A SIMULATION BASED APPROACH FOR DESIGNING OPTIMUM CONFIGURATION OF COMPLEX PROCESSES INFLUENCING PROJECT LEVEL DECISIONS IN CONSTRUCTION INDUSTRY

Hemanta Doloi, *PhD, MIEAust*
Lecturer (Property, Construction and Project Management)
Faculty of Architecture, Building and Planning
The University of Melbourne, VIC 3010, Australia
Email hdoloi@unimelb.edu.au

Abstract: This paper puts forward an integrated framework for proactive and optimal decision making on projects adopting a process simulation approach. Upstream decisions on project selection and scope definition are linked with the downstream operational processes and service delivery of projects. The findings presented in this paper are based on a case study conducted on a tram route redevelopment project in Melbourne. The research adopted the simulation modelling to determine the vehicle queue lengths, delays and traffic flows without utilizing numerical analysis across the signalised road traffic junctions. Based on the traffic flow condition and external uncertainties associated with the operating environment, a number of feasible designs and configuration of the project options has been developed. The project life cycle objective functions are then employed as the basis for decision making to determine the optimised solution throughout the project's life.

Keywords: Process simulation, decision making, design configuration, life cycle analysis

1. INTRODUCTION

Simulation techniques allow design of mathematical-logical models of a real world system and experimentation with different alternatives on the computer. It provides a basis for scenario analysis of the project in real time. Project configuration and underlying construction processes can be simulated in real time and performance impact is estimated for appropriate decision making. The purpose of this paper is to introduce a holistic approach to managing the project deliverables by focusing on the project objectives in the early phase of the project. The approach provides a platform for real time project definition based on technical, functional and operational aspects of the project. Simulation modelling works as a unique management tool for effective front-end planning of capital projects [9]. Simulation modelling is seen as a means of continuous project definition that reduces the overall uncertainty associated with the project. It helps to determine the optimality of decisions on operability, functionality, quality or performance issues vis-à-vis life cycle objective functions.

Definition of project's scope in the concept phase vastly influences the project development and its overall business outcomes. Understanding the complexity of processes in both functional and operational contexts is important in defining appropriate facility of the project [1][6]. The simulation based methodology developed in this research helps visualizing the feasible project options and select the best alternative based on optimisation. The conflicting criteria are identified in the early phase of the project and optimised using evolutionary algorithm. The process level suboptimal decisions are optimised further for holistic decision analysis at the project level.

This paper thus discusses the development of an exploratory model based on the data collected from a tram route redevelopment project in Melbourne. The model and the overall findings demonstrate benefits of computer based simulation for evaluating the operational performance before taking investment decisions in construction projects.

2. PROJECT MODELLING

Project modeling is an important tool to understand and management complexities associated in design, delivery and operational phases of projects. For projects such as design-and-manufacture or design-and-build, the first major source of project complexity is associated with the processes and operational complexities of projects. The definition of projects and their underlying design complexities are linked with overall operational requirements.

Project selection and investment decisions are the processes of evaluating functionality and operability of project facility to choose the right design configuration meeting the target objectives of the organization. It involves a thorough analysis of the business objectives including most important financial aspect to determine the optimum project among a number of feasible alternatives. Simulation based project evaluation and decision analysis allows evaluating project alternatives by reducing uncertainties with a greater confidence. Simulation techniques allow design of mathematical-logical models of a real world system and experimentation with different alternatives on the computer. It provides a basis for scenario analysis of the project in real time [9].

Most project fails due to an inadequate definition of the project objective at the early stage of the project. In public sector projects are even more vulnerable due to increased complexity and involvement of various stakeholders in the decision making process. Continuous definition and improvement of capital projects as business entities is becoming an important challenge for both construction and project management disciplines in a competitive global environment [2].

This paper introduces a holistic approach to managing the project deliverables and operational performances by focusing on the business objectives at the early phase of the project. The approach provides a platform for real time project definition based on technical, functional and operational aspects of projects.

3. STRATEGIC PLANNING AND DECISION MAKING IN PROJECT

The planning is the key to project success in meeting business challenges and changing operating conditions. The size and complexity of modern projects with increased uncertainty requires front end planning throughout the life of a project. Planning is an incremental continuous iterative process and as the project moves on, it provides feedback points for new information and the flexibility to assimilate and act on it. Thus initial planning must concentrate on building viable planning bases for each principal subsystems in the context of life cycle planning of projects [14]. In the case of strategic planning, one takes a set of fixed interests, juxtaposes them within a fixed environment (or world, or set of conditions), and then invents a strategy for attaining one's interests given the constraints imposed by the environment [8].

Current project management philosophy tends to concentrate on the delivery processes and associated functions of contractual scope, time and cost management. Traditional project selection and investment decisions are based on static and simplified assumptions regarding the functionality and operability of the production processes. Economic analysis, reflecting the final customer's or investor's life cycle costs is important during decision making, particularly in the early phase of projects [3]. This is because solutions devised and commitments made at the early phases constitute a major part of the project cost. Modelling of technical and operational functionalities of the end deliverable supports strategic decision making in the early phase of the project. Thus, the project's scope is defined optimally considering the entire life cycle of the project.

4. PROCESS SIMULATION

In recent years, the concept of a modelling has become increasingly important in engineering design. It is no longer sufficient to pay detailed attention to the design of the various elements of a project individually, rather, all elements must be considered in relation to others in order to make the overall system effective. However, good project design is not restricted to detailed design coupled with attention to interrelationships between physical parts and elements. Projects must be analysed and evaluated at a deeper level and in relation to their operational environments [14]. Configuration and scope of projects must reassess and readjust to ensure that the objectives are met at the end. As a result, the overall process to reach these goals becomes iterative, involving in the design of each of the parts and products, which constitute the overall project. Simulation approach allows building a model of the proposed system capturing the salient features of the overall system.

Digital computer models facilitate analysis of complex processes associated in projects. A simulation model is a means for collecting information about the likely performance of a system, based upon user-defined conditions [4]. Simulation models can improve the planner's understanding of the real life situation during conceptualisation and final design or actual construction. For instance, the Hong Kong Airport cargo or freight transfer system was simulated prior to its final design and construction [12. The performance of the system was evaluated under conditions corresponding to operation scale up to 10 years ahead. The model was also used for internal training and as a public relations tool. Marmon [13] describes the similar use of simulation to study a new production facility. By using the simulation model the effect of changes in process design can be justified and fine-tuned.

5. LINKING DECISIONS OVER PROJECT LIFE CYCLE

The emphasis of the holistic decision making on projects is on the evaluation and maximization of project's objective functions over the entire life of projects. In the life cycle project management model (LCPM), such objectives are known as the Life Cycle Objective Functions (LCOFs) [9] [10]. LCPM focuses a set of business and strategic objectives for decision making throughout the project life cycle. It employs an integrated and concurrent project management approach to substitute the process-based and activity-driven project management approach (illustrated in the current practice) with an innovative strategy-based and outcome-driven project management paradigm [5].

Thus, the LCPM components comprise:

- A culture of collaboration based on strategic partnership and unity of purpose;
- A life cycle framework and an integrated single phase approach;
- An integrated project organization structure and real time communication system;
- An integrated project management information system; and
- A set of project strategic objectives, known as Life Cycle Objective Functions or LCOFs. These life cycle objective functions have been derived by adopting the triple bottom line approach [7].

Project investment decision and underlying business objectives have direct influence on the organizational strategy and overall performance of projects [15]. Thus the project organization and its underlying capability are defined integrating optimum project's configuration and inherent business intent.

Once the initial decision is made, the project and project processes undergo a detailed scrutiny towards identifying feasible alternatives, selection and allocation of appropriate resources and establishment of the best project option for development. The process of selecting best project option is facilitated by the simulation technology. The projects are broken down in smaller products and process models are constructed incorporating operational scenarios for simulation analysis [8][9]. The outcome of simulation forms the basis for evaluation of the suboptimal configuration against the target LCOFs of the project. After the project is developed and commissioned, operation is monitored based on the performance on LCOFs, organizational strategy and competitive advantages. The dynamic scanning and assessment processes are then continued in the project operating environment. It is worthwhile to mention that the same process is applied in the multi-project (or portfolio projects) context as well.

6. OPTIMUM DECISION PROCESS

All project planning is based on assumptions. If those assumptions prove to be wrong, then the project might not proceed as planned and therefore consideration of the assumptions in a project plan or bid is likely to reveal risks [12]. Projects development plans and overall operation must be scrutinized to identify the best possible configuration. Decisions on projects normally rely on comparing two or more alternatives. Figure 1 depicts an approach on life cycle decision process through the application of process simulation. As seen in the figure, the project level decision, whether or not to initiate a new project or facility, depends on the process level decisions based on operational viability of projects [16]. Process simulation output on operational processes can aid in project level decisions. In project level decision making process, one must first define both proposed and existing processes within the facilities that permit similar meaningful comparison. The definition includes criteria such as size of the potential sales market, size of the potential production capacity, compatibility of the market place to the existing files support infrastructure and other business and technical aspects.

Investment decisions can be optimised comparing the alternative scenarios and evaluating against relevant life cycle costs. Process simulation capability facilitates optimising project's investments decisions within the LCPM framework [9]. Simulation methodology supports proactive management of the project and product, particularly with respect to LCOFs. In LCPM philosophy, LCOFs must not be evaluated for a selected major process, but for the complete project as a whole to ensure that decisions made on the formulation, design, specification and implementation leads to a viable business solution. For example, the pulp handling system in a paper mill is considered as a major sub-system. Design and specification of this system must be optimised in respect of the overall project vis-à-vis LCOFs. Process simulation can model this design process and its end result fed into the LCPM model for optimising LCOFs.

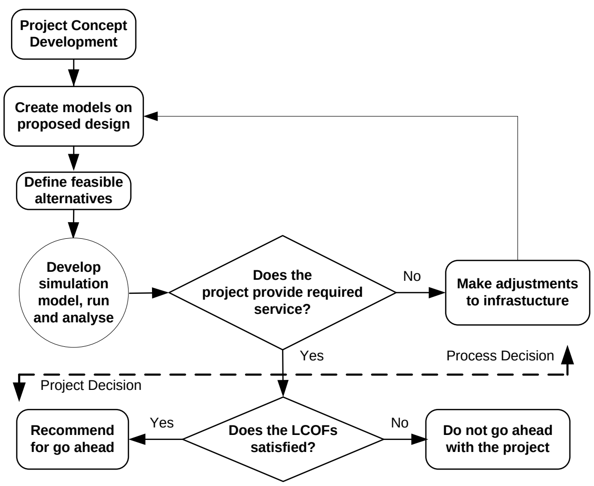

Figure 1: Typical planning level analysis

7. MODEL HIERARCHY

Model hierarchy allows breaking down the complex process into smaller processes for ensuring accurate modeling outcomes. Hierarchy allows models to be subdivided into logical components or sub-models, represented by a single descriptive icon. This simplifies the representation of a model and allows the user to hide and show model details as appropriate for the target audience. Hierarchical capability in the process simulation environment allows the modeler to decompose the model into smaller, more manageable segments. While simulating, the hierarchical modeling loops are simulated as closed systems before being completed the entire model. By utilizing hierarchy, modelers are able to rapidly and accurately create reusable model segments. This speeds model development by allowing the modeler to develop reuse portions of the model [15].

8. PROCESS OPTIMISATION

Once the process model is built, the processes can be optimised on number of factors such as total utilization of processes, utilization of resources, minimisation of queue lengths etc. In the optimization process, project objective functions are defined as functions of key modeling parameters and optimised. Evolutionary Optimizer based on the powerful evolutionary algorithms determines the best possible model configuration in process levels [11]. Project level optimization is performed using life cycle objective functions.

9. CASE STUDY APPLICATION

In order to demonstrate the use and benefits of the simulation framework, a case study on a proposed tram route design is presented. The simulation model representation provided a key decision making platform that quantified the effectiveness of varying level of design and planning to support an optimum operational plan. A significant implementation challenge during a planning level study has been demonstrated by employing simulation based analysis. In the road network design, as the analysis unfolds, there are often congested or problem areas within the network that require some engineering changes and adjustments. The ability to quantify these impacts is a huge benefit of using a simulation model. Once the design is altered to suit the required service requirements, the project's life cycle objectives must be assessed and validated. The framework developed in this research provides the functionality of make such changes and adjust related variables at project levels impacted by the changes.

9.1 Study Background

During the recent years, the tram network in Melbourne metropolitan has been expanding with new and redesigned routes to cater for increasing demand and services. The tram network runs on electric tracks and most of the time, it shares the lanes with other mainstream road traffic. As the vehicular traffic in the city is growing in a faster rate over time, the authority is under increasing pressure for improvement of services in infrastructure and performance of public transport.

Amongst many ongoing initiatives for improvement of public transport performance, the project on the improvement plan of an existing tram route was selected for demonstration of the framework in the paper. While the total length of the proposed route is about 10 kms, only a critical intersection was selected as scope of the study area for demonstration in this paper. The project was aimed to deliver an appropriate project solution by addressing three major benefits, *to reduce tram travel times*, *to improve reliability of services* and *to improve safety and access onto trams*. In the proposed design, there are two options being considered for this project, *the kerb access tram stop* and *the central platform tram stop*, over *the kerb access tram stops* in the base case situation.

10. FRAMEWORK FOR ANALYSIS

Figure 2 shows the base case or existing situation with kerb accesses tram stops. As seen, currently there are two lanes on both routes where one lane is shared between tram and the vehicular traffic.

The aim of this study is the understand the current performance of the network in terms of service delivery and overall efficiency of the public transport system in order to determine the scope of the redevelopment project that ensures optimised services.

The model was built to study the "time delay" experienced by the trip volume in using the existing situation. The simulation model using the Extend Simulation [11][15] environment mimics the real life situation as shown in Figure 3. Simulation model was run and travel times for tram as well as vehicular traffic on both routes were studied to assess the performance in the current situation.

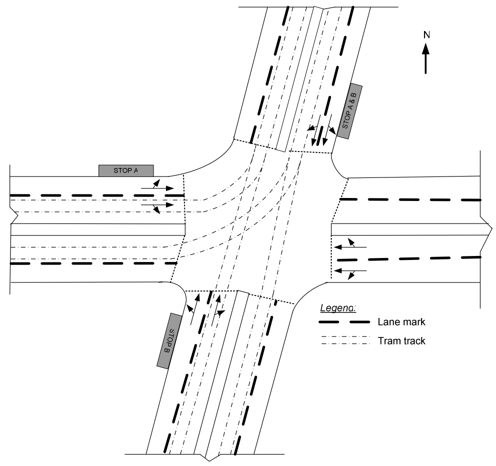

Figure 2: Existing situation

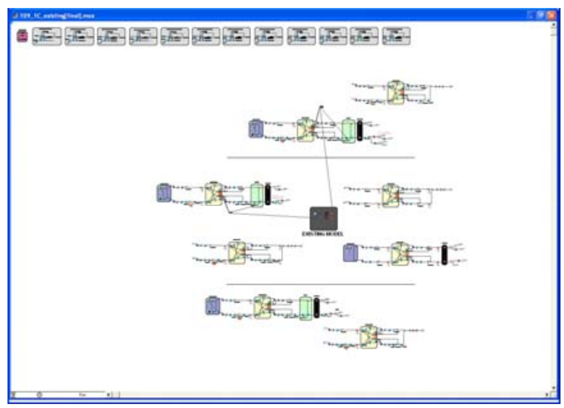

Figure 3: Base case model

Figure 4 shows the proposed design for Route A with new centre platform stop and queue jump lane on either road. Note that Route A is the design priority for performance enhancement over Route B. In the new design, a queue jump lane has been added for south bound trams (shaded lane) and the existing kerb side stop has been moved to the other side of the intersection for both trams. In addition, two dedicated lanes for the vehicular traffic are part of the design near the queue jump lane which was achieved by widening the road.

The model was constructed for the simulation study as shown in Figures 5. Simulation model was run for the equal period of time and time delay for trams as well as vehicular traffic on both routes were studied to assess and compare the performance over the existing situation. Three alternatives have been studied with varied design parameters within the proposed alternative and an optimised operational scenario was devised using the optimiser in the model.

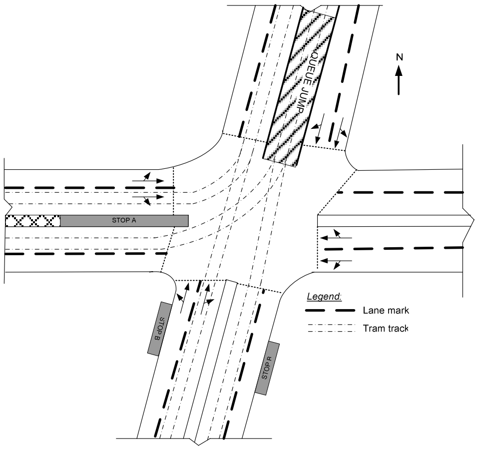

Figure 4: Proposed design

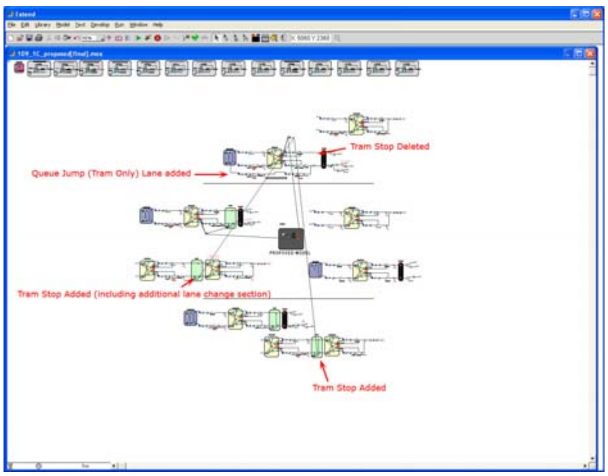

Figure 5: Proposed case model

10.1 Results and Discussions

Figure 6 shows the model outputs depicting number of vehicle over time for the base case situation. As seen, bottleneck was found in the existing operation with long queues. It was found that the traffic flow and travel duration are entirely dependent on the movement of trams and interval of traffic signals at the intersection.

In order to optimise the proposed design, evolutionary optimisation approach was employed on three scenarios and impacts on performance of the traffic flow were analysed. Figure 7 shows an output of the optimiser with approximately 99% convergence for maximum traffic flow in the model. The Genetic Algorithm based optimiser produces significantly better operational performance and utilization of infrastructure over existing situation. The optimiser includes a number of parameters such as the probabilities of crossover and mutation, the population size and the number of generations. Figure 8 shows the reduction of travel time in proposed design over the base case model. As seen, there is about 25% improvement in travel time in the new optimised design.

A factorial experiment has been performed to identify appropriate values for these factors that produce the best results within a given simulation time. The overall objective was to achieve maximum total traffic flow with minimum total travel time. An optimised schedule for tram service and cycle time for signalised intersection was achieved with about 80% efficiency of the resources and overall infrastructure targeted in the model.

Figure 8: Simulation results on the proposed model

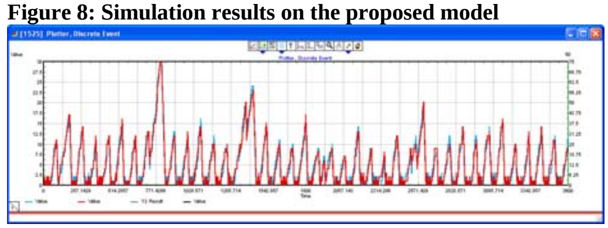

Figure 6: Base case outputs

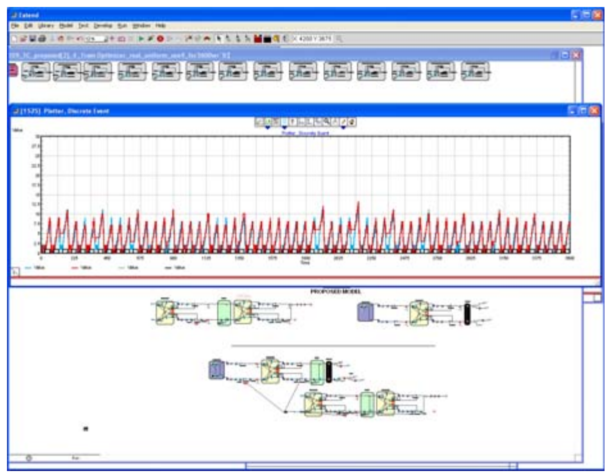

Figure7: Optimisation outputs in proposed design

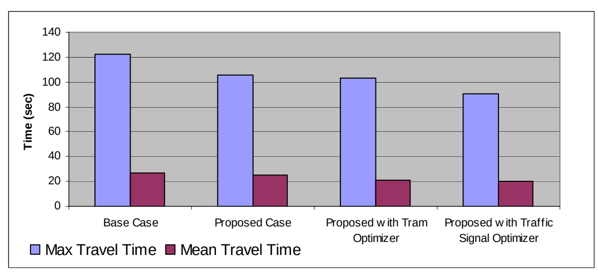

Figure 8: Travel time comparison

11. CONCLUSION

The approach of a simulation based framework provides the engineering assistance in optimizing project's configuration, planning and design and investment decision on capital projects. The simulation model provides a "virtual test bed" to understand how projected operational scenarios are impacting the projects plan and design and appropriate capability evaluation for target requirements.

While for planning purposes, simulation modeling is immensely valued, project selection and overall investment decisions are holistically evaluated incorporating triple bottom line in the life cycle project model. Overall project's life cycle and associated life cycle objectives are the focus in the decision appraisal in the integrated framework. The ability for quick exploration of the multiple scenarios of significant benefits and the capability incorporating results on design and engineering processes in devising the best possible solution on complex projects are the significant contributions in this research.

REFERENCES

[1] Anumba, C.J. (2000), "Integrated Systems for Construction: Challenges for the Millennium", *International Conference on Construction Information Technology 2000*, HongKong, pp78-92.

[2] Anumba, U.C., Thrope, T. and Newnham, L. (2000), "Agent based Decision Support for Collaborative Design and Project Management", *International Conference on Construction Information Technology 2000*, HongKong, pp756.

[3] Alshawi, M. (2000), "Integrated Construction Environments: Technology and Implementation", *International Conference on Construction Information Technology*, 2000. pp36-55.

[4] April, J., Glover, F. , Kelly, J.P. and Laguna, M. (2003), "Practical Introduction to Simulation Optimisation", *Proceedings of the 2003 Winter Simulation Conference*, Boulder, CO 80302, U.S.A.

[5] Chaaya, M. and Jaafari, A. (2000), "Collaboration and Integration of Project Life Cycle Design Information Using IT Systems", *International Conference on Construction Information Technology*, 2000. pp277-291.

[6] Shih, K.C, Huang, C. N, Liu, H., Wu, T. and Wang, M. (2005), "Study on the Storage and Transportation Optimization of Prefabrication Factory", I*nternational Symposium on Automation and Robotics in Construction*, Ferrara, Italy, 11-14 September, 2005.

[7] Doloi, H. (2006), "Developing an Integrated Management System for Optimising Project Options", *Journal of Enterprise Information Management Systems* (accepted and in press).

[8] Jaafari, A. and Doloi, H. K (2002) "A Simulation Model for Life Cycle Project Management", *Journal of Computer-Aided Civil and Infrastructure Engineering*, Vol. 17, (2002) pp.162-174.

[9] Gassel, F. (2005), "The development of a concept for a Dutch construction system for high-rise buildings", I*nternational Symposium on Automation and Robotics in Construction*, Ferrara, Italy, 11-14 September, 2005.

[10] Gero, J. (2000), "Development in Computer Aided Design", I*nternational Conference on Construction Information Technology*, 2000. pp16-24.

[11] Khral, D. (2002), "The Extend Simulation Environment", Proceedings of the 2002 Winter Simulation Conference, E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes (eds), pp.205-213.

[12] Luk, M. (1990), "Hong King Air Cargo Terminals to Work in Synch because of Simulation Applications", Industrial *Engineering*, 1990, 11, pp.42-45.

[13] Marmon, C. (1991), "Teledyne Applies Simulation to the Design and Justification of a new Facility", *Industrial Engineering*, 1991, 3, pp.29-32

[14] Morris, P.W.G. (1998), "Why Project Management does not always make Business Sense", *Project management*, 1998, 1, pp.12-16.

[15] Pidd, M. (1984), Computer Simulation in Management Science, John Wiley & Sons, 1984.

[16] Powers, G., Ruwanpura, J., Dolhan, G and Chu, M. (2002), "Simulation based project selection decision analysis", Proceedings of the 2002 Winter Simulation Conference, pp.1778-1785.