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SPECIAL PURPOSE SIMULATION MODELING OF TOWER CRANES

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ABSTRACT

Historically, simulation tools have only been used and understood by the academic community. Special Purpose Simulation (SPS) techniques have introduced computer modeling to the industry, resulting in reduced model development time and a user-friendly environment. This paper describes the special purpose simulation template, which is based on the tower crane operations performed by PCL Constructors Inc. On-site management of the tower crane resource is based on prioritized work tasks that need to be performed within a set period of time. Traditional SPS modeling techniques use 'relationship logic links' to represent the logic contained in the modeled system. As the number of work tasks increases for the tower crane resource, the model complexity using traditional simulation techniques becomes unmanageable, resulting in limited acceptance by industry practitioners. The tower crane template uses 'priority rating logic' to replace the 'relationship logic links'. Evaluation of the tower crane operations at the Electrical and Computer Engineering Research Facility (ECERF), being constructed in Edmonton, is used to illustrate the advantages of using the 'priority rating logic' modeling approach for tower crane operations. The simulation model analyzes the ECERF tower crane production cycle yielding outputs for total duration, crane utilization, and lift activity hook-time analysis.

1 INTRODUCTION

This paper introduces a Special Purpose Simulation (SPS) tool developed using Simphony (Hajjar and AbouRizk, 1999) to model tower crane operations. SPS is defined as "a computer-based environment built to enable a practitioner who is knowledgeable in a given domain, but not necessarily in simulation, to model a project within that domain in a manner where symbolic representation, navigation schemes within the environment, creation of model specifications and reporting are completed in a format native to the domain itself. By using SPS tools to create an industry specific modeling environment, computer simulation provides many advantages for the industry practitioner including wider acceptance and use in practical settings" (AbouRizk, 1998). Traditional simulation models use 'relationship logic links' to drive process interaction for a specific construction domain. Using 'relationship logic links' to represent tower crane process interaction results in highly complex simulation models, that are difficult to understand by the end user. To fix this problem the SPS tower crane template uses 'priority rating logic' control for model process interaction. Tower crane process interaction consists of a set of activities that need to be completed by the specified tower crane resource, given a certain time frame and urgency. 'Priority rating logic' control means each lift activity has a scheduled arrival time and a set priority based on activity criticality in relation to the other existing activities in the system.

In conjunction with PCL Constructors Inc., a case study is used to illustrate how the SPS tower crane template is used to model a tower crane production cycle at the Electrical and Computer Engineering Research Facility (ECERF) at the University of Alberta. PCL is the on-site project manager who owns and operates the tower crane. Using the ECERF project, two models are developed using Simphony's common and SPS tower crane templates, which represents the use of 'relationship logic links' and 'priority rating logic', respectively. The benefits of using the 'priority rating logic' control for the SPS tower crane template will be discussed based on the results of the case study.

2 PRIORITY RATING LOGIC CONTROL

A practitioner, who understands the criticality of each work task in relation to the project schedule, needs to have a SPS template that will allow the same logic. Traditional object-oriented modeling techniques use 'relationship logic links' or arrows to represent the navigation scheme used for a model framework. For construction domains that have a repetitive sequence of activities, logic represented by 'relationship logic links' has been very successful (i.e. earthmoving, tunneling, etc.). For tower crane operations, each activity occurring in the modeled system does not follow a distinct repetitive process flow, but rather consists of a number of distinct activities that move linearly through the crane model. Each of tower crane activities is performed based on urgency and demand within the modeled system. As the number of lifting activities increases for the tower crane, the model complexity using traditional 'relationship logic links' becomes unmanageable resulting in limited implementation by industry practitioners. The proposed SPS tower crane template will use 'priority rating logic control' to resolve this problem. This means that for each lift selected; the tower crane will choose the lifting activity with the highest priority that is currently available in the model. Using 'priority rating logic control' verses traditional 'relationship logic links' simplifies the tower crane model domain. The benefit of using 'priority rating logic control' is as follows:

1. Establishes a modeling environment that is easy to create and manipulate by a novice practitioner,
2. Reduces development time for new tower crane construction models,
3. Prevents the tower crane models from escalating in complexity as the number of lifting activities increase.

3 CASE STUDY: ELECTRICAL AND COMPUTER ENGINEERING RESEARCH FACILITY (ECERF)

The Electrical and Computer Engineering Research Facility (ECERF) is a seven-storey building constructed on the University of Alberta campus scheduled for completion in August 2001. The ECERF building is the first phase of a two-phase project. The building will house offices for professors and graduate students, classrooms, and state of the art research laboratories. There is one crane located east of the ECERF structure. PCL is the contractor in charge of site supervision and concrete formwork construction for the erection of the sub/superstructure for the ECERF building. For the modeled time period, the primary tower crane activity on site is concrete formwork, using a slab fly-form system. The only secondary sub-trade on site is the rebar contractor.

The construction of each floor for the ECERF building is done in two stages. Each stage takes two weeks to complete, yielding a tower crane production cycle of one week. Therefore, for any given week the crane will be working on week one of stage 1 and week two of stage 2, or visa versa. Stages one and two occupy approximately half of the floor layout (typical floors 2-7). Table 1 describes the tower crane activities for each stage occurring over a one-week period (i.e. one tower crane production cycle). For the purposes of this case study, the computer simulation will model a one-week period representing the production cycle for the tower crane.

Table 1: ECERF Building Tower Crane Production Cycle

	Stage 1 - Week One (South) (21 m elevation)	Stage 2 - Week Two (North) (21 m elevation)
Monday	Rebar Delivery (4-5, 7:30am, 45-80 min., 1 lift, 25-40 min., 4) [From SrcEast]	Set Rebar in Column Forms (18-22, 7:30am, 0, 1 lift, 4-5 min., 3) [From SrcWest] Pour Column Forms (2 trucks, 12:30pm, 40-50 min., 4 buckets, 9-12 min., 3) [SrcSouth] Fly Core Forms (7-8 pcs, 2:30pm, 6-7 min., 1 lift, 10-12 min., 3) [From SrcNorthEast]
Tuesday	Rebar Delivery (3-4, 7:30am, 1-2 hrs., 1 lift, 25-40 min., 4) [From SrcEast]	Rebar to Cores (4, 7:30am, 20, 1 lift, 25-35min., 3) [From SrcEast] Close Core Forms (7-8 pcs., 1:30pm, 0.0, 1 lift, 10-12 min., 2) [From SrcNorthEast] Strip Column Forms (18-22, 2:30pm, 3-4 min., 1 lift, 3-4 min., 2) [To NorthWest Corner]
Wednesday	Rebar Delivery (1-2, 9:00am, 1.5-3 hrs., 1 lift, 25-40 min., 4) [From SrcEast]	Pour Core (4-5 trucks, 8:30am, 15-20 min., 4-5 buckets, 4.5-7 min., 3) [From SrcSouth] Fly Slab Forms (28? forms, 12:30pm, 8-9 min., 1 lift, Tri [9, 14, 21]min., 2) [Floor to Floor]
Thursday	**** Pour Slabs - No Crane Activity* ***	Strip Core Formwork (14-16 pcs., 11:00am, 4.5-5.5 min., 1 lift, 4-5 min., 3) [To NorthEast-Corner]
Thursday	**** Pour Slabs - No Crane Activity* ***	Strip Core Formwork (14-16 pcs., 11:00am, 4.5-5.5 min., 1 lift, 4-5 min., 3) [To NorthEast-Corner]
Friday	Fly Column Forms (18-22, 7:30-8:30 am, 8-12 min., 1 lift, 6-12 min., 3) [From SrcNorth-West]	
Work Package Description (*No. of WorkPackages, Time of First WP, Time between WP, No. Lifts per WP, Duration of Lift, Priority*) [From/To]		

Figure 1 illustrates the east face view of the ECERF building at the completion of the concrete superstructure. Figure 2 views the west face of the ECERF structure while the concrete slab is curing for stage two of the fifth floor. Figure 3 shows the slab fly forms as they are being released from the slab. Placement, preparation and removal of slab fly forms are the primary activities occurring during the tower crane production cycle. Using the jacking device, as shown in figure 4, the legs of the fly-form are unloaded and lowered from the underside of the slab. The legs of the slab fly-form are then raised and rollers are placed to transport the fly form to the edge of the building for tower crane access.

4 ECERF SIMULATION MODEL USING 'SIMPHONY' COMMON TEMPLATE

The 'Simphony' common template is a general-purpose simulation tool that enables the practitioner to model a system using process interaction concepts. Model development using the common template requires the user to have background in simulation techniques. The template includes elements for handling hierarchical modeling, entity

Figure 1: East View of Electrical and Computer Engineering Research Facility (ECERF)

Figure 2: ECERF Building Concrete Slab Construction

Figure 3: Slab Fly Forms Used For ECERF Building Floor Construction

Figure 4: Portable Jack Used for Slab Fly Form Transport

creation and routing, resources, statistics, activities, and tracing. (NSERC, 2000) The common template is used to model the ECERF tower crane production cycle using 'relationship logic links' to represent the process interaction between modeling elements.

The major activities occurring on the project are separated into categories; rebar deliveries, slab work, pour slabs, column work, core work and miscellaneous work. Computer simulation using the common template is a powerful tool for advanced users, providing flexible constructs that can be easily manipulated to represent virtually any construction process. The drawback of using the common template for simulating tower crane operations is the complex relationships that result from having a multiple number of lifting activities that are not driven by process events. But rather, driven by priority ratings between activities and controlled by entity arrival times. That is to say that once a work package is selected by the crane resource it is unaffected by any other work packages or entities that are present in the model. The only prerequisite for tower crane selection is that the specified work package has arrived at the specified source location and that it is the highest ranked work package waiting in the model.

The Simphony 'common' template model shown in Figure 5, illustrates the level of complexity required to model the ECERF project using 'relationship logic links'. Some of the drawbacks experienced during the development of the common template ECERF tower crane model are outlined as follows:

1. The development phase of the model is time consuming, requiring excessive relationship links and coding by the user.
2. The model will change dramatically when applied to a new project.
3. A novice simulation user cannot easily modify the model.
4. The model is difficult to track and understand.

As discussed earlier, many construction operation systems can be broken down to a set of repetitive activities that drive production. Using the 'relationship logic links' approach demonstrated by the Simphony common template is very successful in modeling these systems. However, using the common template to model tower crane operations is laborious and impractical for the industry practitioner.

5 ECERF SIMULATION MODEL USING 'SIMPHONY' SPS TOWER CRANE TEMPLATE

The creation of a computer simulation model using the SPS tower crane template is based on the geographical locations of the crane, source, and destination elements on the model layout (i.e. footprint). Figure 6 shows the element locations in relation to the ECERF building layout and the staged construction zones used for each floor. Including the 10-meter buffer zone in the x and y direction, the precise location of each modeling element is found in Table 2. Inside the source elements (child level), work packages have been created for each tower crane activity represented in Table 1. Data used for unhook and hookup delays were gathered in the field and expert opinion received from the ECERF project coordinator.

Once all the information was gathered regarding the tower crane production system for the ECERF project, setting up the SPS tower crane model was simple and straightforward. The following inferences were made while developing ECERF model using the SPS tower crane template:

1. Parameters needed for each work package is representative of the tower crane construction domain, which results in a transference of knowledge that is effortless for site personal.
2. Creating Site footprint is a useful tool that helps the practitioner envision the actual construction layout. Required information drawn directly from site drawings.
3. Using 'priority rating logic', the development phase of the tower crane template is simple and efficient. 'Priority rating logic' uses work package priority ratings and arrival times to control logic in the modeled system.
4. Model is very flexible, which encourages scenario analysis by the practitioner.
5. By isolating the user from the low level constructs and presenting a model interface that more closely represents the actual tower crane system, the overall environment is simple to understand.

As the results will demonstrate, the SPS tower crane template produces results similar to the common template approach, thus demonstrating the viability of replacing 'relationship logic links' used by the common template with 'priority rating logic control' for modeling process interaction.

6 RESULTS

Each of the simulation model described above is run for 50 iterations to simulate the various conditions reflected by the input parameters. Table 3 shows the results for the total number of crane hours and crane utilization for the common and SPS tower crane template ECERF models, respectively.

Due to greater flexibility in the SPS tower crane model, dynamic quantities for columns, core forms, and rebar deliveries have been entered for the work package input parameters, whereas the common template model only uses static quantities. This explains why the results show a tighter standard deviation for the common template results.

The duration for each lift used in the common template model includes hookup, unhook and crane movement delays, whereas the SPS tower crane model requires the practitioner to input the hookup and unhook delays as the crane movement is calculated separately in the model. Much of the lift delay information received from the ECERF project coordinator, included hookup, unhook and movement delays. In order to separate these delay times, hook-time analysis is performed using the SPS tower crane template to isolate the crane movement delay between the source and destination elements for each specified lift activity (i.e. hookup/unhook delays excluded). Using these results, the hookup/unhook delay for the SPS template is extracted from the original data. Although this provides an accurate estimate for the unhook/hookup times for the SPS template, it results in a slight variation in the total number crane hours and crane utilization when comparing two ECERF models. The percent difference found in the total number of crane hours and tower crane utilization is 1.7 and 1.0, respectively.

Overall, the results show that the common and SPS tower crane models have comparable crane selection schemes and outputs, demonstrating that using 'priority rating logic control' can accurately model tower crane operations while still maintaining traditional modeling logic constraints.

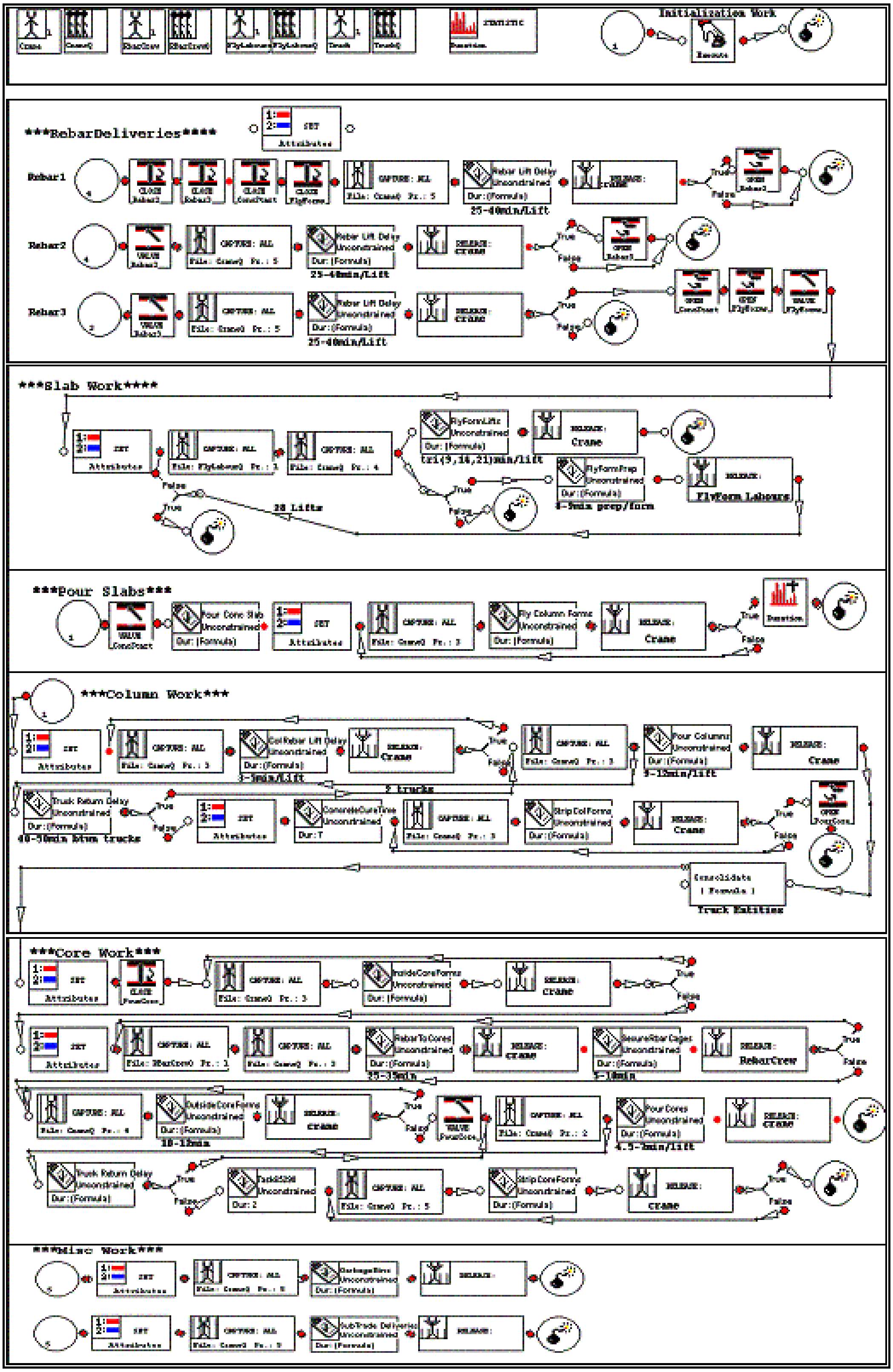

Figure 5: ECERF Common Template Simphony Model

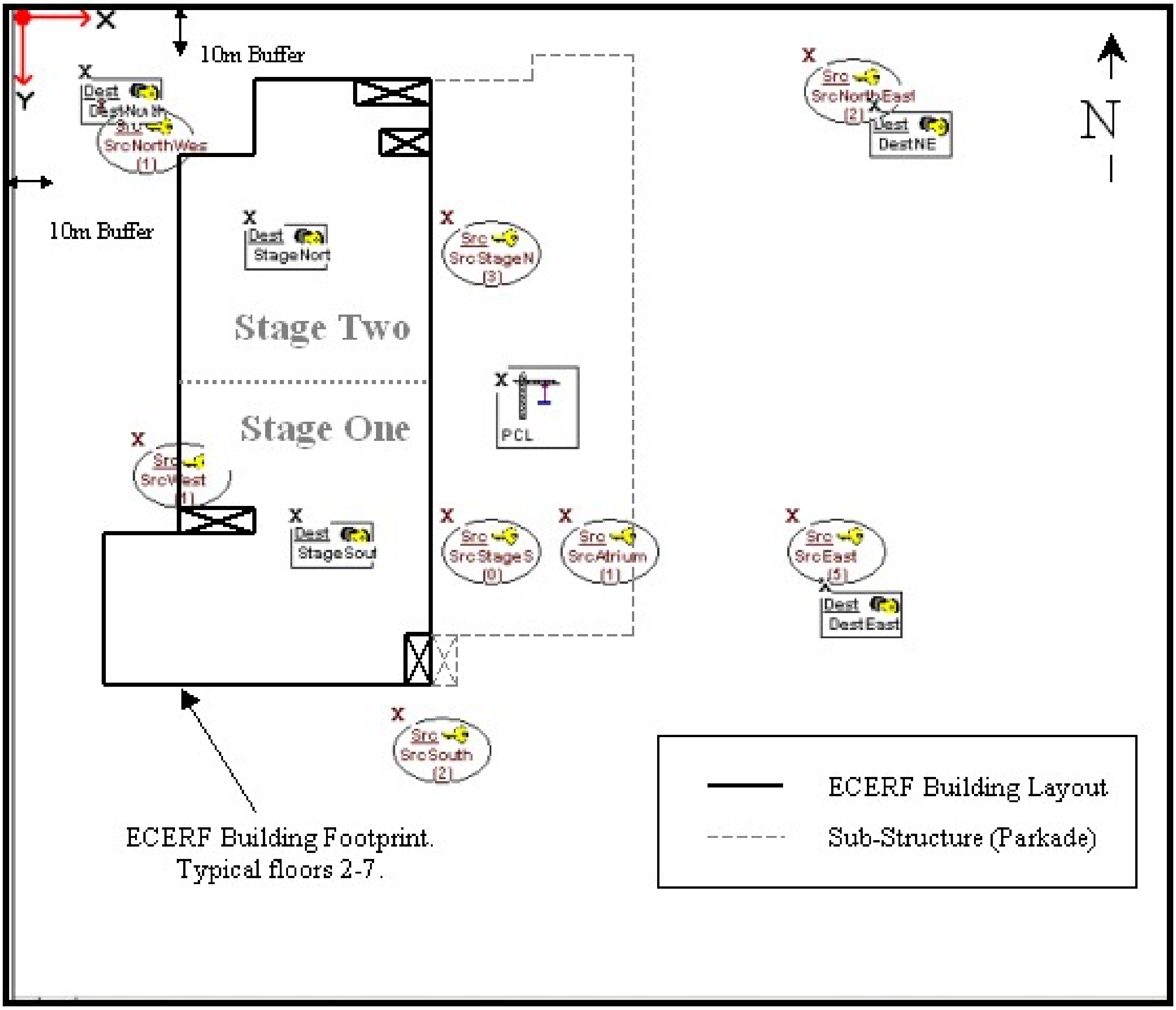

Figure 6: ECERF Building Floor Footprint and Model Elements (Typical Floors 2-7)

Table 2: ECERF Modeling Element Coordinates

Locations	X[m]	Y[m]
SrcNorthWest	10.00	10.00
SrcWest	14.50	50.50
SrcNorthEast	94.00	4.00
SrcAtrium	66.44	59.50
SrcSouth	46.00	83.50
SrcEast	94.00	59.50
DestStageNorth	28.00	23.50
DestStageSouth	33.50	59.50
DestNorthEast	104.00	10.00
DestNorthWest	8.00	6.00
SrcStageN	52.00	23.50
SrcStageS	52.00	59.50
CraneLocation	58.65	43.19
Note: North and West boundaries have a 10m buffer zone		

Table 3: ECERF Case Study - Model Verification Results

		Simphony Template Description	
		General purpose - Common Template	SPS-Tower Crane Template
Number of runs		50	50
Total number of crane hrs	Mean	35.5	36.1
	Std. Dev.	0.2	0.35
	Min.	35.1	35.4
	Max.	35.78	36.81
Crane utilization	Mean	89.2	90.1
	Std. Dev.	0.95	1.97
Total number of crane hrs difference		1.6620%	
Crane utilization difference		0.9989%	

7 CONCLUSION

This paper validates the theory that 'priority rating logic' is a viable replacement for the 'relationship logic links' used by traditional object-oriented simulation techniques. The ECERF Building, located on the University of Alberta campus has been modeled using the Simphony common template and SPS template, respectively. The ECERF case study used to illustrate the merit of using 'priority rating logic control' for simulating tower crane operations.

Each simulation models is run for 50 iterations to simulate the various conditions represented by the input parameters. The total number of crane hours and crane utilization for both models is approximately 36 hours and 90%, respectfully. When comparing the two methods, the percent error for the common and SPS tower crane models was found to be less than 1.7%. Refer to Table 3 for a detailed summary of the model results.

Modeling tower crane operations using the SPS tower crane template provides the following benefits:

1. Parameters needed for each work package is representative of the tower crane construction domain, which results in a transference of knowledge that is effortless for site personnel.
2. Creating Site footprint is a useful tool that helps the practitioner envision the actual construction layout. Required information drawn directly from site drawings.
3. Using 'priority rating logic', the development phase of the tower crane template is simple and efficient. 'Priority rating logic' uses work package priority ratings and arrival times to control logic in the modeled system.
4. The model is very flexible, which encourages scenario analysis by the practitioner.
5. By isolating the user from the low level constructs and presenting a model interface that more closely represents the actual tower crane system, the overall environment is simple to understand.

The results verify that the two ECERF case study models have comparable crane selection schemes and outputs, demonstrating that using 'priority rating logic' control can accurately model tower crane operations while still maintaining traditional modeling logic constraints.

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