Discrete and Continuous Simulation Approach to Optimize the Productivity of Modular Construction Element

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Abstract

Bolstered by significant productivity improvement in manufacturing technology, the construction paradigm has shifted toward industrialized construction methods, such as modular construction. Modular construction has benefitted from the long term development of the manufacturing technologies and core techniques used in the assembly production lines of construction prefabrication plants. Lean production is a methodological approach for assembly line production that aims to eliminate waste, minimize inventory, and maximize production flow.

This research proposes implementation of lean concepts through combined discrete-event and continuous simulation approaches with the aim of increasing the productivity of a modular construction element. The proposed model incorporates a simulation of the system reliability by modeling various problems detected within the production line, such as double-handling. Applying continuous simulation facilitated attaining optimal threshold by detecting the inventory level. In addition, improvements are implemented within the model, such as introducing advanced alternatives for the automated stations and adding parallel stations to increase productivity. The effect of proposed production line improvement, along with each station improvement are examined and investigated.

Keywords

Lean; construction; productivity; simulation

1 Introduction

In the early 1990s, lean production emerged as a new manufacturing paradigm. Studies by Koskela (1992; 2000) were instrumental in integrating lean concepts to the construction process as TFV (transformation, flow, and value) theory of production in construction. This was followed by multiple research efforts to characterize this paradigm shift toward lean construction: (1) introduction of lean contraction workflow planning and Last planer system (LPS) (Ballard 1993); (2) establishment of Poka-yoka and Kanban systems in construction (Milberg and Tommelein, 2003; Arbulu, Ballard and Harper, 2003); and (3) formulation of a cohesive framework of lean construction paradigm and its relationship with lean production (Salem, et al., 2006). In this context, modularization, where units are designed, produced, and assembled off site that consist of various construction elements such as walls, frames, doors, ceilings, and windows, has garnered increasing attention.

Production optimization and plant layout optimization based on lean principles using simulation has been widely implemented in the construction industry (Senghore, et al., 2004; Mehrotra, Syal and Hastak, 2005; Jeong, Hastak and Syal, 2006; Yu, et al., 2011). As the construction industry seeks to increase productivity, reduce costs, and increase quality based on lean principles, Simphony has proven to be an effective simulation tool by which to model construction processes or production lines (Yu, Al-Hussein and Nasseri, 2007). Simphony is software developed at the University of Alberta which supports both general-purpose and special-purpose real-time simulation (Ekyalimpa, AbouRizk and Farrar, 2012; AbouRizk and Hajjar, 1998). This software allows users to model different work stations with their associated resources in a manner that resembles the actual production process. In addition, Simphony provides the opportunity to modify the production process, adjust the parameters of the model, and examine the results by running the simulation as many times as needed. Simphony has been used within the construction domain for many purposes, such as project duration forecasting, resource utilization, and general decision making support (Moghani, et al., 2011; Farrar, AbouRizk and Mao, 2004; Fernando, et al., 2003;

AbouRizk, 2010).

This paper represents the development of a Simphony model (Simphony.NET 3.5) to examine a modular building component prefabrication that is being built to satisfy lean production principles. The aim is productivity increase of the single-door line for All Weather Windows Company. A combined simulation model is implemented using discrete-event simulation for different work stations, and continuous simulation in the distribution area s between the stations. The current production line is modeled to satisfy lean principles based on pull system techniques using the combined simulation approach. The issues affecting the reliability of the current system are modeled. Recommended improvements are proposed to minimize production waste throughout the current lean production line. Thus, waste events are detected and eliminated by fixing the double-handling problems, and investigating the optimal threshold level in order to increase the productivity for the continuous simulated part. All the proposed improvements are implemented and tested using the developed combined simulation model generated within a Simphony environment.

2 Lean Approach of the Single-Door Line

2.1 Project Description

The aim of this research is to increase the productivity of the single-door line and increase the efficiency of various stations within the assembly production line. Therefore, a work study is developed to monitor each stations and its cycle time, in addition to investigate the causes of waste in each station. As illustrated in Figure 1, the current assembly door line consists of various stations that includes an automated door slab picker; door measuring table; door insert/cut-out station required for glass opening; the doors then moves through a conveyer that can install up to 3 doors; install and assembly door sweep; cell and jamb assembly preparation station; doors are then moves through a conveyer to the final assembly station, where doors is enveloped for delivery.

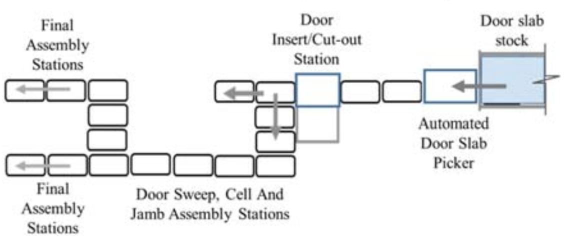


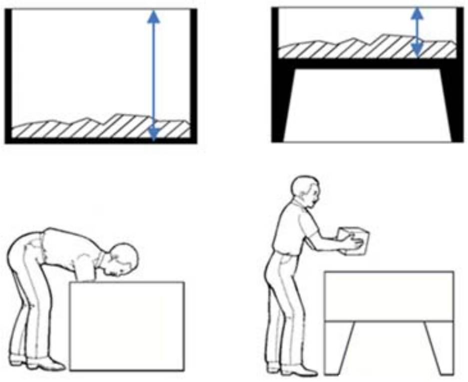
Figure 1. Schematic floor plan of the proposed lean production line

2.2 Lean Implementation

Lean principles were implemented throughout the current construction element of the door production line when it was first built, targeting a total elimination of waste. The floor layout has been improved to eliminate transportation waste by moving all the necessary materials as close as possible to the relevant station. Different Standard Operating Procedures (SOPs) have been developed to eliminate processing waste. However, based on the conducted work study, some areas of potential improvement in the current production line have been identified.

Double handling problems are observed after the door insert/cut-out station, while the work pieces (door slabs) are moving toward the door sweep station. The worker assigned to the door insert/cut-out station and door sweep station leave their stations for an average of 1.00 min for each work piece going to the double-door line in order to adjust the position of the work pieces moving through the first distribution area (from the door insert/cut-out station to door sweep station). Another double handling problem is detected in the automated door slab picker, by which the worker has to leave the work station for 0.25 min in order to adjust the door so the automated slab machine can successfully pick up the slab. In addition, a waste of motion is detected in the door production line.

A waste of motion is identified as the waste caused by a worker's movements, such as bending, twisting, or stretching, that are not necessary for the process. In the door production line, waste of motion is detected when a worker bends over to pick up door shipping blocks to be used for the final assembly station (see Figure 2). This qualifies as a waste of motion because the worker could have bent less and completed the task in less time. In addition, ergonomically it is not recommended to bend over in this manner, as illustrated in Figure 2(a), since this case is more likely to exert high pressure on the spine (90 degree bending). A solution is provided by lifting the entire load of the door shipping blocks to a higher level; this will enable safer lifting of the shipping blocks by workers (a max of 30 degree bending), as illustrated in Figure 2(b).



(a) (b)

Figure 2. Picking up the door shipping blocks required for the final assembly station

3 Current Lean Production Line modeling and analysis

3.1 Model Description

Based on the work study, the double handling problems in addition to the waste of motion problems are modeled and activated through valves. Door slabs are classified as either insert (doors that require glass insert) or non-insert (doors that do not require glass insert) before the door insert/cut-out station, as the processing time for non-insert doors is 2.06 min/door, whereas the processing time for insert doors is 5.03 min/door. Door slab ratio for average production of insert to non-insert doors is 46 to 54. A snapshot of parts of the Simphony simulation model is illustrated in Figure 3.

After the cut-out station, the door slabs are moved to the first distribution area, after which the slabs are distributed as either single-door slabs or double-door slabs. The area is simulated as a continuous simulation process. Door slabs state variable is modeled to continuously vary based on the real time simulation of the door slabs movement. The insert assembly station, the cell preparation station, and the jamb assembly station are modeled based on the pull system to represent the current lean production line. A chart collector has been used after the final two modeled branches to monitor the number of insert and non-insert doors.

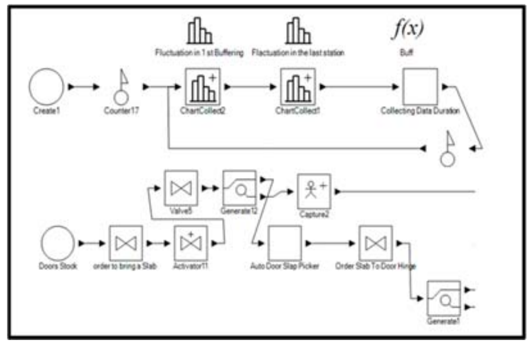


Figure 3. Snapshot of parts of the devolved simulation model by Simphony program

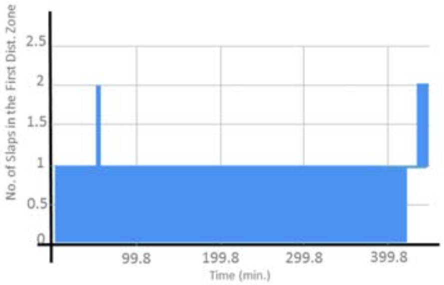
3.2 Production Line Model Analysis

As the actual total current productivity has been found to vary from 95 to 105 door slab/shift, the total productivity based on the developed model in Simphony has been found to vary from 95 to 106 (see Table 1), which indicate the ability of the developed model to accurately model the current production line. Table 1 illustrate the current production line data collected from different runs, along with the total production of the single-door and double-door line. Based on run 1 and 3 in Table 1 that represent the highest and lowest production, the number of single-door and double-doors produced within the lean production line have an inverse relationship. Single-door production is thus affected by the double-door production.

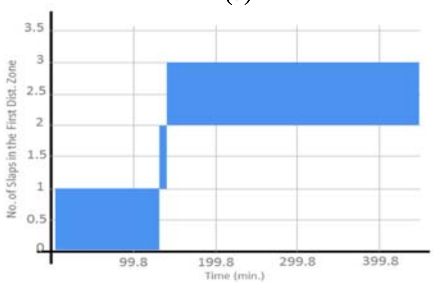
Table 1. Single-door production in relation to double-door production of the developed mode

Number of random runs	Total doors to double-door line	Total doors to single-door line
1	17	106
2	22	102
3	36	95
4	28	99

Based on the continues simulation data in run 1 that extracted from the developed model of the first distribution area, the lowest single-door fluctuation happens when low number of door slabs is going to double-door production line, as shown in Figure 4(a). When number of slabs going to double-door are high, and the number of insert slabs going to single-door production are also high, the fluctuation increase to 3 doors, as shown in Figure 4(b) for run 2. This fluctuation resulted from longer cycle time of insert doors. In the second distribution area, door fluctuation did not seem to be affected by insert door productivity because slabs number did not exceed one slab, as shown in Figures 5(a) and 5(b). This means that no door is waiting in the second distribution zone except the one door moving to the first or second branch of the last station.

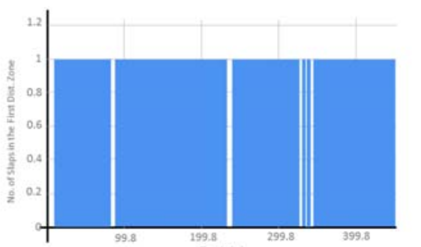


(a)

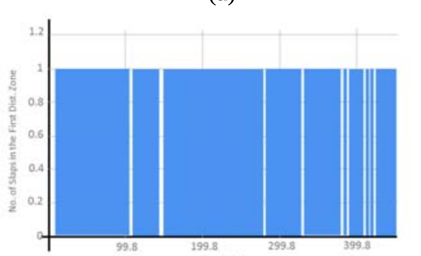


(b)

Figure 4. Bandwidth fluctuation of doors in 1st distribution area for: (a) run 1 and (b) run 2 in Table 1



(a)



(b)

Figure 5. Bandwidth fluctuation of doors in 2nd distribution area for: (a) run 1 and (b) run 2 based on Table 1

3.3 Modifications of Single-Doors Production Line

In the modified model, the waste detected through the work study was eliminated. Both double handling problem and the waste of motion problem was eliminated. Also, a source of imbalance was detected from the doors accumulation problem in the first distribution area, which is due to the longer processing time of the insert doors in relation to non-insert doors. Therefore, a parallel station is created beside the inserting station in order to process insert doors while the production line of non-insert doors continues through the original station.

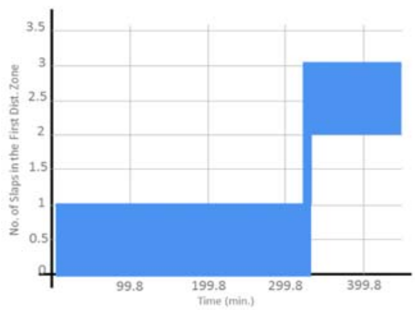
Another source of unbalance is identified in the predecessor station to the first distribution area door insert/cut-out station, which is based on the time difference between the processing of insert and non-insert doors: insert doors are processed in 5.03 min while non-insert doors are processed in just 2.06 min. To overcome this unbalance in the processing time of the door insert/cut-out station, a new Computer Numerical Control (CNC) machine is proposed to replace the current machine. This new machine can reduce the cut-out processing time of the insert doors to 3.60 min. Although the increase in production due to this improvement may cause some accumulation in the first distribution area, the previous improvement of adding a parallel station is expected to reduce this potential accumulation.

3.4 Analysis of the Improved Production Line

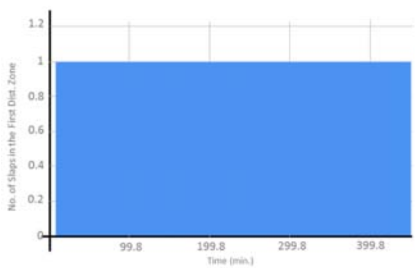
Based on the proposed improvements, the production of single-door line has been increased, as shown in the random runs in Table 2. Although the objective of adding a parallel station was to minimize the inventory to be one work-piece in the first distribution zone waiting for the work in progress, the number of work-pieces was increased to 3 doors in the last quarter of the shift, as illustrated in Figure (6)a. This can be due to the fact of installing the new “door cut-out station.” However, the number of work-pieces in the first distribution zone was reduced back to one when slabs going to the double-door is reduced from 39 to 31 doors, as illustrated in Figure 6(b). For the second distribution zone, the number of work-pieces waiting in the second distribution zone did not get affected as it was a max of one door, as shown in Figure 7 and Figure 8.

Table 2. Number of doors moving to the double-door production line, and the production of modified single-door

Number of random runs	Total doors to double-door line	Total doors to single-door line
1	39	115
2	31	130
3	38	122
4	31	124



(a)



(b)

Figure 6. Bandwidth fluctuation of doors in the first distribution area for (a) run 3 and (b) run 4 in Table 2

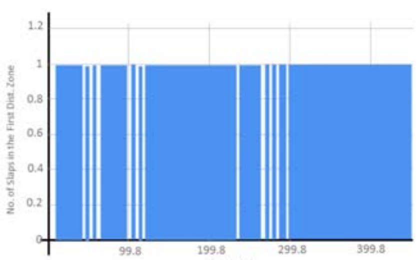


Figure 7. Bandwidth fluctuation of doors in the second distribution area for run 3 in Table 2

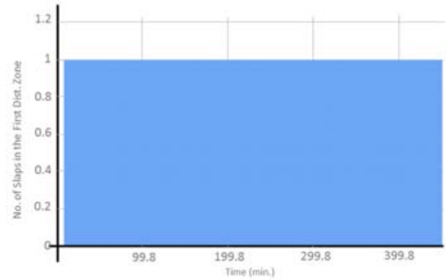


Figure 8. Bandwidth fluctuation of doors in the second distribution area for run 4 in Table 2

4 Conclusion

Using the proposed methodology of a production line improvement based on a real-time simulation approach, the strategy of implementing any improvements of modular construction element can be investigated and refined. The existing single-door production line has been modeled using real-time continuous/discrete-event simulation, and the reliability issues, such as double handling and waste of motion problems, in the current production line have been modeled as well. Using the developed model, the performance of the current production line has been assessed.

Two stations have been found to be the sources of unbalance in the production line, as the unit processing times of these two stations were found to have two separate values depending on the type of the processed doors, whether non-insert or insert. Improving the automatization of one station along with adding another parallel station have been proposed as alternative strategies by which to reduce the sources of the imbalance in the production line. All of the proposed alternatives have been implemented in the modified model. Based on the developed simulation model, single-door production has been increased, including production increasement in “insert”, “non-insert”, and double-door production.

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