IMPROVING SOPHISTICATION AND REPRESENTATION OF SKILLED LABOR SCHEDULES ON PLANT SHUTDOWN AND MAINTENANCE PROJECTS

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ABSTRACT: *Plant shutdown and maintenance, commonly termed as the turnaround project in the industry, aims to ensure safe and reliable production of an existing oil refinery and to expand capacities of existing plant facilities. Subject to constraints such as fixed project period, limited total budget, earliest activity start times, confined working areas and emerging events and found work during project execution, it is challenging to make, track and update detailed hour-by-hour turnaround schedules so as to effectively allocate specialist trades and skilled laborers. The ultimate goal is to complete the turnaround in a fixed time window and bring plant production back on line. Different from common construction project schedules, activity definitions, logical relationships and resources availabilities constantly change. The existing project scheduling methodology and tools are not sufficient or capable to cope with turnaround scheduling. This paper is intended to reveal the complexities of a typical turnaround project. A new methodology framework is proposed to plan resource-constrained, location-based turnaround activities. An in-house developed simulation-based scheduling tool is further employed to generate detailed resource allocation plans, factoring in resource availability limits and shift calendar constraints. The resource configurations can be further optimized, resulting in the shortest total project duration. In conclusion, this research has led to significant improvements on sophistication and representation of skilled labor schedules critical to effective planning and control of turnaround projects.*

KEYWORDS: *Shutdown, Maintenance, Turnaround, Scheduling, Optimization, Resource Allocation, Resource Calendars, Resource Shifts, Resource Breaks, Visualization.*

1. INTRODUCTION

Industrial construction develops and maintains oil and gas process plants. Such projects commonly feature installation of prefabricated modules and involve labor-intensive installation tasks completed by specialist trades. Similar to precast construction, prefabricated modules are shipped and assembled on the industrial site. This can greatly reduce the project time for building a new plant or upgrading an existing one. Song et al. (2005) surveyed construction practitioners to evaluate the feasibility of implementing pre-fabrication, pre-assembly, modularization and off-site fabrication. They concluded that implementation of these processes potentially shortens the project duration and is particularly suitable for executing plant shutdowns, outages or turnarounds; moving labor-intensive jobs to locations with adequate skilled labors eases labor resource shortage on site.

Plant shutdown and maintenance, commonly termed as the *turnaround project* in the industry, aims to expand the current production capacity and maintain the plant reliability during normal plant operations. Previous industrial-construction related research has investigated labor productivity (Lemna 1986; Lu et al. 2000; AbouRizk et al. 2001), access road planning (Varghese and O'Connor 1995), process simulation (Azimi et al. 2010; Taghaddos et al. 2010), tracking resource using bar code (Bell and McCullouch 1988), robotic total station and photogrammetry (Siu et al. 2013). In the present research, we address the challenge of making, tracking and updating detailed hour-by-hour turnaround schedules, so as to effectively allocate specialist trades and skilled laborers to complete the turnaround just on time. Turnaround schedule is subjected to constraints such as fixed project period, limited total budget, earliest activity start times, crowded working areas and emerging events and found works during project execution.

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Georgy et al. (2000) studied data from the US construction industry and concluded that the schedule performance indexes for 42 projects were between 102.9% and 123.2%, implying that most industrial projects would incur delays against as-planned schedules. They also reported that there were 43% project scope changes during the construction phase. The associated re-work (re-fabrication) was identified as one major factor for schedule delay and cost overrun. O'Connor and Tucker (1986) conducted a questionnaire survey for an industrial upgrading plant project and positively correlated constructability improvement to effectiveness in design communication. The schedule is vital to estimate and communicate man-hour consumed, budget cost and available time of limited resources. Critical path method (CPM) is the de-facto technique to schedule industrial construction and turnaround projects. However, CPM is not sufficient to account for turnaround-specific project factors, including (1) turnaround activities are planned on an hourly basis; (2) limited labor resources in turnaround are specialist trades, who perform specific tasks with special permit and license, work 24 hours in multiple shifts; (3) resource provision limits are highly constrained by space and normally vary in different time periods (e.g. during day and night shifts).

The contractor is often pressed to deliver the plant upgrade and maintenance project within a short period of time. Pushing back the plant start-up date by one day can lead to substantial economic losses. To tackle limitations of CPM in planning industrial projects, Siddiqui and Rafiuddin (2012) proposed a flow-line method based on linear scheduling to maintain resource continuity in repetitive industrial projects. They argued that the existing CPM method is not suitable because its incapability to visualize resource spatial conflict and continuous workflow requirements. Recent turnaround scheduling research efforts by Coughlan et al. (2010) and Rieck et al. (2012) proposed the use of mathematical programming to level resources. However, the large quantity of resource induced constraints in a realistic turnaround case may prevent the generation of a feasible solution within a reasonable amount of time. In contrast, the research described in this study sheds light on the importance of location-based resource allocation in turnaround scheduling, subject to field breaks during day and night shifts. The optimization technique is further employed to schedule activities under project constraints, thereby minimizing project duration and project cost.

In this paper, fundamentals of a typical oil refinery plant are first introduced, followed by elucidating on potential challenges in managing industrial construction projects by applying existing workflow tracking and scheduling techniques. A methodology framework is proposed to enhance the schedule management, so as to more effectively manage a resource-constrained, location-based turnaround project. A three-week turnaround project case study is included to illustrate project complexity and demonstrate method application. An in-house developed scheduling tool, named as *Simplified Simulation-based Scheduling* (*S3*) (Lu et al. 2008), is used to generate and optimize the resource allocation plan. Conclusions are drawn by discussing some on-going research in regards to multiple shift resource quantifications, resource-constrained time-cost integrated analysis, and photo-based 3D modeling, all intended to assist in critical decision making processes in scheduling turnaround projects.

2. INDUSTRIAL REFINERY PLANT FUNDAMENTALS

An oil and gas refinery plant is typically composed of a generator and a reactor as shown in Fig. 1(a). Through the introduction of catalyst, chemical reactions take place in the cyclones installed inside the regenerator and the reactor heads, which turn heavy oil (petroleum crude) to light oil (gasoline). The crude first enters the riser at the base to blend with the catalyst stored inside the regenerator. As oil vaporizes, catalytic cracking reactions take place. The hydrocarbons break down into smaller molecules. The vaporized hydrocarbons mixed with catalyst flow into the reactor. The main function of the reactor is therefore to segregate the mixture of hydrocarbon and catalyst into two separated portions. The primary cyclones are connected to the central riser. Through the primary and secondary cyclones (Fig. 1(b)) in the reactor, the catalyst and the cracked hydrocarbon are separated before the catalyst flows back to the regenerator. Some by-products, such as coke, deposit on the surface of catalyst and reduce catalyst reusability. The cyclones collect and return the catalyst to the stripper through trickle valves. The hydrocarbon products flow out from the top of the regenerator and into the fractionator for further light oil separation. Meanwhile, the catalyst flows back to the regenerator at the bottom through a slide valve; at the same time, the oxygen-rich air is induced for coke combustion in the regenerator cyclones. For a more detailed depiction of chemical reactions, readers can refer to Sadeghbeigi (2012).

The workers usually work inside the regenerator and the reactor. The working space is categorized as confined space − a restricted space which may become hazardous to a worker entering it due to the following considerations: (i) the atmosphere can be dangerous or injurious (such as oxygen deficiency or enrichment, flammability, explosivity or toxicity); (ii) the changing circumstances within the space that present a potential for injury or illness; or (iii) the inherent characteristics of an activity can produce adverse or harmful consequences within the space (OSSA 2013). Therefore, during schedule planning and updating stages, the schedulers and planners must be aware of the maximum quantities of laborers that are allowed to enter certain restricted locations at one time.

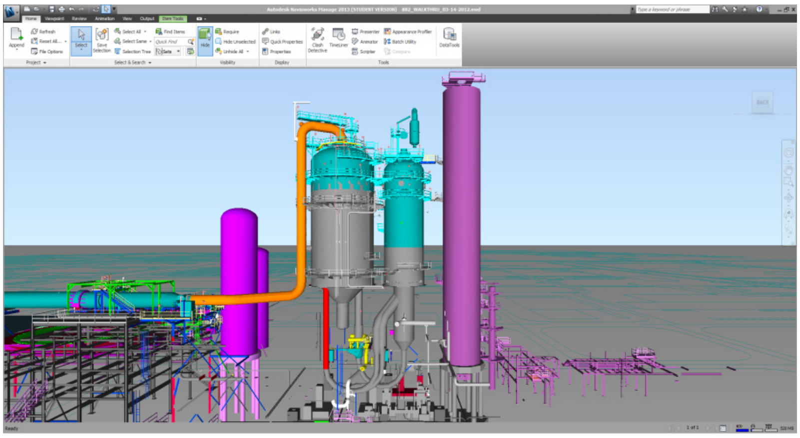

Fig. 1(a): Typical oil refinery plant site layout overview

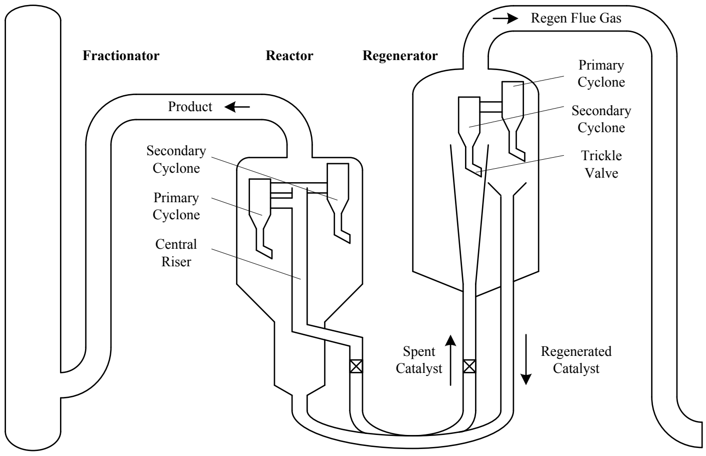

Fig. 1(b): Components and chemical flows inside the reactor and regenerator

3. COMPLEXITIES IN MANAGING TURNAROUND PROJECT SCHEDULES

The turnaround project is composed of three phases: pre-turnaround; turnaround; and post-turnaround. The scope of pre-turnaround is limited to planning temporary structure assembly, material logistics and quality assurance. The plant shuts down during the turnaround period. Plant components are removed, upgraded and repaired. The temporary structures are removed, the old structures are disposed of, and the upgraded plant starts up.

Subject to the contractually stipulated plant shutdown and startup dates, the turnaround is generally expected to complete within the tight time period without any delay. Although a detailed turnaround schedule (baseline schedule at T_0) is prepared, the work scope is partially unknown until the plant is shut down and examined. The existing vessels are opened up for quality inspections. Any existing structure is scrutinized and additional activities can be added to the baseline schedule. The superintendents usually record activity progress by using time-stamped photos. One example is given as of crane lifting sequences shown in Figs. 2(a) to 2(c). The photos capture the crane lifting sequence during the turnaround of the refinery under scrutiny. The actual start and finish times of the activities were tracked in the field.

Fig. 2(a): Reactor lifting

Fig. 2(b): Pipe 1 lifting

Fig. 2(c): Pipe 2 lifting

It presents distinctive challenges for schedulers to track and update the *as-planned schedule* while also coping with emerging events and found works during the turnaround stage. The inter-activity logical relationships are frequently revised during project execution. Note such frequent logic change rarely occurs on building and civil projects, but remains common practice to dynamic turnaround projects. Fig. 3 shows the typical workflow in maintaining turnaround schedules.

The superintendents report the work done during the previous period (day) in the site progress meeting, with the aid of field photos. The schedulers record the completed work, new found work, and expected emerging work based on the as-planned work schedule at T_0. This *newly created as-planned schedule* provides the baseline schedule generated at T_1 as the basis for the next schedule update cycle. In the meantime, the labor resource productivity performances are evaluated. Project management is alerted if labor performance decreases sharply.

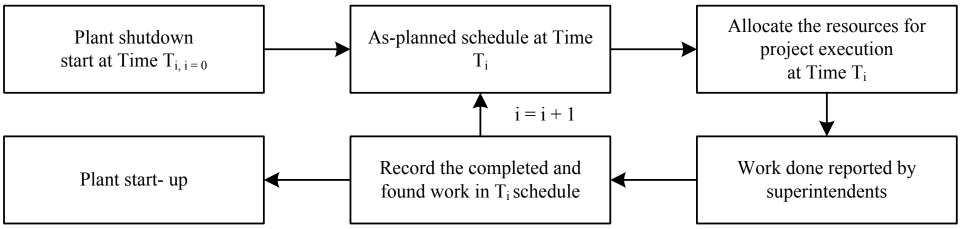

Fig. 3: Work sequence in maintaining a turnaround schedule

Schedule changes are inevitable and some activities may have to relocate to another area, some are irrelevant and removed, while others are newly defined. The schedulers add or remove activities to the schedule and place the week number in the customized column *added work* in the schedule to highlight the changes made for record keeping proposes. Despite the visualization power of advanced 3D plant design software to accurately communicate the actual design to the client (O'Connor and Tucker 1986), the field-level communication largely relies on the 2D drawings, pictures, and the project schedule. Additionally, an accurate and precise turnaround schedule is required to provide the baseline for assessing labor productivity performances.

An updated, valid turnaround schedule is also conducive to resource allocation for jobs to be started, especially allocation of limited, highly specialist trades with multiple shifts and field breaks. The commonly-used scheduling tool, *Primavera P6*, can generate a feasible schedule to cope with labor resources constraints. Nonetheless, this tool can only provide a Gantt chart for scheduled activities, but fail to visualize the work assigned to each individual resource, or determine the optimum quantities of workers as-needed in the field, or account for multiple shifts with field breaks.

In practice, the quantities of skilled laborers as needed are solely estimated based on experiences of the schedulers and managers. The resource leveling function of Primavera P6 simply ignores most resource constraints (such as commonly used activity type of *task-dependent* in Primavera P6) (Siu 2011; Harris 2012). As a result, the Primavera P6 scheduled working hours are solely dependent on activity calendars, regardless of resource availability and calendars being applied. Hence, a valid and detailed resource allocation plan cannot be generated by Primavera P6.

4. METHODOLOGY FRAMEWORK

To improve the current practice of turnaround project scheduling in a resource-constrained, location-based context, a new methodology framework is proposed (Fig. 4). The work breakdown structure is first developed based on the locations of the site. Activities under the same work package are technologically linked to form a local project network. At time T_i, the schedule is updated by incorporating completed and newly defined emerging activities into the as-planned baseline schedule (Fig. 3). Then, activity and resource constraints, including resource availability limits and resource multiple shift calendars with field breaks, are identified. These constraints are imposed to the scheduling-simulation model for analysis in a simulation platform. The resource-constrained schedule is generated in a relatively short time compared with mathematical programming. The above procedures are executed immediately after each turnaround progress meeting. A detailed resource allocation plan showing activity start and finish times, resource allocation details, resource breaks and idling times can be generated for visualization and communication purposes. The schedule can be further optimized by identifying the shortest project duration or the lowest project cost, along with the optimum quantities of resources to employ in the field. The improved schedule presentation can effectively guide the execution of the work flow of each trade or each individual in specific areas on a turnaround site, as illustrated with a practical case study in the ensuing section.

5. INDUSTRIAL TURNAROUND PROJECT CASE STUDY

A three-month industrial turnaround project was executed in Alberta, Canada in May to August, 2012. The project is to upgrade the existing oil refinery facilities including the reactor, regenerator, and the overhead system. Fig. 5 depicts the overall scope of work, including the temporary and permanent structures. The scope for the present case study is narrowed down to the *reactor work package* during the turnaround execution. The work content consists of (1) replacing the four elbows in the reactor; (2) removing the existing head and cyclone assemblies; (3) installing new head and cyclone assemblies; and (4) completing refractory and tie in electrical instrumentation, piping and platforming. As per contractual stipulations, the contractor reported progress achieved on activities on a shift-by-shift basis during the turnaround execution. A three-week schedule was updated on a daily basis.

The project definitions, including activity name, duration, shifts, technological relationships, and resource requirements are tabulated in Table 1. There are totally 109 activities planned for approximately three weeks (only 10 activities are given in Table 1 owing to the paper size limit). The quantities of different skilled laborers required by each activity are given in brackets in the column *resources* of Table 1. The shift calendars are summarized in Table 2. Regardless of day or night shift, labor resources work on an hourly basis. For example, calendar 2×12×7 denotes laborers run on 2 shifts per day, each shift is 12 hours, and each week has 7 work days.

In the current practice, the 2×12×7 shift calendar is commonly applied to schedule turnaround specialist trades, with hourly labor rates doubled for night shift. Production rates (productivity) for day-shift and night-shift crews are generally assumed identical. Figs. 6(a) and 6(b) show the working hour settings in the Primavera P6 based turnaround schedule. It implies one resource type is only associated with one applicable shift calendar while Primavera P6 is not able to distinguish day or night shifts. It is noteworthy that accounting for differences in productivity performance and the effects of varying crew sizes during day shift and night shift are not of the scope of this paper.

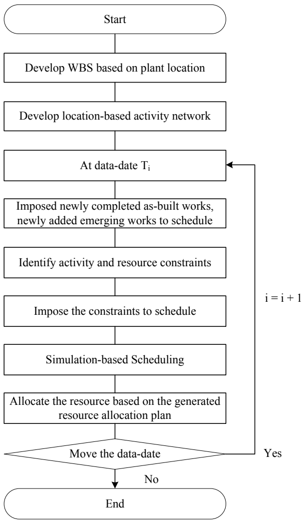

Fig. 4: Methodology flowchart

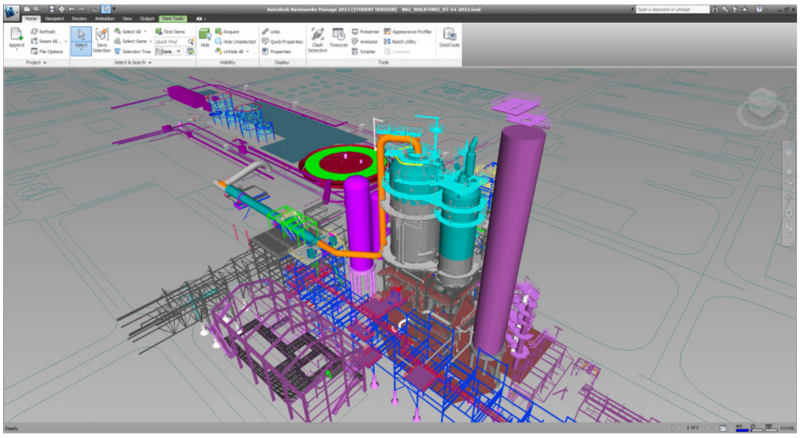

Fig. 5: Overall scope of the plant upgrading project

Table 1: Activity requirements

No	ID	Activity Name	Dur	Shift	Suc	Resources
1	A192440	Install hex on external riser at cut line. Approx. 30 sq. ft.	50h	2x10x7	A190430	KBR Boilermaker Welder[2] KBR Boilermaker [2]
2	A189340	Pre job meeting to install new Reactor head	1h	2x10x7	A193000	KBR MSG80 3600 ton[1] KBR Rigger[6]
3	A193000	Position crane and install rigging on new head	8h	2x10x7	A193010	KBR MSG80 3600 ton[1] KBR Rigger[6]
4	A193010	Lift new head and swing Amine unit	4h	2x10x7	A189400	KBR MSG80 3600 ton[1] KBR Rigger[6]
5	A189350	Remove Rigging and boom clear of work area	4h	2x10x7	A190490, A189410, A209280	KBR MSG80 3600 ton[1] KBR Rigger[6]
6	A189400	Continue swing and lower new Reactor head onto shell	5h	2x10x7	A189350	KBR MSG80 3600 ton[1] KBR Rigger[6]
7	A190490	Hoard in decking on lower dipleg bracing back to shell	10h	2x10x7	A190270	KBR Scaffolder[6]
8	A189410	Fit and Tack New head to Existing Reactor Shell	20h	2x10x7	A189420	KBR Boilermaker Welder[4] KBR Boilermaker[4]
9	A209240	Install landing from stairway to RX Platform 0	10h	2x10x7	A209250	KBR Iron Worker[3] Sterling-130 Ton Crane[5]
			…			
109	A209310	Install Platform 3, Section 0-90 from RX to Reg.	30h	1x10x4	-	KBR Boilermaker[3] KBR Boilermaker Welder[1] Sterling-130 Ton Crane[1]

Table 2: Shift calendars

Name	Weekly working hours		Name	Weekly working hours		Name	Weekly working hours	
1×10×4	Mon-Thur	10 hrs/day	2×10×6	Mon	15 hrs/day	7×24	Mon-Sun	24 hrs/day
1×10×5	Mon-Fri	10 hrs/day		Tue-Sat	20 hrs/day	7×10×2	Mon-Sun	24 hrs/day
1×10×6	Mon-Sat	10 hrs/day		Sun	6 hrs/day			
1×10×7	Mon-Sun	10 hrs/day	2×10×7	Mon-Sun	20 hrs/day			
1×12×7	Mon- Sun	10 hrs/day	2×12×7	Mon-Sun	24 hrs/day			
1×10×6	Mon-Sat	10 hrs/day						

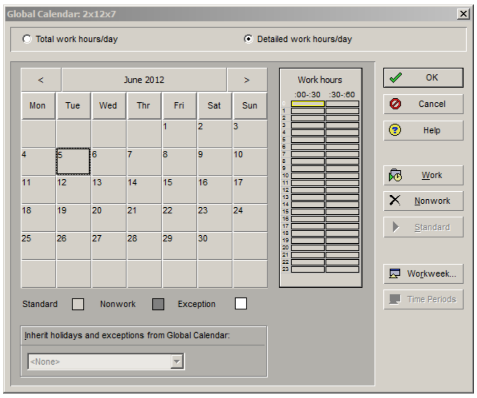

Fig. 6(a): 2×12×7 shift calendar

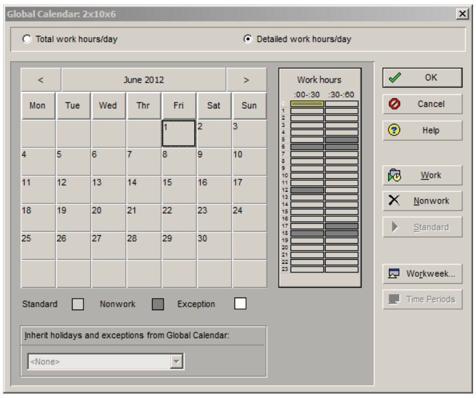

Fig. 6(b): 2×12×6 shift calendar

Table 3: Specialty trade resources

Resource Name	Calendar	Max Units/Time
IOL Complex Process Operator	2x12x7	1
IOL Inspection	2x10x6	1
IOL Supervisor	2x12x7	1
IOL Technical	2x10x6	1
KBR Boilermaker	1x10x6	10
KBR Boilermaker Welder	1x10x6	10
KBR Inspector	1x10x6	1
KBR Iron Worker	1x10x6	5
KBR Liquid Penetrant Inspection	2x12x7	1
KBR MSG80 3600 ton	2x12x7	1
KBR Painter	2x12x7	2
KBR PAUT Inspection	1x10x6	1
KBR Pipefitter	1x10x6	2
KBR Pipefitter Welder	1x10x6	1
KBR Rigger	1x10x6	6
KBR Scaffolder	1x10x6	6
KBR X-Ray	1x10x6	1
Refractory	2x12x7	10
Sterling-130 Ton Crane	2x12x7	5

In this case study, an in-house developed scheduling tool, named as *Simplified Simulation-based Scheduling* (*S3*), was used to schedule and optimize the complicated activity and resource work flows. In previous research, the tool was successfully applied to (1) optimize the resource provisions and activity schedule on a box culvert construction project (Lu et al. 2008) and (2) conduct delay analysis based on resource-constrained schedule (Siu and Lu 2011). Herein, assumptions underlying the simulation-based scheduling model are listed as follows:

- The resources assigned to each activity are engaged at the activity start time, when the budgeted man-hours are consumed as a result. Contrasted with the *task-dependent* activity type in Primavera P6, *resource-meeting* or resource matching on activities are applied which is relevant to resource-constrained construction scheduling. S3 adopts fixed-duration approach to allow users to enter the fixed length of work duration. In the current case study, the activity duration originally defined in the Primavera P6 schedule is directly exported as the fixed duration for S3 scheduling analysis.
- The *maximum unit per time unit* is estimated based on the minimum resource quantities required to execute the reactor works on one shift. For this reactor work package, Table 3 shows the maximum limits available for different trades or laborers involved in one shift.
- The start times set for certain activities are taken as *must start on or after* constraints. For example, one activity is technologically linked to other work packages, or depends on required material and equipment resources delivered to site on specific dates, or availabilities of space resources. The date and time of those constraints are exported from the existing Primavera P6 schedule as shown in Table 4. The value of time point represents the hours after the project start time (16-Jun-12 00:00).

Table 4: Start time constraints

ID	Activity	Time Point	Date	Time
3	A189340	64	18-Jun-12	16:00
10	A209240	81	19-Jun-12	09:00
12	A201270	88	19-Jun-12	16:00
78	A189720	265	27-Jun-12	01:00
94	A201160	332	29-Jun-12	20:00
95	A201180	332	29-Jun-12	20:00
96	A201200	332	29-Jun-12	20:00
102	A202480	357	30-Jun-12	21:00
103	A189730	357	30-Jun-12	21:00

5.1 Resource Allocation Plan Visualization

Fig. 7 depicts the zoom-in view of the obtained *boilermaker* allocation plan from time points 137 to 151. The horizontal axis represents the time line from time 0 (project start hour) to 759 (project end hour). The highlighted grey color indicates the resource breaks. The colored bars denote the work assigned to each individual boilermaker. The event list was also generated (Table 5). In addition to the Gantt chart visualization, the improved representation of skilled labor allocation plan accounts for the field breaks on an individual-laborer level. This lends itself to assisting the schedulers in assigning jobs and communicating to the crews in a straightforward way.

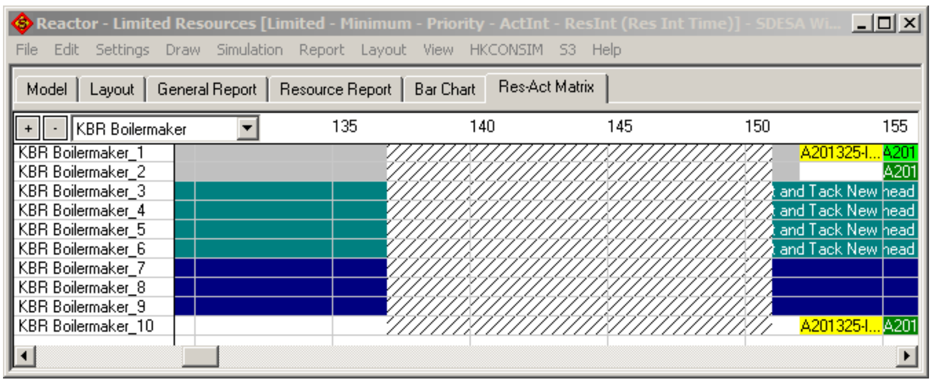

Fig. 7: Resource allocation plan (zoom-in view)

Table 5: Event list from time points 137 to 151

Time Point	Time	Boilermaker ID	Activities
130-137	21-Jun-2012 10:00 to 21-Jun-2012 17:00	1, 2	A192440
		3, 4, 5, 6	A189410
		7, 8, 9	A209280
		10	Idle
137-151	21-Jun-2012 17:00 to 22-Jun-2012 07:00	1, 2, 3, 4, 5, 6, 7, 8, 9	Break
151-152	22-Jun-2012 07:00 to 22-Jun-2012 08:00	1, 2	A192440
		10	(Idle)
151-155	22-Jun-2012 07:00 to 22-Jun-2012 11:00	3, 4, 5, 6	A189410
		7, 8, 9	A209280
152-155	22-Jun-2012 08:00 to 22-Jun-2012 11:00	1, 10	A201325
		2	Idle

5.2 Optimization

The turnaround schedule can be further enhanced by optimizing resource configurations, namely: finding the best combination of the quantities for different skilled laborers on a shift so as to reduce resource idle time and shorten total project duration. S3 implements the particle swarm optimization (PSO) algorithm to seek optimal schedule solutions. In this case, the objective function is set to minimize the project completion time. The simulated schedules before and after the optimization are shown in Figs. 8(a) and 8(b), respectively. The project end time are considerably shortened from 759 to 663 hours. Figs. 8(c) and 8(d) show the resource allocation plans of *boilermaker welder*, *technical* and *complex process operator*. The break patterns for different specialist trades are identical after the optimization.

Table 6 contrasts the resource quantities before and after the optimization analysis. The optimum resource quantities for this case are determined as: 12 *boilermaker welders* (increased from 10 to 12); 20 *boilermakers* (increased from 10 to 20); 10 *riggers* (increased from 6 to 10); 3 *pipefitters* (increased from 2 to 3); and 4 *iron workers* (reduced from 5 to 4). In the original experience-based resource limits setting, the skilled laborer resources were mostly undersupplied. It should be pointed out that after optimization, two independent activities can be scheduled in the same time period and at the same location. Safety or space constraints may prevent the concurrent execution of the two activities. Particular safety measures must be taken or additional precedence relationship must be imposed between them. For instance, the scaffolders working overhead may accidentally drop down tools to the boilermakers' work area; as such, if the two activities are scheduled to concur in the field, a protective net will be installed to provide adequate protection for the boilermakers.

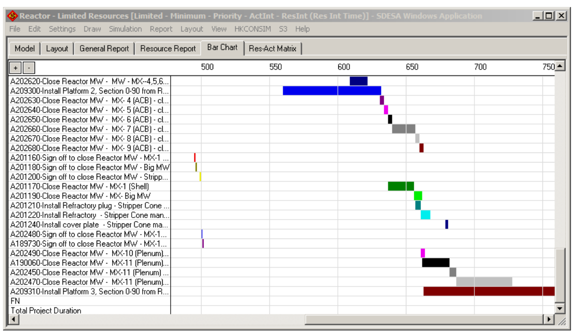

Fig. 8(a): Resource schedule

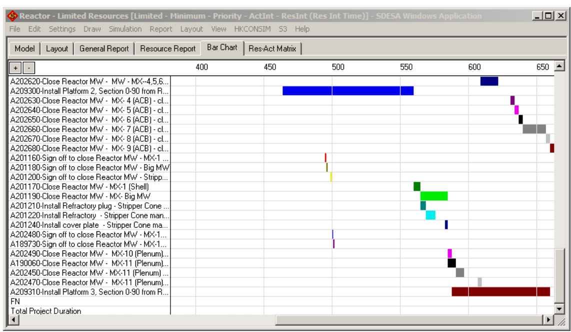

Fig. 8(b): Optimized resource schedule

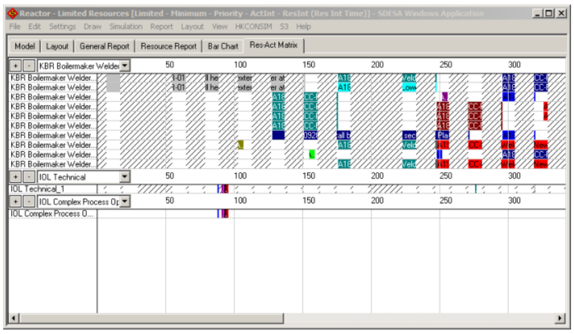

Fig. 8(c): Resource allocation plan

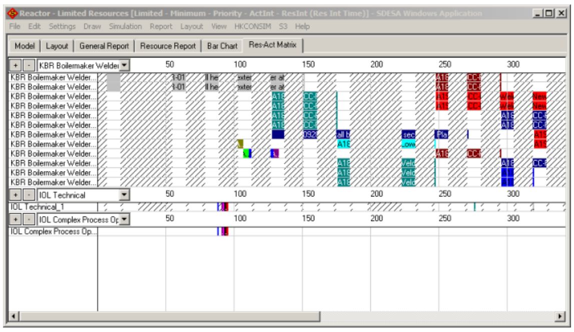

Fig. 8(d): Optimized resource allocation plan

Table 6: Resource provisions before and after optimization

	Before Optimization	After Optimization
KBR Boilermaker Welder	10	12
KBR Boilermaker	10	20
KBR MSG80 3600 ton	1	1
KBR Rigger	6	10
KBR Scaffolder	6	6
KBR Iron Worker	5	4
Sterling-130 Ton Crane	5	5
IOL Technical	1	1
IOL Inspection	1	1
IOL Complex Process Operator	1	1
Refractory	10	10
KBR Pipefitter	2	3
KBR Pipefitter Welder	1	1
KBR Liquid Penetrant Inspection	1	1
KBR Inspector	1	1
IOL Supervisor	1	1
KBR X-Ray	1	1
KBR PAUT Inspection	1	1
KBR Painter	2	2

6. CONCLUSION

The industrial plant shutdown and maintenance turnaround project is difficult to schedule owing to dynamic and complex constraints. Commonly-used scheduling tools, such as *Primavera P6*, fail to generate valid, sufficient schedules to cope with the hour-by-hour resource calendars and labor resource availability limits. The traditional activity bar chart is not sufficient to convey the resource allocation to each skilled laborer resource at an individual level. In this paper, a real-world case study is conducted to illustrate complexities, current practices and limitations in planning turnaround projects. A methodology framework has been proposed to better manage turnaround schedules generation and optimization based on the in-house developed scheduling system of *Simplified Simulation-based Scheduling* (*S3*). As demonstrated by the case study, the resulting resource allocation plans improve the sophistication and representation of skill labor schedules for effectively controlling and communicating the planned workflows.

Further research will be conducted in regard to: (1) Analysis of varied resource limits in day and night shifts such that each resource type, for instance, *boilermaker*, is divided to *boilermaker day shift* and *boilermaker night shift* and the resource limit and break constraints are separately imposed. Further optimization will be useful to objectively estimate the *optimum* resource quantities for both day and night shifts. (2) Resource-constrained time-cost integrated analysis: changing resource provisions may affect both the budgeted cost and the project completion time. The turnaround schedulers make timely decisions in estimating the impact on the budget cost and project completion time of imposing different *resource-time* alternatives on activities. The resource-constrained time-cost integrated analysis will automatically identify the best alternatives at individual activity level and generate the most cost-effective resource-constrained schedule at the global project level. (3) Photo-based 3D modeling integration: the space constraints will be evaluated based on time-stamped photo-based 3D models to ensure safety and productivity in planning turnaround activities. For example, the quantities of laborers allowed to be present at specific work locations can be objectively determined based on the photogrammetric analysis. Hence, the space constraints will be directly integrated to the simulation-based scheduling models. Eventually, the planning and control of highly complicated and dynamic turnaround projects can be effectively managed, and project objectives with regards to safety, time, cost, quality can be achieved.

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