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# Complex System Approach for Dynamic Performance Prediction of International Construction Projects

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## Abstract
International construction projects suffer from more diverse and complex risks, resulting in less profitable performance than that of domestic projects. An extremely unsuccessful project can put a company into a seriously troubled financial situation. Sufficient understanding of the project's characteristics when choosing an international project leads to appropriate strategies to insure a profitable performance. In this study, a complex system approach is adopted to understand the dynamic and interrelated performances of various influencing factors of international construction projects. First, based on the literature review and our earlier work, 50 performance influencing variables are extracted. Then, using system dynamics method, a prototype model is developed where both qualitative and quantitative analyses are possible. Through the proposed model, the cause-and-effect relationship between project performance and influencing factors are effectively represented and analyzed. The model helps to systematize and evaluate factors that critically influence the project's performance. It also considers the impact of external factors and strategies to cope with the undesirable consequences of the unforeseeable events. It is expected that the model promotes better understanding about how various factors are interrelated and how variables' information flow with meaningful feedbacks, ultimately improving the performance prediction and acquiring a promising opportunity.

## Keywords
Risk Analysis, International Construction, Performance Influence Factor, System Dynamics

## 1. Introduction

There are diverse and complex risks in international construction projects such as political, economic, cultural/legal, and technical risks. These risks could make the projects' profitability to be worse than domestic projects and more often than not, an extremely unsuccessful project can put a company in a serious troubled financial situation (Han and Diekmann, 2001). Accordingly, when a construction company engages in a new international project, proper risk control and response strategy should be well established through a sufficient understanding of the project's characteristic to insure profitable performances.

A number of research have been conducted to recognize performance influence factors of construction projects, particularly focusing on isolating critical influence factors that significantly determine a project's success or failure. There is also another research effort on suggesting individual risk factors like conceptual guidelines on success factors of general domestic construction projects (Baker *et al*. 1983). As another approach, Han *et al*. (2003) investigated critical factors on the causes of bad profitability in international construction project and proposed a model to predict the level of profitability. Although these researches were effective to identify hierarchical structures of international construction project's diverse risks and predict performance of new projects, they could not successfully consider dynamic and circular reaction among risk factors in the complex system – a system where a new phenomenon and a changed order are produced through interactions that are quite different from the characteristics of individual system components. Previous models have limitations in evaluating how project's performance vary when sudden change of conditions or external impact occur within a project system, such as currency exchange fluctuations and occurrence of sudden war or terrors.

In this study, the performance influence factors of international construction projects are extracted from the literature review and our earlier work (Han *et al*. 2007). After tailoring those factors to be suitable for constructing a system dynamics (SD) model, a prototype model is developed where qualitative and quantitative analyses are available. SD is used so that the cause and effect relationship between project performance and influence factors are effectively visualized and analyzed. This model helps to systematize and evaluate factors that influence the project's performance. It also evaluates the sensitive impact of external factors and firm's strategies to mitigate the negative impact on the project performance.

## 2. System Dynamics Approach

### 2.1 Precedent studies on System Dynamics

Mostly, SD was applied and developed in the manufacturing industry to solve business problems such as business strategy, organization management, and inventory management (Kwak *et al*. 2002). Recently, SD is also praised as a useful tool to the construction industry in its capacity to represent the complex phenomena. Construction industry is characterized by dynamics, diverse participated parties, interactions, and many nonlinear relationships. Since SD has the advantage of considering change as time goes by, and including feedback by transmitting information, it could be applied to effectively analyze many problems in the construction industry. Several studies where SD is applied to the construction industry were presented: (1) to deal with decision problems and simulations such as an approach to explore performance enhancement in a construction organization (Ogunlana *et al*. 2003), (2) to model the dynamics of design error that induced rework (Love *et al*. 2000); and (3) to handle or support policy-making like Singaporean government's construction Policymaking to improve industry productivity (Park *et al*. 2005) as well as delay factor analysis of public projects (Lee *et al*. 2004). Likely, many previous studies have shown the potential of SD's as applicable to this research domain. The complex interactions of diverse risk factors, especially, could be utilized in quantitative and qualitative analysis of profitability, cost, and time that affect overall performance of international construction.

### 2.2 System Dynamics Methodology

The SD approach describes cause-effect relationship with stock variables, flow variables, and feedback loops (Ogunlana *et al*. 2003). Stock variable denotes the variables stored in the system e.g. project productivity. Flow variable means increase and decrease of stock variable as time goes by e.g. decrease of productivity. Feedback loop represents the relationship of stock and flow variables like making a decrease of duration associated with productivity improvement. Feedback loop may have an algebraic expression or a specific mathematical function. General modeling procedure of SD passes through four phases as shown in Figure 1.

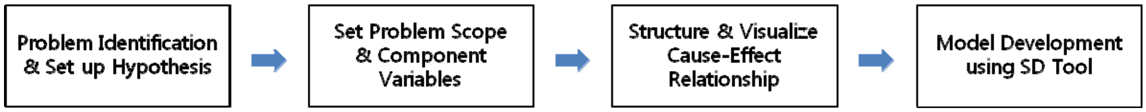



**Figure 1: General Modeling Procedure of System Dynamics**

As shown in Figure 1, the first step of SD modeling is problem identification. From an observed event, identify and define a problem that can be properly modeled by SD. The SD then set up hypotheses from trends or patterns of events that seem to be plausible. Next, it sets the proper problem scope to be modeled and extracts component variables. Using these variables, it can structure and visualize cause-effect relationships. In case of qualitative analysis, apposite and probable cause-effect relationships among variables are important in visually representing the complex interactions. However, in case of quantitative analysis, the relationships of variables as well as classification of variables into stock variables and flow variables are essential because the algebraic structure of a SD model is determined by sorting component variables into measurable one. Lastly, the model is constructed by the adoption of both variables and relationships using SD software such as Vensim PLE, iTHINK, STELLA, etc. These application packages enable users to check and simulate a proposed SD model. In this study, Vensim PLE is utilized and a qualitative aspect of a SD model is developed as an exploratory attempt. A quantitative analysis will adopt the NUMBER (Normalized Unit Modeling By Elementary Relationships) methodology to convert an abstract causal diagram to a stock-flow diagram where quantitative analysis is available. In this methodology, effects from various factors to a certain factor are simply represented as the sum of causal factors' change. For example, if a factor A is affected by factor B and C, change of the factor A would be the sum of B and C's change. The quantitative features of our SD model and its application to real cases will be provided in the future procedural paper.

## 3. Qualitative System Dynamics Model Development

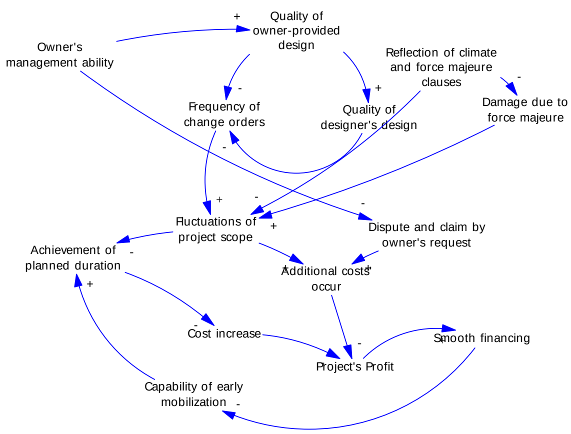
### 3.1 Extraction of Influence Factors

For the purpose of selecting the influence factors that are utilized in the SD model, 50 performance influence factors of international construction projects are extracted from the literature review and our earlier work (Han *et al*. 2007). In the process of extraction, some factors are combined, and some factors are removed. For example, influence of social stability and stability of laws & rules to other factors are similar, they are combined into the social stability. On the other hand, level of community satisfaction is removed because it is not in accord with other factors in project environments. Since these extracted influence factors are modified to suit the SD model, it is hard to strictly classify these factors into specific categories. However, in a broad outline, they could be classified into five parts; attitude and ability of the owner, contract terms, the contractor's ability and experience, commitment of the organization, and project conditions and environments. They are not explained here for the sake of brevity of this paper. Detailed factors and their relationships are shown in the following section.

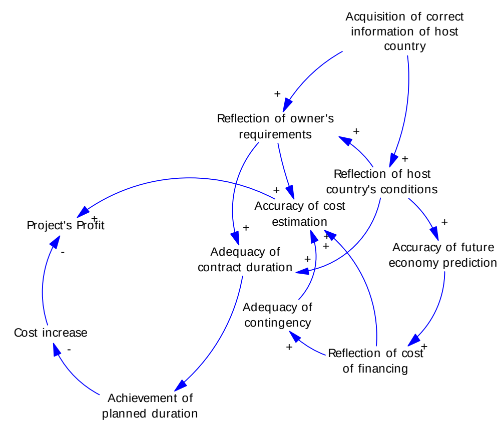
### 3.2 Relationship of Influence Factors

Figure 2 and 3 show a partial part of qualitative SD model. In figures, (+) sign and (-) sign represent the cause-and-effect relationship of factors more clearly. (+) sign means both factor change same direction, while (-) sign means that directions of two factor's change are different. In other words, high owner's management ability in figure 2 (a) brings good quality of owner-provided design, and good quality of owner-provided design incurs low frequency of change orders. Part I in Figure 2 (a) depicts a model about ‘attitude and ability of the owner and related contract terms’. If the owner possesses a good technical and management ability, there is a high possibility of having good quality of owner-provided design and specifications. Following that, it can reduce the frequency of change orders and variation of project scope. This finally leads to a reduction of additional cost and contributes to the better project performance. A contractor will also have smooth financing which contributes to the profitable return by improving the capability of early mobilization and achievement of scheduled duration.

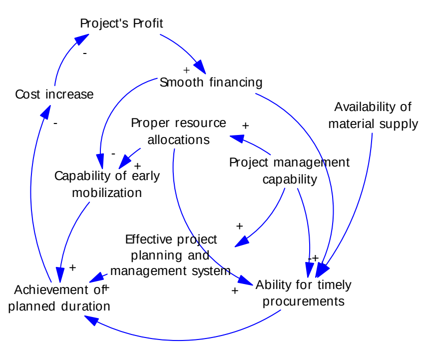
Part II in figure 2 (b) shows ‘contract terms and related factors’. If a contractor acquires correct information about the host country’s condition, they can reflect more accurately the owner’s requirements and host country’s environment. This leads to an accurate prediction of future economy and reflection of financing costs. Then the contractor can appropriate adequate contingencies and project duration. In the end, there is a good chance of achieving scheduled duration and decreasing the possibility of cost increases; thereby improving the overall project’s performance.




(a) Part I




(b) Part II

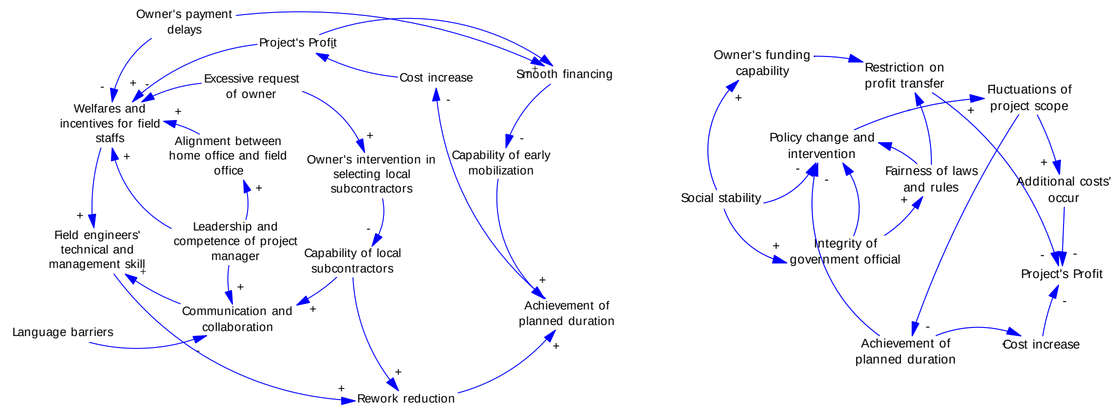



(c) Part III

**Figure 2: Causal-Loop Relationship (Part I, II, and III)**

The relationships of factors about ‘the contractor’s ability and experience’ are shown in Figure 2 (c). In international construction projects, contractors are more likely to have difficulty in supplying material and other resources than doing in domestic projects. Therefore, with the availability of material supply, timely and economical procurement can be achieved by the contractor’s capability to allocate resources under distributed and changeable conditions. In addition, proper resource allocation enables early mobilization, and achievement of scheduled duration. With improved profit repeatedly contributing to smooth financing, the contractor’s ability for timely procurement and proper resource allocations can be repeated and successively it improves the overall performance over again.

Part IV in Figure 3 (a) represents other side of an ‘organization commitment.’ The owner’s payment delay affects not only the contractor’s smooth financing but the staff accommodations and incentives as well. Similarly, the excessive burden from owner’s requirement can often deteriorate the morale of field engineers and staffs. More importantly, project manager’s leadership and competence greatly affect the commitment of field staffs. All these cause a decrease on the performance of field engineers’ technical and management skills; frequently inducing unnecessary reworks, repeatedly blocking the achievement of scheduled duration and as-planned cost, and eventually leading to a reduction of the project’s profitability.




(a) Part IV (b) Part V

**Figure 3: Causal-Loop Relationship (Part IV and V)**

Lastly, a model of ‘project conditions and environment’ is shown in Figure 3 (b). This part includes the specific conditions of a host country. A socially stable country has a tendency to have little changes of policy, law, regulation, and intervention, thus their government officials being expected to be more integral and fair to foreign contractors. These lead to fairness of laws and rules, and little restrictions on profit transfers, taxation, and other business transactions. Moreover, since less policy changes and interventions result in little variations of a project scope, additional expenses consumed by a contractor can also be reduced. On one hand, the stability of a project scope can be of more help to achieve a scheduled duration, which leads to less cost increase and more project profit.

Ultimately, Figure 4 represents the whole causal-loop diagram of international construction performance. Since aforementioned parts of the diagram are kept apart for detailed explanation, it is better to fully depict the whole diagram such that we can understand how all factors are related and where each loop gives feedback to each other. Besides, there are four more factors—social impact such as war and coups, language barriers, occurrence of disasters, exchange rate fluctuations—to represent such as shocking factors that are often crucial for overseas construction projects. By including such factors, the model helps to understand how occurrences of such external factors affect project performance in more organized and intuitive way.

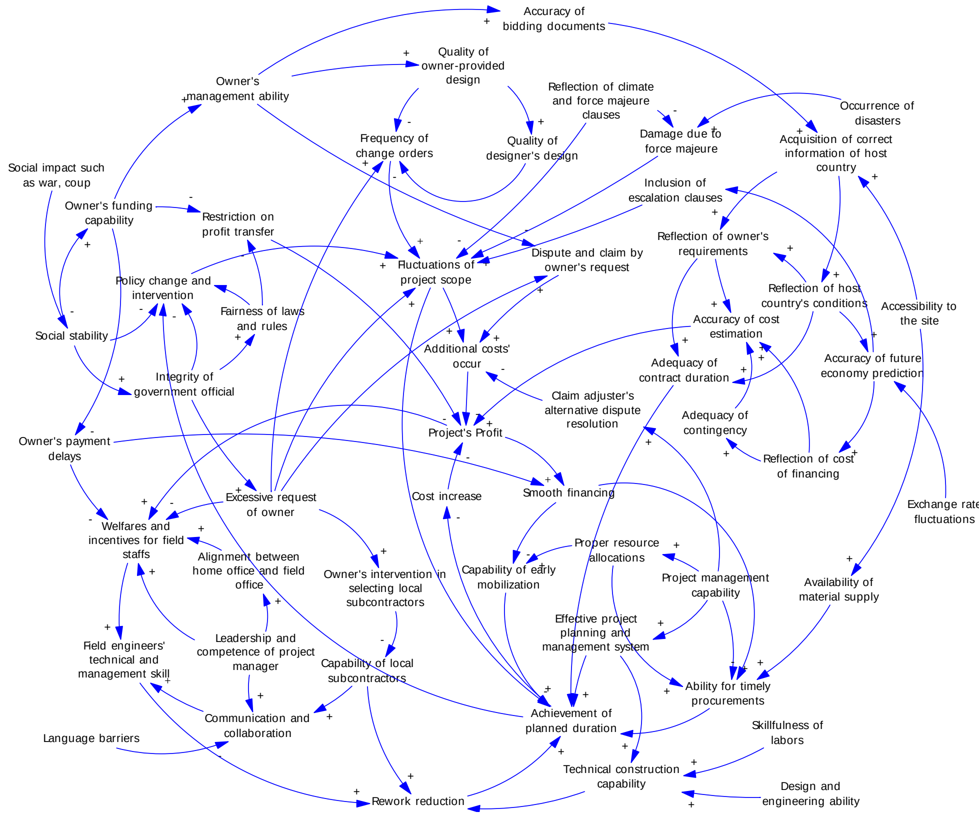



**Figure 4: Whole Causal-Loop Diagram**

## 4. Conclusion

In this study, the performance-influencing factors of international construction projects which are presented in previous studies are first extracted. The SD approach is then applied to capture the mutual and casual relationships among the variables. Fifty factors are extracted in all, and a prototype model is developed where qualitative analysis and observation of relationship variances of factors are available. This model helps to systematize and evaluate factors which influence on the project's performance, and also evaluates the impact of external factors and strategies to cope with the impact of the project. Future research is required to strictly verify performance-influencing factors and their plausible relationships by professional's verification and real cases applications. Armed with the qualitative features of a model, we will center our future research on developing quantitative simulation model. This will lead to a more reasonable refining of factors and causal-loop relationships, which will offer a dynamic simulation associated with time spans as well as various strategies in pursuing a better opportunity and earning a more profit under the uncertain international markets.

## 5. Acknowledgement

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