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Understanding the Interrelationship Between Different Knowledge Areas in PMBOK Through the Development of System Dynamics Model

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Abstract: Last minute changes, error, rework, cost overrun and delays are common issues in project management. Besides that project managers also face the pressure of completing projects within the given time and allocated budget. Project Management Body of Knowledge (PMBOK) by Project Management Institute (PMI) compiles guidelines for project management through the introduction of ten knowledge areas. Although, PMBOK provide detailed, step-by-step guidance through the project management process, there is no discussion on the interrelationship and interdependencies between the knowledge areas. Frequent changes in the projects also lead to uncertainly and unpredictable outcome as project manager's well intentioned efforts to solve a problem sometimes make it worse. This is because the action's outcome are delayed, diluted or defeated by unforeseen reactions of other factors due to the interconnected factors in project management. System dynamics methodology will be used in this study to capture the interdependencies between different knowledge areas that occurred during the pre-construction phase of a residential housing construction project. The developed model can be used by project managers to understand the interconnectivity and interrelationship between different knowledge areas. Also, the model can be extended as a learning tool where project managers can test extreme conditions or strategies to the model and observe its impact before implementing it to the real project.

Key words: Project management, simulation, system dynamics, PMBOK, PMI, interdependencies

INTRODUCTION

Today, organizations face new challenges due to the ever-changing and complex market environment, economic impact and evolving technologies. Project management is no exception, the complexity is rising. Projects of any sizes battle in resource planning, prioritisation and monitoring besides the pressure of completing the project within the given time and allocated budget (Ocak, 2012). Last minute changes, error, rework, cost overrun, delays are the common issues in project management. In order to manage a project efficiently, there is a need to understand the interdependency and interaction between different knowledge areas of project management.

Project Management Body of Knowledge (PMBOK) by Project Management Institute (PMI) is the most widely recognized standard for the conduct of project management (Brewer and Strahorn, 2012). The ten knowledge areas discussed in PMBOK are project integration management, cost management, human resources management, scope management, quality management, communications management, time management, procurement management, risk management and stakeholder management (PMI, 2013). Although PMBOK provide detailed, step-by-step guidance through the project management process, these materials are too technical for project managers (Longman and Mullins, 2004) and there are no discussion on the interrelationship and interdependencies between the knowledge areas.

As discussed in Vidal and Marle (2008) the greatest driver to project complexity is the interdependencies and interrelations within the project systems. Therefore, looking at only one knowledge area or looking at it as a separate entity is not sufficient to understand the whole project dynamic as the decision and planning in one knowledge area will influence other knowledge areas and ultimately impact the overall projects. Moreover, frequent changes in the projects also lead to uncertainly and unpredictable outcome due to the complexity and interdependencies between knowledge areas. Dangerfield *et al*. (2010) emphasised the important of understanding how each part is organized to understand the reason of emerging undesirable outcome

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such as cost overrun and delays. Traditional tools and mental models are inadequate for dealing with the dynamic complexity of projects and as the result, project managers continue to make mistakes (Lyneis *et al*., 2001). Having tools to analyse the complexity provides greater understanding and gives a start as to how to manage the complexity (Geraldi *et al*., 2011).

Therefore, the aim of this study is first, to identify the interconnectivity and interrelationship between different knowledge areas in PMBOK and secondly, to develop a system dynamics simulation model that can be used to simulate the interconnectivity and interrelationship between different knowledge areas in PMBOK.

Literature review

Introduction to system dynamics: System dynamics is a methodology for analysing complex systems and problems with the aid of computer modelling and simulation software (Rodrigues and Bowers, 1996). System dynamics approach originated from the research of Professor Jay W. Forrester at Massachusetts Institute of Technology (MIT) in the late 1950's. Maani and Cavana (2000) defined the word system as a collection of parts that interact with one another to function as a whole and a system is more than the sum of its parts, it is the product of their interactions. The word dynamics is defined as changes in demand and supply over time as the components are constantly evolving, as a result of previous actions (Ruth and Hannon, 2004). Richardson and Pugh III (1981) defined system dynamics as a methodology for understanding certain kinds of complex problems while Sterman (2010) gave a detailed definition of system dynamics by explaining it as partly, a method for developing management flight simulators, often computer simulation models, to help us learn about dynamic complexity, understand the sources of policy resistance and design more effective policies.

While traditional analysis approaches focus on breaking down problems to smaller parts and solving it separately, system dynamics approach, however, involves a broader view, looking at possible interactions among the subsystems to create a better understanding of the big picture (Cheng, 2010). The need for system dynamics arises as many times, our best efforts to solve a problem actually make it worse. This is due to our well intentioned efforts to solve pressing problems lead to policy resistance where policies are delayed, diluted or defeated by the unforeseen reactions of other people or nature (Sterman, 2010).

According to Ruth and Hannon (2004) both the number and complexity of the interconnections have changed over time because of growth in business size, globalization, pressure to improve efficiency, growing competition while trying to live up to customer's expectations and technological advances. System dynamics therefore is a powerful method to gain useful insight into situations of dynamic complexity and policy resistance. It is increasingly used to design more successful policies in companies and public policy settings (Sterman, 2010). As analytical method offers no means to capture interdependency (Warren and Langley, 1999) it is the nature of system dynamics that captures the interdependencies between all subsystems that make up the whole. System dynamics also combines qualitative and quantitative aspects and aims to enhance understanding of a system and the relationships between different system components (Brailsford *et al*., 2004).

System dynamics provides a feasible experimental environment as exploring the effect of policy changes and experimenting with alternative policy formulation are not feasible in the real world. Unlike forecasting or market research that over simplify interactions among important variables and parameters to generate results, policies testing presents alternative images about the future, thus helping managers to face their own logic and assumption (Georgantzas, 2003). Therefore in this study, system dynamics modelling is a well suitable technique, to capture the complexity of construction projects as this technique has been used widely in other areas such as health care, education, manufacturing and transportation.

Application of system dynamics in project management: As interdependencies are the biggest drivers to project complexity, traditional project management tools are not sufficient to capture the reality of interdependence (Vidal and Marle, 2008). Project management is a very suitable field for system dynamics (Lyneis *et al*., 2001) as while project management deals with complexity, uncertainly and hard to measure variables, system dynamics is capable of revealing the underlying conditions and cause of an existing or potential problem (Ocak, 2012). As system complexity increases, many previously separate domains of knowledge become interconnected and systems dynamics becomes essential (Sheffield *et al*., 2012).

Sterman (2010) listed three major advantages of using system dynamics approach in project management where the first is the results can be calculated correctly, multiple factors can be analysed at the same time and thirdly, simulations can be run under any conditions and experimentation with extreme factors, constraints and impossible assumptions can be performed. There are many examples of the application of system dynamics in project management. Rodrigues and Bowers (1996) summarized the development of system dynamics in project management where system dynamics is usually applied in construction projects, research and development projects, software development projects and product development projects.

To illustrate the argument, some examples of system dynamics application in project management are discussed. Dangerfield *et al*. (2010) applied system dynamics to understand the dynamics interrelationship between factors such as social structures, underlying causal structures as well as the differing personal construct and rationalities that contribute to construction project competitiveness. As changes that occur during project's development phase usually have significant and unpredictable impact. Love *et al*. (2002) developed a system dynamics model to better understand the dynamic of change and rework in construction projects. Rodrigues *et al*. (2006) on the other hand used system dynamics model to understand change in new product development project.

A system dynamics model was constructed by Han *et al*. (2013) to assess the negative impacts of design errors in construction projects. Grogan *et al*. (2015) design an interactive model to aid system development processes and resource allocations in a system project management while system dynamics model developed by Zhang *et al*. (2014) is used for assessing the effect of dynamical factors on construction project sustainability. Kapsali (2011) on the other hand examined project management in twelfth health care projects using system thinking and system dynamics by comparing the projects in terms of planning, communicating and task control activities to evaluate the quality, project features and cost effectiveness of the project processes.

Although system dynamics is widely used in project management, most of the studies focus on four themes which are project features, project rework, project control and project ripple effects (Lyneis and Ford, 2007). There is a need for a study that assesses how the interconnecting aspects of project management knowledge area affect each other. Lyneis and Ford (2007) recommended that by integrating system dynamics project models and other project management tools can help to improve the power of the methodology to build theory and improve practice.

Construction project management: Construction industry is the main point within the development process of a nation (Ibrahim *et al*., 2010) as it aids development project such as hospitals, schools, housings, roads and many more. Construction Industry Development Board (CIDB) in 2009 stated that the Malaysian construction sector has contributed about 3-5% to the economy of Malaysia (Yong and Mustaffa, 2012). Moreover under the Tenth Malaysia Plan (2011-2015) about RM138 billion was allocated to construction sector in order to accelerate the growth of Malaysia's economy (Yong and Mustaffa, 2012). Besides that Ibrahim *et al*. (2010) also mentioned that construction sector is within the top three sectors that contribute to the Malaysia's economy after manufacturing and agriculture.

Due to the complex nature of construction projects, it is difficult to conduct and maintain construction performance. Although time is one of the significant indicators to measure the level of project performance, many researcher's stated that the success of a project is depending on the project's time, budget and quality of the yield. According to Meng (2012) time, cost and quality are the common indicators to measure the level of the construction performance. Chou and Yang (2013) on the other hand stated that although the indicator for each project performance varies, the most significant indicators for project performance are cost performance and time performance. This shows that time factor is very crucial and widely used as a reference to measure the performance of each construction project. Besides, project delay has a very high capability in reducing the project performance and in some cases may lead to the project failure.

As Holt (2013) pointed out that project delay can lead to project failure, it also have negative impacts on stakeholder expectation, client's trust and the company overall performance. Once the relationship with stakeholders is broken, it will take a long period of time to repair. On operations wise, project delay can affect project completion, budget, quality of work, productivity, third party warranties claims and termination of contract (Aziz, 2013).

The role of a project manager is becoming increasingly demanding given the dynamic, complex and uncertain environment of construction projects. Project manager no longer can only do the classic role as project manager like planning, conducting and controlling (Sommerville *et al*., 2010) but also need to identify and solve the rising matters that can influence the smooth flow of work in an effort to compete with in the challenging environment. Therefore, it is the aim of this research to integrate both system dynamics with PMBOK in order to understand the interconnectivity and interrelationship between knowledge areas to grasp the complexity of construction project management.

MATERIALS AND METHODS

The modelling process of system dynamics methodology suggested by Sterman (2010) will be applied in this study. System dynamics modelling process can be divided into five phases which are problem articulation (boundary selection) formulation of dynamic hypothesis, formulation of a simulation model, model testing, lastly policy design and Evaluation. The descriptions of the phases are as follow.

Problem articulation (boundary selection): In this phase, the scope, purpose and boundaries of the study are identified. The focus of this study is on the pre-construction phase of a residential housing construction project. Five major areas are involved in the pre-construction phase, namely the preliminary stage, earthwork plan stage, plan approval process stage, construction tendering stage and promotion and sales launching stage. Information and data including historical and statistical records and policy documents are collected. This phase also includes identifying the process and problem areas that commonly occurred at each stage during the pre-construction phase of a residential housing construction project.

Formulating a dynamic hypothesis: This phase is conducted to identify the interconnectivity and interrelationship between different knowledge that occurred at the five stages of the pre-construction phase. A causal loop diagram describing the process that occurred in each stage was developed. Each causal loop diagram has its own story with the interconnectivity and interrelationship between the factors. According to Chuang (2011) causal loop diagram is like a map that has closed loop which linked individual variables with relationships. A causal loop diagram is capable of capturing dynamic processes of a system by demonstrating the chain effect through a set of related variables, back to the original cause or effect. Variables are related by causal links, shown by arrows. Each causal link is assigned a polarity, either positive (+) or negative (–) to indicate how the dependent variable changes when the independent variable changes.

Figure 1 depicts the causal loop diagram of activities involved during the preliminary stage of the pre-construction phase. The causal loop diagram exhibits the interrelationship of all activities occurred in the Preliminary Stage. As the aim of this study is to identify the interconnectivity and interrelationship between different knowledge areas of PMBOK, the causal loop diagram in Fig. 1 is further divided into different relevant knowledge areas. Scope management, cost management and stakeholder management are the three knowledge areas identified in the preliminary stage.

Figure 2 shows the loops for activities that are categorized in Scope management. Loop 1 explains that an increase in uncertainty in scope of project, increases the possibility of change in scope, increases the need to conduct project review, increases the involvement of top management and therefore reduces the uncertainty in scope of project. Loop 2 further exacerbate the uncertainty in scope of project as the increase of change in scope, increases additional work, increases the involvement of consultants (planners) increases work redundancy and therefore increases the level of uncertainty in scope of project.

Figure 3 shows the loops for activities that are categorized under Cost Management in the preliminary stage. Loop 3 illustrates an increase in demand uncertainty, increases the uncertainty in scope of project, increases additional work which will increase budget uncertainty, increases cost estimation and also increases cost variation (deviation from original budget). The increase of cost variation increases the need for market survey (to understand with the updated cost projection what is the specification of residential housing that is currently well received in the market. With the information gathered during market survey, the uncertainty in demand reduces. In loop 4, the increase in cost variation (deviation from original budget) increases the need for layout restructuring, increases additional work, increases budget uncertainty, increases cost estimation and further exacerbate cost variation.

Figure 4 shows the loops for stakeholder management activities involved during the preliminary stage. Loop 5 describes how change in scope will impact the stakeholders that are involved in the project. Loop 5 starts with an increase on change in scope increases the need for project review. This will further increase the involvement of consultant (planner) increase the need for further negotiation with other affected stakeholders. This will then reduce the involvement of top management in the project and therefore reduces the possibility of change in scope.

The causal loop diagrams representing activities in earthwork plan stage, plan approval process stage, construction tendering stage and promotion and sales launching stage will be developed. Similarly, the causal loop diagrams will then be further divided to related and relevant knowledge areas. From the causal loop diagrams, the chain effect (s) of activities in one knowledge area and how these activities affect the other knowledge areas can be identified.

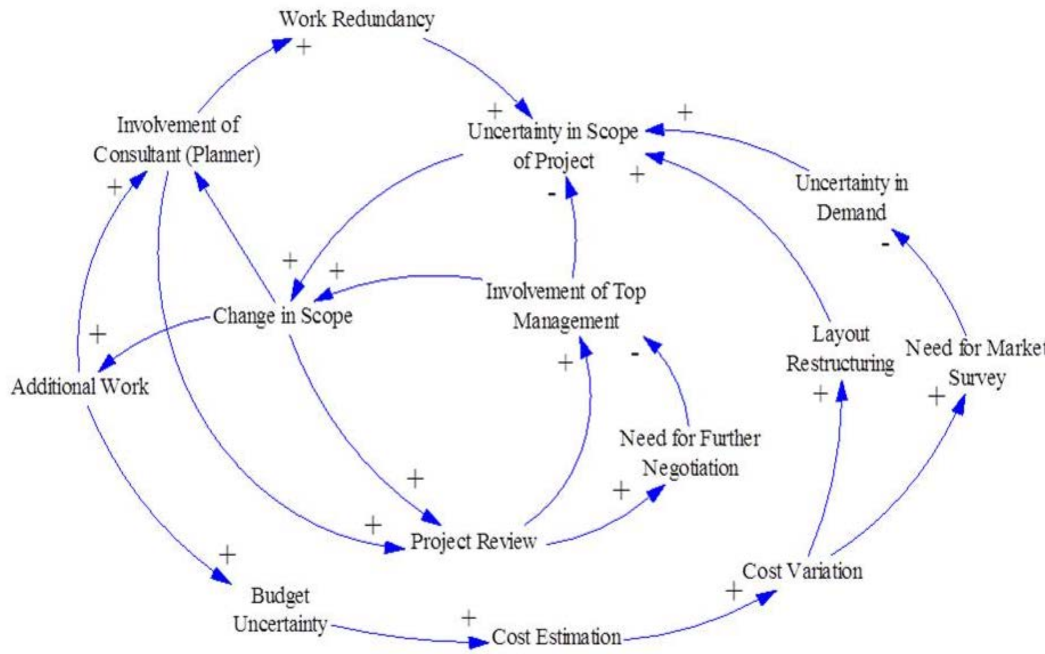

Fig. 1: Casual loop diagram of activities in the preliminary stage; own computations

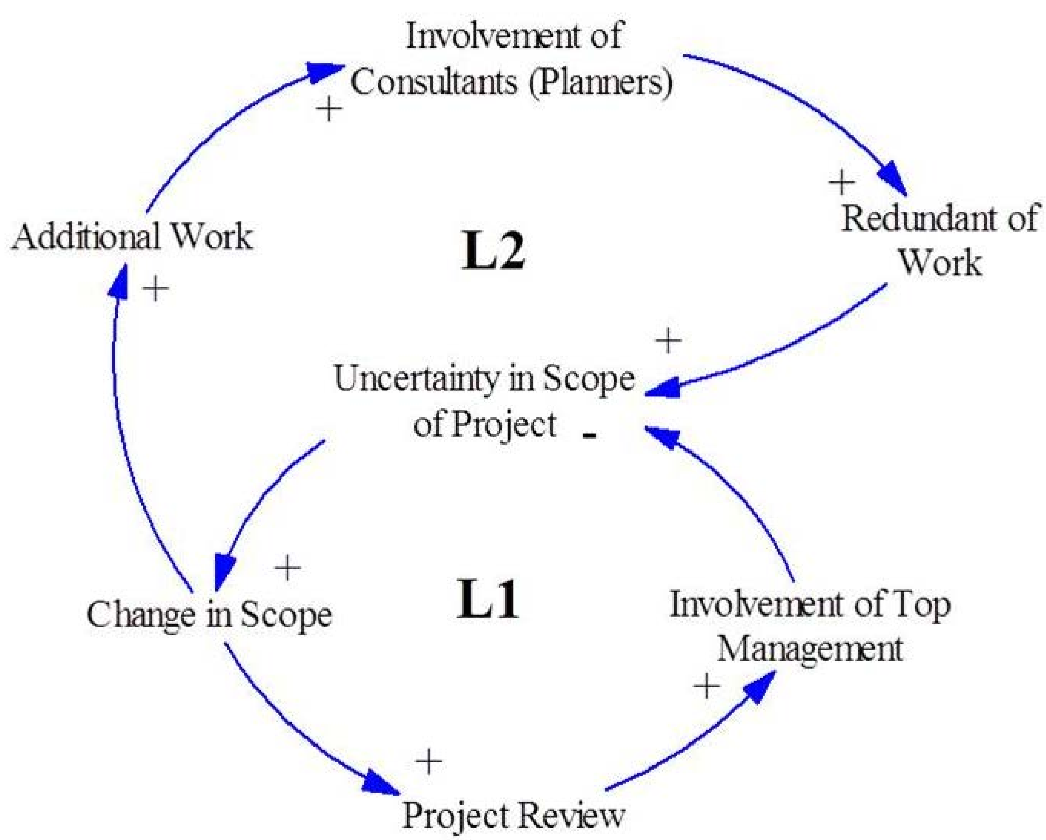

Fig. 2: The scope management loops in the preliminary stage; own computations

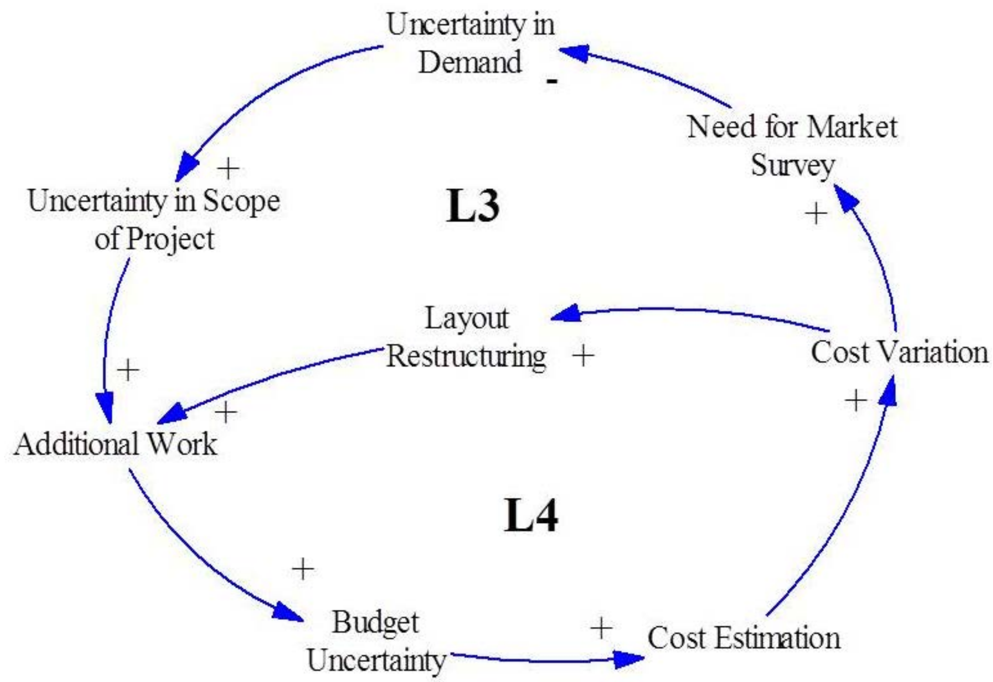

Fig. 3: The cost management loops in the preliminary stage; own computations

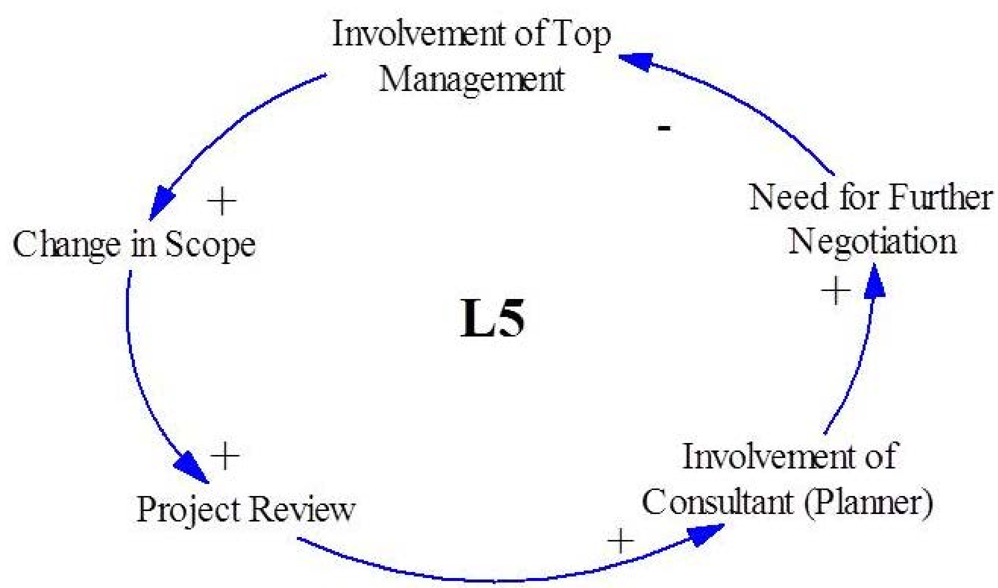

Fig. 4: The stakeholder management loop in the preliminary stage; own computations

Formulating a simulation model: This phase will be conducted to achieve the second objective of this study: to develop a system dynamics model that can be used to simulate the interconnectivity and interrelationship between different knowledge areas in PMBOK. After the initial causal loop diagram of the interrelationship and interconnectivity of all knowledge areas for the five stages in the pre-construction phase are developed, the model will be translated into a stock and flow diagram. The stock and flow diagram composed of four fundamental entities which are stocks, flows, converters and connectors. Table 1 shows the building blocks of system dynamics model.

Table 1: Building blocks of system dynamics model

Name	Description
	A component of the system where something is accumulated. The contents of the reservoir or stock may go up or down with time
	Activities that determine the values of
reservoirs or stocks	
	System quantities that dictate the rates at which processes operate and the
reservoirs/stocks change	
	Define the cause-effect relationships among the different components of the system

The building block of system dynamics can be easily understood through the explanation of the bathtub representation. The interrelationships between the factors can be reflected by the stock and flow which represented by the analogy of pipe and bathtub. This is because any incoming data or information will first enter the flow. After that, the valve of the flow will control the amount of the information that will enter the stock or drain out from the stock. The stock will accumulate all the information entered and drain out the information through the next flow (Bacioiu, 2012). Similar to the bathtub application with the pipe where the pipe represents the incoming information and the bathtub as the place to gather the information. The pipe can control the incoming information and the outlet can control the outgoing data or information.

The stock and flow diagram will be modelled using the iThink modelling and simulation software. The model will then be tested through experiments using the collected data. In this study, the data that will be inputted into the model are the total duration (time) needed to conduct each activity in order to complete the whole pre-construction phase within the prescheduled time. In short, the causal loop diagram developed in earlier phase is converted to a fully specified formal model, complete with equations, parameters and initial conditions.

Model testing: In the testing phase, the simulated behaviour of the model is compared with the actual behaviour of the system in construction project. This phase also serve to validate the developed model by comparing the output of the model with the actual data. The model will be tested under extreme conditions to discover the flaws in the model and set the stage for improved understanding. The confident structure of the simulation model is achieved when the model is validated and approved by experience parties in this study will be the project manager who is in charged and overseeing the pre-construction phase of the understudy residential housing construction project.

Policy design and evaluation: This phase will be conducted to make recommendation of strategy implication based on the interconnectivity and interrelationship between project management knowledge areas. Once the interconnectivity and interrelationship between different knowledge areas are identified, modelled and validated, the developed system dynamics model can be used to evaluate different strategies for improvement. The interactions of different policies can also be considered as real systems are highly nonlinear and the impact of combination policies is usually not the sum of their impact alone.

CONCLUSION

In this study, system dynamics simulation model is developed to capture the interdependencies of the different knowledge areas in PMBOK that occurred during the pre-construction phase of a residential housing construction project.

The development of system dynamics model includes two parts where the first, is through constructing the causal loop diagram of all activities involved in the five major stages of pre-construction phase (the preliminary stage, earthwork plan stage, plan approval process stage, construction tendering stage and promotion and sales launching stage). From the developed causal loop diagram, the activities involved in each of the stage will be broken down to different knowledge areas and therefore, the chain effect (s) of activities in one knowledge area and how these activities affect the other knowledge areas can be identified.

Next, a stock and flow diagram is developed to simulate the interconnectivity and interrelationship between different knowledge areas that occurred in each stage. Project managers can use the developed model to test different strategies and then, observe its impact before implementing it to the real project. Hence, the developed system dynamics model can serve as a learning tool and capable of aiding project managers in making better decision through better understanding of the management of multiple knowledge areas.

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