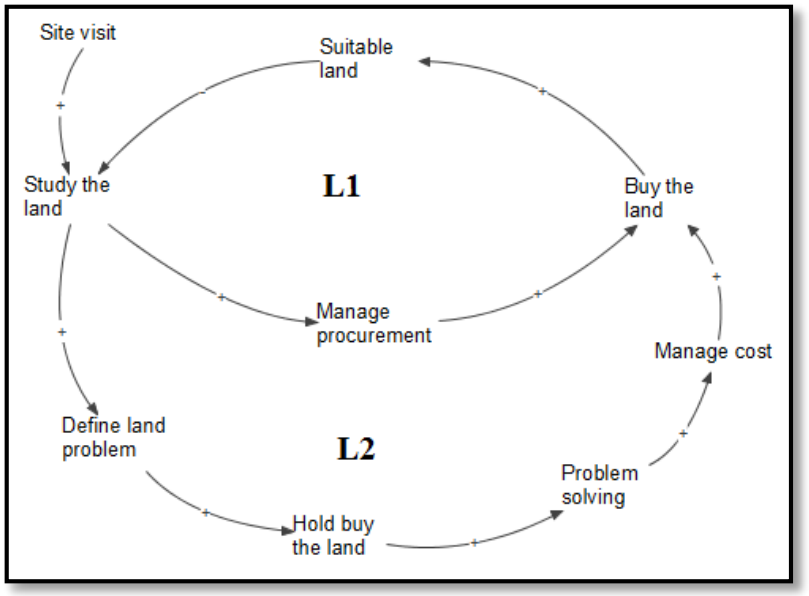
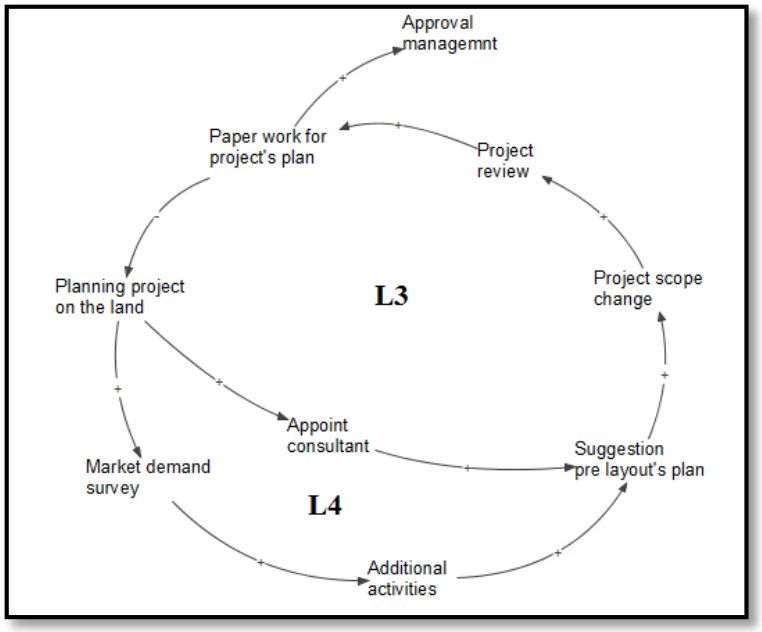
Figure 3: Procurement Management Loops in Preliminary Process



Next, Figure 4 explains the activities that categorized under Scope Management. This loop is named Scope Management because the main aim of this loop is to control the scope changes in order to develop the paper work of the project faster. This feedback process starts with Loop 3 (L3), with an increase in the planning project of the land, increase appoints consultant, and increase suggestion of pre layout's plan. If suggestion pre layout's plan increase, project scope change and project review will also increase. Then, when the paperwork for the project plan increases, this causes an increase in approval management and a decreasing in planning project of the land. The second loop (L4) illustrates the increases in planning project of the land, increase market demand survey, increase additional activities, and increase suggestion pre layout's plan. If the project scope change increases, it will cause an increase in the project review, and also an increase in project work for the project plan. If the paper work for the project plan increases, the approval management will also increase while the planning project on the land will decrease.

From the CLD, people can observe and understand the interconnectivity and the interrelationship between the activities in different knowledge areas, for instance, how the change in one activity can affect the changes in other activities and then can affect the changes as the whole of the project.

Figure 4: Scope Management Loops in Preliminary Process



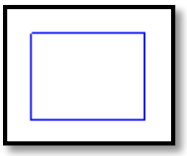
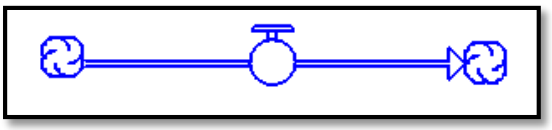
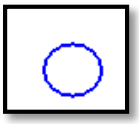
Formulating Simulation Model

The purpose of formulating a simulation model was to answer the second objective of the study, which was to develop a SD model that could be used to simulate the interconnectivity and interrelationship between different knowledge areas in PMBOK. After all the CLD in Preliminary Process were constructed, they were translated into SFD as in the Figure 5.

Table 1 shows the building blocks that needed during the process of developing SFD. The function of building blocks in SD is for easier understanding by representing it in the function of the bathtub. The flow as a pipe in order to control the flow of water while the stock functions as a bathtub to accumulate the water.

International Business Engineering Conference Proceedings
ISSN 9-789670-691916

Table 1: Building Blocks of SD

Building Blocks	Name	Functions
	Stock	To accumulate the information that enters into the stock
	Flow	To control the rate of information that enter the drains into or goes drain out of the stock
	Converter	An equation that helps to change the complex flow into the simpler flow

Source: Sterman, 2000

The purpose of Figure 5 is to translate the explicit information in CLD into the computerization of simulation system dynamics. Through the SFD, the relationship of the feedback process can be analyzed and simulated. After the SFD model already constructed, the information about the amount of work progress in each variable for procurement management and scope management are entered into the SFD model system. Then that information is simulated by the system dynamic's software to see the interrelated between both knowledge areas. The way to measure the progress of the activities in each knowledge area is by comparing the actual work progress with the work planning. From this comparison, the project manager can know how many activities that over the schedule and can see where is the activities that influence more in the change for each knowledge area. Then, the project manager can make a confident decision during managing the project improvement.

The objective of the flow diagram of Procurement Management is to buy the land. In order to identify activities that impact the process to buy the land, whether the process is faster or slower based on the flow that control the amount of the drain that enter into the stock of buy the land. According in the Figure 5, managing procurement flow and problem solving flow are the

variables that influence the purpose to buy the land. Therefore, the project manager can give more attention to both of the flows without ignoring other activities because all the activities are included in the diagram. However, the activities in the Procurement Management will affect the activities in the Scope Management because the activity in the Scope Management diagram can only start after the activities in the Procurement Management diagram have finished its task.

After the activities in the Procurement Management diagram finishes, the activities in the Scope Management diagram can start operating. The goal of the Scope Management flow diagram is to manage the scope change that influences the process for completing paperwork faster. Based on the diagram of Scope Management shown in the Figure 5, the activities that directly influence the progress of finishing the paperwork for the project are the market demand survey flow and project review flow. However, the project review flow should be emphasized more compared to market demand survey flow in order to influence the progress of finishing the paperwork because the project review flow controls the finishing rate of the scope change. According to the project manager, the scope change greatly affects the progress of finishing the paperwork for the project plan.

At the last, those factors that influence the change in each knowledge area are also affect to the change for other knowledge areas. Therefore, it is important to identify the factors that influence the interconnectivity and interrelationship between different knowledge areas in PMBOK during managing the project instead look the knowledge area separately.

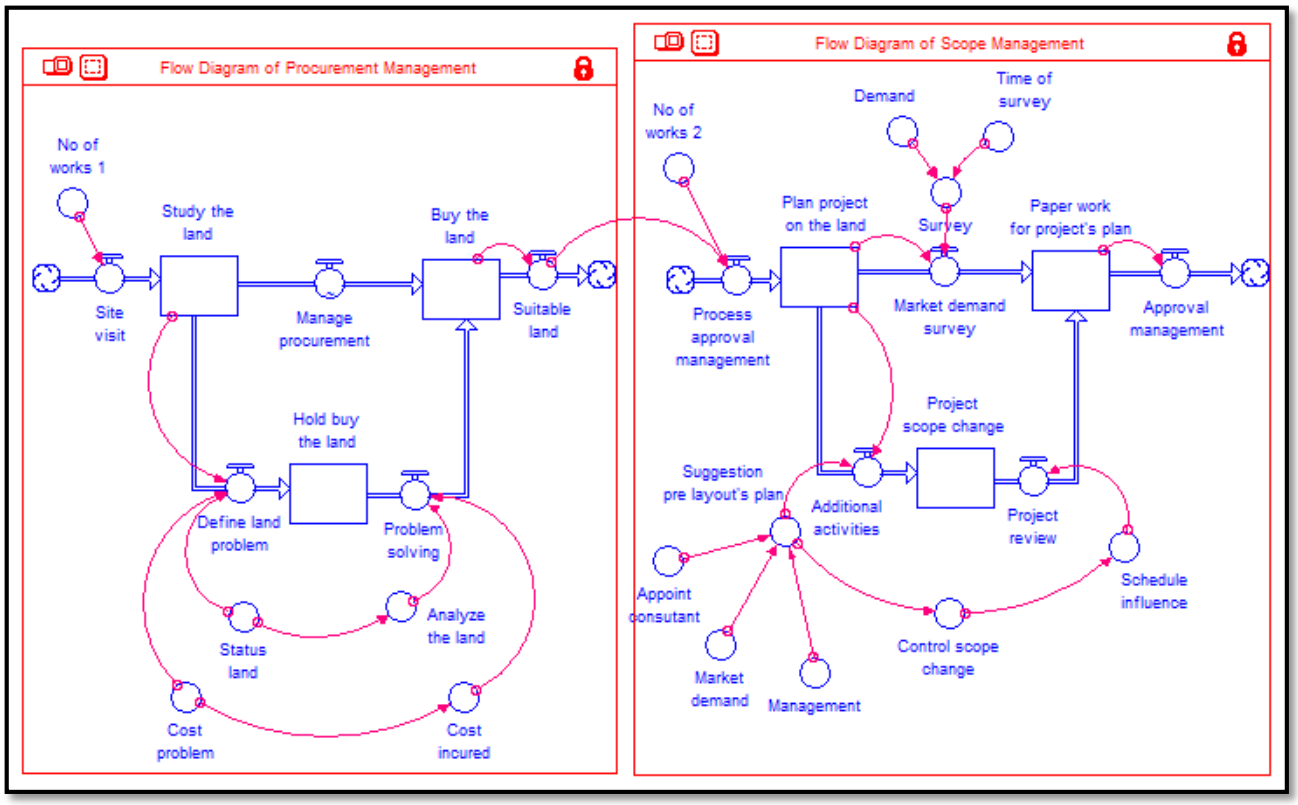


Figure 5: Flow Diagram of Procurement Management and Scope Management

Model Validation

Before conducting the simulation, it is important to check the validity of the SD model to achieve a valid result (Ding, Yi, Tam, & Huang, 2016). In order to validate the model, the first phase is to check the adequacy of the databases and the suitability for the model purpose through the interview with the experts (Wan, Kumaraswamy, & Liu, 2013).

After that, a extreme condition model was conducted to test the confidence level of the model structure. It is to view whether the mode structure responds logically when the subjected to extreme values of the flows change (Wan et al., 2013). As tabulated in Table 2, the extreme condition on the changing rate of the simulation model parameter was tested. When the problem solving flow and manage procurement flow showed zero of work, there would also be no work in buying the land stock which is similar to the real life situation. Same when no work in additional activities flow, there is no work for project scope change.

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Besides that, the comparison between the simulation result and the actual behavior was presented to ensure the simulation result can run closer to the actual behavior as can as possible. This comparison purpose of the validation was to achieve confidence in the simulation model that could represent the actual model and for comparison and verification with actual behavior (Guo & Guo, 2016). Then the model can be considered as structurally valid (Wan et al., 2013). As can be seen in the graph in Figure 6, the simulation result can simulate almost the same with the actual behavior.

Table 2: Result for Extreme Condition of Changing Rate

Extreme condition of model parameter	Value	Test result
Zero problem solving and zero manage procurement	0	No work to buy the land
No project reviewed and no market demand survey availability	0	No work for constructing paper work
No additional activities	0	No work for project scope change
Zero defines land problems generation	0	No work to hold buy the land

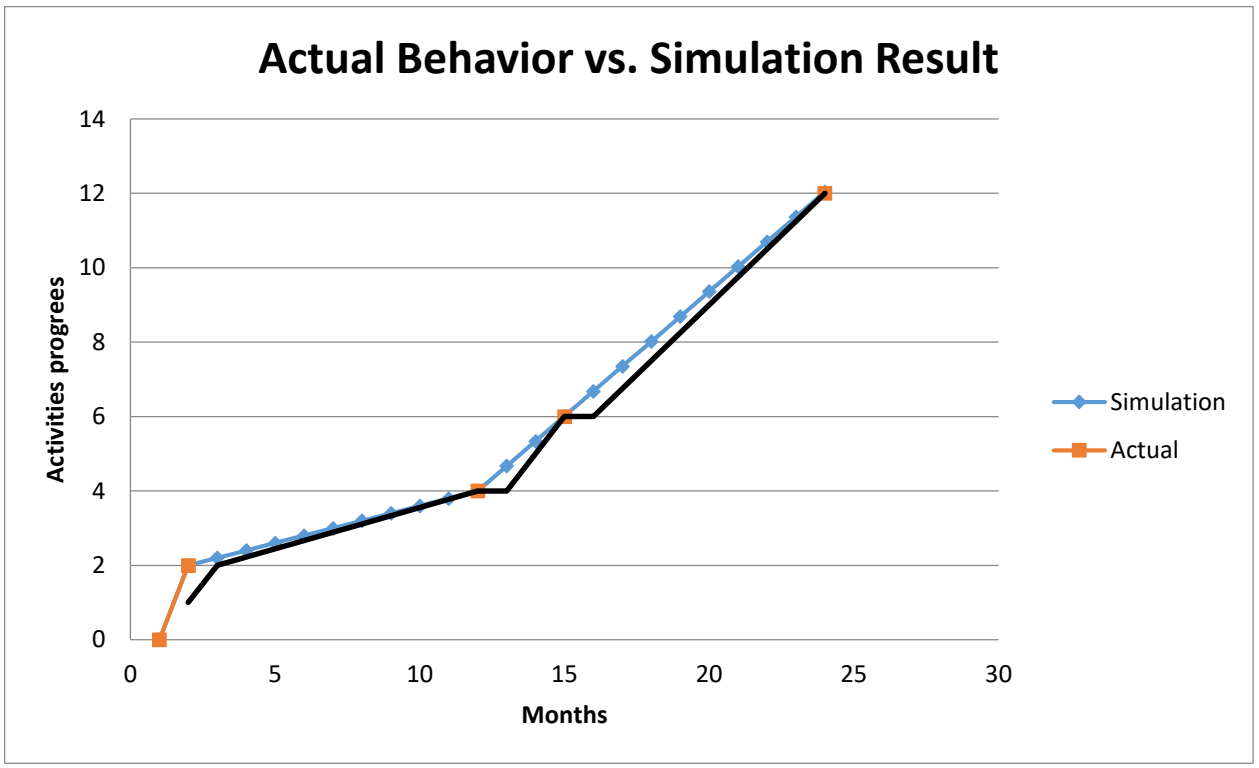

Figure 6: Comparison Between Actual Behavior and Simulation Result

CONCLUSION

The objectives of this study were to identify the interconnectivity and interrelationships between different knowledge areas in PMBOK as well as to develop a system dynamics model that can be used to simulate the interconnectivity and interrelationship between different knowledge areas in the construction project. At the end of the research, both objectives were successfully achieved. According to Ding, Yi, Tam, and Huang (2016), CLD and SFD are powerful tools that can be defined the key variables of the problem and describe the interconnectivity among them. In this regard, the findings of the present study have shown that the main factors that led to change the Preliminary process in the Pre-Construction Phase could be defined. Moreover, SD has also helped to identify the interrelatedness among knowledge areas that identified in the Preliminary process. It is beneficial to project manager to know what factors that needed in order to better the construction project in the Preliminary stage which would eventually help to achieve the goal of the project. However, the present study also had its limitations in the sense that it only concentrated on the activities that were involved in the Preliminary process. Hence, further research on Pre-Construction Phases in the Plan Approval Process and the Tender Process is highly recommended.

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