



DEVELOPING ACTIVITY CYCLED BASED DIAGRAM FOR SIMULATING A BRIDGE CONSTRUCTION OPERATION

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ABSTRACT

Proper planning and control of activities on a construction project is central to successful performance. However the planning function is cumbersome due to the inherent features of construction operations such as high repetitiveness, complexity and uniqueness. Also the more modern the construction methods used, the more tedious planning becomes requiring deeper project analysis.

Bridge construction projects are more challenging among construction projects from the perspective of planning and management, especially with process automation in bridge construction works. For example, incremental launching is an automation recently employed in many bridge projects that increases the level of planning/ management issues. The dilemma that bridge construction projects face today is that schedulers accomplish the planning of a bridge project based on their experiences since construction methods are often new and there is no specific WBS/conceptual framework yet.

The aim of the current study is to facilitate bridge construction projects planning and management by introducing a new technological-based tool (simulation). The paper describes the process followed in the development of a conceptual framework/ WBS which accounts for the interaction between the variety of resources involved on a case study (bridge) project where the incremental launching method is used. An Activity Cycle Diagram is produced alongside conceptual framework and process models with the intent of illustrating the key steps in the simulation modelling procedure. The developed models can eventually assist in scheduling and controlling inherent features; uncertainties, complexities, and repetitions in bridge construction projects, consequently improving their delivery. The study shows the potential application of the simulation-based tool called EZStrobe.

KEYWORDS: Activity Based Cycle Diagram, Bridge Construction Operation, Conceptual Model, System Behaviour, Simulating Procedure, EZStrobe.

INTRODUCTION

Construction projects or operations are a collection of activities that are linked together through resources which are used for their accomplishment according to their logical sequence (Halpin & Riggs, 1992). These series of activities make a chain that defines a project's activity cycle. According to Shi (1997) the cycle could either be closed or an opened



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loop with complex interdependencies of resources that are consumed by the project. The task of every project manager is to plan for the use of resources in a manner that supports these logical sequences required of construction operations. This task is made cumbersome by the complexity and dynamic characteristics of construction projects with Halpin and Riggs (1992) suggesting that the planning function is crucial, knowledge-intensive, often ill-structured and a challenging stage in every development project.

In bridge construction projects (BCP) the planning and analysis function is even more complex because such projects are associated with uncertainties arising from their construction sequence and associated constraints, resourcing issues and structural inadequacies (Chan & Lu, 2012). Ailland, Bargstädt, and Hollermann (2010) conclude that planning methods that feature adequate adaptability; support the description of parallel processes, unexpected incidents and stochastic and fuzzy parameters are therefore to be encouraged for non-stationary construction projects.

A host of simulation-based techniques for scheduling construction projects are in use. Some are/are not specific to the construction industry, while some others have been developed to deal with specific conditions like repetitive or cyclic performances. The selection of an appropriate simulation tool requires prior understanding of and analysis of a construction project.

In the current study, the authors investigate the potentials for the application of simulation-based technique for facilitating the scheduling and management of a bridge construction project that is based in New Zealand. The study takes into cognisance, constraints/uncertainties and complex interactions among the bridge project's components, towards developing a simulation model for the project. The field investigation undertaken is described within the paper to demonstrate the capabilities of EZStrobe simulation tool in developing a conceptual model and eventually scheduling a bridge construction project that uses an incremental launching method.

LITERATURE REVIEW

Simulation Techniques and Tools

There is a host of techniques for planning construction projects. Most of these are not specific to the construction industry while some others have been developed to address specific features of construction operations such as its repetitiveness. The basic steps involved in any planning procedure are: 1/ identifying project activities and determining their duration, 2/ sequencing the activities in a logical manner, and 3/ preparing the project schedule (Hajjar, 1999).

Wu, Borrmann, Rank, Beißert, and König (2009) insists that the creation of a manual schedule of construction projects is time-consuming. Construction project scheduling basically relies on the knowledge and expertise of planners. Therefore, some researches capture human knowledge to overcome the scheduling issues. The developed system on the



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basis of human knowledge could represent the expertise in the form of a set of computational-based data and rules. The case-based reasoning techniques developed by Mikulakova, König, Tauscher, and Beucke (2008) is an example of such systems. Another example is integrated knowledge-based systems for estimating and scheduling of construction projects' costs presented by A. Mohamed and Celik (2002).

There are other techniques like graph based techniques which have been employed to analyse project's tasks, estimate their duration, and identify the minimum time required to complete projects. The most common one is Critical Path Method (CPM) that is used for drawing up robust schedules. It has also been used in the technique presented by Koo, Fischer, and Kunz (2007) to support the rapid development of sequencing alternatives in construction schedules.

Some inherent features of construction projects like complexity and uncertainty enclose any estimation of activity's duration, and consequently make a higher critical schedule. Therefore, to address this problem, Pontrandolfo (2000) used PERT-state and PERT-Path techniques with a focus on network complexity and time uncertainty. Further, the repetitive feature of construction projects have been addressed using Petri-Nets based approach proposed by Biruk and Jaśkowski (2008).

Achieving almost optimum solutions by considering resource consumption and project duration is an aim of recent researches. In this way, multi-constraint optimization algorithms are proposed. This approach presented by Beißert, König, and Bargstädt (2007) was able to generate valid execution schedules considering different construction requirements and execution constraints. Beißert, König, and Bargstädt (2008) applied a simulation approach on the basis of constraints which they called Greedy Randomized Adaptive Search Procedures (GRASP). GRASP is a meta-heuristic technique that generates valid and optimized solutions rapidly. Another optimization model applied in scheduling of linear construction projects is a genetic algorithm-based multi objective optimization that was introduced by Senouci and Al-Derham (2008).

Even though knowledge-based systems have addressed construction projects characteristics within scheduling techniques, they only provide partial schedules. Additionally, extra effort is required to adapt them for practical use. The other drawbacks of such methods, as König, Beißert, and Bargstädt (2007) mentioned, are the tedious and time-consuming progress in the preparation of the input data, and performing a multitude of simulation runs to achieve a significant set of solution. An example is the Monte Carlo simulation technique.

To overcome these aforementioned issues, R. y. Huang, Chen, and Sun (2004) implemented a computer simulation tool called CYCLONE. CYCLONE has been applied in the standardization of mould systems in construction procedure automation, which resulted in increased productivity and improved operational efficiency. Extensive application of computer simulation in construction projects as proposed by Gonzalez-Quevedo, AbouRizk, Iseley, and Halpin (1993), are found in numerous areas such as bridge works, tunnel projects, reverse circulation foundation pile works, concrete delivery from pre-mix concrete plant,



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sewage works, and road works. A developed tool called Symphony™ is a powerful simulation-based modelling approach among those applied in tunnelling works. Fernando, Er, Mohamed, AbouRizk, and Ruwanpura (2003) proposed this model for evaluating different construction alternatives, planning, risk analysis and lean construction process.

Analysis of literature on construction simulation has been done by El Ghandour (2007) using three analysing tools: 1/ based on definition of construction applications areas for simulation, 2/ based on the main functions of construction simulation engines and/or languages according to the objects to be modelled, and 3/ based on tracking of the developed simulation engines and/or languages. This literature analysis on construction simulation covered the period from 1976 to 2002. The results show that some areas such as changes orders, constructability, and quality control have not enjoyed the benefits of simulation. Further, the review shows that simulation models were not able to transfer data well with other software applications within the construction domain, or with other simulation models developed in other areas. There were no flexible generic elements to cover all types of data that need to be transferred. Resource-based simulation engines started in 1987 with Paul and Chew (1987) and followed by researchers within 1992 to 1994. When the Activity Based Cycle was introduced by Shi (1999) cited in (El Ghandour, 2007), the attention to resource-based simulation declined. In the period of 1976 until 2002, there was a trend for developing simulation models based on process or activity elements. Concurrently, new trends such as product-based and function-based approaches have evolved. El Ghandour (2007) suggests that these new trends are the most interesting ones within Research and Design (R & D) in the coming decade.

Decision Making Progress in Construction Activities

Construction engineering is traditionally based on experience and heuristic rules from the prospect of planning and management (Fu, 2013). There is a need to make the right decisions by the project management team. In the other words, project management is challenged to balance trade-offs among different objectives before and during a project (Fu, 2013). There are various techniques and tools that have been developed to support managers with making the right decisions.

According to Mawdesley, Askew, and Al-Jibouri (2004) managers perform planning based on experience rather than careful analysis. In a study of four project planners, for a period of one week, Mawdesley et al. (2004) conclude that project planners made their decisions based on personal preferences. Mawdesley et al. (2004) found that planning procedures differ among the planners for two main reasons, even though construction methods were almost similar on their projects. The first reason relate to the unique feature of construction operations. The second reason is associated with the experience of the managers which enabled them to know the planning problems in advance and then acted reflexively to resolve them. Therefore, the decision making process seems to be subjective and rely highly on individual planners' intuition, knowledge, and experience (Fu, 2013; Mawdesley et al., 2004). In the absence of formalized and systematic approaches in construction projects planning, most of managers approach decision making based on their years of field experience, judgement, and rules of



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thumb rather than theory and analysis (Fu, 2013). Construction managers depend on their skills and common sense during their daily decisions (Y. Mohamed & AbouRizk, 2005). Further, they are unable to track the ultimate effects of their decision on the project's productivity and final cost when they use traditional project management tools, because different effective feedback loops are formed due to mutual interactions between organization effective factors (Y. Mohamed & AbouRizk, 2005).

The use of conventional decision making tools does not allow construction managers to evaluate final effects of different alternatives as there are complex interactions among a variety of organizational and operational effective parameters Y. Mohamed and AbouRizk (2005). The examples of these parameters are 'work start time and finish time', 'duration of work and rest period', 'shift work' and 'the amount of overtime during the week'. In this regard, Y. Mohamed and AbouRizk (2005) proposed that the main problems with most of traditional modelling approaches are that they are only able to capture system interactions at either the operation level or context level of feedback between the context (organizational) level and operation level variables inside the desired systems. Therefore, the complicated behaviours of construction systems cannot be captured especially over the long-term life cycle of that system (Y. Mohamed & AbouRizk, 2005).

Alvanchi (2011) introduced and validated a hybrid approach to improve decision making process by addressing such feedbacks. In this way, Alvanchi (2011) expresses that the contribution of decision making process and organizational policies into project fluctuations over time, on one side, and the uniqueness of construction projects on the other side, always highlight the needs of human communication and judgement during project execution. Therefore, the support of decision making process has received lots of attention in most research that deal with process modelling in construction management. In addition to linear and non-linear optimization models, simulation-based techniques were used for supporting decision making. As Tecnomatix (2006) (cited in (Ailland et al., 2010)) indicated, the use of simulation tools is increasingly attractive when a process is more complex and there are multiple influences which must be taken into account. AbouRizk, Halpin, and Lutz (1992); Song, Wang, and AbouRizk (2006) suggest that modelling and simulation of construction process could support construction planning and assist managers/ planners with reducing the risks associated budget, time and quality. Unfortunately, the use of computationally based modelling approaches such as realistic simulation has been limited in construction industries (Devulapalli, 2002). With the advances in technology in the last decade, simulation models have been developed and evaluated from the aspect of decision making support. Devulapalli (2002) explains that realistic simulation models are able to capture all the inherent uncertainty in project data.

Policy analysis tools have been developed and implemented by Devulapalli (2002) in bridge construction operation, where efficient management of the scarce resource is the most important challenge. The method helps decision makers to manage funds effectively and maintain bridges. Further, Devulapalli (2002) developed the policy analysis tool using



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discrete event simulation, for predicting network health under different scenarios to facilitate the discrete Salem Bridge System.

Decision makers also need to be supported from another prospects such as changing the logic of construction process in a cost-effective way. When mathematical modelling approach is not available, simulation modelling can be useful to achieve the most suitable solution to the construction problem since it could help planners to predict the effect of decisions on such changes in the project without implementing those changes in reality. As Devulapalli (2002) mentioned Discrete Event based simulation (DES) is the most powerful and suitable tool to support decision making in projects where uniqueness, complexity, and dynamism are prominent. Recent development of DES in construction engineering has made the interfaces between operations research and computer science possible. Construction managers are able to improve their operations by experimenting different possible scenarios provided by DES. Thus simulation assists their decision making by determining the best strategy for execution of specific operation in practice (Devulapalli, 2002).

As previously explained, the use of simulation in the construction sector has not received the deserved attention because its implementation requires knowledge and effort. Y. Mohamed and AbouRizk (2005) recent studies to remove this obstacle, focused on developing simulation tools that reduce model development and experimentation time on the construction engineer's side, by packaging most of the required knowledge into the tool itself. Y. Mohamed and AbouRizk (2005) believe that such intelligent tools can influence the way of implementing simulation in day-to-day decision making progress in construction. A combination of simulation experiments along with decision makers' knowledge could provide construction operations with helpful recommendations (in terms of various scenario analyses) that ensure the projects' achievement (AbouRizk (2010).

Simulation of Construction Projects

The ineffectiveness of traditional construction planning methodologies to support today's project features have been suggested by Sriprasert and Dawood (2002) as the main reason for project failures and low productivity. Thus, proper planning is important to ensure timely and economical completion of projects (Puri, 2012). Project planners would therefore need to seek integrated approaches using new technologies in construction management processes. Simulation has thus evolved as a useful model-building tool in the construction domain. This evolution provides construction planners/managers with tools that enable them to quickly model construction operations without requiring them to possess extensive knowledge of simulation techniques (Y. Mohamed & AbouRizk, 2005). Cheng and Feng (2003) have indicated that project planners could use simulation to predict the performance of construction operations in terms of process flows and resource selection. Simulations have also been employed in productivity measurement, risk and site planning (Sawhney, AbouRizk, & Halpin, 1998).



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Simulation modelling methodologies vary depending on the nature of the projects to be modelled, and in the construction domain, simulations are applicable to a wide spectrum of operations (Y. Mohamed & AbouRizk, 2005). For example, AbouRizk, Halpin, Mohamed, and Hermann (2011) demonstrate the usefulness of simulation on the design of construction operation involving multiple interacting factors that produce unpredictable outcomes, and stochastic events which are difficult to anticipate. Moreover, Appleton, Patra, Mohamed, and AbourRizk (2002) conclude that construction simulation is a well-tested decision making tool that allows users to analyse various production scenarios at the pre-construction phase of projects. Thus analysts and construction industry personnel could experiment with different construction technologies and estimate their impact on schedules and costs (Appleton et al., 2002). Additionally, Lucko, Swaminathan, Benjamin, and Madden (2009), show how simulation technology benefits construction industry users by using existing process-related data from schedules as inputs to create a functioning simulation model with little or no user intervention. Most research approaches deal with construction process modelling in support of the decision making process.

Simulation of Bridge Construction Projects

The inherent features of bridge construction projects, which arise from their performance sequences, constraints, resourcing issues and structural adequacies, make their planning and analysis more complex (Chan & Lu, 2012). Hohmann (1997) (as cited in (Ailland et al., 2010)) indicated that factors such as shifting boundary conditions, project time and cost constraints, difficult logistical requirements and the high probability of unexpected incidents occurring, are common to non-stationary construction processes like bridge works. Bridge work planners would therefore need to employ scheduling techniques that are able to give better control and steer the use of resources more efficiently.

Kim (2007) described simulation as a building and investigation process for a computerised model of a system which captures various time measures such as real time, and expanded and compressed time, to improve the behaviour of a process or system. Simulation is able to model any system with any set of conditions in a more practical way since it runs the computerised model of a system rather than finding an analytical solution. This potential of simulation makes it more advantageous than traditional scheduling methods like CPM and PERT. In other words, the considered system does not need to be analytically managed. Moreover, fewer assumptions are required when simulation is used to schedule construction projects.

In the simulation approach, individual activities, and any interdependencies among them, and resource availability are taken into account. This capability makes simulation suitable for the detailed investigation of construction schedules (Wu, Borrmann, Beißert, König, & Rank, 2010). Although simulations have been successfully developed and implemented, more attention is required for its implementation on bridge construction processes.



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A few examples of studies that have applied simulation within the bridge construction domain include work done by Ailland et al. (2010), AbouRizk and Dozzi (1993), R. Huang, Grigoriadis, and Halpin (1994), Chan and Lu (2005) and Marzouk, Said, and El-Said (2008). In their work, AbouRizk and Dozzi (1993) used CYCLONE to facilitate dispute resolution in bridge jacking operations. R. Huang et al. (1994) simulated construction operations in a cable-stayed bridge in Washington by using DISCO simulation software. Chan and Lu (2005) used SDESA to simulate field processes for a pre-cast bridge, resulting in optimal solutions to the pre-cast segment inventory problems.

Others like Marzouk, ElDein, and ElSaid (2007) utilized a simulation model such as STROBOSCOPE as a simulation engine which was coded by Visual basic 6.0 to develop a special purpose simulation model to assist in the planning of bridge deck construction. This simulation engine considers uncertainties and the interaction amongst resources used for the construction work. Marzouk et al. (2007) modelled the 15th May Bridge located in Cairo, Egypt which was constructed using an incremental launching technique. Marzouk et al. (2007) examined the results of the developed model and illustrate its capabilities in modelling two construction methods; single form and multiple form. A sensitivity analysis was performed in their study to evaluate the performance of the system under different combinations of resources. The study eventually enabled planners to estimate the duration and production rate in each combination within those different methods of bridge construction and also provided them with more understandable results for the impact of assigned resources when estimating project duration.

Another research study undertaken on bridge construction by Said, Marzouk, and El-Said (2009), reflects how simulation can facilitate construction process planning. Said et al. (2009) had employed a developed STROBOSCOPE simulation engine, called 'Bridge-Sim' in a case study of the El-Warrak Bridge in Cairo, Egypt, to estimate the total duration of deck execution and the associated total costs. Said et al. (2009) suggests that Bridge-Sim also enables planners and contractors to evaluate different scenarios of construction plant utilization which represents various combinations of construction methods, crew formations, and construction sequencing. For example they compared the cast-in-place on falsework method and cantilever carriage construction methods for the El-Warrak Bridge. Simulating the two construction process methods demonstrated the potent capabilities of simulation methods in the creation of comprehensive documentation systems that helps planners in analysing construction alternatives where the project involves many repetitive activities, complex interdependencies between construction resources, and uncertainties.

STROBOSCOPE seems to be the most advanced simulation engine used in the above examples. It was developed by Martinez (1996) and provides the modeller/user with simpler characteristics of activity based simulators such as CYCLONE coupled with the modelling power of general purpose simulation languages. Martinez (1998, 2001) made further enhancements by developing another version called EZStrobe that does not require programming or coding. It is easier to learn and capable of modelling complex problems with



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little effort. The current study uses EZStrobe to explore its implementation on a bridge construction operation where a novel construction method is applied.

RESEARCH APPROACH

Research can be classified into five categories, based on the purpose of the study (Gray, 2004). These categories are: experimental or quasi-experimental research, phenomenological research, analytical surveys, action research, and heuristic inquiry. The current research does not seek to generate a new theory for construction management/planning, but to explore the capabilities of technological-based modelling methods in construction projects. The main objective is to explore how modelling methods can benefit New Zealand construction sector. Thus the research is both experimental and analytical in line with Gray's classification.

Since the implementation of simulation in New Zealand construction is new, a fieldwork study using a case study project has been selected to conduct this research. The research is designed based on a single/embedded approach in line with Stufflebeam, Madaus, and Kellaghan (2000) to improve, not to prove, planning and scheduling of construction projects. The research objectives of the study are firstly to build a conceptual framework of a bridge construction project where a new method of construction is involved. Secondly the research intends to modify and develop the framework to make it applicable for simulating bridge construction operations, using EZStrobe programme.

In the initial stage of the research, the study carried out thorough fieldwork study to understand the system behaviour. Some data were collected using direct observation and field note techniques. The primary data is in line with simulation procedure for developing a conceptual framework. The collected data include the following information: 1/ the duration of construction activities, 2/ the sequences of performance, 3/ resource allocation and interaction, 4/ identifying the influence of incidents on duration, 5/ identifying the various types of uncertainties and incidents which commonly occur on construction sites, 6/ tracking decision making ability, and 7/ identifying the interaction among human resources.

The case study project involves the construction of four ramps to link a tunnel to a main Highway in New Zealand. Two of the ramps enter the tunnel and two others exit the tunnel. The particular process studied involves the delivery and installation of precast T-beams, using relatively new construction technique. There was no solid Work Break-down Structure (WBS) or conceptual framework developed for the project.

Approximately, three onsite months was spent observing the process and collecting the required data. During the observation period, project documents such as Three weeks Look-Ahead Plan, Last Planner data sheets and some progress meeting reports were also collected. The data collected was used to develop a framework and then a conceptual model, modified to be fed into the EZStrobe simulation programme. Both frameworks are required to be verified in future studies using comparative analysis between the results of simulation and existing plan (either resulting from Microsoft Project Professional or Last Planner System).



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SIMULATION PROCEDURE

Understanding the System Behaviour/ Initial Conceptual Model

There are several basic steps that have been suggested in literature for the development of simulation models. However the steps used in the current study, in line with suggestions made by Robinson (2012) and Al-Ghtani, are: 1/ Identifying work tasks, 2/ Defining resources, 3/ Determining the logic of processing of resources, 4/ Building a model of the process, and 5/ Preparing a diagram of the model.

Authors attempted to create a conceptual model of the selected case study (Zaeri & Rotimi, 2014; Zaeri, Rotimi, & McCorquodale, 2014). They used the primary collected data and built an initial conceptual model. Further in line with Akhavian and Behzadan (2013), one of the model has been developed in which considered the states of the resources. As Halpin and Riggs (1992) suggested, identification of the activity status is important since it can help developing the skeletal framework of a construction operation. Therefore, three major resources involved in beam erection operation were taken into account and their associated statuses have been denoted by traffic light symbols.

The developed conceptual model provided a diagrammatic representation of the operations performed in a way that the sequence of work performance, the dependencies among them and their required resources were depicted. With these key operational process determined, the tasks of undertaking time and motion studies on the operations becomes less cumbersome. Subsequently, by the selection EZStrobe as a simulation tool in the current study, it has been found that the previous model even covered the knowledge on the system behavior but still need to be developed in more details toward being used in EZStrobe program. The procedure of developing the conceptual framework are presented in next sections.

Modifying Conceptual Model Using EZStrobe Standards

EZStrobe is an entirely graphical discrete event simulation system based on extended and annotated Activity Cycle Diagrams and the Three-Phase Activity Scanning paradigm. It has been built in Microsoft Visio and is add-on to and uses STROBOSCOPE's simulation engine. Simulating progress in EZStrobe starts with using custom drag-and-drop graphics and do not require any programming (<http://www.EZStrobe.com/2009/10/EZStrobe.html>).

Therefore at the early stage of modifying the conceptual model toward its feeding into EZStrobe, it is required to know about the graphical elements included in this program. Therefore the EZStrobe standards provided in Martinez (2001) research has been used at this stage.

Based on the examples of implementation of simulation in construction projects included in research works done by Martinez (1998, 2001); Marzouk et al. (2007); Marzouk et al. (2008); Marzouk, Zein, and Elsaid (2006) the steps of simulating procedure are summarized as below:



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- 1- Defining Queues, Activities, Conditions needed to start Activity, and Outcome of Activity.
- 2- Identifying and assigning the content of each Queue.
- 3- Identifying the types of link should be drawn to connect Queue and Activity.
- 4- Assigning the annotations to the link:
 - 4-1 Drawing a link to connect Queue to Activity: Therefore, annotation indicates the required conditions for Activity to start.
Note that if the link connects Combi and Queue, then annotation includes one more section to present how many units will be released (if possible) from the connected Queue.
 - 4-2 Drawing a link to connect Activity to any Node: Therefore, annotation represents the amount of resource that will be released through the link each time an instance of the predecessor activity ends.
- 5- Estimating the duration of each Activity:
 - 5-1 Using Uniform distribution sample to estimate duration of Combi.
 - 5-2 Using Probability distribution sample to estimate the duration of Normal Activity.
- 6- Creating Probabilistic Branch to connect Fork to any other node except Combi. In this way developer determines that which route should be followed regarding to each condition.
- 7- Parameterizing the models:
The Parameters option in EZStrobe allow the designer/developer to assign a symbolic name and description to these values. Also, the model parameters page can present the amount of material (resources) to be moved, the number of machines to be used, the hourly cost of equipment/machines, and some other indirect cost parameters. It should be noticed that using parameters option let developer to create generic models that adapt to a wide range of similar operations, where such models can be used by specifying appropriate parameter value later.
- 8- Customizing Output:
This step can be accomplished using Results option provided in EZStrobe. This option allow modeler to define the formulas to measure the performances which their associated parameters already entered in previous step.

In relation to the steps outlined above, steps 1, 2, have been completed and presented in table 1, and figures 1 and 2.

Table 1: Required information to build the ABC conventional model

Conditions Needed to Start	Activity	Outcome of Activity
- Loaded truck Idle at site - Empty Gantry Crane waiting to load	Beam delivery in Gantry area	- Gantry crane ready to load - Truck ready to Haul - Super T beam Idle
- Loaded Gantry ready to	Moving down the beam to do	- Super T Idle on the ground (Ready for



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Conditions Needed to Start	Activity	Outcome of Activity
<ul style="list-style-type: none"> move down - Unloaded Truck ready to Haul 	preparation (including stranding the stress bars and timbering works over the beam)	<ul style="list-style-type: none"> preparation) - Unloaded Gantry crane idle
<ul style="list-style-type: none"> - Empty Gantry waiting to Load - Super T Beam Ready to Lift 	Lifting up the Super T-beam	<ul style="list-style-type: none"> - Super T beam Idle on the Gantry crane - Loaded Gantry Idle
<ul style="list-style-type: none"> - Loaded Gantry ready to move forward - Super T Beam Idle 	Launching the Gantry forward	<ul style="list-style-type: none"> - Loaded Gantry ready to deliver beam on the desired place - Super T beam Ready to be placed
<ul style="list-style-type: none"> - Loaded Gantry idle on the top of the span - Supports ready for beam placement - Super T Beam ready to be placed 	Placing the Super T beam	<ul style="list-style-type: none"> - Unloaded Gantry Idle - Super T beam ready to be fixed on the supports
<ul style="list-style-type: none"> - Unloaded Gantry idle - Gantry area is empty 	Preparation of the Gantry for next round	<ul style="list-style-type: none"> - Gantry crane ready to load - Truck ready to Haul - Super T beam Idle

The information on Table 1 is captured to layout the conventional ACD model (see figure 1). The model illustrates the sequence of activities and the way of that an activity receives the required resource(s). The states of the resources also have been considered in this model which helps in developing the further model using EZStrobe standards. This conventional model can be used to express the main concepts of a model (object) which is aimed to be simulated.

In simple terms, the process investigated includes the installation of precast super-T beams between bridge spans from the south to the northward ramp. The T-beams are delivered with trucks to the loading area, where they are picked up by the Gantry Crane. The Gantry Crane then lifts the beams (whether intermediate or edge) to the placement points. The entire process from delivery to placement is dependent on the availability of certain resources and constraints which are very often not indicated in normal MSProject/ schedules. Examples of some of the constraints are: shape of the curve of T-beam, edge or intermediate one, length of the beam, placement in between of two piers/abutment and pier, and location of span which may need traffic closure.

With the conventional model developed (figure 1), the next model (see figure 2) is developed based on EZStrobe standards. In some cases, where the queue in Conventional model identified as superfluous one, then it can be removed in ACD EZStrobe. For example, consider the queue named as “Unloaded truck idle and ready to Haul”, this queue can be



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Shaping future directions for collaborative built environment research and practice in New Zealand

removed and being replaced with Haul activity. In this way, the model presents that the Haul activity can be initiated immediately after the Combi activity named as “Beam Delivery to Gantry Area” finishes. It means that the conditions needed for “Haul” activity to start is completely satisfied by the outcome of “Beam Delivery to Gantry Area”.

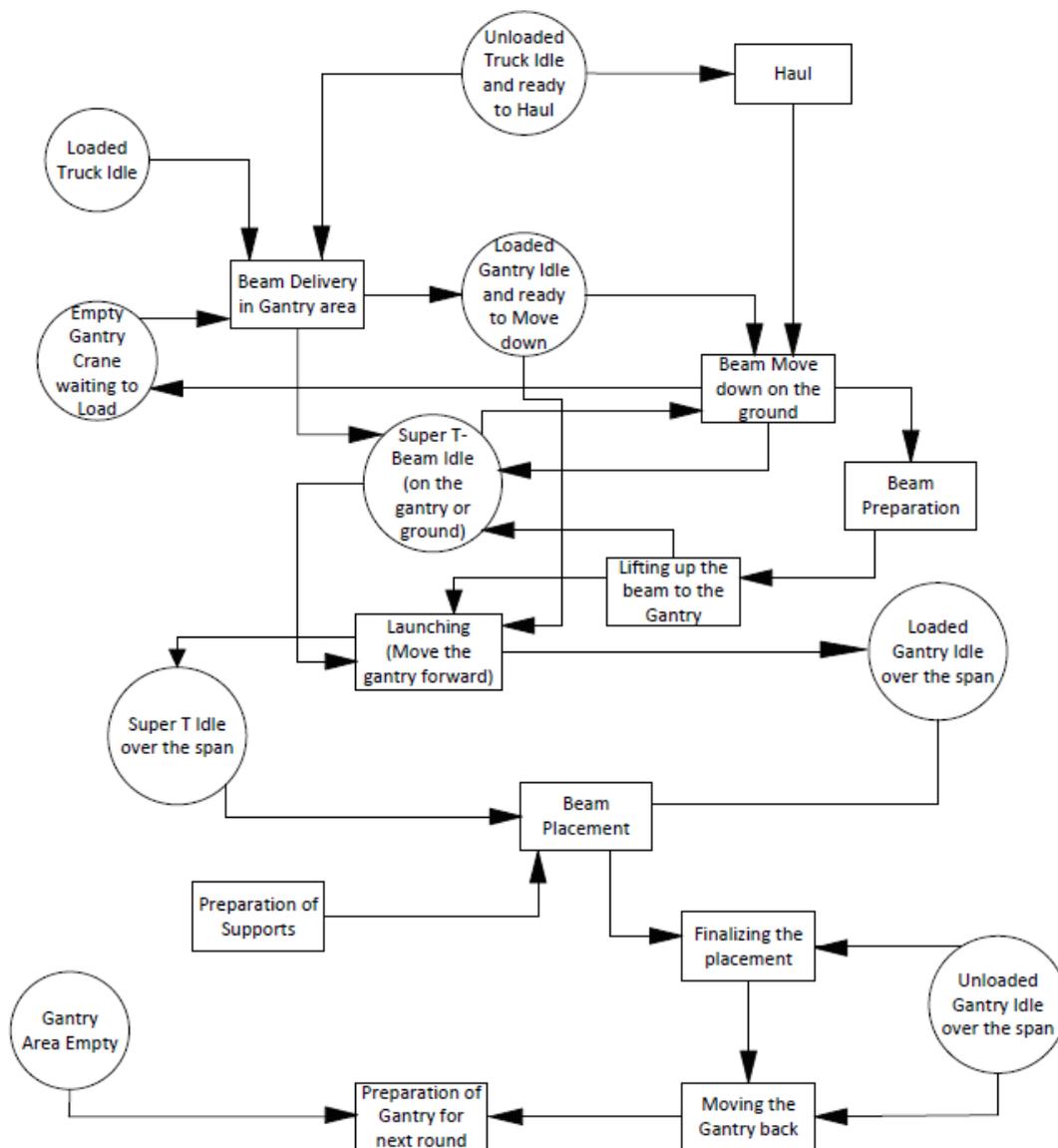


Figure 1: ABC Conventional Model for Beam Delivery Operation using Launching Gantry

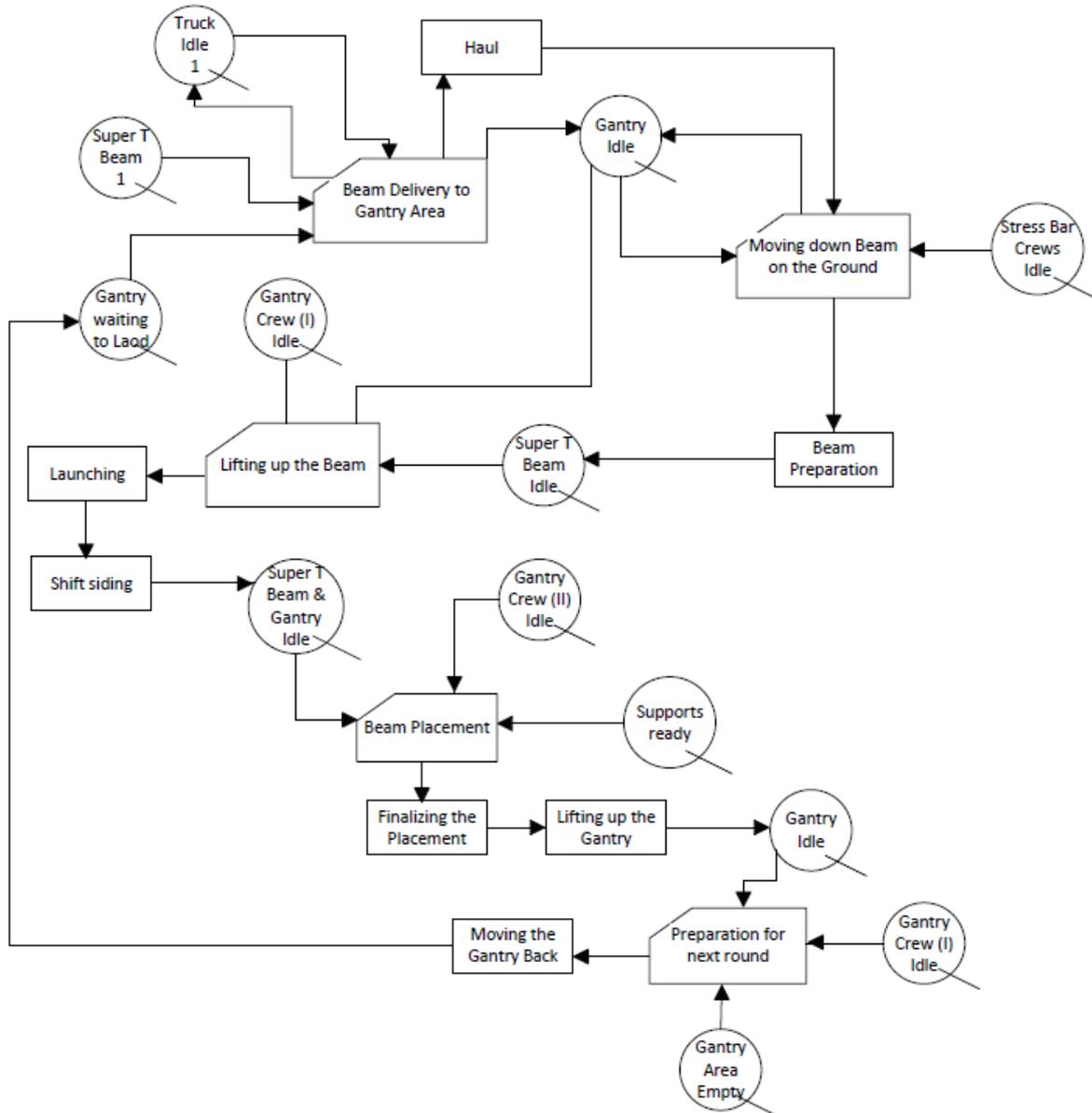


Figure 2: EZStrobe ABC Model for Beam Delivery Operation using Launching Gantry

As mentioned earlier, EZStrobe allows a Modeller to consider probability situation within the modelling. It can be done using Fork and Branch Link elements. As an example, consider the situation that Gantry crane is broke down. Then Fork element lets the Modeller considering two different conditions: 1/ if the probability of Gantry break-down is 5% (for example), then the progress should be routed through performing the Repair Activity, and 2/ in the case of 95% probability, the Gantry works on the routine progress directly switch to next Activity; Launching (see figure 3).

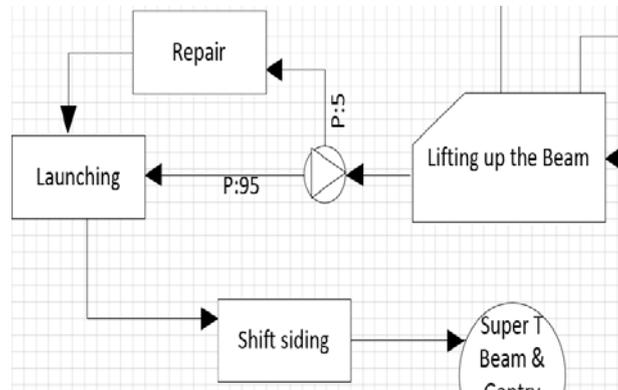


Figure 3: EZStrobe ACD model including Fork and Branch link in the case of Gantry Breakdown

As another example, consider a parameter which has been found important from the aspect of its effect on the duration of the operation in the current fieldwork study. This parameter is associated with the types of the Super T beam (whether edge or intermediate), as the method of placement varies depending on the beam type. Therefore, the model can be developed in this particular section as shown in figure 4. The probability's annotation has been assigned assuming the span includes two edge beams and 4 intermediate beams.

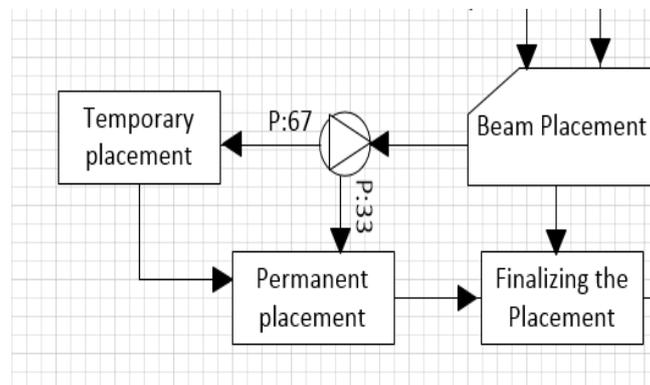


Figure 4: EZStrobe ACD model including Fork and Branch Link to Present the Procedure of Two Different Methods of Beam Placement

Since the main purpose of simulating an operation is to obtain statistical measures of performance, therefore, developing the ACD model in more detail can lead to more accurate results.

In future research, the authors will continue the simulation steps and subsequently run a simulation for this case study project. By so doing, a comparison of the simulation model with durations resulting from normal schedule (MSP) will be undertaken and hopefully this could



NEW ZEALAND BUILT ENVIRONMENT RESEARCH SYMPOSIUM

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improve process activities for the next construction phase for the remaining ramps. The capability of EZStrobe could then be explored and verified.

CONCLUSION

The objective of this study is to develop an ACD model for simulating bridge construction operation. It has been found that analysing the system behaviour plays a vital role in scheduling any complex process. Complexity and uniqueness of systems on one hand, and deployment of new methods of construction on the other hand makes planning and scheduling activities more cumbersome.

The review of the studies on construction/bridge construction operations shows that some advanced technologies could overcome such issues. Simulation-based method is the recent technique that its implementation in construction has been verified from different aspects, such as estimation of duration, decision making support, tracking performance, and estimation of cost. Among those, STROBOSCOPE engine and its simplest version, EZStrobe are found by researchers as useful simulation-based tools in bridge construction. This study therefore employed EZStrobe standards to achieve its objective. The ACD model developed for the case study (bridge construction) project uses an incremental launching technique which is unique to New Zealand. The case study therefore provides an opportunity to present the software enables planners to consider resources' statuses, different logic and constraint decisions and operational methods from the early stage of scheduling. This is the advantage of simulation technique over other planning and scheduling software.

This research contributes to construction operations management and scheduling by providing a conceptual framework for this specific method of bridge construction (incremental launching). The model eventually would be applied to simulate bridge construction operations and assist in their planning and management. The study is significant to New Zealand because the implementation of simulation technique is new to its construction industry. In future works, the EZStrobe simulation will be run using the developed ACD to present more potentials of its application.

REFERENCES

- AbouRizk, S. (2010). Role of Simulation in Construction Engineering and Management. *Journal of Construction Engineering and Management*, 136(10), 1140-1153. doi:10.1061/(ASCE)CO.1943-7862.0000220
- AbouRizk, S., & Dozzi, S. P. (1993). Application of computer simulation in resolving construction disputes. *Journal of Construction Engineering and Management*, 119(2), 355-373.
- AbouRizk, S., Halpin, D., & Lutz, J. (1992, 1992). State of the art in construction simulation *ACM*. doi:10.1145/167293.167911
- AbouRizk, S., Halpin, D., Mohamed, Y., & Hermann, U. (2011). Research in modeling and simulation for improving construction engineering operations. *Journal of Construction Engineering and Management*, 137(10), 843-852. doi:10.1061/(ASCE)CO.1943-7862.0000288
- Ailland, K., Bargstädt, H.-J., & Hollermann, S. (2010). Construction process simulation in bridge building based on significant day-to-day data *Winter Simulation Conference*. Symposium conducted at the meeting of the Proceedings of the Winter Simulation Conference



NEW ZEALAND BUILT ENVIRONMENT RESEARCH SYMPOSIUM

Shaping future directions for collaborative built environment research and practice in New Zealand

- Akhavian, R., & Behzadan, A. H. (2013). Knowledge-Based Simulation Modeling of Construction Fleet Operations Using Multimodal-Process Data Mining. *Journal of Construction Engineering and Management*, 139(11).
- Al-Ghtani, K. Application of Simulation in Construction Processes (Planning and Modeling of Construction). In E. C. King Saud University, Civil Engineering Department (Ed.).
- Alvanchi, A. (2011). *Incorporating the Effects of Complex Dynamic Interactions in the Construction Decision Making Process*. ProQuest, UMI Dissertations Publishing.
- Appleton, B. J., Patra, J., Mohamed, Y., & AbourRizk, S. (2002). Special purpose simulation modeling of tower cranes. *IEEE Symposium* conducted at the meeting of the Simulation Conference, 2002. Proceedings of the Winter
- Beißert, U., König, M., & Bargstädt, H.-J. (2007). Constraint-based simulation of outfitting processes in building engineering Symposium conducted at the meeting of the 24th W78 Conference
- Beißert, U., König, M., & Bargstädt, H.-J. (2008). Generation and local improvement of execution schedules using constraint-based simulation Symposium conducted at the meeting of the Proc. of the 12th Int. Conf. on Computing in Civil and Building Engineering (ICCCBEXII)
- Biruk, S., & Jaśkowski, P. (2008). Simulation modelling construction project with repetitive tasks using Petri nets theory. *Journal of Business Economics and Management*, 9(3), 219-226.
- Chan, W.-H., & Lu, M. (2005). Logistics and operations simulation in precast viaduct construction: case study Symposium conducted at the meeting of the Proceedings of the 2005 ASCE International Conference on Computing in Civil Engineering
- Chan, W.-H., & Lu, M. (2012). Construction operations simulation under structural adequacy constraints: the Stonecutters Bridge case study. *IEEE Symposium* conducted at the meeting of the Simulation Conference (WSC), Proceedings of the 2012 Winter
- Cheng, T.-m., & Feng, C.-w. (2003). An effective simulation mechanism for construction operations. *Automation in Construction*, 12(3), 227-244. doi:10.1016/s0926-5805(02)00086-9
- Devulapalli, S. (2002). Evaluation of Policies for the Maintenance of Bridges Using Discrete Event Simulation.
- El Ghandour, W. (2007). *Integrated information-based construction simulation system*. ProQuest, UMI Dissertations Publishing.
- Fernando, S., Er, K., Mohamed, Y., AbouRizk, S., & Ruwanpura, J. (2003). A review of simulation applications for varying demands in tunneling. *Bridges*, 10(40671), 35.
- Fu, J. (2013). *Logistics of Earthmoving Operations: Simulation and Optimization*. KTH.
- Gonzalez-Quevedo, A. A., AbouRizk, S., Iseley, D. T., & Halpin, D. W. (1993). Comparison of two simulation methodologies in construction. *Journal of Construction Engineering and Management*, 119(3), 573-589.
- Gray, D. E. (2004). *Doing research in the real world*. Thousand Oaks, CA: Sage Publications.
- Hajjar, D. (1999). *A unified modeling methodology for simulation-based planning of construction projects*. ProQuest, UMI Dissertations Publishing.
- Halpin, D. W., & Riggs, L. S. (1992). Planning and Analysis of Construction Operations., *John Wiley and Sons, Inc., New York, N.Y.*, 381.
- Hohmann, G. (1997). Von der Netzplantechnik zur Simulation-Analyse von Bauprozessen mit Hilfe von Petri-Netzen.
- Huang, R., Grigoriadis, A. M., & Halpin, D. W. (1994). Simulation of cable-stayed bridges using DISCO Symposium conducted at the meeting of the Proc., 1994 Winter Simulation Conf., IEEE, Piscataway, N.J.
- Huang, R. y., Chen, J. J., & Sun, K. S. (2004). Planning gang mould operations for building construction using simulations *Automation in Construction*, 13(6), 765-779.
- Kim, J. (2007). *An investigation of activity duration input modeling by duration variance ratio for simulation-based construction scheduling*.
- König, M., Beißert, U., & Bargstädt, H. (2007). Visual simulation-an appropriate approach to support execution planning in building engineering Symposium conducted at the meeting of the Proc. of the 7th International Conference on Construction Applications of Virtual Reality (ConVR)
- Koo, B., Fischer, M., & Kunz, J. (2007). A formal identification and re-sequencing process for developing sequencing alternatives in CPM schedules. *Automation in Construction*, 17(1), 75-89.
- Lucko, G., Swaminathan, K., Benjamin, P., & Madden, M. (2009, 2009). Rapid deployment of simulation models for building construction applications *Winter Simulation Conference*.



NEW ZEALAND BUILT ENVIRONMENT RESEARCH SYMPOSIUM

Shaping future directions for collaborative built environment research and practice in New Zealand

- Martinez, J. (1996). *Stroboscope: State and resource based simulation of construction processes*.
- Martinez, J. (1998). EZStrobe-General-purpose simulation system based on activity cycle diagrams *IEEE*. Symposium conducted at the meeting of the Simulation Conference Proceedings, 1998. Winter
- Martinez, J. (2001). EZStrobe: general-purpose simulation system based on activity cycle diagrams *IEEE Computer Society*. Symposium conducted at the meeting of the Proceedings of the 33rd conference on Winter simulation
- Marzouk, M., ElDein, H. Z., & ElSaid, M. (2007). Application of computer simulation to construction of incremental launching bridges. *Journal of Civil Engineering and Management*, 13(1), 27-36.
- Marzouk, M., Said, H., & El-Said, M. (2008). Special-Purpose Simulation Model for Balanced Cantilever Bridges. *Journal of Bridge Engineering*, 13(2), 122-131.
- Marzouk, M., Zein, H., & Elsaid, M. (2006). Bridge_Sim: framework for planning and optimizing bridge deck construction using computer simulation *IEEE*. Symposium conducted at the meeting of the Simulation Conference, 2006. WSC 06. Proceedings of the Winter
- Mawdesley, M. J., Askew, W. H., & Al-Jibouri, S. H. (2004). Site layout for earthworks in road projects. *Engineering, Construction and Architectural Management*, 11(2), 83-89.
- Mikulakova, E., König, M., Tauscher, E., & Beucke, K. (2008). Case-based reasoning for construction tasks *12th International Conference on Computing in Civil and Building Engineering (ICCCBE-XII)*. Beijing, China.
- Mohamed, A., & Celik, T. (2002). Knowledge based-system for alternative design, cost estimating and scheduling. *Knowledge-Based Systems*, 15(3), 177-188.
- Mohamed, Y., & AbouRizk, S. (2005). Framework for Building Intelligent Simulation Models of Construction Operations. *Journal of computing in civil engineering*, 19(3), 277-291. doi:10.1061/(ASCE)0887-3801(2005)19:3(277)
- Paul, R. J., & Chew, S. T. (1987). Simulation modelling using an interactive simulation program generator. *Journal of the Operational Research Society*, 735-752.
- Pontrandolfo, P. (2000). Project duration in stochastic networks by the PERT-path technique. *International Journal of Project Management*, 18(3), 215-222.
- Puri, V. (2012). *Incorporation of continuous activities into activity cycle diagram based discrete event simulation for construction operations*. ProQuest, UMI Dissertations Publishing.
- Robinson, S. (2012). Tutorial: Choosing what to model—Conceptual modeling for simulation *IEEE*. Symposium conducted at the meeting of the Simulation Conference (WSC), Proceedings of the 2012 Winter
- Said, H., Marzouk, M., & El-Said, M. (2009). Application of computer simulation to bridge deck construction: Case study. *Automation in Construction*, 18(4), 377-385. doi:10.1016/j.autcon.2008.11.004
- Sawhney, A., AbouRizk, S., & Halpin, D. W. (1998). Construction project simulation using CYCLONE. *Canadian Journal of Civil Engineering*, 25(1), 16-25. doi:10.1139/cjce-25-1-16
- Senouci, A., & Al-Derham, H. R. (2008). Genetic algorithm-based multi-objective model for scheduling of linear construction projects. *Advances in Engineering Software*, 39(12), 1023-1028.
- Shi, J. (1997, 1997). A conceptual activity cycle-based simulation modeling method *IEEE Computer Society*. doi:10.1145/268437.268749
- Shi, J. (1999). Activity-Based Construction (ABC) Modeling and Simulation Method. *Journal of Construction Engineering and Management*, 125(5), 354-360. doi:10.1061/(ASCE)0733-9364(1999)125:5(354)
- Song, L., Wang, P., & AbouRizk, S. (2006). A virtual shop modeling system for industrial fabrication shops. *Simulation Modelling Practice and Theory*, 14(5), 649-662. doi:10.1016/j.simpat.2005.10.012
- Sriprasert, E., & Dawood, N. (2002). Next generation of construction planning and control system: the LEWIS approach *Taylor & Francis*. Symposium conducted at the meeting of the EWork and EBusiness in Architecture, Engineering and Construction: Proceedings of the Fourth European Conference on Product and Process Modelling in the Building and Related Industries, Portorož, Slovenia, 9-11 September 2002
- Stufflebeam, D. L., Madaus, G. F., & Kellaghan, T. (2000). *Evaluation models: Viewpoints on educational and human services evaluation* (Vol. 49): Springer.
- Tecnomatix. (2006). *Tecnomatix Plant Simulation, Step-by-step: Handbook Version 8.1.*, Stuttgart
- Wu, I., Borrmann, A., Beibert, U., König, M., & Rank, E. (2010). Bridge construction schedule generation with pattern-based construction methods and constraint-based simulation. *Advanced Engineering Informatics*, 24(4), 379-388. doi:10.1016/j.aei.2010.07.002



NEW ZEALAND BUILT ENVIRONMENT RESEARCH SYMPOSIUM

Shaping future directions for collaborative built environment research and practice in New Zealand

- Wu, I., Borrmann, A., Rank, E., Beißert, U., & König, M. (2009). A pattern-based approach for facilitating schedule generation and cost analysis in bridge construction projects Symposium conducted at the meeting of the Proc. of the 26th CIB-W78 Conference on Managing IT in Construction
- Zaeri, F., & Rotimi, J. O. B. (2014). Simulation of bridge construction works: An exploratory study in new zealand. In W. Suanpaga, S. Yazdani, V. Vimonsatit, A. Singh, & K. Chantawarangul (Chair), *2014 ISEC Press*. Symposium conducted at the meeting of the Sustainable Solutions in Structural Engineering and Construction (ISEC2014), Bangkok, Thailand.
- Zaeri, F., Rotimi, J. O. B., & McCorquodale, C. (2014). Exploring Performances and their interdependencies in Bridge Construction: A Case Study. Symposium conducted at the meeting of the IstanbulBridge Conference 2014, Istanbul, Turkey.