



Automated post-simulation visualization of modular building production assembly line

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ABSTRACT

Simulation is often used to model production processes with the aim of understanding and improving them. In many cases, however, information produced by simulation is not detailed enough and can be misinterpreted. The use of visualization in combination with simulation can provide project participants with a detailed-level model to prevent misinterpretation of information and to understand the production process. The purpose of this research is to automate the visualization process as a post-simulation tool through sharing interactive information between simulation and visualization. The proposed methodology has been applied to the production line of modular buildings with the output of lean, simulation, and visualization in the form of animation. Based on the new scheduling developed by applying lean principles, a simulation model was built and its output was extracted to an ASCII file to be used as input for visualization. 3D visualization was developed using Maxscript in 3D Studio Max for automation of the visualization process. The proposed methodology has been applied to a case study to illustrate the essential features of the work and its benefits for decision making.

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1. Introduction

Modular buildings are pre-fabricated buildings that started to gain popularity in the early 20th century. The Modular Building Institute (MBI), founded in 1983, defines modular as a construction method or process where individual modules, stand-alone or assembled together, make up larger structures. Even though revenue growth in the modular building industry has recently dropped, it remains a market with increasing benefits.

The modular building industry is also becoming more widely recognized for its environmentally-friendly construction process, speed of construction, and waste reduction at cost competitive prices [1]. Further improvement of productivity and potential cost reduction can be gained by redesigning the production process, facility layout, and material handling. Previous research has shown that various disciplines including lean [2,3], simulation, or integrated systems are used to set stable and effective production flow. A combination of these principles has also been used for such purpose; see [5–7].

Computer simulation is defined by Pritsker [8] as the process of designing a mathematical-logical model of a real world system and experimenting with the model on a computer. It can be used to eliminate unforeseen bottlenecks, to effectively use resources, and to optimize system performance before an existing system is altered by the proposed

design. There are many existing simulation tools that have been developed and used in construction. Symphony [9], used in this research, is an example of such tools. Symphony was developed under the Natural Science and Engineering Research Council (NSERC)/Alberta Construction Industry Research Chair Program in Construction Engineering and Management. It can be used either as a general purpose or a special purpose simulation (SPS) tool.

Parallel to the use of simulation several researchers and planners in recent years have focused their work on using 3D visualization in the fields of construction management, productivity and cost analysis, resource management, and assessment of site layout [7–9]. Based on their work, it has been found that 3D visualization provides more realistic and clear feedback of the simulation output and dynamic graphical depictions. These include features such as the state of each task at a specific time, the work space required for construction activities, and clear communication about the work with the project participants.

2. Problem description

Based on lean principles, and in particular the use of Value Stream Mapping (VSM), many researchers such as Haitao Yu [2], Roberto J. Arbulu and Iris D. Tommelein [3], and Ping Wang [4] have developed stable and effective production flow in fabrication shops for improvement of productivity and reduction of cost. These various efforts have not yet seen fullscale success. Although lean production using VSM is a powerful concept for designing a new schedule for

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continuous material and production flow, workforce management, and balance of subtasks on the production line, the proposed design needs to be continuously adjusted and changed until the developer's purposes are obtained. Implementing changes on a real production line without prior validation can be risky, costly, and time-consuming. Alternatively computer simulation can be used as an environment for validating the proposed design. It is an efficient and cost-effective tool to experiment with the potential performance of the proposed design before applying it to a real production line.

Despite its advantages however, simulation describes an abstraction of reality and for many users is difficult to understand on its own. Visualization of simulated construction processes can help in analyzing and communicating simulation results to assist in the decision making process. The use of dynamic graphical depictions in visualization can show the simulated operations as they would be in reality. The main differences between simulation and visualization can be summarized as follows:

- (1) Construction participants who have no simulation knowledge cannot fully understand the simulation results and process flow because it's provided in numerical and logical computation. 3D visualization, on the other hand, creates smooth and natural scenes for quick and easy understanding.
- (2) In a simulation model, the workspace requirement and limitation in production processes is not provided. However, in 3D visualization geometric information such as coordination of all components is provided to identify workspace.
- (3) A simulation model focuses only on a target object's movement. On the other hand, every level of detail of the construction activities can be described in visualization. For example, the only movement in a simulation model could be related to modules on the manufactured production line, but in visualization, all components such as employees, conduit, door, FRP, exterior board, and crane in the production line can be shown and animated.
- (4) In the simulation model, users cannot easily identify errors in the logic of the schedule. However, 3D visualization can provide scheduling animation while animation of all components is running. So, the errors in the schedule can be identified.

3. Proposed methodology

To achieve the objective of this research, two challenges needed to be addressed: 1) how to share information whereby output data from simulation is used as input parameters for visualization and 2) how to reset the animation key frames of the 3D objects and import the simulated input data to the 3D visualization as the output data of the simulation model changes.

The proposed research methodology shown in Fig. 1 is categorized by three distinct phases which are the lean VSM model, simulation, and visualization. The input parameters of VSM as a lean production tool contain information such as the current scheduling, transfer time, subtask process time, and cycle time for stations. Based on the current production process, a VSM is produced. Usually a production manager will study the VSM model produced to analyze the production process as a system and find out where the real problems and wastes are to suggest improvements. To improve the production processes, a proposed system is then suggested based on continuous production flow and takt time, which is related to waste reduction. The focus is on developing an improved future production process to meet customer demands for the products. The takt time is calculated by dividing the net available production time data for a specific period by the customer demand for the same time period. Based on this calculation, the new proposed schedule is drawn. The criteria for the new VSM are takt time and scheduling. The output of the VSM represents the proposed improved scheduling for the production line.

Following the process described above, two simulation models are generated based on the original schedule and the proposed schedule represented by the two VSM models. Both simulation models are built in Symphony with the required data consisting of transfer time, subtask process time, and scheduling. Before building the simulation models, the process times of subtasks are converted to probability distribution functions. The cycle time statistic of the production line, generated from the original and future state simulation models, can be compared in order to validate the proposed scheduling improvement of the production processes. The input information required for the simulation includes the original and proposed schedules and process times for activities at each station. The output from simulation consists of the modular cycle time statistic and the ASCII file. The ASCII file which includes start times and finish times for subtasks and travel times between stations, is a unique file that imports the simulation result into 3D Studio Max. The data in the ASCII file is automatically extracted and stored in a Microsoft Access 2007 database. The generation of the ASCII text file is key to automating the visualization process based on the simulation model.

A 3D visualization model is then built using modular component specification, scheduling fitted in the simulation model, transfer time, 3D components, 3D production modular, and the ASCII file. The proposed scheduling and the ASCII file are criteria input data for the 3D visualization. In particular, the ASCII file is used to simply set or reset animation frame keys of the 3D objects and 3D scheduling chart between their process time points for real movement of components without any reworks in the visualization model. To animate the 3D objects in 3D Studio Max, the Maxscript shown in Fig. 2 is used in this research. Maxscript is a built-in language tool to automate repetitive tasks, to combine existing functionality in new ways, and to develop user interfaces. Therefore, the setup of animation key frames using Maxscript is implemented only once eliminating the need to redesign the Maxscript code when the data in ASCII file is changed due to changes in the simulation outputs. The output of the 3D visualization involves a virtual reality model with a 3D scheduling chart. The 3D scheduling charts are animate subtask bars between specific times, while components related to the tasks are animated simultaneously. The virtual reality model in combination with the 3D scheduling chart is able to effectively validate various assumptions such as the proposed scheduling and requirement and limitation of work space.

4. System architecture

This work builds on a previous work by Haitao Yu [10], who proposed an improved manufacturing production line based on lean using VSM. In this work, simulation is used to validate and verify the results of the proposed model. In addition a 3D visualization model is built to generate the dynamic graphical depiction to assist decision makers in understanding detailed information of the manufactured production line. This information includes the limitation and requirement of workspace and the current state of the production process. It is believed that a combination of lean, simulation, and visualization provides decision makers with a better understanding of the proposed operation and helps to predict the performance resulting from alternative decisions.

To achieve the objectives described above, a system database has been developed to store all the information needed for building Value Stream Mapping (VSM), simulation, and visualization. Fig. 3 shows the architecture of the proposed system. The central database comprises five elements: 3D object libraries designated for modular components, scheduling, component specification, time data, and ASCII file. The time data contains the following information: (1) list of activities, (2) transfer time between each station, (3) start time and finish time of activities, and (4) cycle time. The schedules are managed based on number of employees required for operations at every subtask and prioritized subtasks that must be performed within a set period of time in

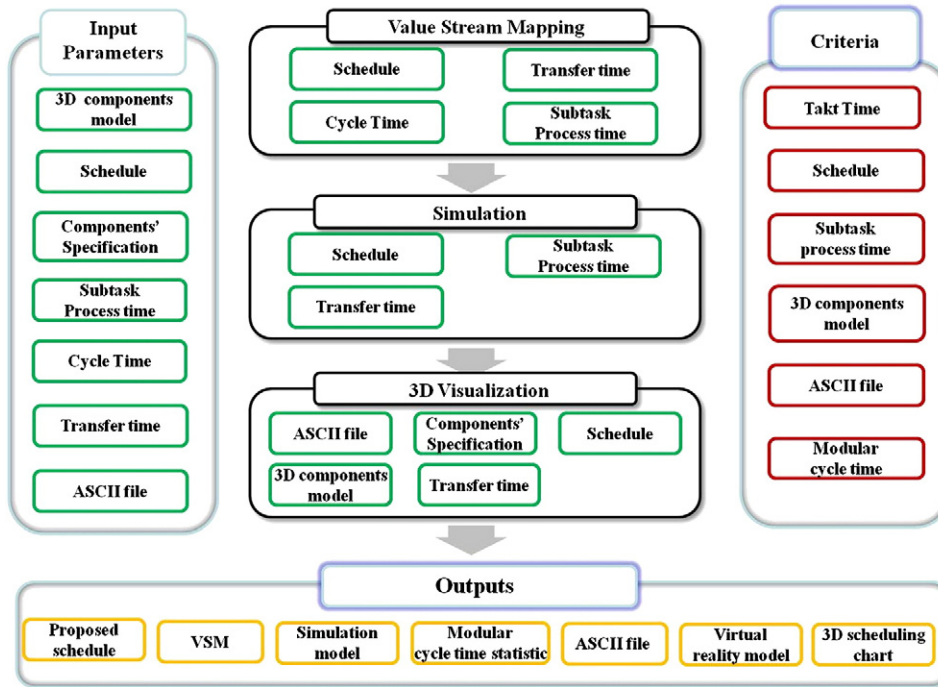


Fig. 1. Main research process.

the production line. There are two types of scheduling: one is based on the old production process and the other is based on the proposed new production process. The VSM, simulation, and 3D visualization share the information stored in the system database and their results.

A main feature of the system is the generation of an ASCII file from the output of the simulation model. The ASCII file represents the link for sharing information between the simulation and the visualization. The simulation model is built to simulate the manufacturing process of modular units. The input data is extracted from the simulation

model to an ASCII file for developing a 3D visualization model based on the results of the simulation. This file is imported to a log file, produced using a built-in language in the 3D visualization environment. The log file consists of an operation window which loads input data to a reality 3D model, simply sets animation frame keys of 3D objects, and controls the animation such as play, stop, and animation speed.

5. Simulation and 3D visualization approaches

In this research, simulation models for manufactured production processes are built in order to describe, experiment, and compare two systems using the enhanced common template in the Symphony environment. Symphony's common template is a general-purpose simulation (GPS) tool for discrete-event simulation.

The critical issue in this step is how output data in simulation can be automatically extracted to the ASCII file to be used to build the 3D animation of production processes in a 3D visualization environment, even when the output data from the simulation is changed. To address this, the “Collect” element in Symphony was designed and developed to connect Symphony as a simulation tool and 3D Studio Max as a 3D visualization tool. It automatically extracts and saves input data for 3D visualization to Microsoft Access 2007. The data in Access is then converted to the ASCII file using Microsoft Excel 2007. In the ASCII file, identification numbers for activities, start time and finish time of activities, are simply updated in Excel even if data from simulation is changed. After simulating the two systems, the original and the proposed system, the results based on productivity and cycle time of production line are compared for validation. A sensitivity analysis is used for this purpose.

To implement 3D visualization based on the output from simulation, two issues needed to be addressed. First, the output of simulation should be effectively conveyed in the 3D visualization environment. This is solved through the generation of the ASCII file explained above. 3D objects to describe the detailed production process are generated and animated between specific times. A time distribution plan is developed to smoothly animate 3D objects. The way this is done is described in the next section. The 3D objects are

```

C5 for station3_1.ms - MAXScript
File Edit Search Debugger Help
|
animate on
(
    disablesceneredraw()

    -- install FRP right 1
    at time FRPtime2[1] rotate c5[2] (quat 0 z_axis)
    at time FRPtime2[1] rotate c5[3] (quat 0 z_axis)
    at time FRPtime2[1] rotate L5 (quat 0 z_axis)
    at time FRPtime2[1] rotate R5 (quat 0 z_axis)
    at time FRPtime2[1] biped.settransform C5[1] #rotation (quat -180 z_axis) true
    at time FRPtime2[1] biped.settransform C5[1] #pos [5.609,4.021,0.248] true
    at time FRPtime2[1] biped.settransform C5[2] #pos [5.641,4.132,-0.578] true
    at time FRPtime2[1] biped.settransform C5[3] #pos [5.659,3.879,-0.578] true
    at time FRPtime2[1] biped.settransform C5[4] #pos [5.4,3.781,0.48] true
    at time FRPtime2[1] biped.settransform C5[5] #pos [5.2,4.361,1.5] true

    at time FRPtime2[2] rotate c5[2] (quat -90 z_axis)
    at time FRPtime2[2] rotate c5[3] (quat -90 z_axis)
    at time FRPtime2[2] biped.settransform C5[1] #rotation (quat -140 z_axis) true
    at time FRPtime2[2] biped.settransform C5[1] #pos [5.6,4.021,0.248] true
    at time FRPtime2[2] biped.settransform C5[2] #pos [5.7,4.132,-0.578] true
    at time FRPtime2[2] biped.settransform C5[3] #pos [5.4,3.879,-0.578] true
    at time FRPtime2[2] biped.settransform C5[4] #pos [5.419,3.919,0.503] true
    at time FRPtime2[2] biped.settransform C5[5] #pos [5.435,4.347,0.953] true

    at time FRPtime2[3] biped.settransform C5[1] #pos [5.6,4.621,0.248] true
    at time FRPtime2[3] biped.settransform C5[2] #pos [5.7,4.132,-0.578] true
    at time FRPtime2[3] biped.settransform C5[3] #pos [5.4,4.721,-0.578] true
    at time FRPtime2[3] biped.settransform C5[4] #pos [5.419,4.519,0.503] true
    at time FRPtime2[3] biped.settransform C5[5] #pos [5.435,4.947,0.953] true

    at time FRPtime2[4] biped.settransform C5[1] #pos [5.8,5.221,0.248] true
    at time FRPtime2[4] biped.settransform C5[2] #pos [5.9,5.332,-0.578] true
    at time FRPtime2[4] biped.settransform C5[3] #pos [5.6,4.721,-0.578] true
    at time FRPtime2[4] biped.settransform C5[4] #pos [5.619,5.119,0.503] true
    at time FRPtime2[4] biped.settransform C5[5] #pos [5.635,5.547,0.953] true
    )
    
```

Fig. 2. Maxscript format.

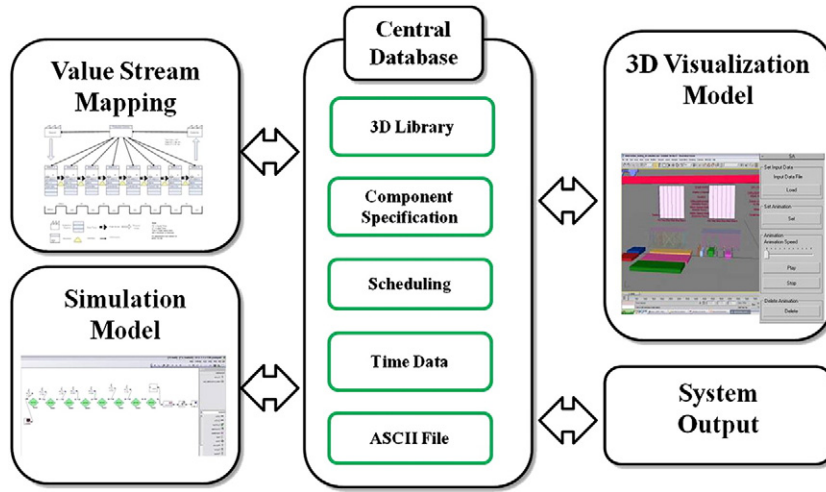


Fig. 3. System architecture.

built using AutoCAD and 3D animation is developed using 3D Studio Max (3DS).

Before creating 3D animation, it is important to understand the relationship between simulation and visualization time to be able to define key frames of sub-activities for 3D objects at desired points on a timeline of 3DS (Fig. 4). The simulation model shows high level descriptions of the activities such as start times and end times of operations. However, the visualization model needs to provide detailed operations of each activity based on specifications and other data. For example, in the visualization model, if the process time for installation of interior gypsum board in equipment room in Station 2 is 300 min, the simulation model shows only that the start time of installation is 0 min and the end time is 300 min. The visualization model describes all sub-activities involved in the installation of the interior gypsum boards, such as operators delivering sources to destination location, installing, moving back to source location, climbing ladders and using the drill.

To build animation of 3D objects in 3DS, key frames are required since 3D objects are animated between the key frames designated on the

timeline. In the animation, many sub-activities of the 3D objects will be required to describe the detailed production process. Movement and installation are animated between the key frames based on the sub-activities frames. The sub-activities of each task except installation are animated between consistencies times which are the sub-activity frames. The frame for one sub-activity of each task is calculated using the following equation:

$$\text{A sub - activity frame} = \frac{M \times 30}{N}$$

where:

- M = end time for the task – start time for the task
- N = number of key frames required for the task.

Usually a minute in simulation can be translated to 60 frames in 3D Studio Max. In this research, however, 30 frames per minute are used to provide smooth animation. Therefore, the time scale factor used for task sub-activities on the production line is 1/30, making 30 frames of

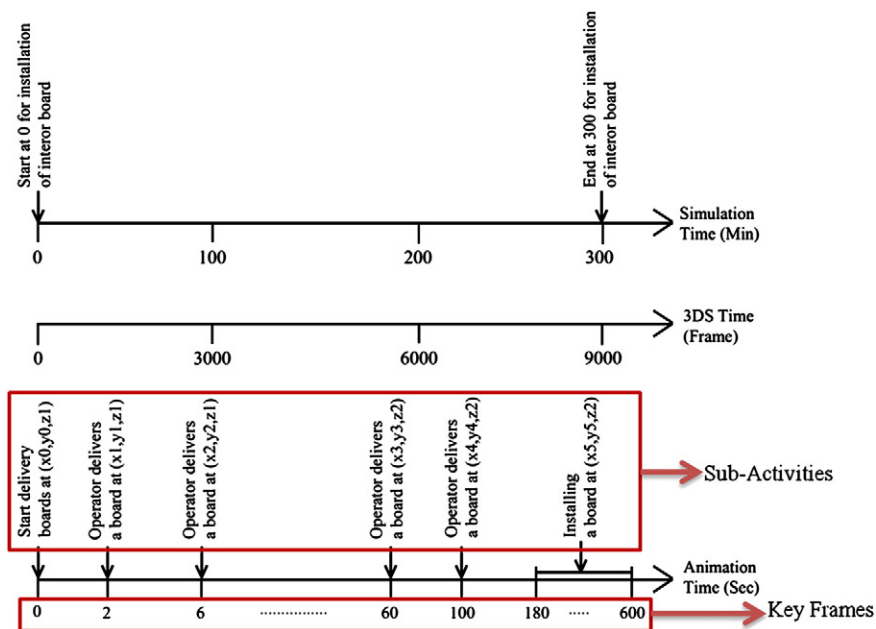


Fig. 4. Relationship between simulation and animation time.

visualization into one minute of simulation time. To convert the simulation time to visualization time, the process time of each task in the ASCII file is multiplied by 30. In this work, the number of key frames required for sub-activities of the task is assumed and is influenced by the installation location of material in each task. However, if the assumption is incorrect, the number can simply be changed in the Maxscript in 3DS.

To create animation in 3DS, a series of key frames representing the defined start and end points of sub-activities for 3D objects are created on a timeline. These can show the state of subtasks at a designated point in time. In the case of interior gypsum board installation for example, to represent the operation of a production line in 3DS, each cycle is divided into the following three actions: 1) operators deliver the source to destination location, 2) operators install boards, and 3) operators move back to the source location. This cycle is operated until the installation is complete. Each action also has many sub-activities in animation. For example, there are two operators required to install interior gypsum boards in the equipment room in Station 2 and eighteen interior gypsum boards are to be installed in total. Before building the animation of 3D objects, the sub-activity frame and the defined key frames for animation of 3D objects should be calculated. Hence the number of key frames and process time for each task are required. The process time is imported from the ASCII file. After calculating the sub-activity frame in each task, sub-activities of each action, such as a step of the operator, are animated between the sub-activity frames. If the sub-activity frame for the interior gypsum board task is 11.10 frames, for example the key frames to animate one step of an operator are defined at frames 0 and 11.10. This means that one step of the operator is animated between frames 0 and 11.10 on the timeline in 3DS. This means that the second step of the operator is animated between frames 11.10 and 22.20. Following this, the animation of the interior gypsum board is built based on the sequence of installation. The sequence and animation snapshots of the interior gypsum board task and 3D bar chart, shown in Fig. 5, are described. The numbers on the right hand side of the top figure shows the sequences of the task. The 3D bar chart shows progress while the animation related to the interior gypsum board in equipment room task is running.

Visualization can identify the requirement and limitation of workspace, accessibility problems for employees, and inconsistencies in the level of detail among tasks in the proposed schedule. The virtual reality model in combination with a 3D scheduling chart can help validate the completeness and consistency of the proposed schedule. It can also help users fully understand the production processes of a manufacturing production line.

6. Implementation of the proposed system: a case study

The proposed methodology has been tested on a case of a modular production line from Kullman Buildings Corp. (KBC). The company is one of the leading modular building manufacturers in the US. It produces a variety of building types such as equipment shelters, dormitories, multi-story residential buildings, correctional facilities, healthcare facilities, and US embassies. Ninety-five percent of the production line constructs 12×30 ft (350×914 cm) or 12×20 ft (350×609 cm) standard modules with similar configurations. In this research, the focus was on the 12×30 ft standard module to implement the proposed methodology. This research used previous results by Haitao Yu [10] to implement simulation and visualization.

In this case study, the production line consists of eight stations that have several tasks each. Two simulation models of the production line, one based on the existing system and one on the new improved system proposed by Haitao Yu [10], were built in Symphony using an enhanced common template. The same sample job, consisting of 50 modules, was loaded into the simulation models. Each simulation model had two levels of hierarchy. Fig. 6 shows the model of the proposed production line represented at the top of hierarchy. This level of hierarchy models the process flow of the production line. The process time required for tasks at each station were also loaded into the Setattribute element at the top of hierarchy. The models were run and the times required to produce each of the 50 modules were recorded in the simulation models. The Collect element in this level extracted and saved the output of the simulation to the ASCII file, including the identification number and start and finish times of each task. The detailed process models for each station are illustrated on the second level of the hierarchy. Each working station at the second level is detailed by a process model simulating the activities and resource interactions. Fig. 7 shows the model of Station 3, represented at one of the second levels of hierarchy in the proposed system. Station 3 has four tasks which are FRP and plywood; ceiling, lights and uni-strut; exterior J-channel for stenni; and wireway and containment pan tasks. A total of six carpenters are required. Two carpenters for the FRP and plywood, one carpenter for the containment pan, and two carpenters for exterior J-channel for stenni to start working concurrently once a module arrives at Station 3. The process times of these tasks are four and a half hours, one and a half hours, and three hours, respectively. The sixth carpenter installs the wireway for five hours, an hour after the module arrives. As soon as the two carpenters

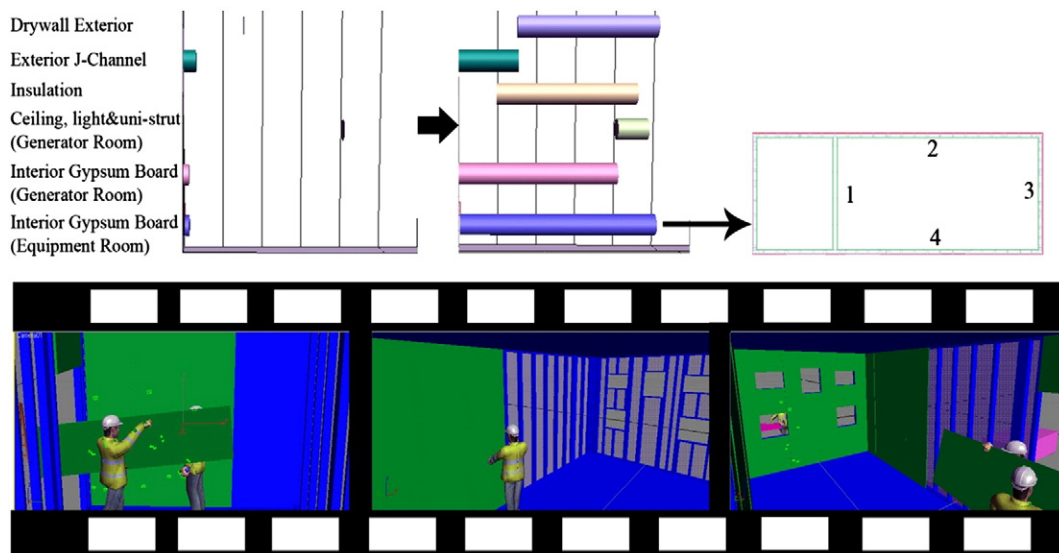


Fig. 5. Animation snapshots of interior gypsum board related to 3D scheduling and sequence.

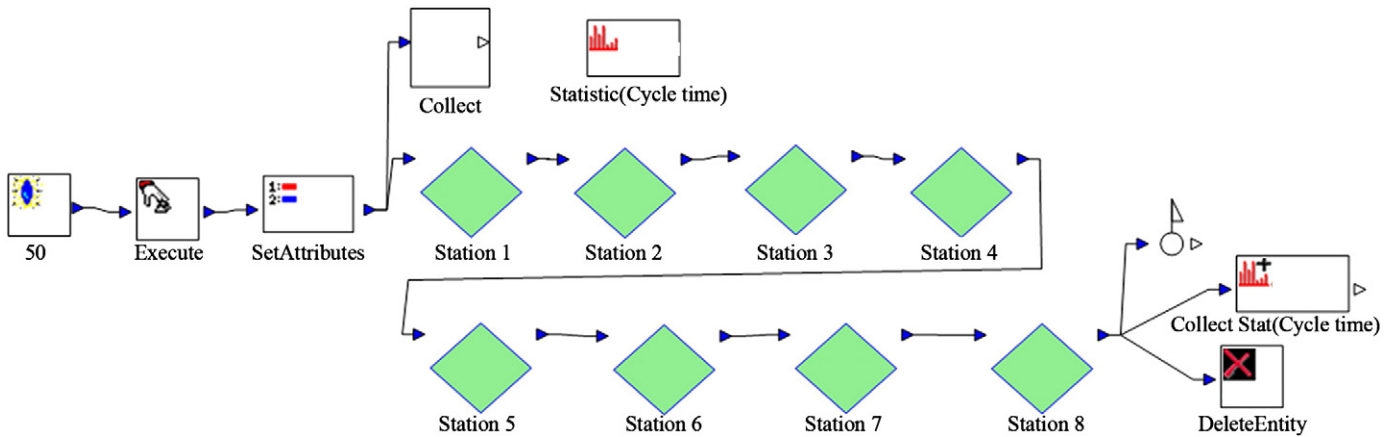


Fig. 6. Top level description of the proposed simulation model.

complete the installation of the exterior J-channel for stenni, they start installing the ceiling, lights, and uni-strut for four and a half hours. After finishing all tasks, the module moves to Station 4.

To validate the output of the original and the proposed simulation models, the cycle times of the two systems for a certain amount of units were compared. Based on eight working hours per day, the average cycle time of the proposed system, 31.53 working days, was shorter than the average cycle time of the original system, 33.85 working days. Each cycle time that produced 50 modules in both the original and the new systems was extracted from the simulation database and analyzed using EasyFit. The cycle time distribution for the original system (Fig. 8) was more irregular than the cycle time distribution of the proposed system, which was more convergent (Fig. 9). The average productivity of the new system, 1.58 modules per day, was better than the productivity of the original system, 1.47 modules per day. Therefore, the new schedule based on lean production was accepted as more effective than the old system. The cycle time calculated by the two simulation models may be shorter in real life since the model did not include certain minor activities, such as rework, due to insufficient information.

The simulation approach is an effective quantitative tool for testing multiple scenarios. The presented case study has thirty-four (34)

tasks in the production line and each could influence the average cycle time of the entire production line. A sensitivity analysis was conducted to identify the tasks that could improve the average cycle time. Based on the thirty-four (34) tasks along the new proposed production line, the process time of each of the thirty-four activities was reduced by an allowable interval while keeping all other tasks' process times fixed. The simulation model was run to calculate the average cycle time of the proposed production line, and the records were analyzed in an Excel file. This process was repeated thirty-four times. Among the thirty-four tasks, the average cycle time was most affected by changes to the follow tasks' process times: the erection of prefabricated panel task in Station 1 (Fig. 10), the grounding holes task in Station 5, the hang door task in Station 7 (Fig. 11), and the final check and ship loose task in Station 8. These tasks strongly influence the reduction of the average cycle time of the production line. Therefore, future strategies to improve the production line should reduce or combine these tasks.

After simulating the proposed production line, the simulated output data used for visualization was generated as an ASCII file. The file was imported to 3D Studio Max using Simulation-Animation Controller (S.A.C.) built using Maxscript. To animate 3D objects smoothly, three actions-delivery to destination location, installation,

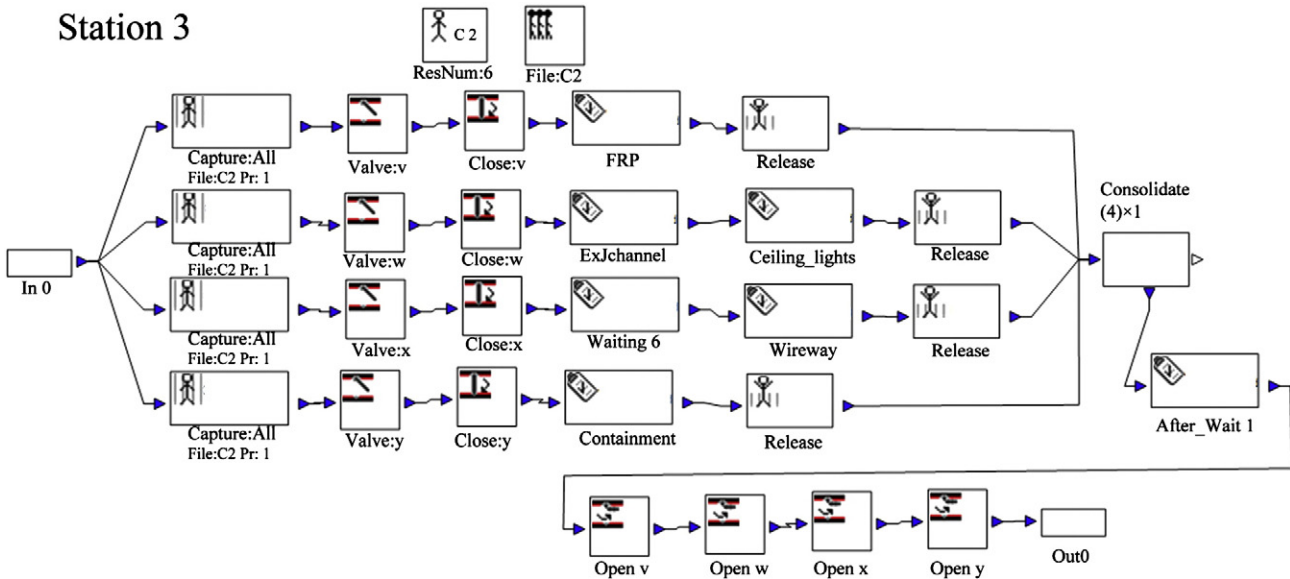


Fig. 7. Second level description for Station 3 in the proposed system.

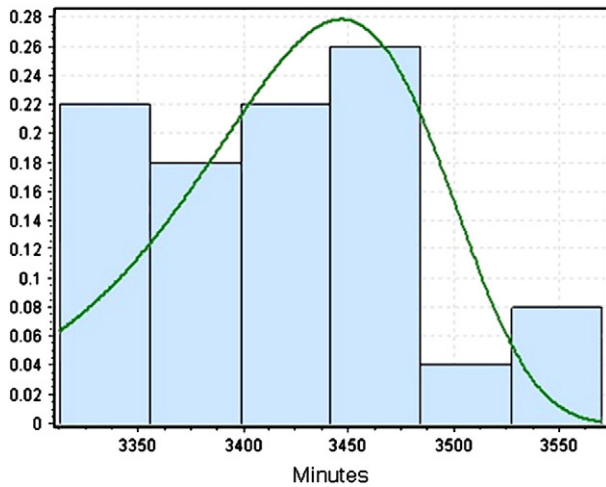


Fig. 8. Cycle time distribution of the original schedule based on output of the simulation model.

and movement to source location—were required. Each action also included sub-activities, where operators walked or installed between designated points, called sub-activity frames on the timeline in 3DS. The sub-activity frame of each task was calculated using the process time of tasks and number of key frames. The process time of each task was then imported to 3DS using the ASCII file. The number of key frames for each task was assumed but was influenced by the installation location of material in each task. For example, the crane was operated to move and install prefabricated panels in Station 1 based on three actions: deliver source to destination location, installation, and movement to source location. This represented one cycle of crane operation. It was continuously animated until the installation of the prefabricated panels for a module was finished. Each action also had several sub-activities. The sub-activities of the crane include the crane movement to the source location, lifting material up, moving to the destination location for installation, and placing it down in the final location. The number of key frames was 322, and the process time was 305.05 min. Therefore, each sub-activity was 28.4 frames. The sequence for the installation of prefabricated panels was base, party wall, front, right, left, rear, and roof. To install the base using the crane, the crane was moved to the source location between frames 0 and 28.4, lifted the source between

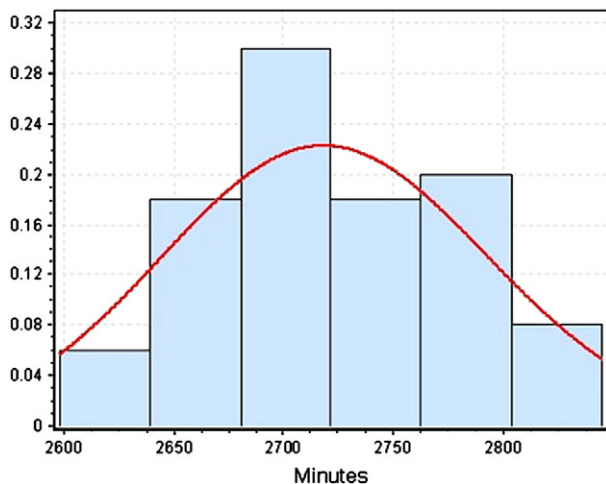


Fig. 9. Cycle time distribution of the proposed schedule based on the output of the simulation model.

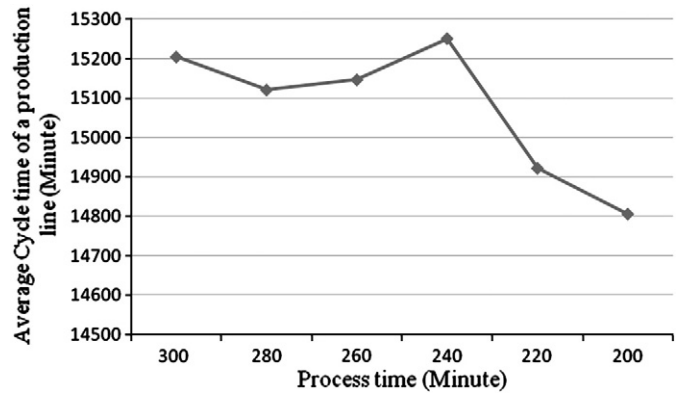


Fig. 10. Sensitivity analysis of the erection of prefabricated panel task.

frames 28.4 and 56.8, moved to the destination location between frames 56.8 and 113.6, and placed the source between frames 113.6 and 227.2. Based on these steps, the 3D animation of the production process was developed. After building the 3D animation, an animation file in AVI format was generated to depict the production line. The size of the file was approximately 790 MB.

In this case, there are two capabilities of visualization that could not have been identified by using simulation alone. First, 3D visualization provided several non-quantifiable details and made the verification and validation of the simulation model much easier. The requirement or limitation of workspace for tasks and accessibility of employees for delivery, installation, and movement back to material cannot be identified in simulation alone, since simulation does not provide geometric information and all components required for tasks but only numerical and logical results. However, visualization does provide clear scenes with all components to identify workspace and accessibility of employees on a computer screen. A clear example was seen in the animation of Station 3 (Fig. 12). The tasks, FRP and plywood; ceiling, lights and uni-strut; and wireway, were concurrently carried out in the same equipment room with six operators. It is possible that the workspace for tasks and accessibility of employees may conflict. Therefore, it was important to carefully develop the animation of these tasks based on operators' movement to identify whether or not there was enough workspace for the tasks and accessibility of employees, so that a new schedule in Station 3 could be adjusted accordingly. In the animation of Station 3, any workspace requirement and employees' accessibility problems were not found. Conflicting or optimized workspaces were not used in this paper since it was out of scope of this research. Additionally, the cooperation in Station 2 is included in the schedule in an effort to save

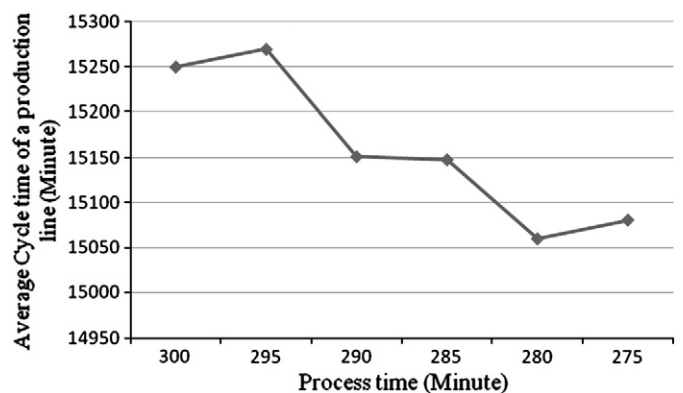


Fig. 11. Sensitivity analysis of hang door task.

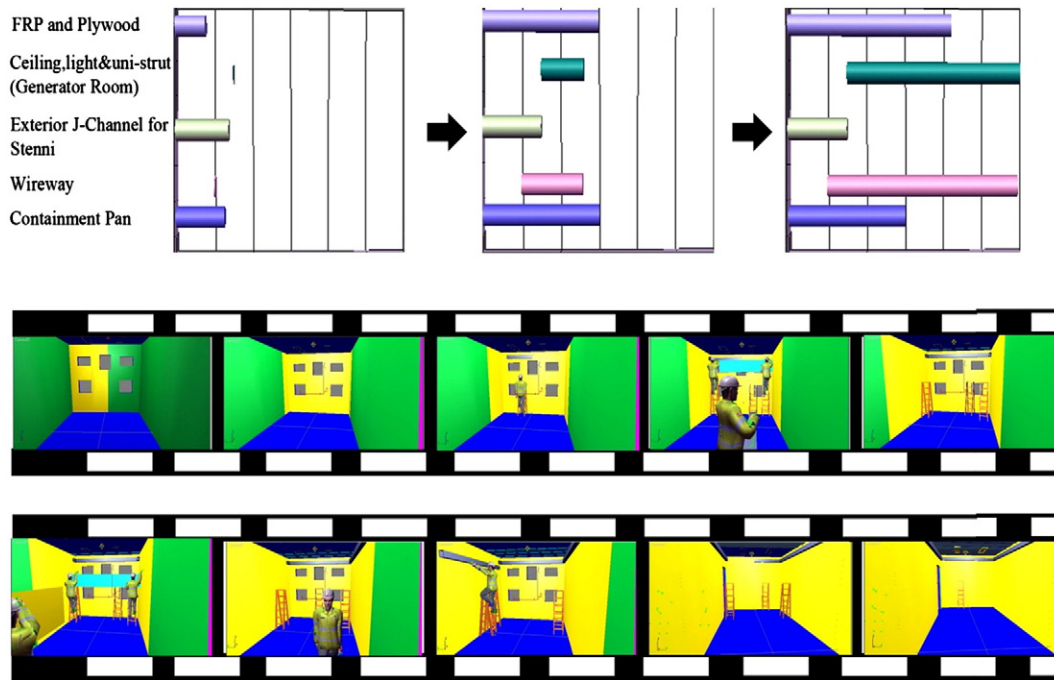


Fig. 12. Animation snapshots of work in Station 3 with 3D scheduling.

process time of the exterior drywall task and to finish it according to the required six-hour takt time. The 3D visualization described this cooperation of operators where after installing interior gypsum boards in the equipment room, two carpenters joined to help other carpenters who were finishing the drywall exterior. To carry out the visualization tasks described above, a S.A.C. (Simulation–Animation Controller) was developed using 3D Studio Max’s scripting language called Maxscript. It is a built-in language tool to automate repetitive tasks and to develop user interfaces in 3D Studio Max. The S.A.C. helps users easily control and reset the animation key frames of 3D objects. It consists of “import input data,” which is used to load the ASCII file to 3DS; “Set,” which defines the animation key frames of 3D objects; “Delete,” which deletes the animation key frames on the timeline; “Play,” which plays the animation; and “Stop,” which pauses the animation at any time for observation. The “Set” option makes it possible to simply reset the animation key frames of 3D objects when the time data, imported from simulation, is changed. That means that users do not need to reset the animation key frames manually.

7. Conclusions

A case study of a manufactured production line of modular buildings was used to validate the effectiveness of the proposed methodology and to illustrate the essential features of the developed models. The research demonstrated that a combination of simulation and 3D visualization can provide important information to assist project managers in understanding the effectiveness of changes made to the new production process. The project manager can also use the system developed in this work to experiment with improving the processes of the production line before implementing the proposed changes in real-world situations. This will decrease rework, reduce cost, and save time. Animation also helps to predict possible spatial interference of crews and identify space limitation, making it possible to decide on whether the sequences of tasks should be adjusted. The Kullman case study was used to verify the proposed production line in simulation models as numeric results and to concurrently validate the results of simulation and lean in 3D visualization. This would be

significantly helpful for lean results’ verification and validation. The simulation with its visualization was presented to the production management at the case study company. It was recognized as a useful tool for identifying improvement focuses and increasing the credibility of lean implementation plan. The effectiveness of the visualization in the different projects was identified in previous research [11]. The dynamic graphical depiction of the production process in 3D visualization with a 3D schedule will provide decision makers with important detailed information such as the state of each task at a specific time to facilitate communication for the results of the simulation and lean.

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