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SIMULATION-BASED APPROACH TO SYSTEMATIC PROJECT PLANNING AND SCHEDULING AT A BRIDGE GIRDER FABRICATION SHOP

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ABSTRACT

This paper addresses a practical planning problem in bridge steel girder fabrication in an attempt to illuminate why the identified problem does not lend it well to existing solutions for construction planning. A simulation-based approach is presented for project scheduling and production planning at a structural steel fabrication shop. The shop simultaneously produces girders for various clients in construction of multiple bridges. Particular emphasis is placed on how to interpret and represent simulation outputs in terms of customized schedules of various details so as to cater to the needs of different stakeholders involved at multiple management levels. The applicability of the proposed approach is demonstrated with a case study based on real-world settings.

1 INTRODUCTION

In the particular domain of *steel bridge girder fabrication*, the industry is still coping with problems such as fabrication errors, frequent change orders, constrained floor space, skilled craftsmen shortage, which eventually add up to the complexity of fabrication planning (Thomas and Sandiv 2000; Alvanchi et al. 2012). Herein, shop production planning is similar to planning field execution of a conventional project, which entails establishing the workflow logic between all the jobs and allocating sufficient resources to complete planned jobs within limited budgets and finite timeframes (Halpin and Riggs 1992). In fact, planning operations for made-to-order structural components in a typical fabrication shop is subject to varied product designs from different projects, limited skilled laborers, finite space resources and client-imposed deadlines, which is no lesser a challenge than planning construction operations in the field (Hasan et al. 2019). A well-formulated production plan for a structural steel fabrication shop is vital to deliver bespoke structural components on site by respective deadlines while keeping production costs within budget limits (Song and AbouRizk 2006). In the current practice of structural steel fabrication planning, industry practitioners largely rely on the rule of thumb and past experience in production planning and control. In fact, planning multiple one-of-a-kind fabrication projects subject to limited labor and space resources and client-imposed deadlines is overwhelmingly complex and dynamic, rendering critical path method (CPM)-based project scheduling to be inadequate. On the other hand, well-established process simulation modeling tools are still far from cost-effective to account for sufficient details and adapt to constant changes in the real world (Lu et al. 2019).

This research has three fold contributions. First, it addresses the practical challenge of panning the operation of bridge girder fabrication shop. Second, it illuminates the reasons why existing construction planning methods are deemed to be ineffective in tackling the identified planning problem. Third, a simulation based dynamic project planning and scheduling approach is introduced in order to tackle the challenging problem and deliver sufficient and valid solutions in the practical application context.

2 PROBLEM BACKGROUND

2.1 Challenges in Bridge Fabrication Planning

To generate a practically feasible work plan, each individual worker's job schedule needs to be linked with project resource allocation schedule (Ahuja et al. 1984). At the same time, the work plan needs to be role-specific, contain no redundant information, and be straightforward for the worker to act on. Therefore, aside from a technology and process focus (i.e., what is to be done, how to do it in what sequence), a resource use focus is equally important (Haplin and Riggs 1992). The bridge girder fabrication shop floor problem features variations in product design specifications and fabrication process requirements. With such inherent deviations, the basic lean principle of reducing variation (e.g., six sigma) is not readily applicable (Dedhia, 2005). At the same time, the problem is tightly constrained by resource use (labor intensive), space, material handling systems and safety protocols - analogous to established workface planning problems in construction. Nonetheless, product sequencing plays a crucial part in shop production planning, dictated by construction technology (e.g., splicing) and site demand (e.g., delivery timing.). Herein, the site demand poses a hard constraint: just in time delivery is required as there is no buffer space on site (late delivery penalty would be imposed due to idling field crews and project completion delay; early delivery penalty would incur due to laydown yard cost and extra material handling cost). The cost in connection with inventory and extra material handling in the shop is prohibitively high due to the bulky size of the product and the finite shop space limit. Hence, once production starts, it would not be flexible to change the sequence of products. The trades and assets in the shop are limited resources with expensive hourly rates. Therefore, it is critical to have detailed workface plans formulated beforehand in order to effectively guide job allocation to particular trades and specific workstations, while ensuring utilization of resources as fully as practically possible.

The commonly applied Critical Path Method (CPM) for project planning and scheduling entails the representation of activity breakdown and predecessor relationships in the form of Activity on Node (AON) diagram. AON has been proven to be cumbersome and ineffective in modeling repetitive workflows performed on non-uniform work units, potentially resulting in an extra-large, overwhelmingly complex network model (Hyari and El-Rayes 2006). In the application context of bridge girder fabrication, resource use planning is the governing factor. Resource loaded critical path scheduling could provide the solution for this problem, e.g., resource-activity CPM proposed in Lu and Li (2003). For example, a simple project for simultaneously processing two products (ID: GA and GB) of similar type (still requiring slightly different processes) is shown in an AON diagram (Figure 1).

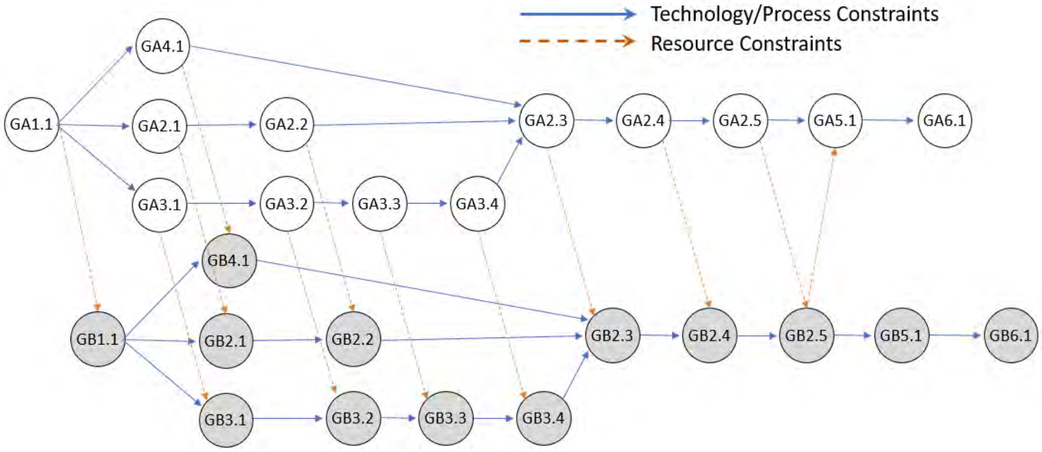

Figure 1: AON diagram with imposed technological/process constraints and resource constraints.

In Figure 1, the two products follow separate processes with no logical dependency when only technology constrains are imposed to link activities. However, when resource availability constraints are imposed (such as finite laborers and workstations), work flows on GA and GB become intertwined. As such, multiple arrow links between activities are inserted in AON for denoting resource-constrained precedence relationships, resulting in the transform the original AON structure. Imagine the CPM scheduler would need to double or triple the number of arrow links between all the activities in an AON network model consisting of thousands of activities; meanwhile, those arrow links are subject to constant change given the dynamic nature of processing different jobs in parallel in the fabrication shop. This kind of schedule is difficult to form, communicate and update. At the same time, the planning problem is no longer clearly structured for ensuing scheduling analyses. Note resource-specific work plans represent a particular sequence of jobs each having varied work content and entailing different time duration. The resource can be a welder, a workstation, or a crane available in the shop. In reality, it would be practically infeasible for the shop manager to account for resource-constrained precedence relationships in developing a valid AON network model.

2.2 Operations Simulation for Construction Project Management

Over the past few decades operations simulation has been widely applied in modeling various nonlinear complex manufacturing and construction systems. Reviews of extensive applications in a variety of industries, such as automobile manufacturing, shipbuilding, and bridge fabrication are available in Banks (1998); Law and Kelton (2000); and AbouRizk (2010). There are two distinct features that make the simulation of the operations at a bridge girder fabrication shop more challenging.

First, most simulation applications treat products in a production system as identical entities that follow rather straightforward processing logic; instead, statistical distributions of job processing times are generally applied to account for differences in products in simulation analysis. Nonetheless, in a made-to-order construction fabrication facility, each shop product must be uniquely modeled in a simulation model as it has different routing in a shop and consumes a different amount of processing time (Rose 1999).

Second, product sequencing in connection with a laborer or a workstation plays a crucial part in shop production planning, which is dictated by fabrication technology (splicing) and site demand (delivery timing). Therefore, activity duration of these manual operations needs to be explicitly determined based on product features and job sequencing, instead of being randomly sampled from possible ranges based on probability rules.

To adapt the process-interaction simulation paradigm to better cater to construction simulation needs and simplify construction operations modeling, Lu (2003) formalized the simplified discrete-event simulation approach (SDESA). It is an activity-based simulation method, which mimics the common practice of using CPM in construction planning but requires less modeling efforts for adequately representing repetitive work flows and resource transit in construction operations. In processing a sequence of activities or jobs, the start time of any activity is delayed until demanded resources are available and specified logical conditions are satisfied. SDESA essentially provides a generic process mapping and simulation methodology for integrating site layout and operations planning in construction. In contrast with AON, SDESA enriches the definition of resource workflow models or project network models by defining resource pools, flow entities, and resource transit information relevant to a construction operations system. Since its introduction, SDESA, along with the in-house developed computing platform, has been successfully implemented in many research and practical implementation cases. For instance, it was utilized to model the process of erecting the prefabricated structural elements using cranes in the construction of the steel structure of a stadium (Chan et al. 2006) and to model the operations of installing the precast deck segments considering site constraints of limited site space and logistics on a precast viaduct construction project in the real world (Chan and Lu 2008).

3 STEEL BRIDGE GIRDER FABRICATION PROCESS

3.1 Product Modeling

3.1.1 Girder Line

Girders underlie a bridge spanning a physical obstacle, such as a body of water, valley, or road. Steel plate girders are generally prefabricated I-beams arranged in parallel girder lines, providing longitudinal support for the above bridge deck. Along each girder line, multiple girders are connected to achieve the as-designed length of the bridge span. Each segment separated by "Field Splice" denotes a girder. Herein, "Field Splice" is the bolted connection between individual girders. Figure 2(a) and Figure 2(b) are schematic representation of the girder lines and girders with splice joints, respectively.

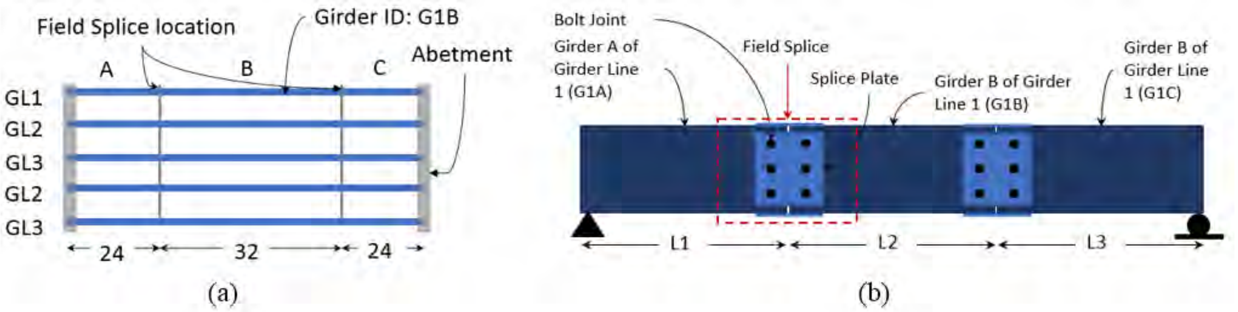

Figure 2: Schematic diagram of (a) typical girder line and (b) individual girder separated by the splice joint of steel girder bridges.

3.1.2 Girder

In steel girder fabrication, the unique product is the steel plate girder. A girder consists of a main middle plate (the web) which is connected perpendicularly to two other plates (flanges) at the top and the bottom. There are also rectangular plates (stiffeners), which are fitted perpendicularly into the web and the flanges. The main materials required for girder fabrication are, therefore, plates of different dimensions. Table 1 summarizes the attributes of the girders that define a unique type of girder as defined by industry practitioners. Generally, the exterior girders are different than the interior ones in light of the stiffener arrangement. Besides, depending on the type of girder, a particular girder undergoes certain processes on the shop floor. How to sufficiently define these specific girder attributes and specify girder types is conducive to accounting for the detailed steps relevant to fabrication operations in the shop.

Note some attributes are relative to the standard girder having certain features and requiring a specific amount of labor-hours to fabricate. The complexity factor for the standard girder is equal to one by default. The complexity factor (CF) for other girders with specific features can be set against the effort in fabricating the standard girder using Eq. 1. For example, given stiffener welding, if the total cutting length for 30mm thick stiffeners plates is 100 m and the cutting productivity is 0.6 Labor-hour per meter (LH/m), total cutting effort would be (100 x 0.6) = 60 LH. If this feature is set as the standard, and for 40mm thickness of steel plate the cutting productivity increases to 0.8 LH/m; as such, for 120 m cutting length of new girder stiffeners, as according Eq. 1 the complexity factor is calculated as: (120 x 0.8/60) = 1.6.

$$CF = \frac{LH\ required\ to\ work\ on\ specific\ feature\ of\ new\ girder\ type}{LH\ required\ to\ work\ on\ specific\ feature\ of\ standard\ girder} \tag{1}$$

Table 1: Different girder attributes to define a girder as a unique product in simulation.

Component	**Attribute ID**	**Attribute Description**	**Variation**
Flange (FPL)	FPL.Attr1	Length of the flanges (Top and Bottom)	Dimension as per structural design
	FPL.Attr2	Width of the flanges (Top and Bottom)	Dimension as per structural design
	FPL.Attr3	Thickness of the flanges	Any standard plate thickness as per structural design
	FPL.Attr4	Number of drills in one end	Dimension as per structural design.
	FPL.Attr5	Number of flange splices	$N_1 = \frac{Length\ of\ the\ girder}{Individual\ flange\ plate\ length} - 1$ Here, N_1 is upper rounded whole number
Web (WPL)	WPL.Attr1	Length of the web plate	Dimension as per structural design
	WPL.Attr2	Number of the web plates	$N_2 = \frac{Length\ of\ the\ girder}{Individual\ web\ plate\ length}$ Here, N_2 is upper rounded whole number
	WPL.Attr3	Width of the web plates	Dimension as per structural design
	WPL.Attr4	Thickness of the web plates	Standard plate thickness as per structural design
Girder (FG)	FG.Attr1	Length of the girder	Dimension as per structural design
	FG.Attr2	Number of the field splice	= 0 If there is only one girder in the girder line = 1 If there are multiple girders in the girder line and girder is the abutment side girder. = 2 If there are multiple girders in the girder line and subject girder is the middle one with two other girders at each end of it.
	FG.Attr3	Stiffener complexity (compared against a standard condition)	Any positive number. Can be determined using Eq. 1.
	FG.Attr4	Stiffener welding complexity (compared against standard condition)	1, when the angle between the web and stiffeners is 90 degree, 1.5, when the angle between the web and stiffeners is 45 degree, 2, for all other cases.
	FG.Attr5	Girder shape complexity (compared against the standard girder)	Can be determined using Eq. 1 (1 for the standard one).

3.2 Shop Floor Processing Logic

Steel plates of different dimensions and grades are transformed into steel girders as per engineering design in the constrained space of the fabrication shop. The fabrication operation mainly consists of the following six major workflows. These are: 1) Receiving Plates, 2) Web Preparation, 3) Flange preparation, 4) Stiffener preparation, 5)Girder Splicing, 6) Girder Finishing. Here, each workflow breaks down into special processes, and each process itself consists of special activities. Table 2 summarizes all major workflows and associated activities.

Table 2: Major workflows of steel girder fabrication process.

Work Flow	**Process ID**	**Process**	**Activities in sequence**
WF1: Receiving Plates	WP1.1	Receiving plates	1.Unloading plates, 2. Checking plates, 3. Stack for processing
WF2: Web Preparation	WP2.1	Web splicing	1. Move WPL to splicing station, 2. Web edge cutting (camber 7 cleaning), 3. Preset plates for camber, 4. weld web side 1 and grinding, 5. Blast web side 1, 6. turn WPL, 7. Weld web side 1 and grinding, 8. Blast web side 2, 9. Move to web inspection, 10. Web inspection
	WP2.2	Web cutting	1. Move to web cutting station, 2. Web layout camber, 3. Web cutting and cleaning
	WP2.3	Girder assembly	1. Hang Flanges and layout, 2. Press and tack flanges, 3. Move to girder welding station, 4. Girder grind side 1, 5. Girder weld side 1, 6. Turn girder, 7. Girder grind side 2, 8. Girder weld side 2
	WP2.4	Stiffener fitting	1. Move to stiffener welding station, 2. Stiffener layout and fitting and checking side 1, 3. Turn girder, 4. Drill webs and gussets, 5. Stiffener layout and fitting and checking side 2, 6. Stud layout, 7. Stiffener weld to side 2, 8. Turn girder, 9. Stiffener weld to top flange, 10. Turn girder, 11. Stiffener weld to side 1, 12. Turn girder, 13. Stiffener weld to bottom flange
	WP2.5	Studding	1. Shoot Stud and test and clean, 2. Turn girder, 3. Bearing and camber check
WF3: Flange Preparation	WP3.1	FPL Pre blasting	1. Move to flange blasting station, 2. Pre blast plates: Side 1, 3. Turn: Flange Plates (FPL), 4. Pre blast plates: Side 2
	WP3.2	FPL Cutting	1. Move to flange cutting station, 2. Prepare flange layout, 3. Preheat, 4. Cut flanges, 5. Cleanup & hardness test
	WP3.3	FPL Straightening	1. Move to flange straightening station, 2. Straightening, 3. Move back to shop space, 4. Flange setup and drill
	WP3.4	Flange Splicing	1. Move to splicing station, 2. Grinding & fitting, 3. Weld Side 1 of FPL, 4. Grind Side 1 of FPL, 5. Turn FPL, 6. Back Gouge and Weld, 7. Layout and scarf cut, 8. FPL inspection, 9. Move to assembly station
WF4: Stiffener Preparation	WP4.1	Stiffener Preparation	1. Stiffener layout, 2. Stiffener cutting
WF5: Girder Splicing	WP5.1	Flange Splicing	1. Move to splicing station, 2. Initial set up, 3. Cut ends and setup, 4. Hang splice plates and fit-up, 5. Splice Drills, 6. Pull apart, 6. Match marks and grinding
WF6: Girder Finishing	WP6.1	Finishing girder	1. Move to sand blasting station, 2. Final blast side 1, 3. Turn girder, 4. Final blast side 2, 5. Turn girder, 6. Final dressing, 7. Loading and shipping

Figure 3 shows the overall fabrication shop floor operation in the format of an AON diagram. Note: detailed activities under each process are not elaborated herein due to limited space; no resource constraints are shown in presenting logic in the AON. Once shop drawings and all the required materials are ready, girder fabrication starts with detailing raw flat plates, including pre-blast, cut, and drilling. Then, webs and flanges are made from these cut plates by straightening and splicing. For all the connections (e.g., splicing flanges, splicing webs, and assembling flanges and web), tack welds are applied as temporary connections to hold components in position before final welding is performed. After the preparation of webs and flanges is done, one web and two flanges are assembled into a girder by tack welds. In this step, specific machinery (e.g., overhead cranes and squeezer) is utilized for lifting, handling, and fixing the web and flanges. Flanges need to be fitted tightly to the web with no gap. Once the web and flanges are assembled, final welding permanently connects web and flanges. Next, stiffeners and studs are attached to the assembled girder based on engineering drawings.

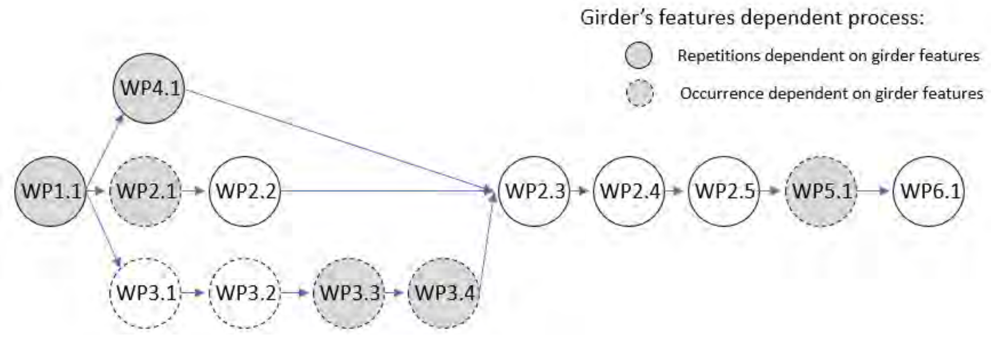

Figure 3: Fabrication shop workflow logic.

Upon finishing this step, the girder undergoes the following step of drilling holes for field splicing, which allows two adjacent girders in the same girder line to be connected by bolting in on-site installation. At this step, the two adjacent girders are aligned in the fabrication shop. Drilling is then performed on the girder splice end, flange splice plates, and web splice plates, followed by sandblasting, painting, and other surface finishing work. The fabricated plate girders are inspected prior to being shipped to the site for installation. It is emphasized most work packages in Figure 3 denote processes, the repetition of which or the occurrence of which are dictated by girder's particular features. In other words, had the operation processes been elaborated, each girder type will be associated with a unique AON network model which can be large in size and complicated in dynamic, logical relationships. This would render the conventional CPM analysis to be ineffective.

The case study in the ensuing section applies SDESA simulation as the alternative methodology to AON/CPM in coping with exploding detail and dynamic complexities inherent in this practical problem.

4 CASE STUDY

A case study was conducted on a steel bridge fabrication shop located near Edmonton, Alberta. The girder configuration is shown in Figure 4. The SDESA shop-floor workflow model is developed according to the existing shop space configuration, resource use constraints, and resource availability constraints. Simulation logic was then face validated by domain experts involved in the partner company by tracing step by step computing details. Thus, instead of collecting historical data to fit statistical distributions, constant productivity data (work unit/hr) denoting most likely values were provided by experienced shop managers and used in simulation analysis.

This case study consists of a total of 15 girders making up five girder lines for one bridge project as shown in Figure 4. Four distinct types of girders are defined by the attribute list presented in Table 1. Any variation in values in the set of attributes basically results in a new unique girder type. The parameters of the attributes specified for four girder types are given in Table 3. Note, GL1A, GL1C, GL5A, and GL5C are classified as Type 1 girders; GL1B, and GL5B are Type 2 girders; GL2A, GL2C, GL3A, GL3C, GL4A, and GL4C are Type 3 girders; GL2B, GL3B, and GL4B are Type 4 girders. Relevant resources available in the shop considered for this case study are shown in Table 4.

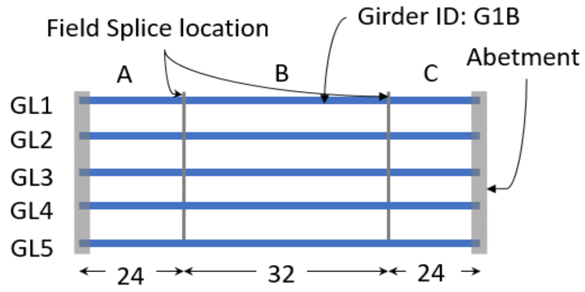

Figure 4: Girder configuration for the case study problem.

Table 3: Properties of different girder types of the case study problem.

Attribute ID	Description	Girder Type 1	Girder Type 2	Girder Type 3	Girder Type 4
FPL.Attr1	Length of the flanges (Top and Bottom)	24 m	32 m	24 m	32 m
FPL.Attr2	Width of the flanges (Top and Bottom)	0.6 m	0.6 m	0.6 m	0.6 m
FPL.Attr3	Thickness of the flanges	0.06 m	0.06 m	0.06 m	0.06 m
FPL.Attr4	Number of holes in one end of the flange	30	30	30	30
FPL.Attr5	Number of flange splices	0	1	0	1
WPL.Attr1	Length of the web plate	24 m	32 m	24 m	32 m
WPL.Attr2	Number of the web plates	1	2	1	2
WPL.Attr3	Width of the web plates	2.7 m	2.7 m	2.7 m	2.7 m
WPL.Attr4	Thickness of the web plates	0.02 m	0.02 m	0.02 m	0.02 m
FG.Attr1	Length of the girder	24 m	32 m	24 m	32 m
FG.Attr2	Number of the field splice	1	2	1	2
FG.Attr3	Stiffener complexity (compared against a standard condition)	1	1	1.5	1.5
FG.Attr4	Stiffener welding complexity (compared against standard condition)	1	1	1.5	1.5
FG.Attr5	Girder shape complexity (compared against the standard girder)	1	1	1	1

Table 4: Shop resource list for running fabrication operation.

Resource Name	Quantity	Resource Name	Quantity
Journeyman	8	Stiffener Welding Station	2
Crane	6	Flange blasting Station	2
Sub arc Weld	3	Flange cutting station	1
Power Drill	2	Flange Straightening Station	1
Receiving Area	1	Flange Splicing Station	1
Web Splicing Station	2	Field Splicing Station	2
Web Cutting Station	2	Finishing Station	2
Girder Assembly Station	2		

The shop manager is responsible for planning six main work flows which are further elaborated into thirteen distinct processes. Besides, each process consists of a certain number of activities (ranging from two to thirteen, depending on the girder features listed in Table 2). Each activity is then specified with specific requirements on resource use. A screen shot from the SDESA simulation program is presented in Figure 5 to illustrate the resource use complexity. Note, eight journeymen are allocated, grouped, and regrouped from job to job over 600 hours to complete one bridge fabrication project consisting of fifteen girders arranged in five girder lines. Similarly, job sequencing plan at for particular workstations or equipment in the fabrication shop can be produced from simulation modeling. They are not presented due to the paper size limit. In the current case, the total number of scheduled activities is 1,807.

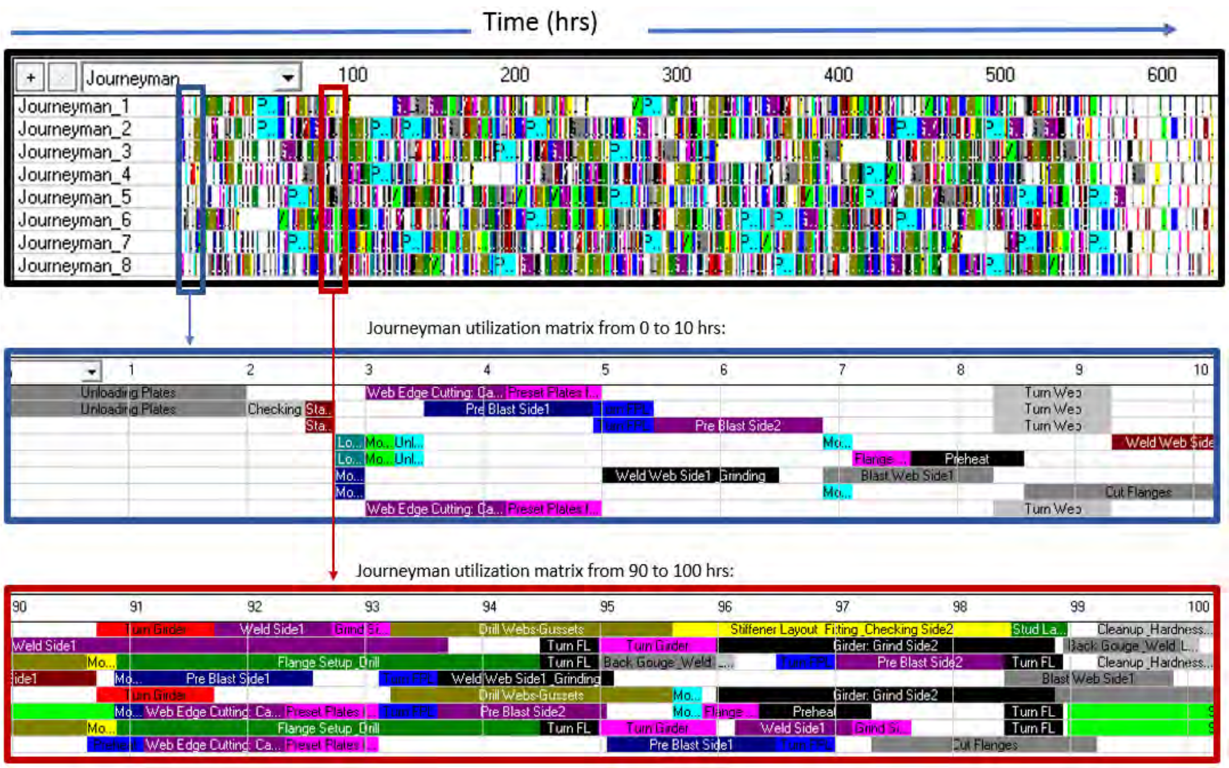

Figure 5: Journeymen utilization matrix for different hours of operation.

4.1 Multi-Level Plans and Schedules

For this case, if the production manager's objective is to minimize the total labor-hours spent in this project, he or she can choose the production sequence GL1 – GL2 – GL3 – GL4 – GL5 with seven journeymen engaged in the fabrication (namely, Scenario ID 3 in Table 5). If there is a particular deadline to meet, an alternative solution can be considered.

In addition to job processing plans and resource allocation plans, shop managers can also customize any necessary plans in connection with various management functions by extracting relevant data from simulation results. Figure 6 shows the roll-up bar chart schedule with each girder's start and finish dates for this case study project starting from April 1, 2019. It is noteworthy at a given moment, multiple girders will be processed concurrently in the fabrication shop; at one time, a maximum of 5 girders can be simultaneously fabricated by the shop. Moreover, the simulation model provides detailed data for (1) generating the project plan with start and finish dates for each individual girder and (2) scheduling specific tasks for a particular workstation, a journeyman and a major machinery (e.g. crane). For example, Table 6 summarizes the “to do list” generated from simulation for Journeyman ID 1 for the first two working days; Table 7 summarizes work plan and schedule for a web preparation workstation to process particular girders in the first working week.

Table 5: Experimentation results from simulation model.

ID	**Job Sequence**	**Journeyman No.**	**Labor hours**	**Utilization Rate**	**Project Duration**
1	GL1 – GL2 – GL3 – GL4 – GL5	9	5454	65.18%	606 hr.
2	GL1 – GL2 – GL3 – GL4 – GL5	8	5128	69.25%	641 hr.
3	GL1 – GL2 – GL3 – GL4 – GL5	7	5145	69.36%	735 hr.
4	GL1 – GL2 – GL3 – GL4 – GL5	6	5112	68.73%	852 hr.
5	GL1 – GL2 – GL3 – GL4 – GL5	5	5230	67.87%	1046 hr.

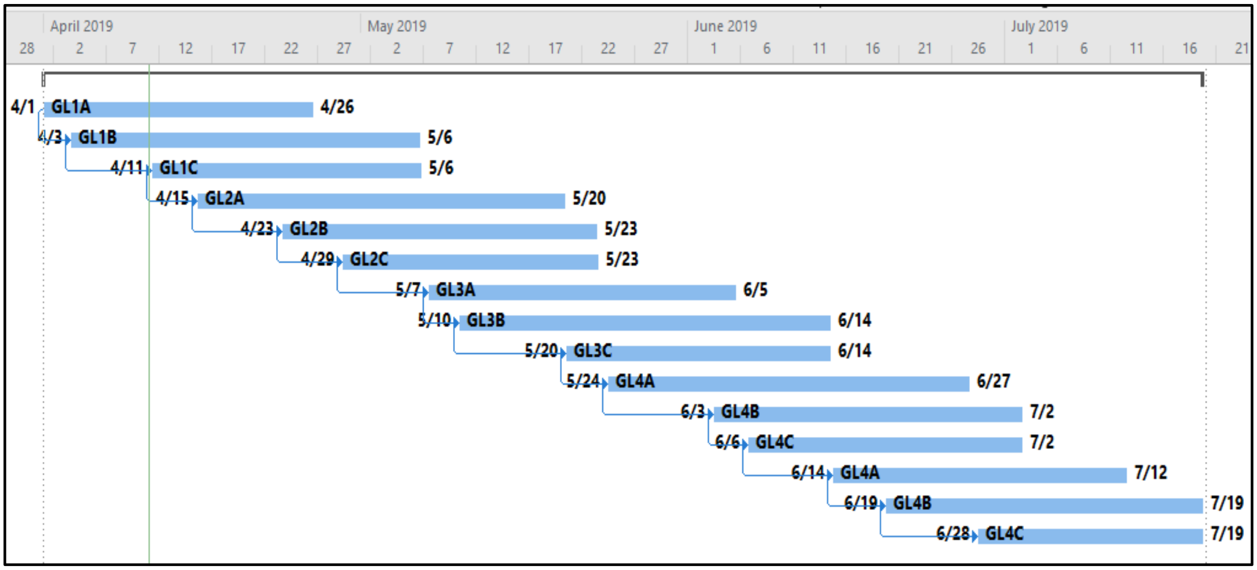

Figure 6: Girder by girder start and finish schedule for the case study project.

Table 6: Task to do list for the first two days (staring at 1 April 19) for journeyman ID 1.

Task Name	**Start**	**Finish**
Unloading Plates	4/1/2019 8:00	4/1/2019 10:00
Web Edge Cutting: Camber & Cleaning	4/1/2019 11:00	4/1/2019 13:12
Preset Plates for Camber	4/1/2019 13:12	4/1/2019 14:00
Turn Web	4/1/2019 14:00	4/1/2019 15:00
Load Transfer Table	4/1/2019 15:00	4/1/2019 15:15
Move: Flange Blasting Station	4/1/2019 15:15	4/1/2019 15:30
Unload Transfer Table	4/1/2019 15:30	4/1/2019 15:45
Move: Web Inspection	4/1/2019 15:45	4/1/2019 16:45
Move: Web Cutting Station	4/1/2019 16:45	4/1/2019 17:00
Flange Setup & Drill	4/2/2019 8:00	4/2/2019 11:36
Move: Flange Straightening Station	4/2/2019 11:36	4/2/2019 11:51
FPL-Straighten	4/2/2019 11:51	4/3/2019 8:39

Table 7: Work plan for “Web Preparation Station” for first two days stating from 1 April 2019.

Task Name	Start Date	Finish Date
Processing Girder GL1A	4/1/2019 8:00	4/15/2019 13:01
Move: Web Splicing	4/1/2019 8:00	4/1/2019 8:15
Web Edge Cutting: Camber & Cleaning	4/1/2019 8:15	4/1/2019 9:27
Preset Plates for Camber	4/1/2019 9:27	4/1/2019 10:15
Weld Web Side1 & Grinding	4/1/2019 10:15	4/1/2019 11:45
Blast Web Side1	4/1/2019 11:45	4/1/2019 14:11
Turn Web	4/1/2019 14:11	4/1/2019 15:11
Weld Web Side2 & Grinding	4/1/2019 15:11	4/1/2019 16:41
Blast Web Side2	4/1/2019 16:41	4/2/2019 9:08
Move: Web Inspection	4/2/2019 9:08	4/2/2019 10:08
Move: Web Splicing	4/2/2019 10:08	4/2/2019 10:23
Web Edge Cutting: Camber & Cleaning	4/2/2019 10:23	4/2/2019 11:35
Preset Plates for Camber	4/2/2019 11:35	4/2/2019 13:23
Weld Web Side1 & Grinding	4/2/2019 13:23	4/2/2019 14:53
Blast Web Side1	4/2/2019 14:53	4/2/2019 16:19
Turn Web	4/2/2019 16:19	4/3/2019 8:19

5 CONCLUSION

Classic AON network would explode in size and complexity once all the relevant resource-induced precedence relationships are imposed on a project model denoting the detailed operations in a steel fabrication shop. In consequence, this would turn shop production planning and scheduling from a well-structured problem into an ill-structured one. As such, the AON network would be of little value for making execution plans and conducting scheduling analysis. The production manager at a bridge girder fabrication facility generally resorts to experiences, guessing, and gut feel to support critical decision making. The current management practice remains an art instead of a science. To tackle above-identified limitations, this research study proposes a simulation-enabled job planning approach for defining a sufficient problem statement. The simulation model is established based upon the three-tiered methodology proposed by Lu et al. (2019) in order to achieve a balance between ease of use and complexity of the problem. In the case study, the Simplified Discrete Event Simulation Approach (SDESA) was utilized (Lu 2003) as the platform for features-dependent and resource-constrained process mapping and simulation. The work breakdown structure, along with job sequencing and resource constraints, have been defined from the perspective of experienced shop managers of the partner company. Deterministic time requirements and resource use requirements have been evaluated in collaboration with industry professionals based on design features of individual girders. As demonstrated with the case study, simulation modeling is able to bring chaos into order by transforming the identified problem in the domain of project management and construction into a structured one ready for analysis.

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