SIMULATION-BASED ASSESSMENT OF THE INFLUENCE OF REQUESTS FOR INFORMATION ON INDUSTRIAL MODULE CONSTRUCTION PIPING WORK

Amin Amini Khafri [(a)], Wenying Ji [(b)], Seungjun Ahn[(c)], Simaan AbouRizk[(c)]

[(a),(b),(c),(d)]University of Alberta
Edmonton, Alberta, Canada

[(a)]amin.amini@ualberta.ca, [(b)]wenying1@ualberta.ca, [(c)]seungjun@ualberta.ca, [(d)]abourizk@ualberta.ca

ABSTRACT
Engineering errors (e.g., missing information and ambiguities) in isometric drawings result in significant labor productivity loss and schedule delays in industrial modular construction projects. Given this background, this paper aims to assess the influence of requests for information (RFIs) on module construction duration using computer simulation. In particular, pipe installation tasks are of interest in this paper due to the large number of RFIs related to pipe designs occurring in many modular construction projects. A hybrid modeling approach combining discrete event simulation (DES) and continuous simulation (CS) was used to model the piping work of a module construction project in Alberta, Canada, considering the impacts of RFIs on construction duration. Through simulation, it was assessed that RFIs will increase the piping work duration by 8% on average on the most-likely scenario of the project.

Keywords: simulation, request for information (RFI), module construction

1. INTRODUCTION

Over the past few decades, modularization has been implemented widely in lieu of the conventional stick-built construction in Alberta oil sands projects. Modularization has contributed to not only reducing the time and cost of on-site construction under northern Alberta's harsh weather conditions, but also improving the safety and quality performance of the projects.

Industrial modular construction is a construction method involving large-scale use of offsite prefabrication and preassembly (Taghaddos et al. 2014). The offsite, open-space locations where modules are assembled are called module assembly yards, or module yards. A typical industrial module construction process includes erection of structural steel, installation of pipe spools, equipment and electrical units, insulation, hydro testing, and fireproofing work. Due to the unique design and internal components of modules, each module in a project can be seen as a unique sub-project.

In a module construction project, requests for information (RFIs) are commonly issued by the constructor when they require further clarification or information on the module design from the engineer (Hanna 2012). Responses to RFIs should be provided in a timely manner to mitigate the impact of design uncertainties on construction schedules. The number of RFIs and the response duration have been cited as significant factors influencing productivity loss and schedule delays in projects (Song 2009).

Given this background, this paper aims to assess the influence of RFIs on module construction duration using computer simulation. It is expected that assessing the schedule impacts of RFIs can help practitioners develop more accurate estimations of module construction durations.

In particular, pipe installation tasks are of interest in this paper due to the large number of RFIs related to pipe designs occurring in many module construction projects. Piping is usually the most complex work of industrial module construction due to the complicated design of pipes, the various types of work involved with different pipe sizes and shapes, and the various resources required. Figure 1 shows the distribution of RFIs on different types of work in an industrial module construction project in Alberta, Canada. In this particular project, piping-related RFIs made up 53% of the total number of RFIs. Such a large number of piping-related RFIs can significantly decrease labor productivity and delay the entire project schedule.

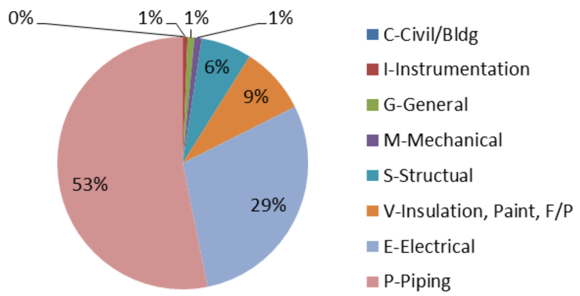

Figure 1: Pie Chart of RFIs

In the next section, an overview of simulation applications in construction, as well as a review of previous research efforts for simulating industrial module construction processes and assessing the schedule impact of RFIs is presented. In the methodology section, a hybrid modeling approach combining DES and CS is introduced. Then, the piping work process is described and a simulation model for estimating piping work duration and piping work man-hours is presented. Lastly, the simulation results from the model are analyzed and the impact of RFIs on piping work duration is discussed.

2. LITERATURE REVIEW

As construction projects involve complex and uncertain processes, it is difficult to use conventional techniques to manage them (AbouRizk 2010, 2011). Construction simulation is "the science of developing and experimenting with computer-based representations of construction systems to understand their underlying behavior" (AbouRizk 2011). A simulation model is a composition of objects that represent the abstraction of a construction system. Once a simulation model is developed, the model output can be used to predict the process cycle time, productivity, resource utilization, etc. (AbouRizk 2010). Typically, simulation research is conducted in four phases: 1) product abstraction phase; 2) process abstraction and modeling phase; 3) experimentation phase; and 4) decision-making phase (AbouRizk 2010).

Mohamed et al. (2007) developed a discrete event simulation model to schedule resource-constrained module assembly processes. Taghaddos et al. (2009) tackled the scheduling complexity issue of a module assembly yard using the high level architecture technique. In addition, Taghaddos et al. (2014) attempted to schedule a module assembly yard using a simulation-based auction protocol to optimize module assembly yard layout.

Piping work is usually the most complex work in a module assembly yard, and therefore, it has a high rate of RFI occurrence. If an RFI is issued, workers are usually assigned to another workface until a response to the RFI is made, but such an interruption significantly decreases labor productivity (Hanna 2012). Many researchers have attempted to study the impacts of such interruptions on project duration. Christian and Hachey (1995) found that crews without interruptions improve their working productivity as time passes. Han et al. (2007) studied the effect of non-value adding activities, such as RFIs, on the project schedule and budget using a system dynamics simulation approach. However, there have been few research efforts to assess the schedule impact of RFIs in module construction.

3. METHODOLOGY

Assembling pipe spools in module construction involves multiple tasks, such as support welding, spool erection and pipe welding. The duration and man-hours required to conduct these tasks are dependent on the complexity of work. Since each module has unique specifications and combinations of pipes and supports, there is no normal or average size and quantity of pipes that can represent the typical module.

To deal with the different levels of work complexity involved in piping work, spool erection tasks are usually grouped into several work categories by the pipe size (diameter) in module construction projects. Then, based on the historical data, production rate is calculated for different work categories, and the rate is used to estimate construction durations. An assumption made here is that pipes under the same category are assembled with the same production rate. This kind of work rate information that is available in module construction projects is compatible with continuous simulation modeling (CS). Discrete event simulation (DES) modeling is usually more compatible with other construction tasks. Therefore, a hybrid simulation approach combining CS and DES was used for modeling piping work processes, considering RFI impacts.

3.1. Discrete Event Simulation (DES)

DES is an approach for modeling and simulating a dynamic system. DES models are simulated by advancing time in discrete steps based on the events that take place in the model. Since most of the operations in construction could be discretized to activities with specified start and finish times, DES is a suitable approach for modeling and simulating construction operations (Puri and Martinez 2012). Furthermore, DES is useful for representing repetitive processes, which are very common in construction tasks. In DES, activities can be modeled either stochastically or deterministically. Once a model is developed, detailed resource interactions and utilization in different scenarios can be observed through simulations. In addition, interruptions, such as RFIs, equipment breakdown, and shifts of work can be easily modeled in DES due to its discrete-time nature.

3.2. Continuous Simulation (CS)

CS is another approach for modeling and simulating a dynamic system. In CS, dynamic models are processed by incrementing time in equal steps (i.e., time steps). Therefore, changes in the model variables can occur at each of the time steps in CS. In certain circumstances, the simulationist may consider a construction operation as having a continuous nature (e.g., concrete pouring). To model a continuous phenomenon using CS, two types of variables, stocks and flow rates, are commonly used. A stock can be thought of as a container whose contents are changed by inflow and outflow, and a flow rate is a variable that determines the rate of the inflow or outflow. An illustrative example of this is a water tank; the tank is the stock, and the valve changes the inflow and outflow rate, and as a result, the stock value can change gradually.

3.3. A Hybrid Approach Combining CS and DES

The need to combine CS and DES models arises when we need to include both continuous variables and discrete events that can occur in one system (Klingener 1996). If the piping work in module construction is

modeled in DES, it would be challenging to define the exact start and finish time due to the continuous nature of pipes. On the other hand, CS is compatible with modeling a continuous nature process (i.e., work that can be best modeled by work rates). However, CS has limitations in modeling discrete events, such as interruptions. Therefore, a hybrid approach combining DES and CS could be a suitable approach to simulating the piping work in module construction.
To build a combined DES and CS model, the simulationist first needs to define the discrete events that can occur in the system and identify the variables that can be best modeled as a continuous variable. In the context of our research, the work sequence and possible interruptions are modeled in DES, while the production rate is modeled as a continuous variable.

4. MODEL DEVELOPMENT

In this section, a DES-CS hybrid simulation model developed to represent the piping work of a module construction project in Alberta is presented.

4.1. Model Description

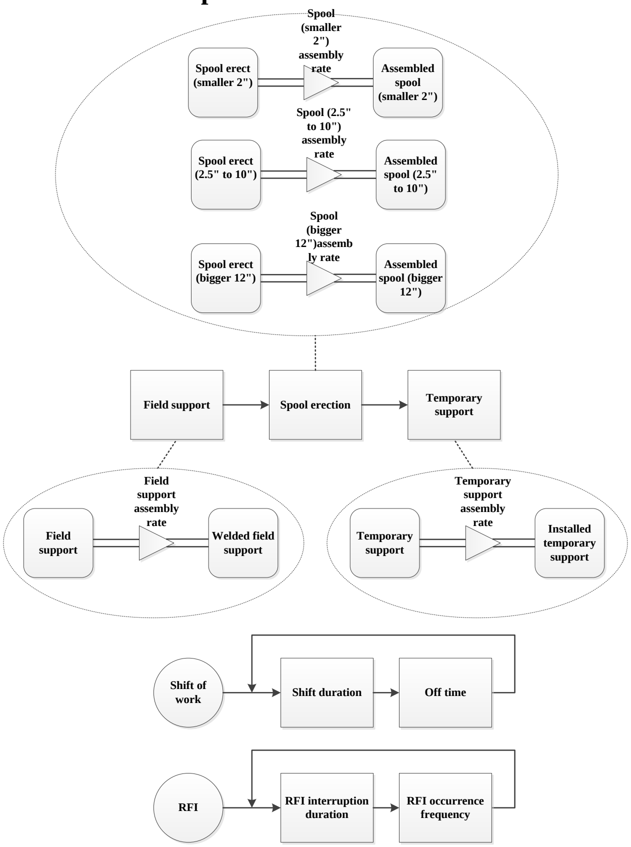

Figure 2: Conceptual Model of the Pipe Assembly Process

Figure 2 illustrates the conceptual model of the pipe assembly process. As shown in the figure, the high-level processes were modeled as discrete events, while the sub-processes—shown in the ovals in Figure 2—were modeled as continuous processes. Each piping task was also modeled as a continuous variable in the model. A quantity was assigned to each piping task as the stock value, and a production rate was assigned to each variable as the outflow rate of each piping work task (i.e., the outflow of products). Each task was regarded as completed when the stock value became zero (i.e., there was no more work to do).
Table 1 shows the description of different piping tasks for simulating the piping work of the module construction project. In this particular project, three different categories of pipe spools (P1, P2 and P3) based on the pipe spool diameter, were used, as shown in Table 1.

Table 1: Tasks of Piping Work in the Industrial Module Construction Project

Task	Description
P1	Spool Erect - 2" (50 mm) & Less
P2	Spool Erect - 2-1/2 -10" (63 - 250 mm)
P3	Spool Erect - 12 -34" (300 - 850 mm)
P4	Field Supports
P5	Temporary Supports (Shipping)

The shifts of work and RFI interruptions are modeled as discrete events in the proposed model. The routine eight hour shifts of work take place every sixteen hours in the model. RFI interruptions are randomly generated according to an occurrence interval preset in the model. The piping work progress stops when an RFI is issued or during the non-working hours.

4.2. Model Inputs and Settings

In the simulation model, all inputs were set based on the real data collected from the case project. The real data were collected from the projects through their stored historical data or interviews with experienced managers/foremen. Table 2 shows the input settings for variables.
Based on the observations at the module assembly yard, the size of piping crews was determined to be nine to twelve, and two cranes were assigned to be shared among three modules. When an RFI is issued, it is likely to take three to five hours to start work on another work face. This duration includes checking the drawings, notifying the foreman and preparation work for the new task. Based on the interviews conducted with on-site experts involved in the studied case, it was found that RFI interruptions happen on average once a week to each of the modules. Literature shows that exponential distribution is suitable for modeling the RFI inter-arrival time (Nasrallah and Bou-Matar 2008).
Take-off quantities for each task for three particular modules in the project were collected from the module design package, and were utilized as the input value for the required amount of work. Table 2 shows the take-off quantities in linear meters for all the piping tasks for the selected three real modules.

Table 2: Take-off Quantity of the Tasks to be Executed on Each Module (P1 – P5 are Different Types of Piping Tasks)

Task	Quantity of Each Task (Linear Meter)		
	Module 1	Module 2	Module 3
P1	194.75	86.63	127.54
P2	38.81	14.32	62.42
P3	27.51	65.74	128.13
P4	261.07	166.69	293.72
P5	17.18	16.17	25.91

As per the Construction Industry Institute (2011), estimated productivity can be calculated for each task of the piping work using the following equation.

$$Estimated\ Productivity = \frac{Estimated\ Man{-}hour}{Quantity} \quad (1)$$

Take-off quantity and man-hour estimation data were utilized to determine the distribution of production rate for each task. Normal distribution was selected to represent the data set for the tasks P1, P2, and P3, and a constant production rate was used for P4 and P5 (i.e., temporary and field pipe support tasks), because of the pattern in the distribution of production rates. All fitted data sets passed the Kolmogorov-Smirnov test, which means the fitted curve was sufficient to represent the distribution of real data. The production rates for all five tasks of piping work are shown in Table 3 and Table 4.

Table 3: Production Rate Distribution for P1, P2, and P3 Based on 100% Labor Effectiveness
(n: Sample Size; L: Low; H: High)

Task	Data Description	Productivity ($\boldsymbol{P_i}$) Distribution
P1	n = 129 L = 1.11 H = 1.69	Normal(1.533,0.096) K-S = 0.097
P2	n = 128 L = 1.69 H = 2.97	Normal(2.395,0.367) K-S = 0.079
P3	n= 121 L= 2.85 H= 6.92	Normal(4.927,1.091) K-S = 0.115

Table 4: Constant Production Rate for P4 and P5 Based on 100% Labor Effectiveness

Task	Productivity ($\boldsymbol{P_i}$)
P4	0.35
P5	1.10

It should be noted that the production rates shown in Table 3 and Table 4 are for each laborer. Therefore, the production rate needs to be multiplied by the number of workers in each crew to get the entire crew production rate.

In addition, a few assumptions, which are based on the result of observations and interviews, were made for setting the simulation model, as follows:
1) A piping crew foreman is assigned to manage a ten-laborer crew for all three modules.
2) The piping crew works eight hours per day.
3) RFIs occur once per week on average, and follows an exponential distribution.
4) The number of workers is determined at the beginning of each working day, and varies from three to five.
5) 50% of labor effectiveness is assumed based on a study of the Alberta labor force (Hewage et al. 2011).
Through simulation, the total piping work duration and man-hours are measured for all three selected modules.

4.3. Model Validation

In order to validate the proposed model, the simulation parameters were first adjusted for the scenario of 100% production rate and no RFI occurrence, and the man-hours estimated by simulation were compared to the existing man-hour estimate. The results showed that the difference between the model output and the company's man-hour estimation was within 15% error, and this was regarded as acceptable, considering the simulation model was not intended to capture every factor that can influence the production rate of piping work. Since the base model is validated with the company's estimation data, the end user can now add more labor productivity factors to the model to get more realistic results with simulation.

5. SIMULATION RESULTS

Resource utilization is one of the things that can be observed from simulation, and it can be an indicator of how efficient the entire operation system is. Figure 3 shows the crane utilization during the piping work for the three modules in simulation. The crane utilization was estimated to be 72% on average during the pipe assembly process for all three modules. For tasks P4 and P5, cranes are not required, and thus the crane utilization for these tasks is zero. In contrast, during pipe spool erection tasks, P1, P2, and P3, cranes are shared between three modules. Practitioners can further optimize crane utilization based on this kind of simulation result. For example, during the period of tasks P4 and P5, the cranes can be shared with other groups of modules to increase the utilization of the cranes.

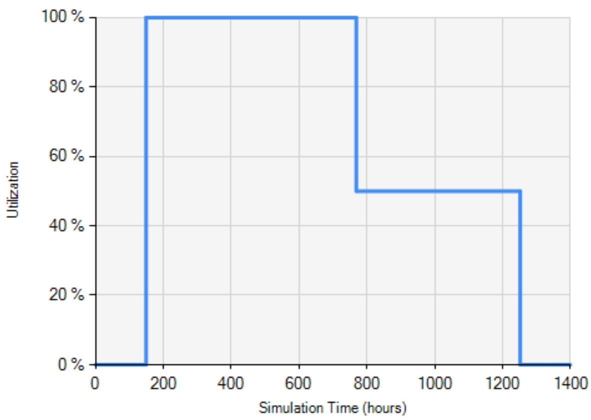

Figure 3: Crane Utilization

Another thing that can be observed from simulation is the pattern of work progress for each module. As an example, Figure 4 illustrates the piping work progress over time for Module 3. As can be inferred from Figure 4, task P1 could not begin until task P4 was completed. The different slope of each task progress is determined by the pipe assembly production rate, which depends on the randomly assigned production rate (according to the probability distribution) and the number of workers each working day. Horizontal segments in the graphs in the figure result for two reasons: 1) working shifts after each working day, and 2) work delays due to the RFI interruption.

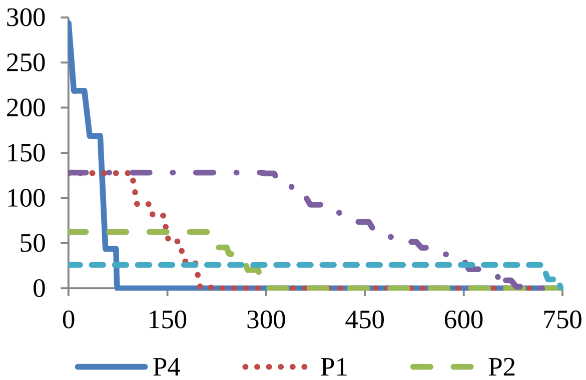

Figure 4: An Example of Work Progress Graph Generated from Simulation (Module 3)

As a next step, a sensitivity analysis was performed to see the impact of the RFI occurrence rate on the module construction durations/man-hours. Table 5 shows the results of running the model 100 iterations with different RFI occurrence rates. As expected, the total piping work duration is increased as the number of RFIs increases. In the most likely scenario, the duration was increased by four and half days (around 8%) of the total duration for constructing all three modules.

Table 1: Simulated Duration for Finishing Piping Work on Three Modules

	RFIs Occurrence per Week			
	0	1 (Most Likely)	2	3
Total Piping Duration (Days)	54.5	59.0	63.6	68.5

Similarly, simulation results also show that total man-hours required for piping work also increased as the number of RFIs increased. In the most likely scenario, total man-hours required to finish the piping work for all three modules increased by 7.7%. Table 6 shows the comparison of man-hours required to finish the piping work for different numbers of RFIs.

Table 6: Simulated Man-hours for Finishing Piping Work on Three Modules

	RFIs Occurrence per Week			
	0	1 (Most Likely)	2	3
Total Piping Man-hours (Labor-hours)	2047	2204	2391	2560

As a result of this sensitivity analysis, for the most likely RFI issuance frequency scenario (once a week), it was estimated that RFIs will increase total piping duration by 8%, and increase the total man-hours for the piping work by 7.8%.

6. CONCLUSION

In this research, a simulation model was developed using a hybrid simulation approach combining DES and CS, and the simulation was implemented using Simphony.NET 4.0 (Hajjar and AbouRizk 1999) to assess the RFI influence on piping work duration and man-hours in an industrial module construction project. Historical data from a real industrial module construction project in Alberta, Canada was used to build the model and to validate the simulation results. Simulation results showed that RFIs have an average of 8% impact on piping work duration.

It is expected that the simulation model for estimating piping work man-hours, taking into account the schedule impact of RFIs, can help estimators with assessing the impacts of different numbers of RFIs and achieving more accurate estimations. Work progress and resource utilization could also be observed from the simulation. The results show the proposed hybrid model performed well to analyze the pipe assembly process and to assess the schedule impacts of productivity factors.

Future work may include: 1) expanding the model for the entire module construction process; 2) collecting more data from real projects to train the models; 3) developing a more user-friendly estimation tool for industry use; 4) using different labor production rates for the beginning and end of each shift of work.

REFERENCES

AbouRizk, S., 2010. Role of simulation in construction engineering and management. Journal of Construction Engineering and Management, 136(10), 1140–1153.

AbouRizk, S., Halpin, D., Mohamed, Y. and Hermann, U., 2011. Research in modeling and simulation for improving construction engineering operations. Journal of Construction Engineering and Management 137, 843–852.

Christian, J. and Hachey, D., 1995. Effects of delay times on production rates in construction. Journal of Construction Engineering and Management, 121(1), 20-26.

Hajjar, D., & AbouRizk, S., 1999. Simphony: an environment for building special purpose construction simulation tools. In Proceedings of the 31st conference on Winter simulation: Simulation---a bridge to the future-Volume 2 (pp. 998-1006). ACM.

Han, S., Lee, S., Fard, M. G. and Peña-Mora, F., 2007. Modeling and representation of non-value adding activities due to errors and changes in design and construction projects. Proceedings of the 39th Conference on Winter Simulation, 2082-2089. December 9-12, 2007, Washington, DC, USA.

Hanna, A., Tadt, E. and Whited, G., 2012. Request for information: Benchmarks and metrics for major highway projects. Journal of Construction Engineering and Management, 138(12), 1347–1352.

Hewage, K. N., Gannoruwa, A. and Ruwanpura, J. Y., 2011. Current status of factors leading to team performance of on-site construction professionals in Alberta building construction projects. Canadian Journal of Civil Engineering, 38(6), 679-689.

Klingener, J. F., 1996. Programming combined discrete-continuous simulation models for performance. In Proceedings of the 28th conference on Winter simulation (pp. 833-839). IEEE Computer Society.

Mohamed, Y., Borrego, D., Francisco, L., Al-Hussein, M., AbouRizk, S. and Hermann, U., 2007. Simulation-based scheduling of module assembly yards: Case study. Engineering, Construction and Architectural Management, 14(3), 293-311.

Nasrallah, W. F. and Bou-Matar, R., 2008. Exponential, gamma, and power law distributions in information flow on a construction site. Journal of Construction Engineering and Management, 134(6), 442-450.

Puri, V., & Martinez, J. C. (2012). Modeling of simultaneously continuous and stochastic construction activities for simulation. Journal of Construction Engineering and Management, 139(8), 1037-1045.

Song, L., Mohamed, Y. and AbouRizk, S. M., 2009. Early contractor involvement in design and its impact on construction schedule performance. Journal of Management in Engineering, 25(1), 12–20.

Taghaddos, H., AbouRizk, S. M., Mohamed, Y. and Hermann, U., 2009. Integrated simulation-based scheduling for module assembly yard. Proceedings of the 2009 ASCE Construction Research Congress 1270-1279. April 5-7, 2009, Seattle, WA, USA.

Taghaddos, H., Hermann, U., AbouRizk, S. and Mohamed, Y., 2014. Simulation-based multiagent approach for scheduling modular construction. Journal of Computing in Civil Engineering, 28(2), 263–274.