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SIMULATION BASED PROCESS MAPPING FOR THE FABRICATION OF BRIDGE GIRDERS

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ABSTRACT

Modern construction projects have been shifting to offsite prefabrication with hopes of enhancing performance and improving productivity. Off-site construction of structures such as heavy structural steel bridges involves the fabrication of a significant portion of the required construction components including bridge girders and assemblies in off-site fabrication facilities in a more controlled environment before delivering finished components to the construction site for erection. Unlike manufacturing, steel fabrication is labor intensive and less automated while undergoes frequent change orders and shop layout changes. These features make tracking the daily utilization of the workforce and thus labor cost and productivity difficult. To address this issue, a simplified discrete simulation approach (SDESA) is implemented to build an integrated data-driven system as an effective tool for modeling the operational details involved in the fabrication of bridge girders which supports estimating, scheduling and analyzing production.

1 INTRODUCTION

Despite the information and technology advances in the construction industry in the past two decades, the practice of construction engineering and project management have not changed much. Regardless of the significant advantages of off-site construction to construction projects, the extent of using this technique is still limited (Lu 2009). Thomas and Sanvido (2000) classify off-site construction fabrication problems as late and out-of-sequence deliveries, fabrication errors, rigid inspection run by a third party, and incompatible fabrication rates of on-site erection operations. Off-site construction fabrication shops typically also suffer from existing limitations such as space, workers, equipment, and material, which add to the complexity of fabrication planning. In addition, changing shop layouts due to switching methods of fabrication further complicates the off-site construction planning process. These problems increase the complexity to a level where shop foremen and project managers cannot develop a dependable plan for the job.

In the current practice of structural steel design, fabrication, and construction, labor productivity estimation is the critical information to manage projects and perform tasks such as estimating, scheduling, and project control (Song and Abourizk 2006). Practitioners still rely on the rule of thumb and “gut-feelings” to make critical decisions, instead of data-driven, quantitative analytics. Project planning in construction fabrication shops, such as in a steel fabrication shop, still employs the experience of production engineers as its primary source in decision-making. A scientific technique for analyzing a variety of short-term and long-term planning problems encountered during daily operations would, therefore, be of great benefit. Due to the complexity of the large construction projects such as heavy structural steel bridges, simulation is frequently the best and occasionally the only possible tool to address the above-mentioned issues and analyze processes of construction operations (Martinez 2010). Using simulation, engineers can test out different construction scenarios, estimate resource utilization, find bottlenecks, and forecast time and cost requirements without having to go to site. In this research, a practical simulation-based approach was used to capture the complexity involved in particular off-site construction projects. This case study elaborates on an experimental case of an off-site steel bridge girder fabrication process in which managing the production process became challenging for project managers. Though, the results achieved in this research can be extended to other types of off-site structural steel construction, such as building construction or industrial plant construction. Specifically, the research presents solutions in modeling process flow and labor productivity that are unique issues in modeling the steel fabrication process. A prototype model developed for an Edmonton-based (Canada) steel bridge girder fabricator is used to illustrate the development of the system and its application in project planning.

2 SIMULATION MODEL

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 fit perpendicularly into the web and the flanges. The main materials required for the girder construction are, therefore, plates of different dimensions. The operation of girder fabrication mainly includes the following steps: receiving plates, flange and web prepration, assembling girder by fitting and welding flanges to web, stiffener fitting and welding, studding, field splicing, sandblasting. Overhead cranes are used to turn and move the assemblies between stations. In order to understand the nature of how girder fabrication activities are being performed in fabrication shops, extended visits to a heavy steel girder fabrication shop located in Edmonton, Alberta were conducted to observe and document the fabrication activities, sequences and resources required. With the aid of an experienced production manager, all the process activities, which are required for fabricating a complete girder from raw plates, were identified and mapped. Both crew composition information and space constraint were also collected to simulate a more realistic image of the fabrication shop.

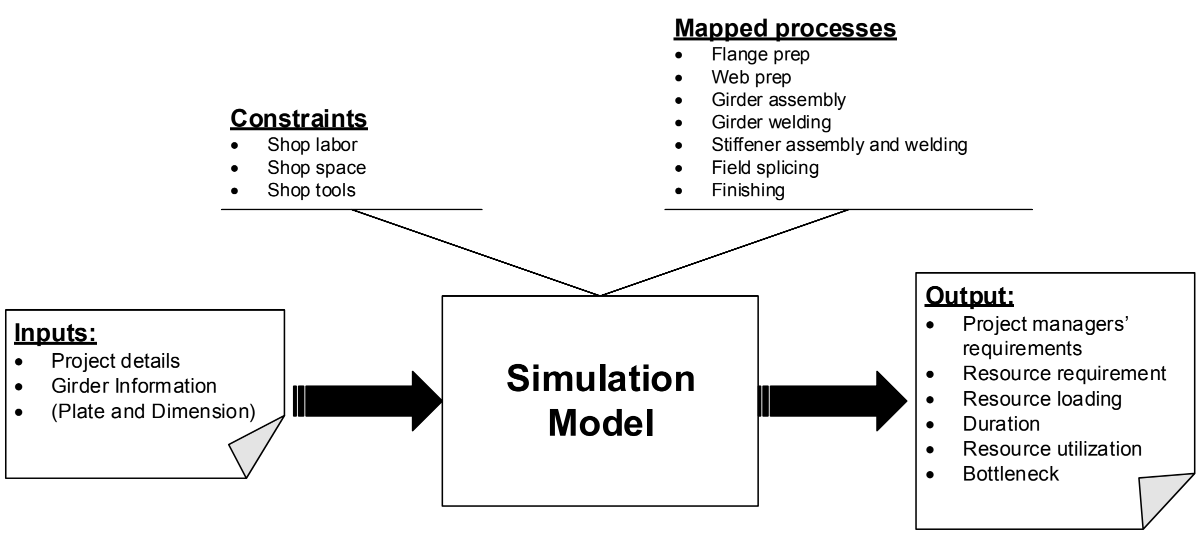

Figure 1. High-level representation of simulation model

The key enabler of the proposed experimental method is the accurate modeling of the actual and complex shop production environment for short-term project planning. The statistical and discrete simulation model is developed based on a three-layer architecture proposed for the shop model. The system has a database layer, an application logic layer, and a user interface layer. The primary consideration in developing this three-layer architecture was to offer users an integrated, collaborative, and user-friendly environment for experimental planning, and to cope with potential alterations to shop configurations and various component models. From another point of view, three sources of information are fed into the simulation model: (1) Mapped processes which needs to performed, (2) Duration of the activities and processes, and (3) Resource constraints of the fabrication shop. The main processes for fabricating a steel girder are flange preparation, web preparation, girder assembly, girder welding, stiffener fitting and welding, field splicing and finishing. Each of these abovementioned processes consists of several internal activities and steps. Durations for each activity inside the processes are derived based on the properties of the product under process. Calibrated regression models were developed by using the company's historical data and subject experts' knowledge which create a meaningful relationship between product features (i.e. girder) and the activity durations. Constraints affecting a projects are also set in three categories of human resources (labors), Equipment and tools, and space. Figure 1 shows the high-level representation of the processing logic and building blocks of the simulation model.

Because the fabrication shop and its processes may be subject to frequent changes, the modeling tool allows a model specialist to modify the shop layout, resources, and the fabrication process easily in order to represent the latest shop configurations. In the context of steel girder fabrication, shop changes are result of differences in the fabricated product. For instance, a project that has fewer flange splices might cause a bottleneck in the welding stations versus a project with high splicing that can result in a bottleneck in the splicing station. The developed model provides simulated results for both scenarios and justifies the solutions for such situations and provides proactive measures versus reacting to project differences. Virtual experiments can be conducted to test the various configurations of production plans to assist in the decision-making process. In the current practice, and even by using the most sophisticated scheduling and estimating methods there is no clear way of knowing the outcomes before performing a task. In other words, simulation provides a proactive approach to scheduling and resource balancing in the steel fabrication shops. In order to provide accurate and reliable feedback to users regarding the system performance, activity durations and labor performance of the actual fabrication shop must be represented properly.

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