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A FRAMEWORK FOR SIMULATING INDUSTRIAL CONSTRUCTION PROCESSES

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ABSTRACT

In an industrial fabrication shop, such as pipe spool and steel fabrication, a product usually travels in the system in the form of raw materials or components of the product. During the fabrication process, different components are assembled together to fabricate the final product. In this paper, to increase the accuracy of modeling fabrication processes, we propose a platform that can automatically model the raw materials and the assembly process of components of a product based on the unique features of a product. For this purpose, a Special Purpose Simulation (SPS) template for industrial fabrication is developed. The platform is used to develop a simulation based decision support system using a real case study of a pipe spool fabrication shop.

1 INTRODUCTION

The term "industrial construction" is used for construction of facilities for basic industries such as petrochemical plants, nuclear power plants and oil/gas production facilities (Barrie and Paulson 1992). Some parts of industrial construction projects can be processed in the controlled environment of the fabrication shop; however, there is no mass production in industrial fabrication shops, which distinguishes them from the category of job shops (Karumanasseri and AbouRizk 2002).

In industrial fabrication shops, each product is unique and requires specific processes. As a result, the fabrication process is complex and associated with a high amount of uncertainty. This complexity makes it difficult for planners to consider the combined impact of uncertainty of different products and resources and produce a reliable project estimate (Ahuja and Nandakumar 1984). Traditional management methods such as CPM/PERT fail to model the dynamic nature of these complex processes, because they lack certain modeling components such as probabilistic branching, resource interaction, and production cycling (Pritsker 1986). Moreover, most of the developed optimization algorithms (e.g., Hopp and Spearman 1999) are based on static models and highly simplified assumptions (Song et al. 2006).

Simulation has been proposed as an indispensable problem-solving methodology for analyzing complex and uncertain processes such as construction projects (Halpin and Riggs 1992). Researchers widely apply simulation techniques for various industrial and construction processes (Banks 1998; Law and Kelton 2000). Discrete event simulation is a very powerful tool for modeling real life situations and has been successfully used in industrial construction projects in recent years (Mohamed et al. 2007; Wang 2006). To create an accurate simulation model, the physical features of each product should be modeled uniquely. Song et al. (2006) developed a modeling structure in which a unique product/process model is defined for each entity in the simulation model.

Moreover, products in industrial construction are usually decomposed into smaller assemblies to make the fabrication process easier; each assembly may have a number of detailed components. Therefore, each product does not travel in the system as one entity and usually travels as raw materials or different components. Since each entity is unique, the process of assembling and decomposing the elements depends on the entity's unique features. Traditional simulation models assign user-defined ID values to different entities of a product in order to simulate the assembly process (Wang 2006). In this paper, we propose the Work Breakdown Structure (WBS) of a Product Model (Song et al. 2006) for modeling the assembly process. This approach can generate the raw material entities for a product, based on the product's unique features. It is also capable of automatically assembling the entities to generate a component or the final product. This approach is illustrated through an actual case study of a pipe spool fabrication process.

2 BACKGROUND

Pipe spool modules are used in developing modular construction units in refineries and oil-processing plants (Mohamed et al. 2007). The piping process involves drafting, material procurement and supply, shop fabrication including pipe spools and steel pieces, module assembly in the yard, and module installation on site. This process is very complicated and is associated with many uncertainties (Wang 2006).

The main activities for fabricating spools in a fabrication shop are cutting, fitting, and welding. Each spool is composed of a number of pipes and fittings that are welded together. The pipes are cut to their required size in a cutting station. They are then tagged together (fitted) and welded at each joint. Quality control can be done at any stage of the process. Some of the spools may need hydro-testing, Post Weld Heat Treatment (PWHT), or painting depending on the required specifications from the owner. The welding process includes roll welding and position welding. In roll welding, the pipe is welded by means of a roll welding machine (positioner machine) (Figure 1(a)). Position welding is used when the pipe has long legs and can not be roll welded (Figure 1(b)). Since the process of position welding is much slower compared to roll welding, fabricators try to find the sequence of steps that maximize roll welding and minimize position welding for each spool. Each spool is composed of a number of assemblies that can be fabricated only by a roll welding process. Different assemblies are then position welded to build the complete spool (Figure 1(c)). A spool may go back and forth a number of times between roll welding and position welding before it is complete.

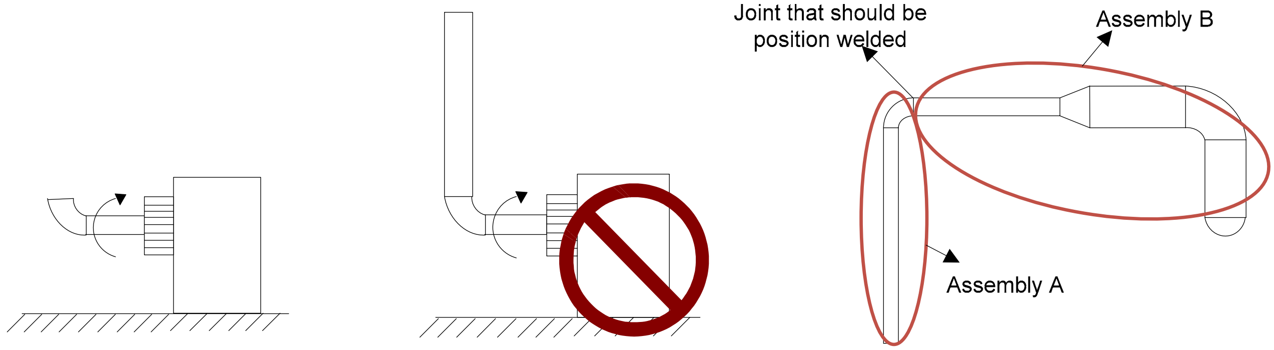

Figure1: a) Rolling a spool in a positioner machine, b) A long spool not fitting in a positioner machine, c) Assembly components of a spool

3 MODELING APPROACH

In this research, we provide a platform for industrial fabrication processes. This platform extends the function of the virtual shop modeling approach by Song et al. (2006) in order to model the flow of raw materials and components of a product as individual entities in a simulation model.

Song et al. (2006) suggested a "virtual shop modeling system" to model the unique characteristics of each product entity in a simulation model. In their approach, a Product Model (PM) is defined for each entity that includes its physical features and its Work Breakdown Structure (WBS) features. An example of a PM of a spool is shown in Figure 2. Each part or component of a product can be represented by a node in the WBS.

During the fabrication of a product, some processes are performed on the raw materials, which are at the lowest level in the PM of an entity. Raw materials are then assembled together to produce higher level components, and this process continues until the final product is produced. For example, in the spool fabrication process, the cutting machine works on the pipe level (level 3 in Figure 2), roll welding is done on the assemblies (level 2 in Figure 2), the process of position welding takes place on the spool level (level 1 in Figure 2), and material handling can takes place at any level of the WBS of a spool. Different components of a spool can flow in a simulation model as different entities, so when a process requires a specific level in the WBS, the entity should be sent to the required level. Therefore, a level of the WBS can be assigned to each process.

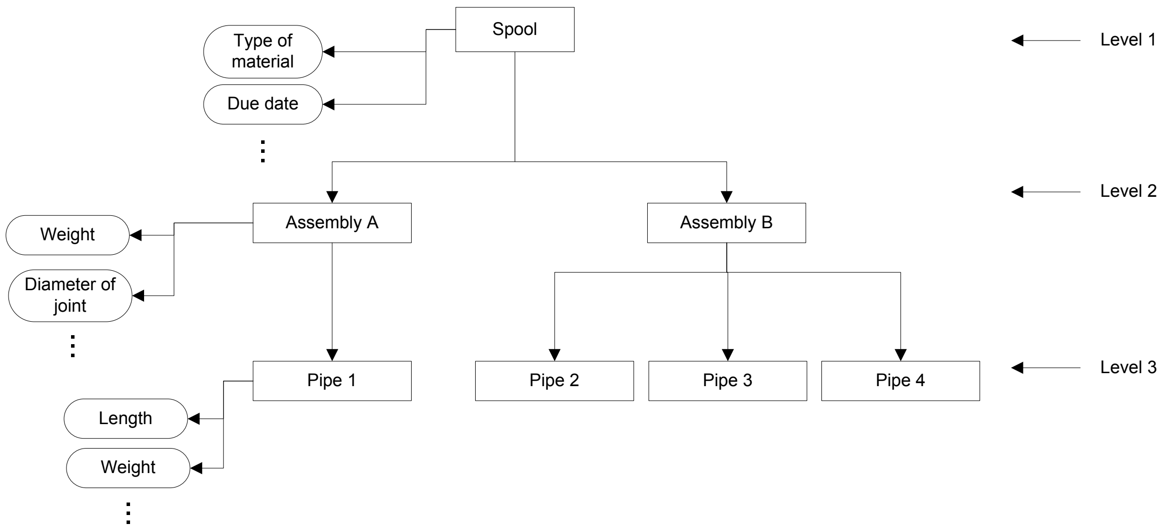

Figure 2: Product model including physical and WBS features

In our proposed methodology, raw materials or entity components of a product represent a node in the WBS and have access to the entire PM. Since the entities that exist in a simulation model at the same time should be mutually exclusive, they can not be ancestors or descendants of another entity in the WBS. For example, for a spool with a product model of Figure 2, we can have 4 entities representing "pipe 2", "pipe 3", "pipe 4", and "assembly A" in a simulation model, but it is not possible to have "pipe 3" and "assembly B" at the same time in a model.

A level of WBS is assigned to each process in the simulation. Before an entity starts a process, the level of WBS is adjusted to the required level of that process. A "level adjusting" element is designed to assemble the entities based on their WBS automatically (Figure 3). For assembling an entity to an ancestor component, the level adjusting element checks the required components for the assembly process using the WBS of the entity. The entity waits until all the components arrive to the element, and the assembly process proceeds afterwards.

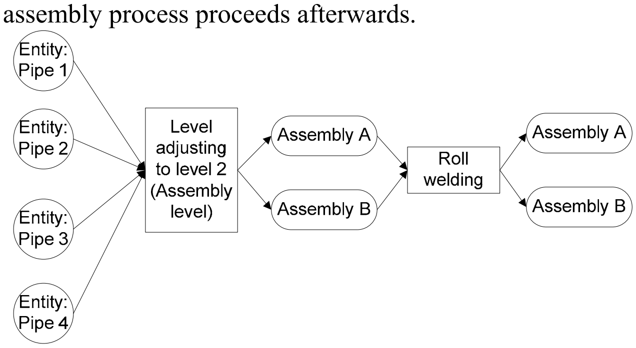

Figure 3: Level adjusting element: assembling an entity

To produce the raw materials at the start of the simulation, an element first generates each product and its PM and sends it to the level adjusting element to immediately decompose it to the lowest level of its WBS. Figure 4 shows how the level adjusting element decomposes an entity to its raw materials.

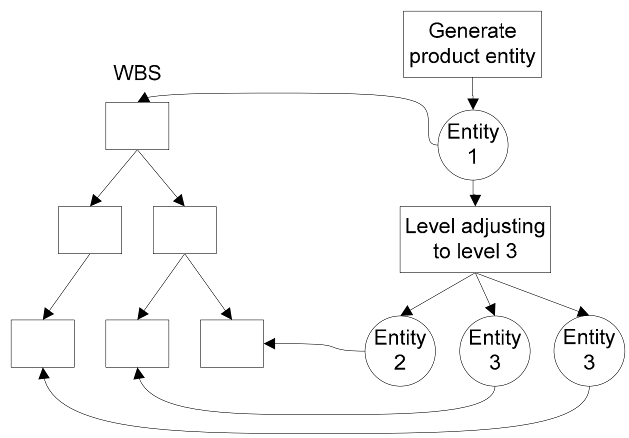

Figure 4: Decomposing an entity to its raw materials

4 CASE STUDY: SIMULATION BASED DECISION SUPPORT SYSTEM

The proposed methodology is used to develop a simulation based decision support model for an actual case study of a pipe spool fabrication shop. The model is capable of estimating the production and bottlenecks of the shop. Also, it is possible to use the model to explore different if-then scenarios to determine possible improvements in the shop. The developed model integrates a VB program with a discrete event simulation model.

4.1 Simulation Model

Simphony is an integrated simulation environment for building Special Purpose Simulation (SPS) templates (Hajjar and AbouRizk 2002). SPS templates allow an expert who is not necessarily knowledgeable in simulation, to easily model a project using visual modeling tools. It provides a high degree of similarity to the actual construction process in a specific domain (AbouRizk and Hajjar 1998).

A SPS template in Simphony was developed to model the pipe spool fabrication process of an industrial construction contractor in Alberta. Job characteristics are captured in the form of probabilistic values, and the "spool generator" element generates the spool's PM based on those characteristics. Simphony provides the capability of assigning different attributes to an entity. This feature has been used to assign a unique PM to each entity. The rest of the elements that have been developed for this model are as follows:

- Fabrication shop: The parent element of all elements in the fabrication shop. The period for running the simulation model such as day, month or week and the working hours of one shift per period are the inputs of this element. The element collects statistics such as Production per period.
- Station: Represents a station that is doing a specific fabrication process such as cutting, fitting, or welding. Different types of stations are considered for each process based on the size and specifications of the entities. For example, for welding process, large, medium long and position welding stations are considered. Number of each type of station, and type and required amount of resources are the inputs of this element. The outputs are statistics such as production, utilization and waiting hours for the station.
- Level adjusting: Before processing an entity in a station, a "level adjusting" element adjusts the level of the entity to the required WBS level of its PM.
- Next station: This element decides on the next appropriate station for an entity based on the entity's physical features and the characteristics of the station. For example if a component is long and needs to be welded, this element sends the component to the long welding station.
- Material handling: This element models the process of handling materials within or in/out of the shop. The element decides whether the material requires an overhead crane or not form the characteristics of the entity and its level in the WBS.
- Worker: This element represents different types of workers (i.e. cutter, welder, fitter), their skill level and working shift (day or night shift).
- Overhead crane: This element represents the overhead cranes in the shop that are used for handling heavy materials.
- Waiting file: The entities will wait in this element until they receive their required resources or matching pieces for the assembly process.

Since most of listed elements are common between different industrial fabrication processes, we have developed the SPS template in a general form usable for various industrial fabrication applications. For example, any type of station can be modeled with the station element by determining its input parameters such as duration and the required resources.

For modeling the duration of processes, probabilistic distributions can be used to represent the variation of durations (Law and Kelton 2000.). These variations, which are a result of uncertain factors about the environment and product features, are appropriate if their range is not too wide. The duration of the material handling process is modeled using this approach. Since the duration of processes such as cutting, fitting, and welding are highly affected by the spool features and the workers' experience, we tried to reduce the uncertainty and increase the reliability of the project by considering the knowledge about the workers and the spool features (AbouRizk and Sawhney 1993) In our proposed model, the duration of these processes is estimated by accounting for three factors:

1. Amount of work units of each spool: The amount of work that is required for each spool is estimated based on the characteristics of the joints such as diameter and type of weld.
2. Historical productivity: Probabilistic distributions of the productivity (amount of work per manhour) of different types of stations are derived from historical data.
3. Workers: The number of workers at each station and their skill level are considered. The skill level of a worker plays an important factor in the duration of a process, as a skillful worker can weld up to twice as fast as a novice worker.

4.2 User Interface of Simulation Model

A Visual Basic (VB) application has been developed to control the input to the simulation model, making its use more readily accepted by industry practitioners (Figure 5). The user can enter the historical data, and see the simulation results in the interface. Since the layout is not fixed in the fabrication shop, the user can change the site layout as well as the job characteristics and resource specifications through the user interface. This feature also provides the capability of experimenting with different if-then scenario to come up with the best possible site layout. The user can also update resource specifications such as productivity factor and number of workers. The VB program analyzes the simulation results and highlights the bottlenecks and underused resources in the interface (Figure 5). This analysis is based on statistics that are captured for different resources: If the waiting hours for a specific resource are relatively high, that resource is highlighted as a bottleneck. The utilization percentage is used for recognizing underused resources.

The VB program was delivered to the project managers of the fabrication shop. For the validation purpose, they run the developed model for various weeks and compared the results of the model with the actual shop production, available from the historical data. The results of the validation were completely satisfactory to the users and very close to the actual production experienced by the fabrication shop, with less than 5% error.

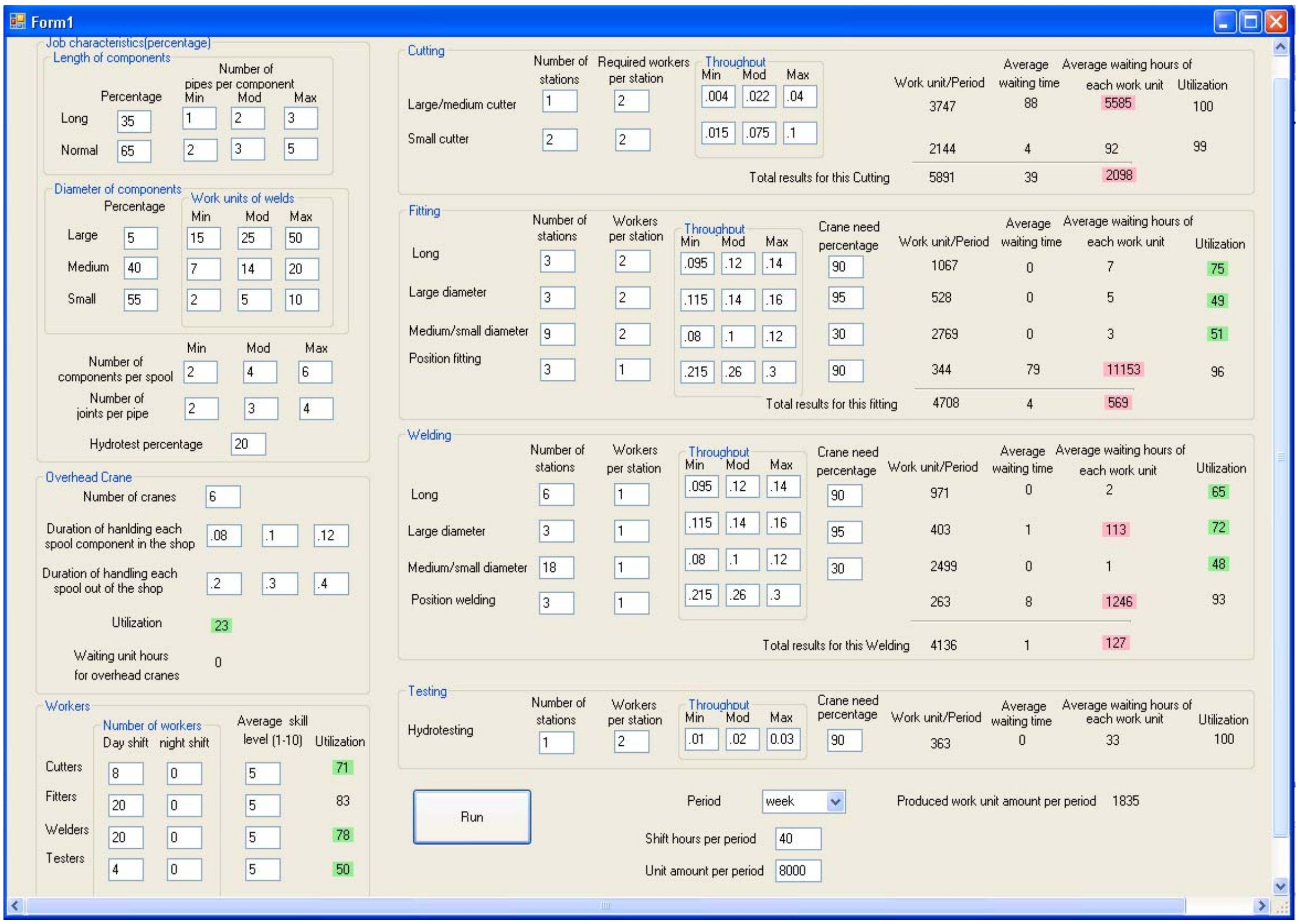

Figure 5: User interface for simulation model developed in Visual Basic

5 CONCLUSION

In this paper, we have developed a platform for simulating industrial fabrication processes, which is capable of simulating a process to the level of raw materials and components of a product. Previous simulation models assign user-defined ID values to the entities to model the assembly process during fabrication. We have proposed the use of a WBS of a Product Model to model the assembly process. This methodology allows the assignment of different levels of WBS to different processes. A node in the WBS is assigned to each entity, and a level adjusting element is designed that can automatically assemble or decompose the entities to the required level of each process. This approach has been implemented using an actual case study to develop a simulation based decision support system for a pipe spool fabrication shop. The results show that the method is practical and useful. A SPS template that can be used for any industrial fabrication process has been developed in Simphony. This platform provides a detailed and practical approach for modeling the complexities in industrial fabrication projects.

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