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INCORPORATING CONTEXT LEVEL VARIABLES TO IMPROVE OPERATION ANALYSIS IN STEEL FABRICATION SHOPS

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ABSTRACT: Construction system modeling can enhance work performance by following the behaviors of a system. System behaviors may originate from physical aspects of a system, namely operation level variables, or from non-physical aspects of a system known as context level variables. However, construction system modelers usually focus on only one type of system variable (i.e., operation level or context level) which can lead to less accurate results. Hybrid modeling with System Dynamics (SD) and Discrete Event Simulation (DES) is one of the approaches that has been utilized to address this issue. In this research, an SD-DES hybrid model of a steel fabrication shop is developed, and the benefits of capturing context level variables together with operation level variables in the model are discussed.

Keywords: Construction management; Hybrid methods; Feedback control; Steel; Fabrication

1. INTRODUCTION

Construction systems are influenced by operation level and context level variables over the system life cycle, while these system variables interact with each other and evolve as a result of feedback interactions (in which the current condition of one component affects itself later on in the system life cycle) and sequential interactions (which are interactions that follow only one direction, while interacting components are not impacted later on by their previous conditions).

Operation level variables are the variables whose values can be determined by measuring the physical and tangible aspects of a system component, such as dimensions, weight, speed, and capacity. Some examples of operation variables include work duration, number of workers, capacity of rail cars, and travel speed of a truck. On the other hand, context level variables are variables that originate from non-physical aspects of the system, such as organization and human behavior. Worker skill level, worker fatigue level, and organizational policies are some examples of context level variables in a system.

Because of their more tangible influences on construction systems, construction system analysts tend to simplify the modeling process by only capturing the effects of operation level variables and their sequential interactions. However, without considering the effects of feedback between the context level and operation level variables within a system, the complicated behaviors of construction systems cannot be properly captured, especially over the long-term life cycle of the system. In an effort to address this issue, new approaches based on hybrid System Dynamics (SD) and Discrete Event Simulation (DES) have been developed to model systems since the late 1990s and early 2000s [1] [2] [3].

ACCORDING TO THE MIT SYSTEM DYNAMICS IN EDUCATION PROJECT DEFINITION, "SD DEALS WITH THE INTERNAL FEEDBACK LOOPS AND TIME DELAYS THAT AFFECT THE BEHAVIOR OF THE ENTIRE SYSTEM"

(http://sysdyn.clexchange.org). In the SD modeling approach, every single system behavior is considered to be an effect of one or several causes. As well, every cause is an effect of other causes. This series of causes and effects usually result in long woven chains of causes and effects which form feedback loops. The causes and effects might stay at either the context or operation level of a system. The validity of SD models has been challenged with the argument that they lack the ability to capture the physical structure and operation details of systems [5].

On the other hand, DES attempts to mimic the system's behavior as it evolves over time by tracking the system's changes as separate events. DES models usually stay at the operation level of the system and follow the detailed physical structure of the system. Sequential interactions, such as sending and receiving semi-products from one operation to another, are a main component of DES-based models. There are also feedback interactions, such as different types of controlling or inspecting stations, which can be captured with DES models. However, DES does not have the capacity to capture the mutual effects between the context and operation level variables of a system.

SD-DES hybrid modeling approaches aim to combine the complementary modeling parts of SD and DES so that the respective weaknesses of each tool are remedied. By utilizing an SD-DES hybrid model, it is expected that both the physical details of the system and the interactions between the context and operation level can be captured. Thus, the hybrid model more thoroughly reflects reality and can provide more accurate analyses for decision makers in the construction industry.

In this paper, the necessity of incorporating context and operation variables and their mutual interactions is discussed using a fabrication shop as an example. An SD-DES hybrid model, which utilizes the complementary capabilities of SD and DES, is proposed to be used for capturing the effects of both context and operation level variables. As well, at the end of the paper, two cases of hybrid SD and DES hybrid models are explained and discussed to illustrate some benefits of the hybrid modeling approach.

2. STEEL FABRICATION SHOP

There are two main phases in structural steel construction projects: (1) steel fabrication and (2) structural steel erection. A fabrication shop is specifically set up equipments for building shippable structural steel pieces for the job site. The fabricated steel pieces are then erected at the job site. The mobilization of efficient operating equipments to job sites adds too much cost to steel construction projects. Therefore, fabrication shops are used to speed up the entire process of steel construction and to reduce the final cost of projects by setting up a synchronized set of efficient steel fabricating equipments at a shop.

The steel materials purchased for steel construction projects are sent to the material yards located close to the fabrication shop. According to the scheduled fabrication plan, raw steel materials are delivered from material yards to the fabrication shop where different types of cutting machines perform the determined cutting jobs on the raw materials. The cut materials are then sent to the fitting stations to be temporarily fitted together according to the design drawn for the steel pieces. The steel pieces usually consist of a main body of steel beams which have different components attached to them. The fitting stations are classified based on the different sizes of structural steel, namely small, medium, and heavy duty. The fitting stations have different classes according to the assigned equipments and area. After that, the fitted pieces are sent to the related welding stations.

At the welding stations, the temporary fitted components are completely welded and permanently set. All welded pieces go to the inspection stations to be inspected and are fixed if they have any visible flaws. The pieces might require painting before they are prepared to be sent to the field. If so, the welded pieces are sent to the painting station to be painted. After that, the fabricated pieces are ready to be shipped to the field.

3. HYBRID MODEL OF STEEL FABRICATION SHOP

While the fabrication shop operations make up the first phase of structural steel construction, any deficiencies in this phase will subsequently affect the erection phase. One steel fabrication shop usually serves multiple projects at a time. Moreover, structural steel construction projects generally require thousands of fabricated steel pieces which should be erected in ordered sequences. Modeling a fabrication shop system enables fabrication shop managers to keep track of fabrication shop performance according to the set fabrication schedule. As well, the effects of changes occurring in the fabrication shop system (e.g., material shortages and equipment breakdown) can be followed up on. Therefore, modeling fabrication shop systems can support fabrication shop managers in crucial decision making, providing them with a tool to examine the effects alternative decisions have on the fabrication shop.

Furthermore, the more thoroughly a model can capture reality, the more accurate its results will be, which will lead to more effective decision making. The SD-DES hybrid modeling approach has been utilized for capturing the sequential and feedback interactions between fabrication shop system components at both the operation and context level. The hybrid model developed here follows the hybrid architecture proposed by Alvanchi et al. [4]. The programming component of the model has been coded by Visual Basic.Net 2008 and the program reads required data (e.g., schedules and specifications of the pieces) from a customized MS Access 2007.

The communication architecture of the fabrication shop hybrid model is based on the High Level Architecture (HLA). HLA is a framework for developing distributed simulation modeling introduced by the United States Department of Defense in the 1990s [6]. An HLA-based framework recently developed by a construction engineering and management group at the University of Alberta (UA), known as Construction Synthetic Environment (COSYE) distributed simulation package (http://irc.construction.ualberta.ca/cosye/), has been used during hybrid model development.

Users can easily customize the developed fabrication shop model for different steel fabrication shops. The number of cutting, fitting, welding, inspecting, and painting stations is easily determined in the fabrication shop DES form (Fig. 1). There are also different forms provided to enable users to customize mid-buffers and material movers (see Figs. 2 and 3).

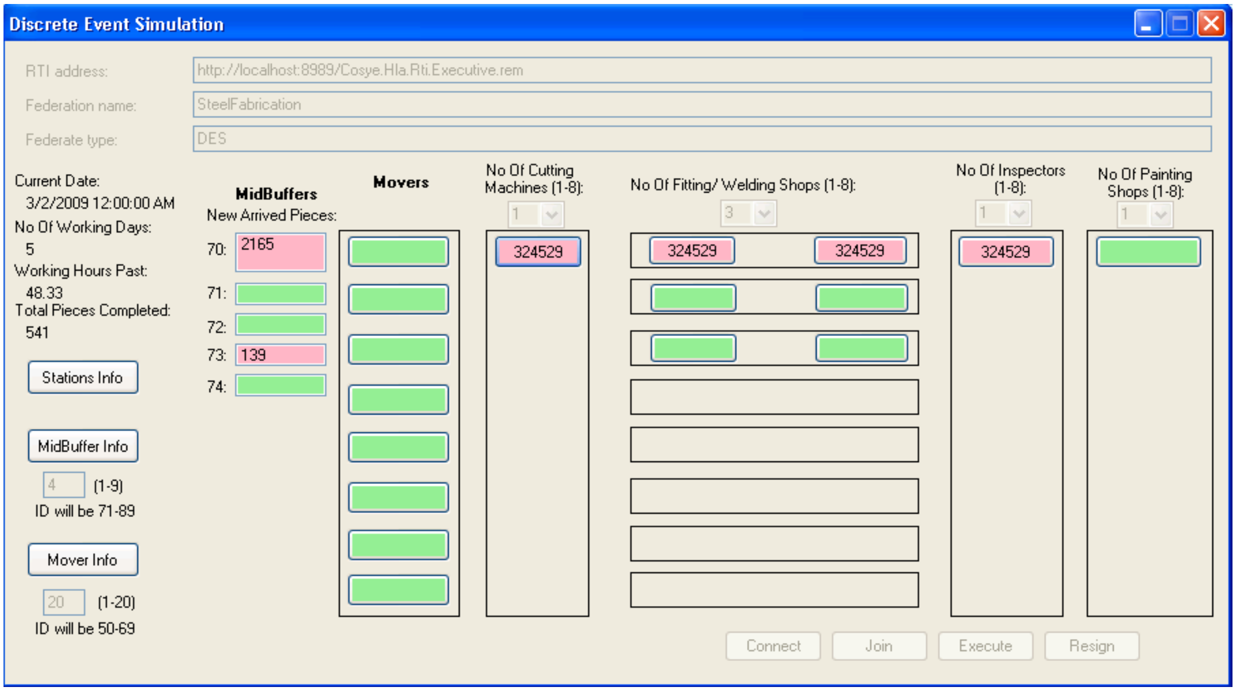

Fig. 1. Main form for setting a fabrication shop's physical specifications

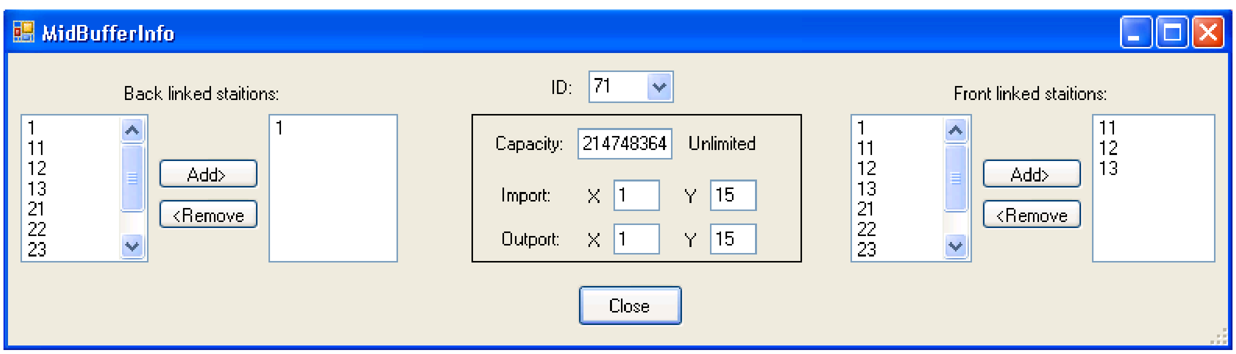

Fig. 2. Form for setting the mid-buffers information

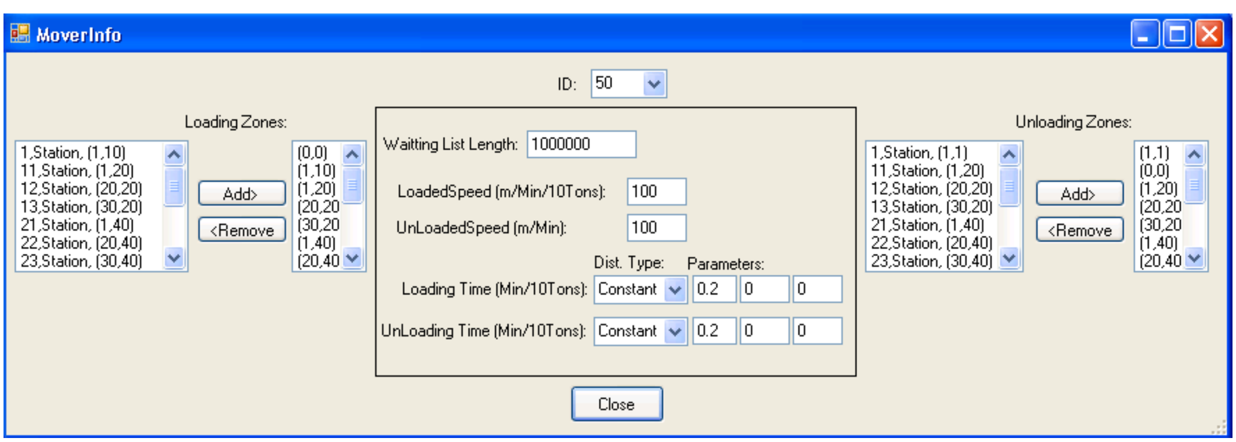

Fig. 3. Form for setting the movers information

4. TWO CASES OF HYBRID MODELS

The fabrication shop contains many physical details regarding the layout of the shop, the capacity and production rate of the equipment, and the job sequences. DES is the proper modeling tool to capture the physical details of fabrication shops. However, there are also various non-physical effective factors within the shop (e.g., operator skill level and fatigue, and shop managers' policies for balancing the work loads at the shop) that DES is unable to capture. Yet, by using an SD based modeling tool (i.e., following the causes and effects and forming the causal feedback loops), the effects of these factors can be modeled. Multiple SD based modeling parts were explored using the fabrication shop and were linked to the DES model. Two of these parts are described in detail as follows.

To capture the effects of changes in skill level within the shop, a main causal feedback loop was examined (see Fig. 4). While the shop floor initially has a certain number of skilled and unskilled operators, the combination of skilled and unskilled operators evolves over time. As time passes, unskilled operators become skilled. In our built model, there is a 60 day delay set for an unskilled operator to become skilled. As well, new operators are hired and there is a chance that operators will leave the company. Operators hired/leaving also alter the level of skill at the shop floor. Hiring operators is the effect of the work load which is measured by delay to the scheduled delivery times and utilization of the operating stations.

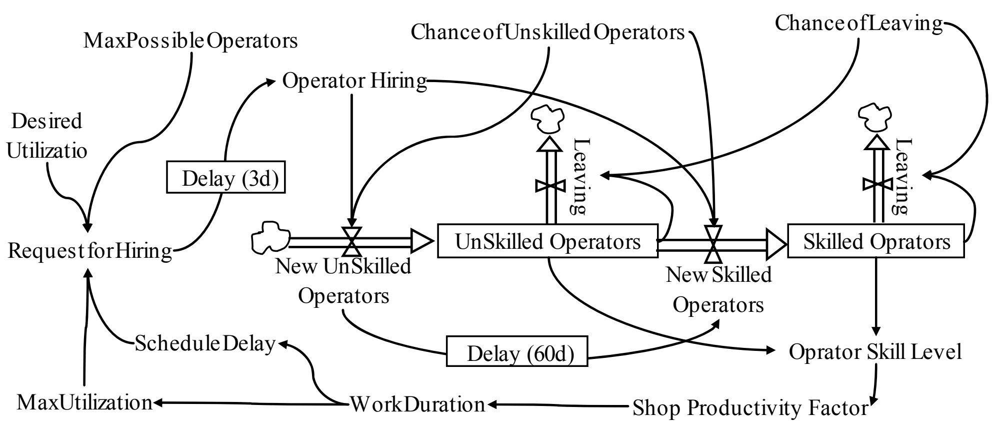

Fig. 4. SD model part which captures the effect of changes in skill level

Furthermore, the skill level of the operators sets the shop productivity factor and adjusts the duration of the assigned jobs at the stations. The shorter the work duration, the less delay and station utilization will be achieved. Considering the effects of these changes on the DES model of the fabrication shop, shop productivity is the main interacting variable between SD part to DES part of fabrication shop model. The durations of the assigned jobs at different stations in the DES model are set based on the latest received productivity from the SD model. On the other hand, schedule delay and utilizations are calculated according to the achieved results from the DES model and are sent to the SD model.

Another developed SD model was built in this research to capture the effects of the policies of fabrication shop managers in regard to exchanging operators among different stations. Shop managers attempt to balance the work loads of different stations within the fabrication shop. Whenever a certain station is experiencing a high volume of work while another station with similar functionalities has plenty of idle time, a shop manager will decide to move some operators from the latter to the former station. This operator balancing policy can be modeled with an SD model (Fig. 5). The illustrated model controls every group of stations with the same functionalities (e.g., welding group or fitting group stations).

There is a set desired utilization for the stations within the fabrication shop. Shop managers keep track of utilization rates at different stations over time. If for a period of time the maximum utilization of stations within one group is greater than the desired utilization, and the minimum utilization is smaller than the desired utilization and this difference is meaningful (e.g., more than 10%), the operator exchange occurs. Operator exchanges affect the rate of performing the job at the participating stations and alter work duration. The number of operators is set in the SD model and sent to the DES model. On the other hand, the utilization rate of the stations is the main output from the DES model to be used in the SD model.

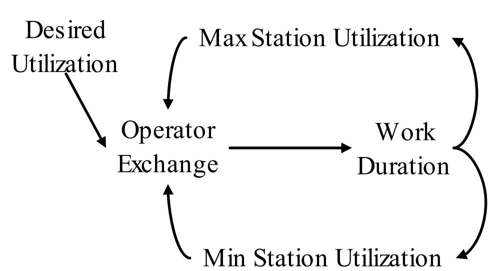

Fig. 5. SD model part for capturing the operator balancing policy

The two SD-DES hybrid models described above are both considerably effective in terms of capturing more parts of reality. While changes in operator skill level occur over a long period of time (e.g., more than 2 months), considering the effects of these changes enables more accurate modeling of fabrication shop behavior over the long-term. However, operator balancing occurs more often (e.g., daily) within the fabrication shop, and its related hybrid model can more efficiently represent the fabrication shop system even for a shorter period of time.

For example, in a fabrication shop that has recently employed many new operators, the skill level of the operators will be low for several months of work (e.g., 70%). Then, as the months pass, these operators will become skilled and the skill level will increase (e.g. 90%), which can cause significant changes in the duration of the assigned works (e.g., around 20-30%). The operator balancing policy can also have a significant impact on the delivery time of steel pieces, as applying this policy results in critical stations being recognized and rectified.

Conversely, by missing the effects of skill level or the operator balancing policy, various critical changes within the fabrication shop—such as the shop productivity in terms of skill level and number of operators at each station—are ignored. Sometimes the effects of ignoring such changes result in incorporated inaccuracy being drastically increased and the developed model becoming useless.

5. CONCLUSIONS

In addition to operation level variables, there are also context level variables that change during the system life cycle and affect construction systems' behaviors. Hybrid modeling integrating SD and DES is one approach that can assist model developers in capturing the effects of both operation and context level variables and the feedback interactions among them. By using the steel fabrication shop as an example, a few of the potential benefits of incorporating context and operation variables in a unique hybrid model have been explained. In our future research efforts, we plan on extending the hybrid simulation to the entire steel construction process, including field work and supportive services such as shipping and material handling.

Ultimately, the hybrid modeling approach discussed here is applicable to a wide range of construction based systems, particularly when the system involves efforts originating from both humans and physical equipment. Whereas system analysts tend to select one type of simulation approach, it is highly recommended that hybrid modeling be considered as an effective alternative modeling approach.

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