

# A PIPE SPOOL FABRICATION SIMULATION MODEL

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## ABSTRACT

When dealing with larger and more complex construction operations, which are more difficult to manage using traditional project management tools, computer simulation methods have shown to be effective in designing and analyzing construction processes, regardless of the complexity or size. A simulation model can be built to describe the construction activities of a scope of work ranging from large, complex industrial projects to a simple room of a small building. Using simulation, engineers can test out different construction scenarios, estimate resource utilization and find bottlenecks, and forecast time and cost requirements without having to go to site. This paper describes the pipe spool fabrication model built at Consolidated Contractors Group (CCC).

Keywords: pipe spool fabrication, discrete event simulation

## 1. INTRODUCTION

On a large industrial project, pipe spool fabrication is a major component of the construction operation. It is also a relatively short term, complex construction process often riddled with uncertainty due to the intrinsic unique nature of its outputs and the numerous factors affecting its activities. As such, it is important for all stakeholders to have a good grasp of the performance of pipe fabrication shops and their ability to meet the site pipe installation schedules. The ability of computer based modeling and simulation to model resource and activity interactions, queuing, and uncertainties renders it a good fit for modeling the pipe spool fabrication process.

## 2. PIPE SPOOL FABRICATION MODEL

### 2.1. Background

Construction contractors on large industrial projects often build one or more project specific pipe fabrication shops to handle the pipe spool fabrication scope. These shops are built to handle a specific set of pipe fabrication activities including cut and bevel, fit-up, welding, QC inspection, post weld heat treatment, non-

destructive testing, and painting. Each of these activities is repeatedly performed by a specific type of crew on pipe spools. Each time it is performed, a crew is utilized for a certain duration and the result is specific progress of a pipe spool along its path to completion. With the large number of spools and their diverse characteristics and resource requirements, forecasting pipe spool fabrication activity completion and optimizing resource allocation and utilization becomes a complex task well suited to computer modeling and simulation.

### 2.2. Simulator Design and Development

The simulator was developed to aid stakeholders in arriving at answers to the issues stated above. The first step was the abstraction of the real world situation into a simulation model representing the operations of a pipe spool fabrication shop, including detailing the product and process definitions for all the main activities. In order to understand the nature of how pipe spool fabrication activities were performed on construction sites, extended visits to multiple mega industrial projects were conducted to observe and document the above mentioned set of activities. Benchmarking for every activity was conducted via numerous observations of the activity being performed on different spools of varying characteristics. Both crew composition information and productivity figures were collected. In this paper we will not deal with the analysis of the observed productivity data; this matter will be dealt with at a different time. Instead, for this paper, we will assume the resulting productivity norms deduced from the observations as our activity productivity norms for the tasks. The simulator was developed as a discrete event simulation model with spools as the main entity. For the welding tasks, welds are the entities - where spools are split into their constituent welds - in order to process welds individually and collect their artificial history.

### 2.3. Product Definitions

Product definition for spools to be processed by the simulator is a straightforward process where only those spool characteristics required for simulating the fabrication activities were specified for each spool. It is

organized into a two-level hierarchy for spools and their relevant joints. Data for spools include spool ID, current spool status, line class, material type, paint code, surface area, and spool specific priority information. Data for joints include weld type, inch-dia, post weld heat treatment (PWHT) requirement and non-destructive testing (NDT) requirements.

Spool ID	Staubs	Material	Paint Code	Surface Area	Priority
A140-A141-B92SL-15139D-S101	3	CS	6D	0.03	180
	2	SB	0.75	0	0
	4	SB	0.75	0	0
	5	SB	0.75	0	0
A140-A141-B92SL-15139D-S102	3	CS	6D	0.01	180
A140-A141-B92SL-15139D-S103	3	CS	6D	0.15	180

Figure 1: Sample Spool-Weld Hierarchy

## 2.4. Process Definitions

For the process definitions we needed to define the activities and flow required to fabricate the different spools. For each activity, the type of resource (crew) required and its relevant productivity had to be identified. For the purpose of this paper, we will only cover the main activities of the pipe spool fabrication process, and not include logistical activities such as crane and trailer operations.

### 2.4.1. Pipe Spool Fabrication Activity Flows

The following three figures are snapshots of the different activities represented in the DES model. For each activity, the required crews and time to perform the activity is decided based on spool characteristics. Figures 2a, 2b, and 2c, below, depict the DES flow of spools through the “Cut,” “Bevel,” and “Fit-up” activities.

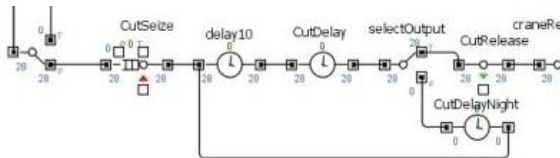


Figure 2a: Cut

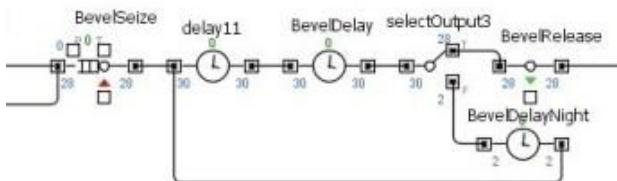


Figure 2b: Bevel

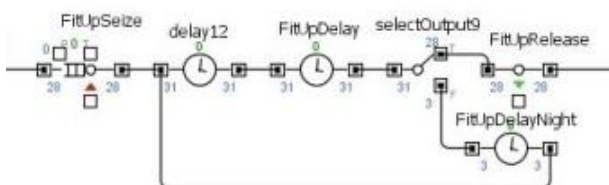


Figure 2c: Fit-up

Figures 3a, 3b, 3c, and 3d depict the DES flow of spools through the welding process. Based on spool configuration, spools are routed either to manual welding stations, or to automatic welding machines. For welding, each spool entity is split into its welding entities, based on the number of shop welds required. Based on spool and weld characteristics, (1) the appropriate number of welders is assigned to each weld, and, accordingly, (2) the weld duration is derived. Splitting the spool entity into weld entities allows us to process welds independently and collect their respective artificial history individually. Once all welds are processed, the weld entities are batched into a spool entity again, which then undergoes “QC Release.” In QC Release a certain fraction of spools, based on norms derived from site observations, is sent back to repair due to defects in the welding process.

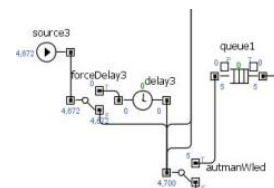


Figure 3a: Routing to Manual or Auto-Welding

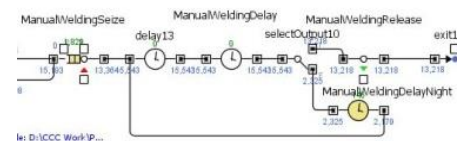


Figure 3b: Welding

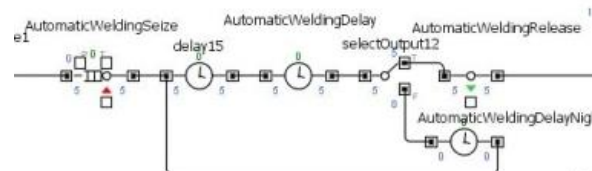


Figure 3c: Auto-Welding

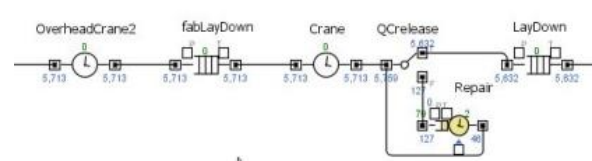


Figure 3d: QC Release

Figure 4 shows the DES flow of spools through the PWHT, NDT and painting activities. Not all spools require PWHT, and not all spools require NDT. The flow and logic control of the model automatically detect this from the spool information and associated tasks are initiated accordingly.

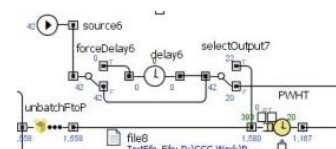


Figure 4a: PWHT

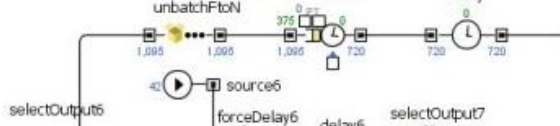


Figure 4b: NDT

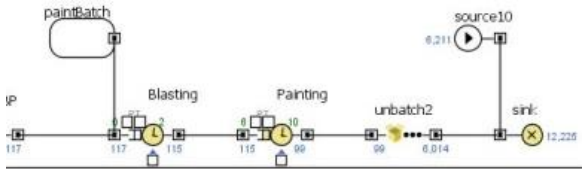


Figure 4c: Painting

**2.4.2. Resource Definitions**

Each of the pipe fabrication activities is associated with a resource type. Each resource type is typically a crew composed of a group of workers required to perform a specific task. Following is a table showing typical crew compositions on a large industrial construction project. Notice that certain worker types are shared amongst the various crew types.

Crew Type	Worker								
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7	Type 8	Type 9
Cut	1	2	1	2					
Bevel		1							
Fit-up		2	2		1	4			
Weld Size 1			1				1		
Weld Size 2			2				2		
PWHT			1					2	
Painting	1	3							4

Figure 5: Typical Crew Compositions

A table showing typical worker availability over time on an industrial project is shown below. Workers available make up the required crews (resources) for the activities which are then captured to simulate the performance of a task on a spool or weld.

Worker Type	Month							
	1	2	3	4	5	6	7	8
1	21	23	25	25	25	25	25	25
2	85	90	95	95	100	100	100	100
3	80	82	85	86	104	104	104	104
5	37	38	40	41	42	42	42	42
6	90	95	100	100	110	110	110	110
7	92	99	112	129	135	135	135	135

Figure 6: Typical Worker Availability Over Time

**2.5. Model Structure**

All the above pieces come together as in the structure shown in the figure below.

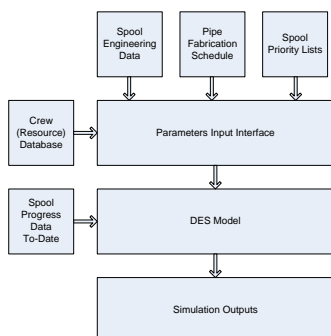


Figure 7: The Overall Model

**2.5.1. Parameters Input Interface**

This module allows the user to define the different parameters of the simulator and run the model. “Spool Engineering Data,” “Pipe Fabrication Schedule,” “Spool Priority Lists” and “Crew Database” feed into the “Parameters Input Interface” module. “Spool Engineering Data” provides engineering characteristics of the spools; “Pipe Fabrication Schedule” and “Spool Priority Lists” provide, respectively, the activity schedule information related to pipe fabrication and the priority lists for spool fabrication requirements produced by the engineers; “Crew Database” provides resource information, namely the number of crews available over time of each crew type. Through the “Parameters Input Interface” the user can change the location of the feed data, assumed productivities for the different tasks, working hours, and fix the number of crews at a constant level throughout the simulation duration instead of reading them from the relevant feed.

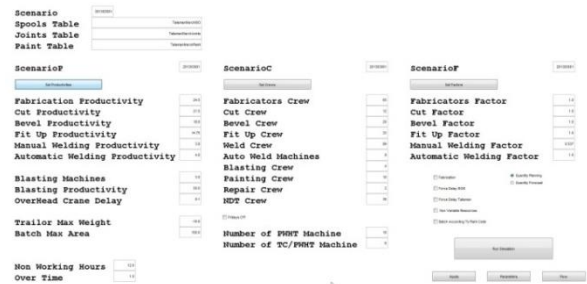


Figure 8: Parameters Input Interface

**2.5.2. Discrete Event Simulation Model**

The discrete event simulation model (DES) carries all the DES flow and logic required for running the simulation model. It includes all the tasks along with their corresponding parameters, resource pool requirements, and duration formulas.



Figure 9: DES Components

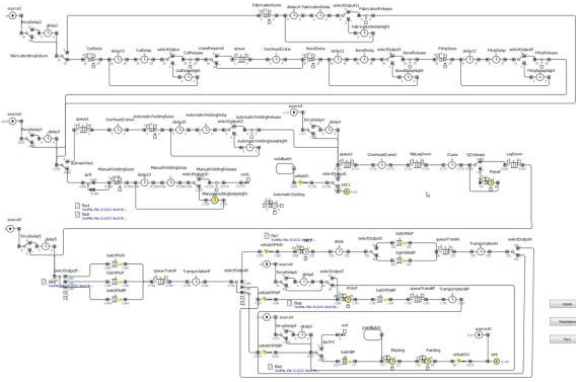


Figure 10: DES Flow

It also receives from the “Spool Progress Data To-Date” the latest spool statuses snapshot which allows it to insert each spool into the DES model at the correct stage through the flow. This enables users to run simulations on existing site data taking into account the current situation of the project.

### 2.5.3. Simulation Outputs

The simulator produces, as its main output, a comprehensive set of data comprised of the artificial history of the simulated pipe fabrication operations. The result set (as in the figure below) contains a record of the activities performed on the corresponding entities (spools or welds) utilizing the required resources. For each entity/activity/resource occurrence, the data contains a start date and time, an end date and time, and a number of resources utilized for the duration.

Scenario #	Spool ID	Weld No	Activity	Start Date and Time	End Date and Time	Resources
1304152	A140-A141-B925L-15139D-S101	2	Welding	03/04/2013 11:01	03/04/2013 11:23	1
1304152	A140-A141-B925L-15139D-S101	4	Welding	03/04/2013 11:01	03/04/2013 11:23	1
1304152	A140-A141-B925L-15139D-S101	5	Welding	03/03/2013 15:01	03/03/2013 15:23	1
1304152	A140-A141-B925L-15139D-S101		Painting	3/14/13 8:00	3/16/13 10:00	1

Figure 11: Sample Simulation Outputs

### 2.6. Verification, Validation, & Accreditation

Credibility of a model which is expected to help manage large industrial construction projects is of utmost importance in order for stakeholders to accept and adopt the model.

In order to verify the model, both unit tests on each of the tasks within the model, and an overall system test were run. Outputs after the tests were compared with expected results based on predetermined inputs and ensured the model and its components were correctly implemented.

Validation of the model was done in two steps. First, the model flow and logic were compared and confirmed against a conceptual model design based on workflows and information collected from actual pipe fabrication operations on large industrial projects. Then, the model was run with historical data from multiple projects and its outputs compared to historical results to ensure the model was behaving as per its design purposes.

Initial informal accreditation was done through a test implementation of the model at a large industrial construction project. Stakeholders gave positive feedback and are employing the simulator to forecast pipe spool fabrication progress based on pre-determined resource availability. Further accreditation of the model within the corporate environment is planned through more implementations on upcoming industrial projects.

## 3. DISCUSSION

### 3.1. Potential Benefits

The pipe spool fabrication model described in this paper provides the stakeholders and end users with a tool which allows them to proactively perform low level resource planning on pipe fabrication activities on large industrial projects. The model is able to run in a predictive mode where no progress on site has been made or in a management mode where progress information for spools is already available and forecasting can be made using existing progress data as a starting point for the model to run. Retrospective running of the model is also possible for change impact assessment or lessons-learned analysis. Simulation model run results include a complete simulated history for each activity/spool(weld)/resource combination with resource and time requirements to be performed. Simulation run results can be analyzed to answer performance questions including, but not limited to: Which of my resources along the flow is acting as a bottleneck in the operation? Which of my resources is under employed? What is the expected resource histogram for the pipe spool fabrication operation to finish on time? With the available resources, how much time will the pipe fabrication operations need to finish? Will my fabrication activities meet my schedule milestones? Will the fabrication activities finish on time for a certain priority sub-area?

### 3.2. Future Work

The pipe spool fabrication model described in this paper is a first step at aiding in the management of pipe spool fabrication operations. Further development and enhancements to this model include:

1. Integration of a material constraint module. The current model assumes drawings and material to be ready and available for pipe spool fabrication to commence. As observed on projects, material availability is sometimes an issue for pipe spool fabrication shops. A simulation model which manages material availability in accordance with spool engineering data and material delivery schedules will potentially add value to the inputs of the current pipe spool fabrication model.
2. The flow of the current model ends once spools are painted (and transported to laydown) and are waiting to be installed on site. A further foreseen development is the

addition of a pipe installation simulation model which covers the pipe spool construction process until the spools are installed in place on site and given final release.

#### 4. CONCLUSION

This paper presented a special purpose discrete event simulation model for managing pipe spool fabrication operations in pipe fabrication shops on industrial projects. The simulation model helps stakeholders manage their activities and perform low level resource planning for all shop pipe spool fabrication activities. The main benefits of the model are (1) predictive analysis of fabrication resource requirements, and (2) managing operations and forecasting resource and time requirements during project execution. Future work includes adding enhancements to the model including a material constraint module and a pipe installation module.

#### ACKNOWLEDGMENTS

The pipe fabrication model described in this paper was developed and implemented at Consolidated Contractors Group (CCC) to aid in estimating, planning and managing pipe fabrication operations on large industrial construction projects.

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