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MEANINGFUL LEVEL OF CHANGE IN HYBRID SIMULATION FOR CONSTRUCTION ANALYSIS

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ABSTRACT

Hybrid models of System Dynamics (SD) and Discrete Event Simulation (DES) in the construction industry aim to provide decision makers with more accurate analysis. However, there are certain issues that can limit the applicability of SD-DES hybrid models for real construction job situations. Meaningful Level of Change (MLC) is a concept that has been proposed to prevent the time advancing issue in the hybrid models used within the construction domain. It is claimed that by utilizing the MLC, the running time of hybrid simulation models can be reduced while only slightly contributing to model inaccuracy. In this paper, we investigate the effects of utilizing the MLC for SD-DES hybrid models used for construction systems. First, the theoretical aspects of applying the MLC in hybrid models are investigated. Second, the effects of using different set values of MLC in an experimental model of a real construction system are illustrated.

1 INTRODUCTION

Hybrid models of System Dynamics (SD) and Discrete Event Simulation (DES) attempt to capture more parts of reality by combining two different system modeling tools (i.e., SD and DES) (Lee et al. 2007). However, the difference between SD and DES modeling tools raises some challenging issues (Alvanchi et al. 2009). One of these issues results from the fundamental difference between the ways that SD and DES advance time. While SD continuously follows the system behavior over time and selects an even step for its time progress, DES follows the uneven time steps based on the prescheduled time of system events.

The difference in the time advancement approaches of SD and DES may cause situations in which the simulation runs are computationally overloaded, which subsequently drastically increases the simulation time. The Meaningful Level of Change (MLC) (Alvanchi et al. 2009) concept has been introduced to address the computational issue in such situations. The MLC is intended to keep the accuracy of simulation results at a reasonable level, according to the accepted level of changes, while significantly decreasing the running time of simulation. Different values can be set for MLCs of different interacting variables in an SD-DES hybrid model. However, the effects that different chosen values for the MLC, or the accepted level of inaccuracy for interacting variables, have on the final simulation results have not yet been thoroughly considered.

To address this issue, the current paper aims at investigating how selecting different values for the MLC could affect the prospective results of hybrid simulation. The paper consists of the following 4 sections: (1) the essence of the MLC concept; (2) the theoretical acting mechanism of the MLC; (3) experiencing the effects of different values for the MLC in a simplified hybrid model of a real steel fabrication shop; and (4) brief conclusion.

2 COMPUTATIONAL PROBLEM OF TIME PROGRESS IN HYBRID MODELS

The fundamental difference between the SD and DES simulation time advancing methods (i.e., the continuous method of time advancing in SD and the discrete time advancing method in DES) is the source of potential deficiencies during hybrid simulation runs. SD simulation models are categorized as continuous simulation models. However, the implementation of SD computer simulation is not actually continuous, but instead follows evenly set time advancing steps. The set time advancing step should be small enough to be able to capture all significant changes within the system, but should not be so small that it only counts the time and delays the simulation runs without any expected significant changes in the system. For example, if an SD model keeps track of labor hiring/ firing, a time step of a second will waste the time of the simulation runs, as it can easily be assumed that any factors that affect labor hiring/ firing will not exhibit critical changes within such a short increment of time.

The time of a DES model is changed based on the prescheduled events that usually follow uneven steps. The progress method in DES originates from the fact that we can follow system behavior over time by following the system's states over time. Every significant change in the system state is called an event. A DES model of a system can be developed when the deterministic or probabilistic time distances between occurrences of all possible types of events can be determined by knowing the occurrence time of a set of initial events. The time advances in a DES model by changing the current time to the time of the event that has an occurrence time closest to the current time. After the occurrence of each event, all related events—which have happenings that can be determined by the occurrence of the occurred event—are scheduled and listed to occur sequentially in the future.

The potential computational problem in SD-DES hybrid models is raised when a variable in an SD modeling part interacts with a variable in the DES part that sets the duration time between event occurrences. If the time step in the SD modeling part is significantly (e.g., ten times) less than the duration time of the event occurrence in the DES part, before an event occurs in the DES part of the model, the interacting variables will interact with each other multiple times. As a result of any changes initiated by the SD part, not only are the values of the interact receiver in the DES part being changed, but the scheduled events that are related to the interact receiver variable of the DES part should also be found and withdrawn from the list of the scheduled events, calculated by a new set value of variables, and finally rescheduled and added to the future event list. This consequent series of changes will add too many calculations to the hybrid model, specifically when this process is going to happen numerous times before the occurrence of next scheduled events.

3 MEANINGFUL LEVEL OF CHANGE (MLC)

In the literature, two different approaches can be found that try to reduce the number of interactions and thus decrease the negative effects of the time advancing issue. One of these approaches considers adapting criteria for SD time steps, based on the fourth-order Runge-Kutta method, to adjust the length of time steps according to the chronological rates of change (Fehlberg 1970). Proposed by Venkateswaran et al. (2004), the other approach limits all required data exchanges among different SD and DES parts within the SD-DES hybrid models to the set time intervals.

The adjusted time steps in the first approach are based on the recent trend of the changes in the SD part, which will reduce the number of null interactions (i.e., the interactions that send the same value as the previously sent value). However, if the interacting variables in the SD part are changed at every short time interval, this approach cannot help in improving the simulation time. On the other hand, by adjusting the length of time steps based on the chronological rates of change, there is a possibility that the unexpected fluctuations of the SD variables over a short period of time will be neglected.

In the second approach, the SD and DES model parts work separately according to their regular solving methods, and a time step is set for the data exchanges among the different parts. The set time step in this approach should be big enough to cause no interruptions to the DES parts due to sent interactions from the SD parts. On the other hand, the time step should be small enough to be able to capture all significant changes within the SD model parts. While the system behavior and rate of the changes in different parts of the system may vary during the system life cycle, by setting a constant time step for hybrid interactions among different model parts, this approach may not efficiently capture all hybrid interactions during the system life cycle.

To address the time advancing issue while eliminating the undesired side effects, a concept called the Meaningful Level of Change (MLC) is utilized in the hybrid models for construction analysis (Alvanchi et al. 2009). This concept suggests setting a meaningful level of change for interacting variables in the SD parts that may cause the time advancing issue. By setting the MLC for a variable, the achieved changes for that variable that are less than the set MLC are assumed to be trivial and are consequently not reported to the interacting parts of the model. For example, when there is a set MLC of 1% for the skill level variable, as an interacting variable from an SD part, and the last reported skill level is 80%, the new skill level is reported if its value crosses 79% or 81%. However, construction related models, especially in the SD parts, usually deal with many approximately estimated variables, such as skill level, productivity level, fatigue level and safety level. Taking this into account, putting a limit on the variable updates (i.e., setting the MLC) will not have a significant influence on the quality of the provided analyses.

The MLC concept has the same role as the thresholds in quantization based filtering in distributed discrete event simulation discussed by Zeigler et al. (2002). However, the quantization approach is used to reduce the number of interactions within a distributed DES model rather than an SD-DES hybrid model. Zetigler et al. (2002) have thoroughly discussed the benefits that can be achieved for the distributed DES models in terms of simulation time by using the thresholds and quantization based filtering. By applying the MLC concept, it is also expected that we can enhance hybrid simulation models by reducing their simulation time while accepting some inaccuracies; to visualize this, a comparison with an unlimitedly interacting hybrid model, namely the base hybrid model, is conducted.

4 ESTIMATING EFFECTS OF SET MLC ON FINAL RESULTS

By setting the MLC for an interacting variable in the SD part, we are accepting a level of inaccuracy. But what are the main influencing factors that contribute to lessened accuracy in the final simulation results? The immediate and apparent influencing factor is that the higher the value set for the MLC, the more inaccuracy in the final results. This means that by increasing the set MLC value for an interacting variable, the number of crossings will be reduced and, consequently, the number of initiated interactions by that variable will be decreased. An increase of the MLC will also make the interaction receiving parts blind to the variable changes within a broader range of variable changes, which will result in the simulation results having a lower level of accuracy.

The effect of the changes at the MLC value is not the same at different interacting variables, although the significance level of the variable participation in the hybrid model also plays a main role. Within a hybrid model, the effects of changes in the model variables are captured through different formulas that represent different aspects of the system behaviors over time. The significance level of the variable participation can be defined based on: 1) the importance of the system behaviors that the variable participates in and their related formulas; 2) the range of values that a variable can have; and 3) the places that the variable stays at in the formulas (e.g., multiplicand, addend, base or exponent at exponentiation, and numerator or denominator in a fraction). An example for estimating the effects of the MLC on the final simulation results is discussed in the next section.

5 EXPERIMENTAL CASE

To test the effects of using the MLC concept on a real hybrid model, a simplified experimental case of an actual structural steel fabrication shop is used. Through this case study, we examine the effects of setting different values for the MLCs of variables, which can result in the time advancing issue, on the final simulation results.

5.1 Interacting Variables

Variables that come from either the SD or DES model parts may initiate or receive hybrid interactions. However, the MLC will be set only for some of the interaction initiator variables in the SD parts which usually have significantly faster updating rates than the related interaction receiver variables in the DES part. According to the comparison conducted for the rate of updates, station productivity was found to be one of the variables that may cause the time advancing issue for the fabrication shop hybrid model. The station productivity variable is set based on the shop productivity factor and station utilization. The more utilization of a station, the more fatigue will occur for the station operators, which results in less station productivity being achieved. The utilization of a station is equal to the busy portion of the station during the working day and is actively changed at any set time step. In our model, the set time step is one second and, correspondingly, the station productivity is changed at every second.

Station productivity, which is set in the SD model part, participates in the operation duration formula, which is used in the DES model part. Usually, operation duration within the fabrication shop exceeds several minutes. This affirms that in the base hybrid model of the fabrication shop, where there is no MLC concept used for the model, the duration of each single operation will be changed hundreds of times before the operation is finished. According to the explanation of the time advancing issue, this will be a potential point for creating the time advancing issue and a value is set for the MLC of the station productivity variable.

5.2 Analyzing the Effects of Set MLC for Station Productivity

To obtain an estimation of the expected changes in the final results, according to the set values for the MLC, an assessment is conducted based on the three steps introduced in Section 4.

1. Importance of the related system behaviors: Station productivity sets the operation duration at each station, which defines the main behavior of the fabrication shop system. No duration for the station operations means that there is no work to be done and this station becomes practically closed. However, it should be considered that station productivity sets the productivity at each station, not the entire fabrication shop. Taking the total number of n stations within the fabrication shop into account, the importance of each single station falls to the one nth (1/n) for the fabrication shop.

2. Station productivity is measured based on a percentage. Theoretically, this variable can be any real number greater than zero. However, in real job situations, receiving productivity values less than 50% and greater that 150% is rare.
3. Role of station productivity in the operation duration formula: operation duration is related to the two main factors: (1) the volume of the job and (2) the rate of doing the job.

$$SOD = \frac{VJ}{RDJ}$$

Where:
SOD = Station Operation Duration
VJ = Volume of the Job
RDJ = Rate of Doing the Job

Station productivity contributes in the rate of doing the job. However, there are different factors that set the rate of doing the job, as presented in the following formula:

$$RDJ = NRRJN \times ENOS \times POTI \times SP$$

Where:
RDJ= Rate of Doing the Job at Each Station
NRRJN = Normal Rate Related to the Job Nature
ENOS = Effect of Number of Operators at the Station
POTI = Percentage of Over Time Increase
SP = Station Productivity

While station productivity is a multiplicand factor in the operation duration formula, the created inaccuracy is directly transferred to the duration. For example, if the MLC is set at 2%, real station productivity is 98% and last reported productivity is 97%, and the duration will face 1% of inaccuracy. As a result, for our specific problem, the expected maximum inaccuracy for the duration of the fabrication shop jobs is equal to the set MLC value, but considering the existing randomness in the model, it is also possible that for the limited number of observations, the final results will also show higher inaccuracy. However, there are usually several other factors that urge the final inaccuracy to a lower level than the set MLC.

For example, when the MLC is set at 2%, an approximately 2% inaccuracy will be achieved only in the cases in which the current productivity always has a difference of approximately 2% with the last reported productivity. But in the real model runs, the current productivity will usually yield different values, in both negative and positive directions, within the set MLC interval, which will reduce the final inaccuracy. As well, as there are multiple stations in the fabrication shop, there is a slight probability that all unreported productivity variations (because of the set MLC) will have the same direction of inaccuracy. However, inaccuracies pointing in different directions push the system to a more balanced situation.

5.3 Experiencing the Effects of Set MLC for Station Productivity

To visualize the real effects of MLC changes on the final simulation results, different modeling scenarios with different MLC values of 1%, 2%, 3%, 5% and 10% were set and run in the hybrid simulation model of a fabrication shop. The achieved results from different scenarios were compared among themselves and to the base hybrid model (i.e., the hybrid model in which no MLC is set and all changes to station productivity are reported regardless of their significance). Three months of material feeds (from January 20, 2009 to April 20, 2009) from the fabrication shop were simulated for each model. During this period, the steel materials were fed through the steel fabrication shop at the scheduled date to pass cutting, fitting, welding and painting operations. The simulation runs were completed after all of the fed materials were fabricated and prepared to be shipped to the field.

Two types of comparison were conducted for this research. The first test was performed to compare the total duration for fabricating all the fed materials at the fabrication shop. The second test was conducted to assess how the MLC concept affects the simulation time. Figure 1 shows the comparative achieved results for the duration of the steel fabrication at the specified period of material feeds, while Figure 2 presents the simulation time of different runs. The presented results for each class are based on five runs of hybrid model simulation. While obtaining a more rigorous conclusion for the conducted experiments requires a greater number of simulation runs, during this experiment, we aim to perform a preliminary investigation in order to determine visual trends of applying the MLC to hybrid model outputs.

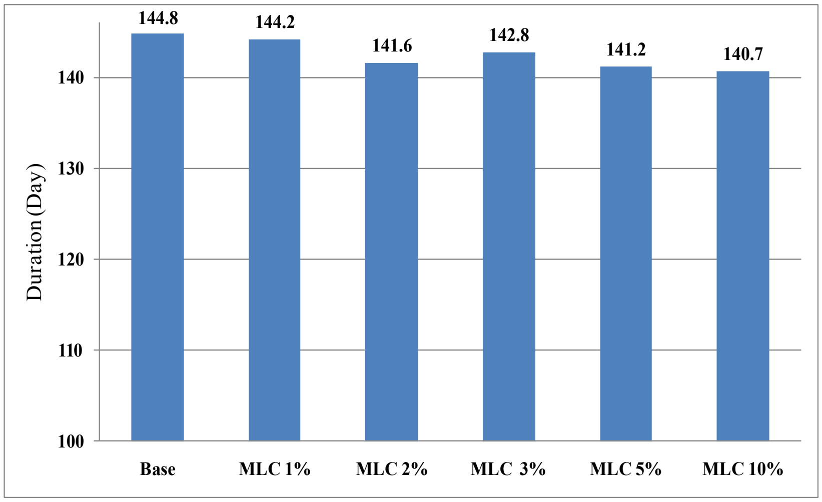

Figure 1: Comparative results for the fabrication duration of different scenarios

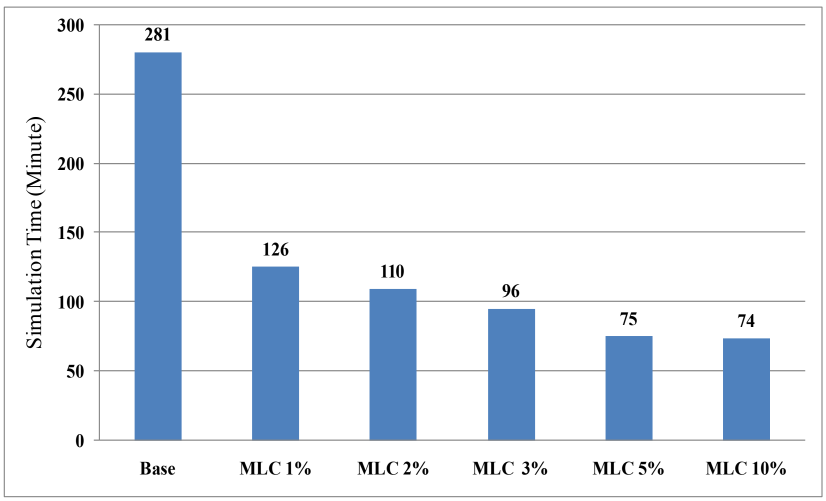

Figure 2: Simulation time of different scenarios

In Figure 1, the achieved results for the duration time of steel fabrication show that the inaccuracy goes up by increasing the value of the MLC. All inaccuracies stay within the set MLC; the only exception is the MLC of 2%, as its difference with the base model goes up to 2.2%. This case can be explained based on the limited number of runs (i.e., five runs for each scenario). What is significant about the achieved results for the fabrication durations is that all of the MLC scenarios have shorter duration than the achieved duration of the base hybrid model. This demonstrates that during the operation of the stations, the reported productivities have had a higher level than the real productivities, which has caused shorter durations for each single operation and consequently for the fabrication shop duration. In other words, the productivity changes have usually followed the declining direction. The declining direction for productivity during operation results from operators' fatigue and the station experiencing a busy time. However, growth in productivity usually occurs during the idle time of stations, which does not have any effect on the work duration (because there is no job to be done at that time).

Figure 2 presents the expected simulation time reduction by using the MLC concept. The simulation time shows a significant reduction in MLC based models compared to the base hybrid model. The trend of the results shows that by increasing the value of the MLC, a shorter simulation time is attained.

The comparisons conducted illustrate two different aspects of the set MLC values. The lesser the value selected for the MLC, the lesser accepted inaccuracy will be achieved, but with a greater simulation time. In the developed hybrid model, the MLC concept has been applied for one interacting variable (i.e., station productivity) and its inaccuracy is directly transferred to the work duration (see section 5.2). Consequently, the set value for the MLC will stay at the upper limit of the expected inaccuracy. In this case, it is suggested that the MLC value be set to the maximum acceptable inaccuracy level for the output results to get the shortest possible simulation time while staying within the acceptable level of inaccuracy. For example, if the maximum acceptable inaccuracy is 5%, the suggested MLC value for station productivity will be 5%.

6 CONCLUSION

The MLC concept is proposed as a solution for the existing time advancing issue in SD-DES hybrid models. It is claimed that the MLC is capable of considerably reducing the simulation time with insignificant effects on the accuracy of the final results. This paper assesses the theoretical and practical aspects of using the MLC in SD-DES hybrid models by applying the concept to a simplified hybrid model of a real steel fabrication shop. At this stage of the research, we have focused on investigating the trends of the achieved results. In future, a rigorous assessment with a greater number of simulation runs and a more detailed hybrid model will be conducted.

The trend of the results shows that using the MLC can increase the speed of SD-DES hybrid simulation. The significance of the effects of different set MLCs on the final results depends on the significance of the effects of their related variables. Thus, it is recommended that before setting values of MLCs, their effects first be theoretically estimated at the final simulation results. By considering the possible effects of any chosen value and by preventing the occurrence of a high level of inaccuracy, such theoretical investigations can build the confidence of model developers.

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