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BI-LEVEL PROJECT SIMULATION METHODOLOGY TO INTEGRATE SUPERINTENDENT AND PROJECT MANAGER IN DECISION MAKING: SHUTDOWN/TURNAROUND APPLICATIONS

Ming-Fung Francis Siu
Ming Lu
Simaan AbouRizk

Construction Engineering and Management
Department of Civil & Environmental Engineering
The University of Alberta
Edmonton, Alberta, CANADA

ABSTRACT

The critical path method (CPM) provides the standard approach to scheduling construction projects. Limited crew resources compound CPM analysis by imposing resource availability constraints. However, there is no generalized methodology yet to quantitatively determine the optimal quantities of resources to execute specific work packages based on CPM analysis. Furthermore, in project evaluation and review technique (PERT) simulation, the occurrence of uncertain events is represented by probability distributions for activity durations in an implicit fashion. In this paper, a bi-level project simulation methodology is proposed to (1) determine the optimal resource quantities and activity times for each work package and (2) estimate total project duration and man-hour budget at the upper level for project planning through Monte Carlo simulation, based on defining a limited quantity of likely scenarios for each work package. An industrial plant shutdown and turnaround project serves as case study to illustrate application of the proposed methodology.

1 INTRODUCTION

The critical path method (CPM) for project scheduling was formalized in the 1950s (Kelley and Walker, 1959) and has been widely applied for construction project planning. Previous research has shown that CPM analysis becomes convoluted when operation processes involve uncertain events and are subject to resource provision constraints. Methodologies for resource allocation or leveling have been proposed to improve the accuracy of the CPM analysis (Lu and Li 2003; De la Garza and Kim 2005). Previous research also attempted to optimize the schedule aimed at reducing resource utilization fluctuation (Easa 1989; Hegazy 1999; Christodoulou et al. 2010).

How to select the most cost-effective method to execute individual activities on a CPM project so as to achieve the lowest total project cost is generally referred to as the time-cost trade-off problem (Ahuja et al. 1994; Hegazy and Kamarah 2008; Ng and Zhang 2008). The major pitfall of the time-cost trade-off technique lies in that it only considers resource and time requirements on individual activities, largely ignoring resource availability constraints in CPM network analysis.

In contrast, this research focuses on the determination of the optimal resource quantities for a CPM network in order to arrive at the shortest work package duration, subjected to resource availability constraints. Note, in the shutdown and turnaround project application, a work package is defined as a sub-project consisting of multiple work items articulated by precedence relationships; on a higher level, a project is also defined as a CPM network, consisting of a grouping of work packages articulated by precedence relationships. In this research study, the optimal resource quantities and activity times for each work package are determined based on CPM simulation and optimization analyses constrained by predefined ranges of available quantities of each type of resource. Furthermore, a limited quantity of likely scenarios in terms of uncertain events associated with each work package are considered.

In practice, the quantity of resources allocated to specific work packages is roughly estimated by planners. The maximum limit of resource provision (unit per time) is assigned solely based on experience. Commonly-used scheduling software such as Primavera P6 levels resources by delaying less critical activities until limited resources become available observing pre-defined heuristic priority rules (Harris 2008). However, it is difficult to maintain activity sequence in the levelled schedule as activity priorities may change when updating the schedule (for example, total float used to define its priority can significantly change). Instead, schedulers' common practice is to set activity type as *task dependent* in P6 and thus bypass resource leveling in order to preserve the stability of activity sequence (Siu 2011).

The working schedule for operations, known as a Level-5 schedule in industry (AACE International Recommended Practice 2010), provides the finest planning details for work execution and resource allocation. It elaborates work items to be performed by crews on an hour-by-hour basis. It is imperative to decide the optimal resource quantities as needed to complete all the work items in a work package within the shortest time. Yet, Primavera P6 does not offer such functionality to identify optimal resource provision limits – the best crew setup to handle the project. The only solution is to manually adjust the heuristic rule for P6 scheduling while observing whether the work package duration can be compressed. It is tedious and time-consuming, if not impossible, to attempt to generate an "optimal" P6 schedule when available resource quantities are defined in likely ranges (lower bound and upper bound), factoring in practical constraints (availability, space and safety).

Simulation models, on the other hand, can not only represent project logic compatible with CPM analysis [e.g. project evaluation and review technique (PERT) simulation], but also depict construction processes at the operation level. Uncertainties in activity duration can be dealt with by a random sampling process (Monte Carlo Simulation). Recent applications of project scheduling systems based on simulation are presented by Lu et al. (2008), Lee et al. (2010), and Chen et al. (2012). To identify the optimal provision of resources aimed at achieving project objectives under project constraints, researchers generally evaluate results from simulating limited predefined resource-provision scenarios.

PERT was developed to aid in producing the U.S. Polaris missile system in 1958 (Moder et al. 1983). A task duration is represented by a statistical distribution to account for uncertainties when the scope of activity or resource use information is only partially known in the planning stage. PERT simulation lends itself well to revealing the random nature of project completion time (Sawheny and AbouRizk 1995). Nonetheless, the occurrence of uncertain or unknown events is commonly represented by probability distributions for activity durations in an implicit fashion, as shown in Figure 1(a). Random sampling from activity time distributions does not account for correlations between resource requirements and sampled activity times, thereby causing potential bias in the observed simulation output. For example, an unknown event E1 requires 2 boilermakers and 1 boilermaker welder to complete in 20 hours. Its probability of occurrence is 70%. The predecessor of E1 is Activity A1 defined with the same resource requirements as E1. Therefore, there is a 30% chance that A1 is completed in 20 hours without E1, while a 70% chance that a collection of A1 and E1 requires 40 hours to complete. In this case, it is not appropriate to express the duration of A1 as a continuous distribution on the range [20 hours, 40 hours] in that it can be pointless to characterize the resource requirement of A1 in relation with a sampled duration of 30 hours. Instead, two discrete outcomes should be sampled, as shown in Figure 1(b), namely: Outcome 1 with a 30% chance that 2 boilermakers and 1 boilermaker welder are required to complete in 20 hours and; Outcome 2 with a 70% chance that A1 and E2 are completed sequentially in 40 hours by 4 boilermakers and 2 boilermaker welders.

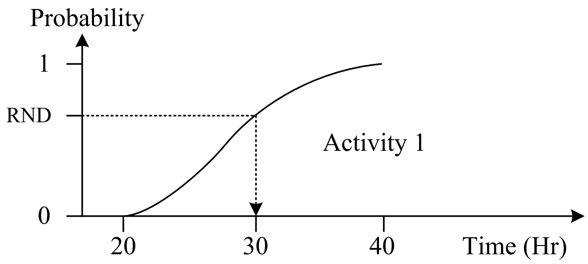

Figure 1(a): Probability density functions of continuous distribution.

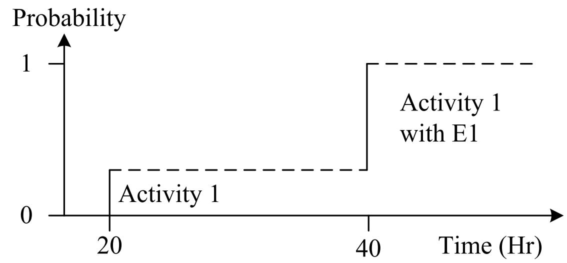

Figure 1(b): Probability density functions of discrete class.

By taking advantage of simulation and optimization analyses, the present research develops a new approach which effectively integrates work-package-level resource allocation and project-level resource budgeting. This research sheds light on (1) how to determine optimal resource quantities while simultaneously shortening the time duration for each work package of a project, and (2) how to estimate total project duration and man-hours budgeting at a high level for project planning through Monte Carlo simulation by analyzing a limited quantity of likely scenarios defined for each work package. The hour-by-hour labor schedule generated for each scenario can be presented to foremen and superintendents, while statistical simulation outcome provides decision support for project management to schedule total project duration and assign a control budget in a realistic and reliable fashion.

2 BI-LEVEL PROJECT SIMULATION METHODOLOGY

In general, the complete work scope of a construction project is logically decomposed to a number of work packages. Each work package is a measurable and controllable unit of work to be performed (CII Cost/Schedule Task Force 1988). Considering a project consists of two work packages as shown in Figure 2, the superintendent allocates the crew to execute Work Package 1 (WP1), followed by Work Package 2 (WP2). Activities (A1 to A5) to be executed by individual laborers (LB1 to LB5) is scheduled as per the resource allocation plan. In the consideration of the uncertain events (E1 and E2), two possible scenarios [Scenario 1 (S1) and Scenario 2 (S2)] for the work package, each being associated with a certain probability of occurrence, would result in different completion times and resource allocation schemes (Figure 2).

The proposed bi-level project simulation methodology addresses the following two critical issues: (i) *How to optimize resource quantities while shortening work package duration by assessing the CPM-based schedule for each scenario*? For example, 3 laborers are currently assigned to perform A1 to A3. If extra laborers are available, can the work package be completed in a shorter period of time? (ii) *How to estimate total project duration and resource use budget based on Monte Carlo simulation factoring in uncertain events*? For instance, there are four possible combinations, how many man-hours should be budgeted for this project?

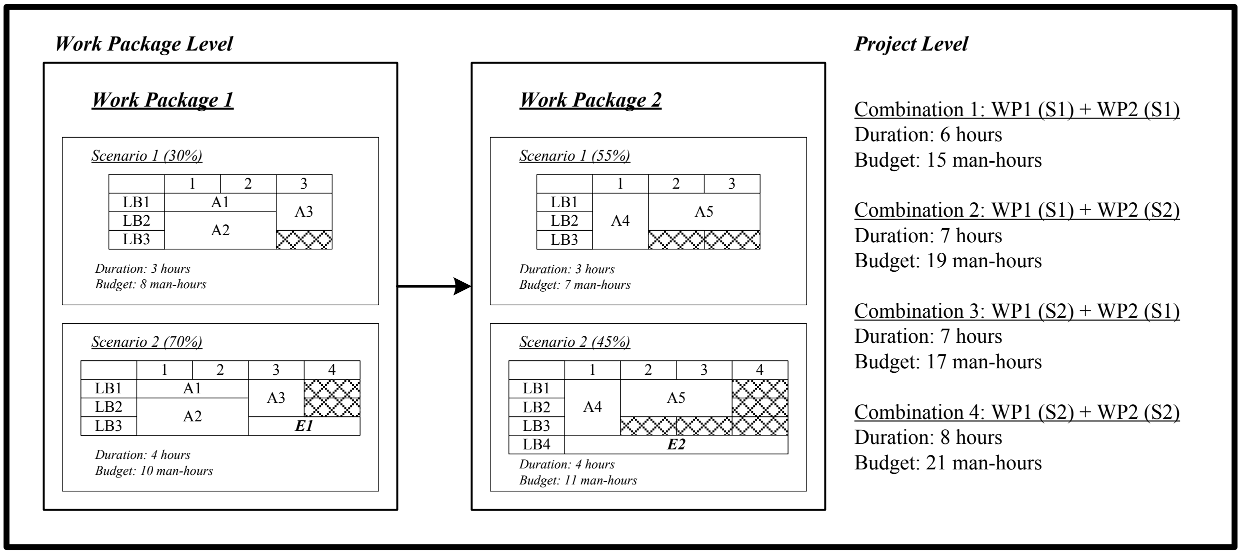

Figure 2: Relationships between project, work package, activity and corresponding budget.

Figure 3 shows the flowchart of the proposed bi-level project planning methodology. The framework is divided into two levels, namely, (i) lower level: work-package-level optimization and (ii) upper level: project-level simulation.

The methodology begins with forming the network model by articulating all the work items in a work package. Then, work-package scenarios are defined by considering likely events based on historical data or superintendents' experience. For each scenario, CPM-based optimization analysis is performed based on the initial estimate of resource quantities available and likely ranges of available quantities for each type of resource as specified. Such information can be generally provided by experienced field superintendents.

The optimization can be performed by simultaneously adjusting (1) relative priorities in processing multiple work items and (2) different resource availability limits, without violating precedence relationships as specified between work items, while satisfying time and resource requirements for each work item contained in the work package. The goal is to generate the resource-constrained schedule with the shortest duration and identify the optimal resource quantities, given a likely scenario for the current work package. The optimization results facilitate job planning and resource allocation such that each individual resource (laborer) can be assigned to particular work items over particular time periods.

The next step is to assign the probability of occurrence for each scenario. Note, the field superintendent's experience (subjective estimate of probabilities for each scenario) is integrated with the use of computer power (Monte Carlo simulation) in order to characterize time and resource consequences for each scenario associated with one work package. All the work packages are logically related according to precedence relationships between them, forming the upper-level project network. A simulation model is then developed and executed. Based on probabilities of occurrence and the consequences in terms of resource requirement and time duration requirement as of each different scenario, Monte Carlo simulation is performed and statistics such as the 80th percentile of the project completion time and total man-hours consumed can be collected.

In brief, this proposed bi-level project simulation methodology benefits both field superintendents and project managers in terms of job scheduling, resource allocation and budgeting. A case study of industrial shutdown and turnaround project is presented in the following section.

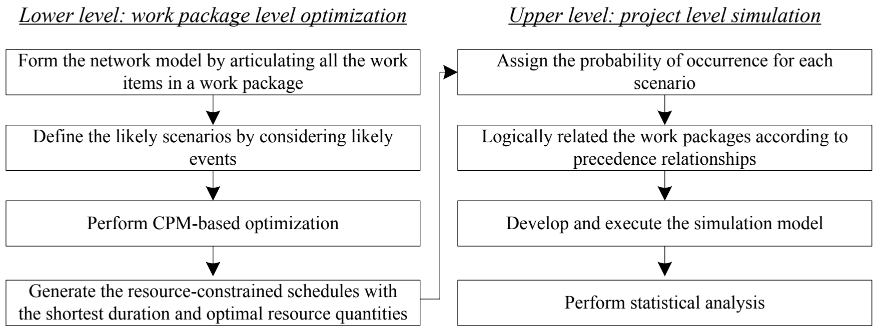

Figure 3: Proposed bi-level project simulation methodology flowchart.

3 SHUTDOWN AND TURNAROUND CASE STUDY

The proposed methodology is applied to a three-month industrial shutdown and turnaround project located in Edmonton, Alberta, Canada. The project scope is to upgrade the existing oil refinery facilities including the reactor, the regenerator, and the overhead system.

On a turnaround project, extra work items which may be overlooked in a P6-based turnaround schedule are likely to be found in the field. Lenahan (2005) defined extra work as "work generated from existing tasks (such as repairing a crack found during an inspection)" and additional work as "the tasks that are not part of the original plan, but inserted or requested during the turnaround". Probabilities for these extra work items to materialize can be best estimated by experienced field personnel who have worked on the same or similar plant shutdown projects before. Those extra work items have a significant impact on resource allocation, project scheduling and budgeting, which is evaluated by utilizing the computer power (simulation and optimization analyses) at the work-package level in order to render relevant decision support.

In turnaround scheduling, the time unit of scheduling is an hour instead of a day. The resources are supplied 24 hours a day, and 7 days a week. The ultimate goal of a turnaround project is to complete all the planned maintenance activities by employing available resources within the stipulated time period, while also coping with time and cost impacts resulting from uncertainties on the project.

The project scope presented in this case study narrows down to reactor upgrading. Work items are sampled to represent approximately ten days turnaround planning for four major trades, namely: boilermakers, boilermaker welders, pipefitters, and pipefitter welders. Table 1 shows work item names, time requirements, resource requirements (BM: boilermaker; BW: boilermaker welder; PF: pipefitter; PW: pipefitter welder) and precedence relationships for six work packages contained in the case project. There are 37 planned work items and 8 additional uncertain events (E1 to E8). In the original plan, the crew assembled for handling these work packages in the current case study consisted of 5 boilermakers, 5 boilermaker welders, 3 pipefitters and 3 pipefitter welders.

3.1 Lower level: Work package level optimization

At the work package level, the network model sequences all the work items, which is further optimized by adjusting relative work priorities and resource availability limits. In this research study, an in-house developed optimization-simulation-scheduling platform, named *Simplified-Simulation-Scheduling* (*S3*) (Lu et al. 2008), is utilized to optimize the CPM network for each scenario in processing each work package.

Figure 4(a) shows the network of Work Package 3 (WP3) without adding uncertain events. The CPM schedule levelled by Primavera P6 indicates this work package can be completed in 140 hours by 5 boilermakers, 5 boilermaker welders, 3 pipefitters and 3 pipefitter welders. Prior to optimization, available resource quantities are defined in likely ranges [lower bound, upper bound] as follows: boilermaker [4–10], boilermaker welder [3–10], pipefitter [3–6], and pipefitter welder [1–6].

Table 2 summarizes the work package duration and the associated crew assembly, before and after optimization. After optimization analysis, all work items can be completed within 70 hours. Note that the optimization does not change time duration and resource requirement on each work item, while also not violating any precedence relationships specified among work items due to technology and safety constraints. The resulting best crew setup consists of 10 boilermakers, 8 boilermaker welders, 3 pipefitters and 3 pipefitter welders.

Furthermore, two additional scenarios are analyzed by including likely events E3 and E4 in connection with this work package. It is emphasized that the duration of WP3 is not fitted as a statistical distribution in order to account for the probabilistic occurrence of events E3 and E4. In contrast, two possible outcomes are considered, as shown in Figures 4(b) and 4(c). The optimization results with respect to the two additional scenarios are summarized in Table 2. The results show that the duration could be reduced to nearly half of the original schedule resulting from P6. Depending on actual site situations, the superintendents allocate the quantity of resources corresponding to a particular scenario. For instance, the inspector reported that only the bolting should be repaired after inspection of the riser, then 9 boilermakers, 8 boilermaker welders, 3 pipefitters and 1 pipefitter welder should be assigned to execute this work package in accordance with the detailed resource schedule in connection with the network shown in Figure 4(b).

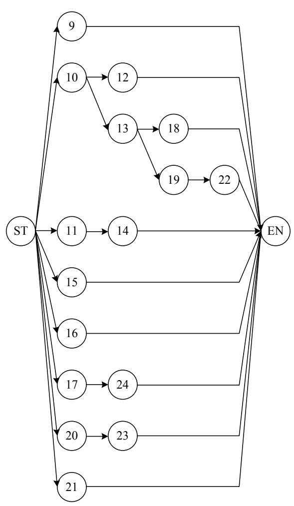

Figure 4(a): WP3.

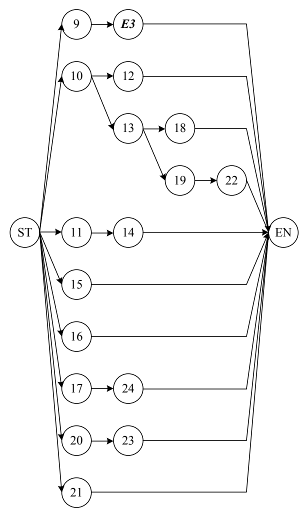

Figure 4(b): WP3 (E3).

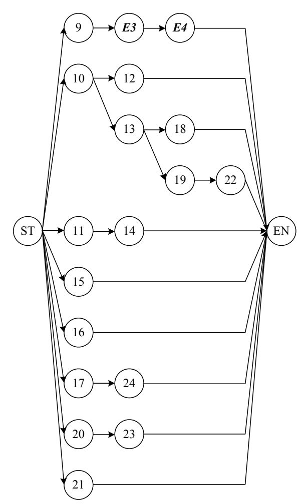

Figure 4(c): WP3 (E3 E4).

Similar to WP3, all scenarios on 5 other work packages are analyzed and results are tabulated in Table 3. Field superintendents can benefit from setting up their optimal crews by automatic optimization analyses empowered by computers. The event list generated can further assist superintendents to allocate specific crew resources to handle work items on an individual-worker basis (Siu et al. 2013). Simulated resource allocation plans can also improve the sophistication and representation of skilled trade labor utilization schedules for effectively controlling and communicating planned workflows. The quantities of each particular resources inside a specific crew, as derived from optimization analysis, provide valuable insight and relevant decision support to schedulers and superintendents during the planning stage at the work-package level.

Table 1: Activity and resource requirements of the project.

Activity ID	Activity Name	Hour	BM	BW	PF	PW	Successor
Work Package 1							
1 -A212030	Shed Row 18, Patch repair shed on N. side of riser as per WPR-128	20	2	1			A212040
E1 - A212040	Shed Row 18, Patch repair shed on S side of riser as per WLR-128	20	2	1			A212050
2 - A190360	Reinstall horse collar	30	2	1			
3 - A190430	Riser - Prep cut line on old riser	4	1	1			
4 - A212050	Shed Row 19, Patch repair shed on N.E side of riser as per WLR-128	20	2	1			A212060
5 - A212060	Shed Row 20, Patch repair shed on W. side of riser as per WLR-128	20	2	1			
Work Package 2							
6 - A211500	M2 Cover (76" Main) -Install new sections of termination ring per WLR-115	20	1	1			A191150
E2 - A195310	Spent Riser - Install plate ring and retaining plates around spent line	20	1	1			
7 - A191150	M2 Cover (76" Main) -Install anchors in manway cover areas (35 sq. ft x 4 anchors/sq.ft)	10	1	2			
8 - A191910	Overflow Well - Install plate ring and retaining plates around overflow line	20	1	1			
Work Package 3							
9 - A212070	Shed Row 20, Patch repair shed on E. side of riser as per WLR-128	20	2	1			A212100
10 - A189420	CC-R-01-Weld Out New Reactor head to Existing Reactor Shell (25%)	20	3	3			A189260; A189520
11 - A189460	CC-R-01- Lower riser into position, fit and tack	20	4	1			A190580
E3 - A212100	Shed Row 20, Repair the bolting on shed on N. side of riser as per WPR-128	20	2	1			A212080
12 - A189260	CC-R-01-CC-PT-195, Weld connect pressure tap piping from riser to shell. Located just below riser outlet horn.	10			2	1	
13 - A189520	CC-R-01-Weld Out New Reactor head to Existing Reactor Shell (50%)	20	3	3			A189530; A189550
14 - A190580	CC-R-01- Weld Out New Riser duct to Existing Lower Riser Section	40	2	2			
15 - A190210	Cut back sheds that are at hot spot locations flush with the refactory	10	2	1			
16 - A189250	CC-R-01-CC-PT-193, Weld connect pressure tap piping from riser to shell. Located above level "A" riser bracing	10			2	1	
E4 - A212080	Shed Row 22, 23,24 Repairs to teeh and sheds in (4) areas per WPR-128	20	2	1			
17 - A189660	Install Refractory Anchors in Reactor cone section. RHI to Layout Pattern - 160 anchors	12	2	2			A212880
18 - A189530	CC-R-01-Weld Out New Reactor head to Existing Reactor Shell (75%)	20	3	3			
19 - A189550	CC-R-01-Backgouge Reactor Weld of New Shell to Existing Shell	10	4	2			A190600
20 - A189690	Install Refractory Anchors for refractory repairs at large manway	10	2	1			A193350
21 - A189290	CC-R-01-CC-TI-550, Weld connect TI piping from riser to shell. Located above level "A" riser bracing	10			2	1	
22 - A190600	CC-R-1 - Weld inside of New Shell to Existing Shell	20	4	2			
23 - A193350	Demo old steam coil, inside vessel	10			3		
24 - A212880	Install Refractory Anchors in Stripper cone section. RHI to Layout Pattern - 80 anchors	10	2	2			
Work Package 4							
25 - A195290	Spent Riser - Install shroud on spent bellows	10	3				
E5 - A195540	Grid - Clean off grid before pouring grid refractory	5	4				
26 - A191890	Overflow Well - Install shroud on overflow bellows	10	3				
27 - A200730	Torch Oil - Shop to replace Tips on 4 torch oil assemblies	10			1	1	A192330
28 - A192330	Torch Oil - Install new assemblies (4) to ensure the "T" mark at the top position	20			2		

Table 1: Activity and resource requirements of the project (continued).

Activity ID	Activity Name	Hour	BM	BW	PF	PW	Successor
	Work Package 5						
E6 - A212910	Steam Sparger - Grind remove old sparger nozzles	50	2	1			A212920
E7 - A189440	CC-R-01-Layout & Install Refractory Anchors on Reactor Head Weldout area - 288 anchors	20	2	2			
29 - A209360	Install riser manway and seal weld	8	2	1			A209370
30 - A209290	Install Platform 1, Section 0-90 from RX to Reg.	30	3	1			
31 - A209370	NDE on riser manway cover	1	2	1			
E8 - A209390	Final cleaning of ACB	4	2				
32 - A202500	Close Reactor MW - MX- 4 (ACB) - install refractory plug	6	1	1			A202510
33 - A202510	Close Reactor MW - MX- 5 (ACB) - install refractory plug	6	1	1			A202520
34 - A202520	Close Reactor MW - MX- 6 (ACB) - install refractory plug	6	1	1			A202530
35 - A212920	Steam Sparger - Install new sparger nozzles	50	2	1			
36 - A202530	Close Reactor MW - MX- 7 (ACB) - install refractory plug	6	1	1			
	Work Package 6						
37 - A192350	Grid - Install grid floor manway	10	1	1			

Table 2: Optimization results of work package 3.

Work package 3	Duration	BM	BW	PF	PW
		Work package 3			
Without optimization	150	5	5	3	3
Optimized	***70***	***10***	***8***	***3***	***3***
		Work package 3 with E3			
Without optimization	160	5	5	3	3
Optimized	***80***	***9***	***8***	***3***	***1***
		Work package 3 with E3 and E4			
Without optimization	180	5	5	3	3
Optimized	***90***	***10***	***8***	***3***	***1***

3.2 Upper level: Project level simulation

To account for the occurrence and consequence of uncertain events found on the turnaround project, superintendents and schedulers brainstorm on likely events and associated probabilities based on historical data or past experiences. Using Monte Carlo simulation, total project duration and total budgeted man-hours can be predicted at an upper level for project planning, which factors in a limited quantity of likely scenarios defined for each work package.

Based on the lower work package level optimization, the best crew combination assigned to each work package for each different scenario is obtained. Table 3 shows the probabilities of each scenario with respect to each work package. As the work packages are interconnected by precedence relationships, the whole project is represented by a project network diagram, as shown in Figure 5. Random sampling of likely scenarios on each work package, as per predefined probabilities and associated consequences in time and resources, is performed by computer-based Monte Carlo simulation analyses.

The simulation platform used in this research study is *SDESA* (Lu et al. 2008), with the results cross checked by using the simulation platform of *Simphony* (AbouRizk 2010). Each work package is modelled as a task. The tasks are logically linked with the branch elements. When the entity arrives at this element, random number sampling is done such that the entity is routed out through particular paths (scenarios of work package) according to the probability assigned to each route. The simulation model defines the work flows for executing the work packages according to the project network diagram.

The model was first validated by inspecting the simulation event list in a chronological order which is consistent with the turnaround schedule for the case project. The schedule resulting from each simulation run can be analyzed in order to identify specific scenarios being executed as for each work package. For example, uncertain events E3, E4, E5, E6, E7, and E8 are scheduled during the 1st simulation run, while events E1, E3 and E5 are scheduled during the 2nd simulation run, as shown in Figure 6.

The *SDESA* simulation results, such as total project duration, were cross-checked against *Simphony*, as shown in Figure 7. In total, 1000 simulation runs were performed on each platform. The 80th percentile, the average, and the standard derivation of project duration and budgeted man-hours are summarized in Table 4. The results show that statistics collected by both simulation engines exhibit insignificant differences. For example, the mean of total project duration is 253.72 hours by *SDESA*, which is comparable to 252.06 hours by *Simphony*. As such, the simulation results in terms of total project duration and consumed man-hours are independently verified.

The 80th percentile of the total project duration and the total budgeted man-hours are 270 hours and 4070 man-hours, respectively. With 80% likelihood, the total project duration and total man-hours budget will be controlled under those values. The resulting total duration and man-hours are much more reliable as they are derived based on a seamless integration of superintendent experience and computer power, facilitated by the proposed bi-level project planning methodology.

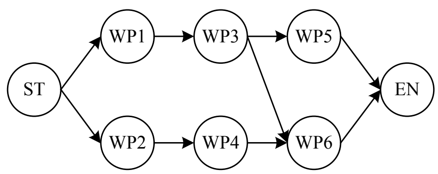

Figure 5: Project network.

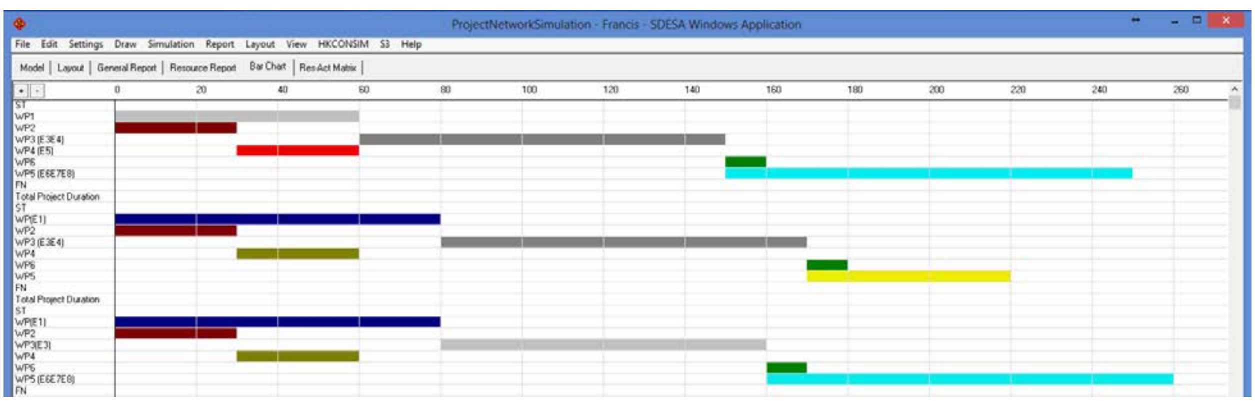

Figure 6: Three simulated schedules generated by *SDESA* simulation platform.

In addition, for verification purpose, the simulation results are also contrasted against P6 when only the most-likely work packages are considered (namely: E1, E3, E5, E6, E7 and E8). The crew configuration is set as originally given by the superintendent as mentioned in Section 3. It is noteworthy the total project time is shortened from 370 hours to 260 hours after performing optimization by the proposed methodology. The resource budget is given in Table 5. The total budgeted man-hours before and after the optimization are 5390 hours and 3790 hours, respectively.

Worth mentioning is the close match between P6 and the proposed new methodology based on the optimized crew formation also verifies the proposed new methodology to a certain extent (3790 man-hours vs. 3870 man-hours). Note this does not serve a rigorous validation of the proposed new methodology, but only gives “ballpark” reference values showing the new methodology produces realistic outputs. Additionally, a significant budget reduction is observed by contrasting the optimized plan against the original plan (5390 man-hours vs. 3790 man-hours).

Table 3: Probabilities of each event.

	Probability	Duration	BM	BW	PF	PW
WP 1	30%	60	6	3		
WP 1 (E1)	70%	80	5	3		
WP 2	60%	30	3	4		
WP 2 (E2)	40%	30	4	5		
WP 3	5%	70	10	8	3	3
WP 3 (E3)	60%	80	9	8	3	1
WP 3 (E3, E4)	35%	90	10	8	3	1
WP 4	30%	30	3		3	1
WP 4 (E5)	70%	30	5		2	1
WP 5	10%	50	6	3		
WP 5 (E6)	10%	100	5	5		
WP 5 (E6, E7)	30%	100	5	5		
WP 5 (E6, E7, E8)	50%	100	5	5		
WP 6	100%	10	1	1		

Table 4: Simulation results of the project.

	Project Duration (hours)	BM (man-hour)	BW (man-hour)	PF (man-hour)	PW (man-hour)	Total man-hours
80^{th} Percentile	270.00	2040.00	1580.00	330.00	120.00	4070.00
Average	253.72	1925.23	1496.61	325.86	121.88	3869.58
Standard Derivation	19.02	111.61	123.34	22.76	26.08	

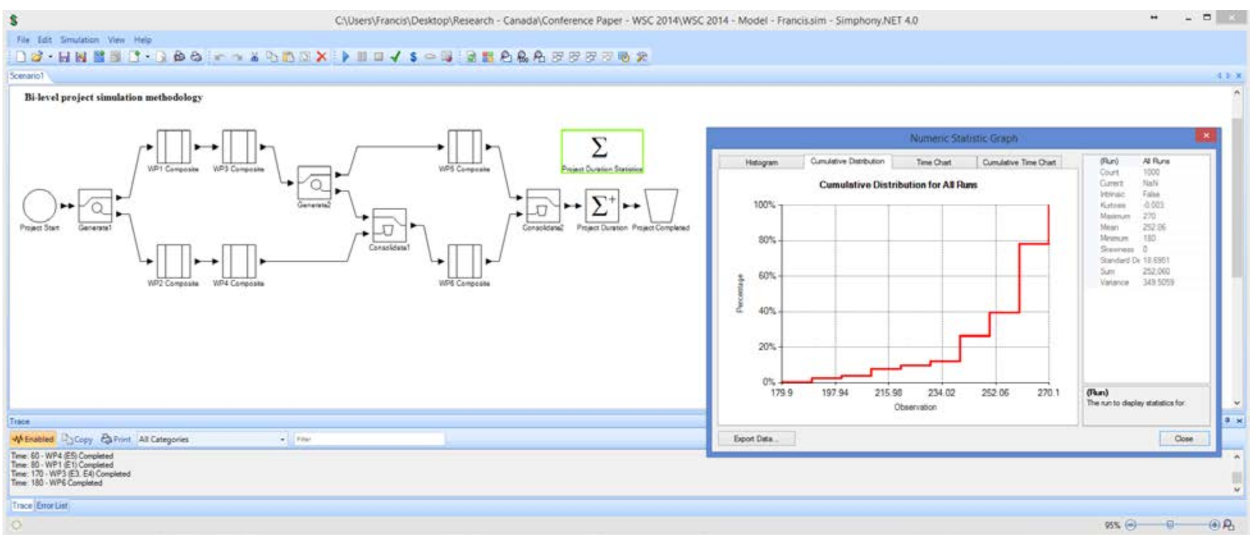

Figure 7: Simulation results verified by *Simphony* simulation platform.

Table 5: Budgeted man-hours based on the most-probable work packages.

Resource	Before work package level optimization	After work package level optimization
BM	2200	1870
BW	2050	1510
PF	570	300
PW	570	110
Total	5390	3790

4 CONCLUSION

Due to limitations of traditional CPM and PERT analyses, achieving a balance between resource supply and demand on a dynamic shutdown project can be difficult in the project planning stage. Commonly-used scheduling tools, such as Primavera P6, are not capable of identifying optimal combinations of resources as needed to complete all the work items in a work package within the shortest time duration, nor are they sufficient to consider probabilities and consequences of additional scenarios likely to be encountered due to the occurrence of uncertain or unknown events. This research proposes a new bi-level project simulation methodology aimed to (1) quantitatively determine the optimal resource quantities and the shortest time duration as needed for accomplishing each work package by resource scheduling optimization, and to (2) estimate total project duration and man-hours budget at an upper level for project planning through Monte Carlo simulation, by considering a limited quantity of likely scenarios specified for each work package. This is intended to enable the effective integration of work package level planning and project level planning. The detailed job execution plan on a job package is optimized with the best crew formation and shortest job duration. The hour-by-hour labor schedule generated for each scenario can be presented to foremen and superintendents, while statistical simulation outcome provides decision support for project management to control total project duration and assign a reliable man-hour budget with high confidence. A case study based on an industrial turnaround and plant shutdown project has been carried out in order to illustrate the effectiveness of applying the proposed methodology in a real-world setting.

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AUTHOR BIOGRAPHIES

MING-FUNG FRANCIS SIU is currently a Ph.D. Candidate at the Hole School of Construction Engineering in the Department of Civil and Environmental Engineering at University of Alberta. He was certified as Project Management Professional (PMP)® in 2010. His research interests are in the integration of project scheduling simulation modeling, applied photogrammetry, augmented reality to advance knowledge and practice of industrial construction and maintenance project planning, execution and control. His email is siumingfungfrancis@gmail.com.

MING LU is an Associate Professor in the Department of Civil & Environmental Engineering at the University of Alberta. He has been committed to achieving excellence in research and teaching in areas of construction engineering and project management. In 2010, he assumed a position of Associate Professor at the University of Alberta, Canada. He is the recipient of Fiatech 2013 Superior Technical Achievement Recognition (STAR) Award. His research interests are construction surveying and automation, operations simulation and scheduling in construction. His email address is mlu6@ualberta.ca.

SIMAAN ABOURIZK holds an NSERC Senior Industrial Research Chair in Construction Engineering and Management at the Department of Civil and Environmental Engineering, University of Alberta, where he is a Professor in the Hole School of Construction Engineering. He received the ASCE Peurifoy Construction Research Award in 2008. He was elected fellow of the Royal Society of Canada in 2013. His email address is abourizk@ualberta.ca.