AN ACD DIAGRAM DEVELOPED FOR SIMULATING A BRIDGE CONSTRUCTION OPERATION

Fahimeh Zaeri, Auckland University of Technology, New Zealand
James Olabode Bamidele Rotimi, Auckland University of Technology, New Zealand

ABSTRACT

Success in the performance of construction projects can be substantially enhanced if plans are formulated more realistically, ahead of time. Planning includes identifying project activities, required resources, interdependencies, and also recognizing the uncertainties in the duration of activities. Inherent features of construction projects, such as high repetition, complexity and uniqueness on the one hand, and advances in technology and methodologies on the other, create more difficulties in planning construction delivery. This is true for bridge operations. This study presents an innovative incremental beam launching method with twin truss gantry. This construction method has significant advantages in terms of cost and speed of performance, but increases the level of planning and management required for the bridge operation. Further, because of the newness of the method, no specific Work Breakdown Structure nor conceptual framework has been developed as yet. The aim of the current study is to explore the use of a simulation-based tool (EZStrobe) to facilitate the planning and management of a bridge construction operation (case study). The process followed in the development of a conceptual framework for the case study project is described. An Activity Cycle Diagram is produced alongside the conceptual framework and process models, with the intent of illustrating the key steps in the simulation modelling method. The developed models could assist in scheduling and controlling inherent construction features such as uncertainties, complexities, and repetitions in bridge construction projects, consequently improving their delivery.

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 form a chain that defines a project's activity cycle. According to Shi (1997) the cycle could either be a closed or an opened 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 project resources in a manner that supports the logical sequences required for construction operations. This task is made cumbersome by the complexity and dynamic characteristics of construction projects, with Halpin and Riggs (1992) suggesting 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, and are therefore to be encouraged for non-stationary construction projects.

A host of simulation-based techniques for scheduling construction projects are in use. Some may or may not be 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 and analysis of a construction project.

In the current study, the authors investigate the potential for the application of simulation-based techniques 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 a bridge project's components, and moves towards developing a simulation model for the project. The field investigation undertaken is described within the paper, to demonstrate the capabilities of the 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 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) insist 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 researchers capture human knowledge to overcome scheduling issues. The system developed on the basis of human knowledge could represent 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 Abdulrezak and Celik (2002).

There are other techniques, such as graph based techniques, which have been employed to analyse a project's tasks, estimate their duration, and identify the minimum time required to complete projects. The most common one is Critical Path Method (CPM), 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, such as complexity and uncertainty, affect the estimation of an activity's duration, and consequently form 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 has been addressed using a Petri-Nets-based approach as proposed by Biruk and Jaśkowski (2008).

Achieving almost optimum solutions by considering resource consumption and project duration is an aim of recent research. In this way, multi-constraint optimisation 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 optimal solutions rapidly. Another optimisation model applied in scheduling linear construction projects is a genetic algorithm-based multi-objective optimisation that was introduced by Senouci and Al-Derham (2008).

Even though knowledge-based systems have addressed construction project 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 solutions. An example is the Monte Carlo simulation technique.

To overcome these aforementioned issues, Huang, Chen, and Sun (2004) implemented a computer simulation tool called CYCLONE. CYCLONE has been applied in the standardisation 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), is found in numerous areas such as bridge works, tunnel projects, reverse circulation foundation pile works, concrete delivery from pre-mix concrete plants, sewage works, and road works. A developed tool called Simphony™ 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 a lean construction process.

An analysis of literature on construction simulation was carried out by El Ghandour (2007) using three analysing tools: 1/ based on the 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 the tracking of the developed simulation engines and/or languages. This literature analysis on construction simulation covered the period 1976 to 2002. These results show that some areas such as change orders, constructability, and quality control have not enjoyed the benefits of simulation. Further, the review shows that simulation models were not well able to transfer data 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 needed to be transferred. Resource-based simulation engines started in 1987 with Paul and Chew (1987) and were followed by research from 1992 to 1994. When the Activity Based Cycle was introduced by Shi (1999) cited in (El Ghandour, 2007), attention to resource-based simulation declined. In the period 1976 to 2002, there was a trend toward developing simulation models based on process or activity elements. Concurrently, new trends such as product-based and function-based approaches evolved. El Ghandour (2007) suggests that these new trends will be the most interesting ones within Research and Design (R & D) in the coming decade.

Decision Making Progress in Construction Operations

Construction planning and controls aim to ensure a well-coordinated and successful project. Therefore, the integration and quantification of the various aspects of performance are required for carrying out progress monitoring more effectively. Moreover, project performances are typically assessed based on personal experiences and without a set evaluation procedure. However, performance of the same project with similar data is feasible to be assessed differently by two project managers (Rad, 2003). Analysing these decisions is important to reach the most appropriate conclusion on analysing and assessing project performance. This way of comparing alternatives and decisions analysis is cost-effective. However, various techniques and tools have been developed in this domain to support construction managers with making the right decisions.

As the literature review shows, the decision-making process is subjective and relies heavily on an individual planners' intuition, knowledge, and experience (Fu, 2013; Mawdesley, Askew, & Al-Jibouri, 2004). Construction managers depend on their skills and common sense to make their daily decisions (Mohamed & AbouRizk, 2005). Further, they are unable to track the ultimate effects of their decision on a project's productivity and final cost when they use traditional project management tools, because different effective feedback loops are formed due to mutual interaction between organisations effective factors (Mohamed & AbouRizk, 2005).

The use of conventional decision-making tools does not allow construction managers to evaluate the final effects of different alternatives, as there are complex interactions among a variety of effective organisational and operational parameters Mohamed and AbouRizk (2005). 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, Mohamed and AbouRizk (2005) proposed that the main problem with most traditional modelling approaches is that they are only able to capture system interactions at either the operation level or context level of feedback between the context (organisational) 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 (Mohamed & AbouRizk, 2005).

Alvanchi (2011) introduced and validated a hybrid approach to improve the decision-making process by addressing such feedback. In this way, Alvanchi (2011) advises that the contribution of the decision-making process and organisational policies into project fluctuations over time, on one side, and the uniqueness of construction projects on the other, always highlight the need for human communication and judgement during project execution. Therefore, support of the decision-making process has received lots of attention in most research that deals with process modelling in construction management. In addition to linear and non-linear optimisation 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) and Song, Wang, and AbouRizk (2006) suggest that modelling and simulation of the construction process could support construction planning and assist managers/ planners with reducing the risks associated with 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 operations, 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 a policy analysis tool using discrete event simulation, for predicting network health under different scenarios to facilitate the discrete Salem Bridge System.

Decision makers also need to be supported in other aspects, such as changing the logic of the construction process in a cost-effective way. When a mathematical modelling approach is not appropriate, simulation modelling can be useful to achieve the most suitable solution to a construction problem, since it can help planners to predict the effect of decisions on such changes in a 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 interfaces between operations research and computer science possible. Construction managers are able to improve their operations by experimenting with different possible scenarios provided by DES. Thus, simulation assists their decision making by determining the best strategy for execution of specific operations in practice (Devulapalli, 2002).

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

Simulation of Construction Projects

The ineffectiveness of traditional construction planning methodologies in supporting today’s project features has 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 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 (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).

Simulation modelling methodologies vary according to the nature of the projects to be modelled, and in the construction domain, simulations are applicable to a wide spectrum of operations (Mohamed & AbouRizk, 2005). For example, AbouRizk, Halpin, Mohamed, and Hermann (2011) demonstrate the usefulness of simulation in the design of construction operations involving multiple interacting factors that produce unpredictable outcomes, and stochastic events that 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 that 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 the simulation approach makes it more advantageous than traditional scheduling methods like CPM and PERT. In other words, the system under consideration 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, 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 development is required for its implementation on bridge construction processes.

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), 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. 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 pre-cast segment inventory problems.

Others, such as Marzouk, ElDein, and ElSaid (2007), utilised 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 illustrated 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) employed a 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 utilisation that represent 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 help 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, which does not require programming or coding. It is easier to learn and capable of modelling complex problems with 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

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 could benefit the New Zealand construction sector. Thus, the research is both experimental and analytical, in line with research categories proposed by Gray (2004).

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 the EZStrobe programme.

In the initial stage of the research, the study carried out thorough fieldwork study to understand the system's behaviour. Some data were collected using direct observation and field-note techniques. The primary data was in line with simulation procedure for developing a conceptual framework. The collected data included 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 that commonly occur on construction sites, 6/ tracking decision-making ability, and 7/ identifying the interaction among human resources.

The case-study project involved 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 a relatively new construction technique. There was no solid Work Break-down Structure (WBS) or conceptual framework developed for the project.

Approximately, three on-site months were spent observing the process and collecting the required data. During the observation period, project documents such as the 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 the Microsoft Project Professional program or the Last Planner System).

SIMULATION PROCEDURE

Understanding the System Behaviour/Initial Conceptual Model

There are several basic steps that have been suggested in theliterature 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.

Researchers have 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. As line with Akhavian and Behzadan (2013), one of the models has been developed to consider the states of the resources. As Halpin and Riggs (1992) suggested, identification of the activity status is important, since it can help in developing the skeletal framework of a construction operation. Therefore, three major resources involved in a beam erection operation were taken into account and their associated statuses have been denoted by traffic light symbols.

The conceptual model developed provided a diagrammatic representation of the operations performed in such 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 knowledge on system behaviour, but, it still needs to be developed in more detail to be used in EZStrobe program. The procedure of developing the conceptual framework is presented in the following sections.

Modifying a 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 was built in Microsoft Visio and is an add-on to and uses STROBOSCOPE's simulation engine. Simulating progress in EZStrobe starts with using custom drag-and-drop graphics and does not require any programming (http://www.EZStrobe.com/2009/10/EZStrobe.html).

Therefore, at the early stage of modifying the conceptual model for feeding into EZStrobe, it is necessary to know about the graphical elements included in this program. Thus the EZStrobe standards provided in Martinez's (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 procedures are summarised as below:

1- Defining Queues, Activities, Conditions needed to start Activity, and Outcome of Activity (developing Activity-Based Construction (ABC) model)
2- Identifying and assigning the content of each Queue
3- Identifying the types of link that 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 a Uniform distribution sample to estimate duration of Combi

5-2 Using a 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 the developer determines which route should be followed regarding to each condition

7- Parameterising the models:
The Parameters option in EZStrobe allows the designer/developer to assign a symbolic name and description to these values. Also, the model parameters page can represent 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 the parameters option lets the developer create generic models that adapt to a wide range of similar operations, where such models can be used by specifying the appropriate parameter value later

8- Customizing Output:
This step can be accomplished using the Results option provided in EZStrobe. This option allows the modeller to define the formulas to measure the performances which their associated parameters have already entered in the previous step

In relation to the steps outlined above, steps 1 and 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 move down - Unloaded Truck ready to Haul	Moving the beam down to do preparation (including stranding the stress bars and timbering works over the beam)	- Super T Idle on the ground (Ready for preparation) - Unloaded Gantry crane idle
- Empty Gantry waiting to Load - Super T Beam Ready to Lift	Lifting up the Super T-beam	- Super T beam Idle on the Gantry crane - Loaded Gantry Idle
- Loaded Gantry ready to move forward - Super T Beam Idle	Launching the Gantry forward	- Loaded Gantry ready to deliver beam at the desired place - Super T beam Ready to be placed
- 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	- Unloaded Gantry Idle - Super T beam ready to be fixed on the supports
- Unloaded Gantry idle - Gantry area is empty	Preparation of the Gantry for next round	- 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 an activity receives the required resource(s). The states of the resources have also been considered in this model, which helps in developing the next 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 by 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 the T-beam, edge or intermediate, length of the beam, placement between two piers/abutment and pier, and location of the span, which may need traffic closure.

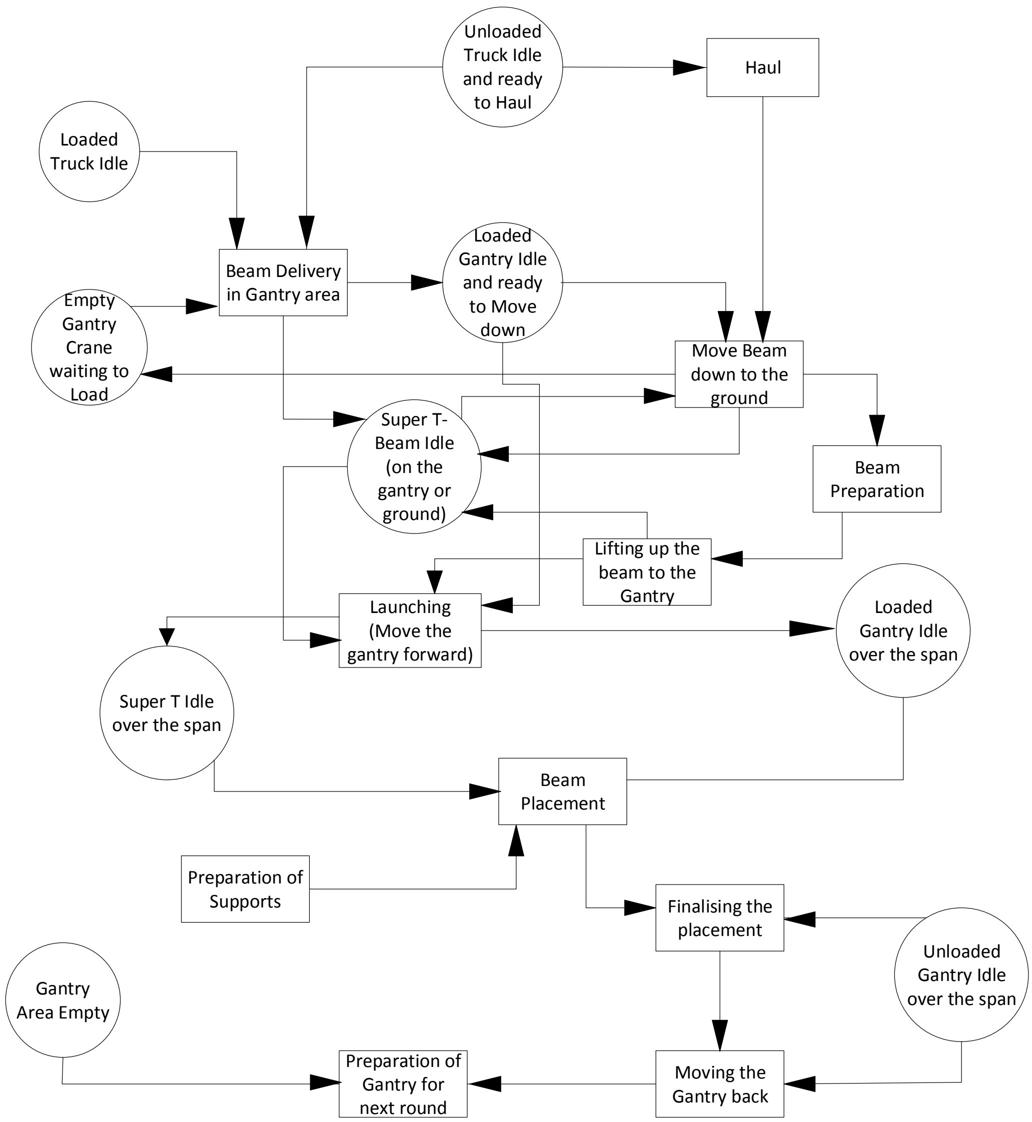

Figure 1: ABC Conventional Model for Beam Delivery Operation using Launching Gantry

With the conventional model developed (Figure 1), the next model (see Figure 2) can be developed using EZStrobe standards. In some cases, where the queue in the Conventional model is identified as superfluous, it can be removed from ACD EZStrobe. For example, consider the queue as "Unloaded truck idle and ready to Haul"; this queue can be removed and be replaced with Haul activity. In this way, the model presents that Haul activity can be initiated immediately after the Combi activity named as "Beam Delivery to Gantry Area" finishes. This means that the conditions needed for "Haul" activity to start are completely satisfied by the outcome of "Beam Delivery to Gantry Area".

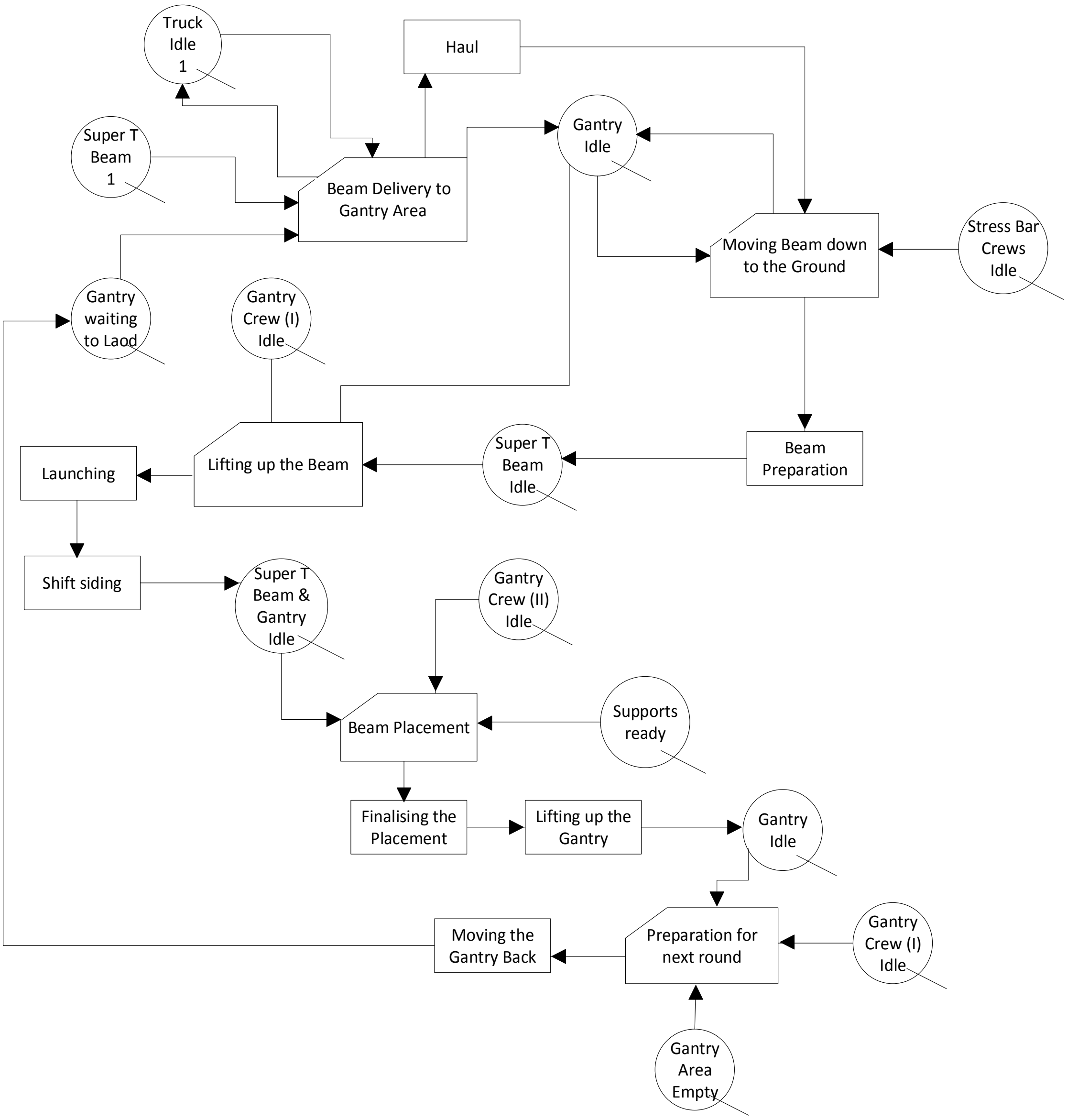

Figure 2: EZStrobe ABC Model for Beam Delivery Operation using Launching Gantry

As mentioned earlier, EZStrobe allows a Modeller to consider probability situation within the modelling. This can be done using Fork and Branch Link elements. As an example, consider the situation that the Gantry crane has broken down. Then the Fork element lets the Modeller consider 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, and directly switches to the next Activity; Launching (see figure 3).

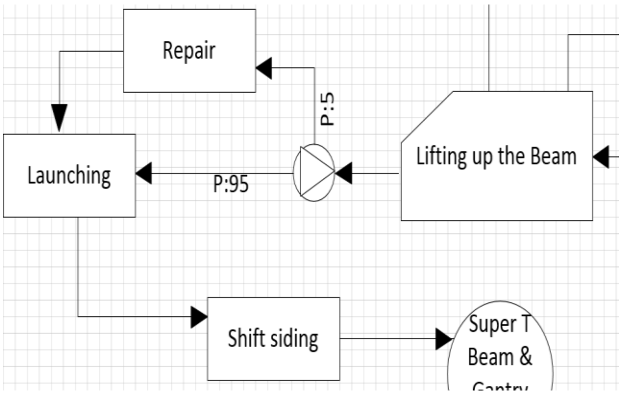

Figure 3: EZStrobe ACD model including Fork and Branch link in the case of Gantry Breakdown

As another example, consider a parameter which has been deemed 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 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.

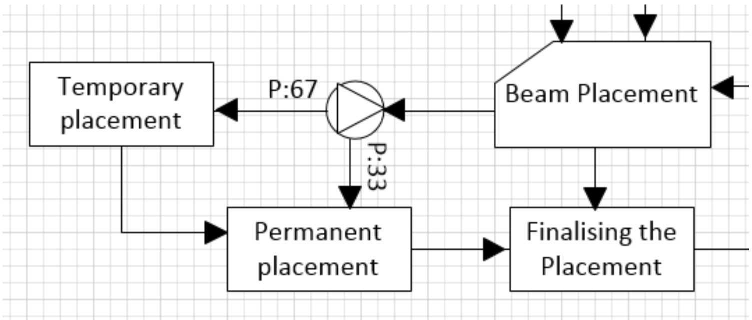

Figure 4: EZStrobe ACD model including Fork and Branch Link to Present the Procedure of Two Different Methods of Beam Placement

Since the main purpose of simulating an operation is to obtain statistical measures of performance, 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 a normal schedule (MSP) will be undertaken, and hopefully this could 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 operations. 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, 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. A Simulation-based method is the recent technique where 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, the STROBOSCOPE engine and its simplest version, EZStrobe, are found by researchers to be 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 that enables planners to consider resource status, different logic and constraint decisions and operational methods from the early stage of scheduling. This is the advantage of the simulation technique over other planning and scheduling software.

This research contributes to construction operations management and scheduling practice by providing a conceptual framework for this specific method of bridge construction (incremental launching). The model eventually could 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 techniques is new to its construction industry. In future work, the EZStrobe simulation will be run using the developed ACD to present further potential of its applications.

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