IMPROVING THE PERFORMANCE AND RELIABILITY OF CONSTRUCTION SUPPLY CHAIN USING SIMULATION: A CASE STUDY FOR DOORSETS MANUFACTURING -DOORSSIM-

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ABSTRACT: Successful supply chain management calls for robust supply chain design and evaluation tools. In adition, a set of performance and reliability measurement tools are strongly needed to evaluate the overall supply chain effectiveness.

Simulation is a widely used technique for modelling manufacturing and other types of complex systems. A literature review reveals that there are only few studies on determining the bottleneck in supply chain and in particular, product components like doorsets.

The objective of this ongoing research is to determine the impact of various operating conditions on the performance of the doorsets manufacturing system in order to capture some Key Performance Indicators (KPI's) and bottlenecks within the production cycle. A case study is implemented in the doorsets manufacturing industry.

The ultimate objective of this research is to develop a doorsets simulation model to evaluate the production performance and reliability of the manufacturing processes.

Process mapping methodology (IDEF0) has been used as an effective tool for process modelling purposes. A detailed level simulation model of the doorsets manufacturing (DOORSSIM) is developed to answer questions related to effects of the various operating conditions on the productivity performance of the job-shop.

This simulation model, provide details about the dynamic of the operations and functioned as a convenient "what if" evaluator of proposed operational changes.

KEYWORDS: process mapping, simulation modelling, job-shop, performance measurement.

1 INTRODUCTION

Supply chain management is a process of integrating suppliers, manufacturer, warehouse, and retailers, so that finished products are delivered at the sufficient quantities, required qualities, and at the right time (on due date), while minimizing costs or wastages, as well as satisfying other customer requirements.

One of the tools, which permit the evaluation of supply chain operating performance prior to the implementation of a supply chain, is simulation. (Yoon and Makatsoris 2001)

Process modelling and simulation are commonly used tools in manufacturing process supply chains improvements and their uses as bottlenecks diagnostic and an improvement tools are still more important and profitable.

Simulation provides the capability to evaluate performance of a system operating under current or proposed configurations, policies, and procedures. It is very applicable to evaluation of strategic and operational level plans for supply chains. It is especially useful for exploring the viability of a supply chain before beginning production.

Many examples could be found in the literature where the use of simulation in the manufacturing industry is reported.

The doorsets manufacturing industry is facing serious economic and technical problems that are limiting its profitability and growth and therefore was selected for this research. The increasing cost of doorsets components along with labor intensive manufacturing methods have pushed manufacturing costs close to unprofitable levels. If the industry is to survive and grow under such pressure, it must be able to recognise and solve some fundamental manufacturing problems such as satisfying delivery commitments on the predefined due date.

As one of the goals of a system is to process a large number of different products effectively and efficiently in a given time, the throughput is of significant economic concern.

The throughput of all systems is limited by the capacity of the different machines and depending on the nature of the system; some machines may affect the overall throughput more than other machines. Usually, the limitations of the system can be traced to the limitations of one or two machines, commonly called constraints or bottlenecks. (Christoph, et al 2006)

To detect bottlenecks in the doorsets manufacturing industry, several innovative technologies could be adopted to investigate more alternatives and choose the best one.

These technologies might be included, using high capacity machines and other improvement techniques such as adopting different loading rules, which have been successfully employed in other manufacturing industries, and have also been proposed in this study for improving the performance of the doorsets manufacturing industry.

Computer simulation is an ideal tool for analyzing the manufacturing systems. Using computer simulation, alternate processing technologies under different operational circumstances can be thoroughly studied before their costly introduction into a real manufacturing system.

Section 1 introduces the topic and the context of the project. Section 2 demonstrates some literatures concerning this field. Section 3 presents the definition of the problem being studied. Section 4 presents the description of the doorsets manufacturing system, which refers to doors as one of the joinery products. Section 5 addresses the approaches and techniques used for developing of the simulation model and demonstrates how simulation can be applied to analyze doors manufacturing processes. Section 7 presents some results obtained by running the DOORSSIM model with full analysis and interpretations for the potential improvements, followed by a conclusion of the paper in section 8.

2 LITERETURE REVIEW

There are a number of relevant research projects on the utilisation of simulation to improve the performance of wooden products manufacturing systems. Felipe and Jose 2004, presents a discrete event simulation model of sawmill machines. The model was constructed in order to perform a bottlenecks analysis of the wood process and to proposed many alternatives that would yield an improvement in the process productivity.

Robert and Christopher 2000, presents an advanced simulation model for the furniture manufacturing to satisfy the following objectives: (1) Determination of staffing level in a machining cell (2) Determination of batch sizes and perform a line-balancing act between multiple machine cells and (3) Determination of buffer sizes at the major staging areas. Many performance measures are collected by the ProModel output database include: Buffer Levels Over Time, Operator Utilisation , and Cycle Times of Each Unit.

Timothy 1997 discussed two types of simulation programs in lumber processing; one type is Process Simulation program, which determines the best way to manufacture rough dimension parts from lumber. The other simulation program is Flow Simulation, which allows the user to try out different plant layout scenarios as well as engineer a plant prior to construction.

These programs allow users to address the many "what-if" questions that arise in the design and the everyday operation of rough mills and the performance indicators for these programs were (1) Yield (2) Throughput (3) Resource Utilisation.

Kline, et al 1992, describes a simulation modelling procedures applied to wood products manufacturing system (example on furniture "hardwood" roughmill system) in order to effectively provide timely information and assist in making effective management decisions for wood products manufacturing systems. Ultimately, the simulation model was used to compare and test alternate management decisions, the outputs includes mill throughput, operation expense, inventory levels, processing efficiency, and material flow delays due to the processing bottlenecks.

Major conclusion from the theory reveals that there are more needs to use simulation as a tool for improving the performance of wooden doors manufacturing supply chains.

The next section will define the faced problems in such industry and other related project goals.

3 PROBLEM DEFINITION

The doorsets manufacturing industry suffer from inability to satisfy customer's demand in terms of achieving orders on due dates for many reasons. One of the most common reasons is the production flow, which might become slow or not ideal due to high queues in the Work In Progress (WIP) areas. Reasons for this can be using either low performance machines, limited capacitated machines, or adopting not appropriate loading rules.

The overall goal of this research is to develop a simulation model that can effectively provide a Decision Support System (DSS) that could assist in making effective management decisions such as using better processing equipment technology, adopting appropriate loading rules and other managerial decisions for doorsets manufacturing systems.

The project goals were as follows:

1. Design a process mapping for the doorsets manufacturing in order to capture the hierarchal structure of such industry or to understand the production flow.
2. Design of a detailed simulation modelling procedures applied to doorsets products manufacturing systems.
3. Improve the performance and reliability of the doorsets manufacturing supply chain using the developed simulation model.
4. Identification of areas that potentially limits the ability of the supply chain (bottlenecks).
5. Evaluation of the proposed supply chain configurations.

4 DESCRIPTION OF THE DOORS MANUFACTURING SYSTEM

Manufacturing of joinery product elements is essentially performed in a job shop environment. That is, each door produced may be different from all other doors depending on the order type. The manufacture of joinery products;

parts are processed by different processing machines. (Five processing machines)

The production plan deals with each of the elements of manufactured joinery through the seven key stages in the manufacturing process. (Figure 1 shows the doors manufacturing stages)

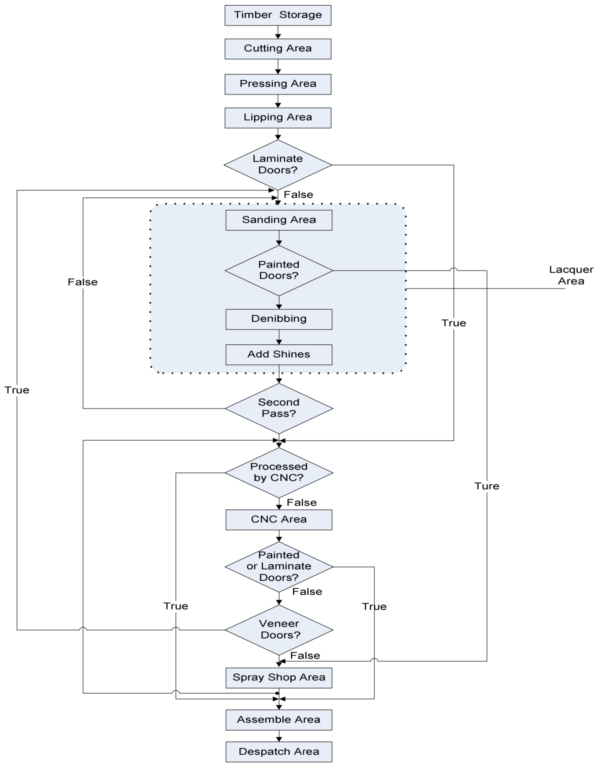

Figure 1. The doors manufacturing process sequences.

In figure 1, by depending on orders' types, a number of processing areas might be revisited by the same order. For instance, veneer doors may have to visit the Lacquer machine twice to have the required layers of lacquer.

Each type of doors has different process flow route and different assembly sequence. Therefore, the flow in this manufacturing system was extremely complex.

Quality Control System (QCS) is also used at the assembly area in order to refurbish the defective doors before assembling and dispatching them.

Despite door types variety (possibly in the scale of hundreds), we focus in our research on the production of some common produced types (Laminate, Painted, and Veneer doors) and analyze quality and productivity issues for that final product.

The purpose of building IDEF0 functional model is to enable a better understanding of the complex activities involved in developing a doorsets manufacturing system, This, developed model focuses only on developing a doors manufacturing system as partial modelling requirements. (Figure 2 depicts the top level of the general process plan)

5 SIMULATION MODELLING DEVELOPMENT TOOLS

Simulation modelling has been actively applied in industry or performance context. In the context of the topic of this paper, there has been limited work in the area of using simulation to evaluate supply chains performance of the doorsets manufacturing industry.

The simulation model is developed to be completely data driven. This allows the simulation model to be a generic doorsets supply chain simulator. While a number of capabilities will have to be developed in the simulator to be truly generic, the intention was to build a basic set of capabilities that can be data driven.

We constructed a simulation model of doorsets manufacturing using ARENA, a simulation software tool. In order to have a better understanding of the complex activities involved in such an industry besides some modelling facilities, IDEF0 functional model has been developed as a tool to assist the simulation modelling process.(Figure 2 depicts the top level of the general process plan)

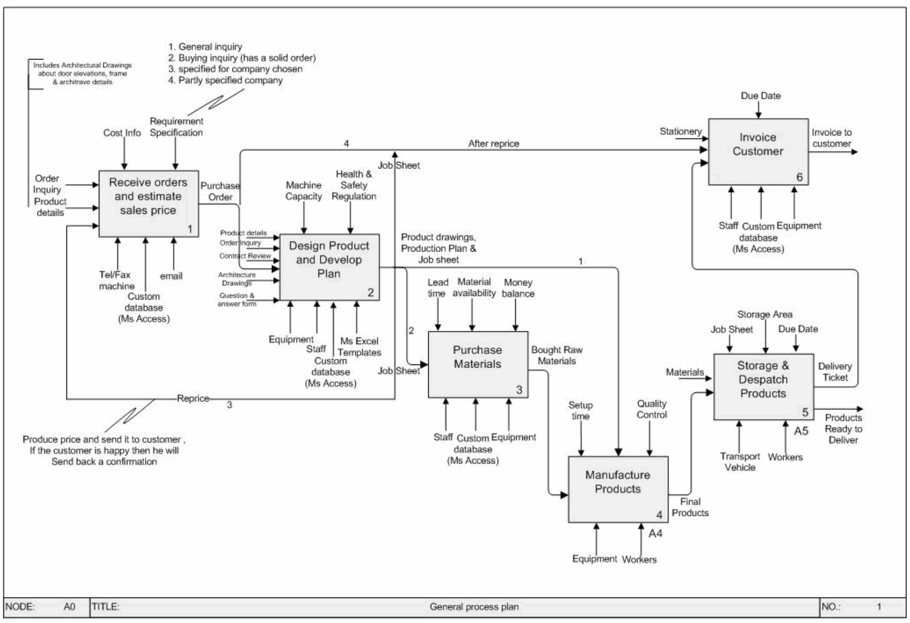

Figure 2. General Process Plan.

This developed model focuses only on doors manufacturing system as a partial modelling requirement.

Figure 3 shows a screenshot of the developed DOORSSIM supply chain simulation model with it's production control unit. The flow of materials is from left to right on the screen.

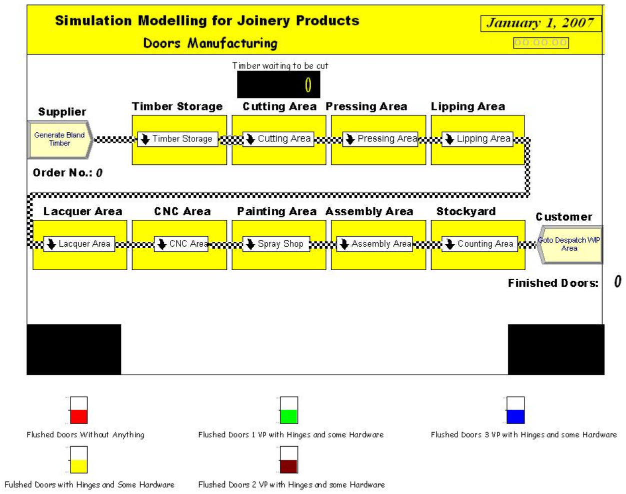

Figure 3. Snapshot for the developed simulation model DOORSSIM.

The Object-Oriented Programming (OOP) is used to model all the manufacturing processes. Many model assumptions were assumed while constructing this model, some of them are:

1. Each order is processed by different process areas depending on the order's type.
2. All machines can process only one order at a time.
3. Each machine is not reliable and subject to failure but we did not consider failure factor in this study by considering the ideal status of machine only.
4. Setup time process of the machines is considered in this model. (see figure 4)

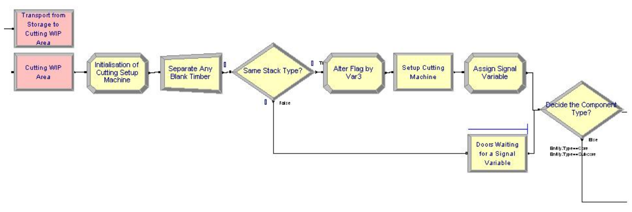

Figure 4. Snapshot of the setup process by using OOP.

5. Any transportation time taken up by either conveyor or forklift is considered as a delay time.
6. A 24-hour working period is adopted instead of a working shift system.

The data for simulation model

All information which are needed in DOORSSIM model were gathered using databases and doing on site data collection are deterministic and then analyzed for inclusion into the model.

Since machine processing time and setup times are available from the historical data, no source of randomness is associated to machines and the system could be modeled in a deterministic way in order to give us a realistic schedule. (Mark 1997).

Model verification and validation

The researcher carried out verification initially by watching the animation of the entities and using trace function to track entities through the system, this technique made it possible to ensure that entities were traveling to the proper location in accordance with the entity flow diagram. In addition, to ensure that the model accurately reflected the data supplied and that it generated the outputs required by the conceptual model. Two separate interviews are done, one with the production manager and other with a wider group of workers, to access the impact of the simulation on the users during the validation step.

We performed the validation by comparing the theoretical value of cycle time from the dataset and the cycle time obtained from simulation. From this outcome, it could be proven that the model reflects sufficiently accurately the actual cycle time of the selected processes.

Implementation

Key outputs from the simulated performance were tracked to understand the behavior of the supply chain. The bottlenecks in the flow were identified and associated capacities adjusted in consultation with the supervisors. The initial run of the simulation experiment with 15 orders (800 doors) has been done and the effects of the current available resources on the supply chain simulator performance are identified.

The initial run reveals that cutting machine and the heating system are having the highest utilisation 94% and 83% respectively. The cutting machine will cause a huge bottleneck for the whole system because it is the first manufacturing stage, which will decide the delay time for other orders to be entered in the manufacturing system.

Minimisation of bottlenecks

In doorsets manufacturing, more competition and ever changing consumer demands, manufacturers are frequently realising the necessity to reengineer their facility to satisfy the needs of many product groups and styles.

Designing facilities that recognise the need for flexibility to reduce costs require a clear understanding of the interdependent relationships naturally occurring in complex cellular manufacturing environments.

Discrete Event Simulation Modelling is used to analyse and detect the reasons behind the aforementioned bottlenecks to improve the ability of the supply chain to run in a more efficient workflow without any disturbance.

6 RUNNING EXPERIMENTAL WORK

The following scenarios will be considered after detecting the bottlenecks occurs in the doors supply chain in order to come up with some improvements, which might improve the performance of the supply chain.

1. Scenario1: Using different machines capacities such as current capacity, double capacity and high capacity.

2. Scenario2: Using different loading rules such as First Come First Served (FCFS), Last Come First Served

(LCFS), Shortest Processing Time (SPT), Minimum Orders to be processed firstly (Min Order), Earliest Due Dates (EDD).

3. *Scenario3:* Scenario1+Scenario2

By running the simulation model for each scenario and both together, the results of the effects of different scenarios can be determined for the entire throughput time, number of tardy jobs and utilisation of the bottlenecked machines, which reveals the potential improvements that, might have, happened after tackling the bottleneck.

Figure 5 shows the influence of using different cutting machine and heating system capacities on the total throughput time.

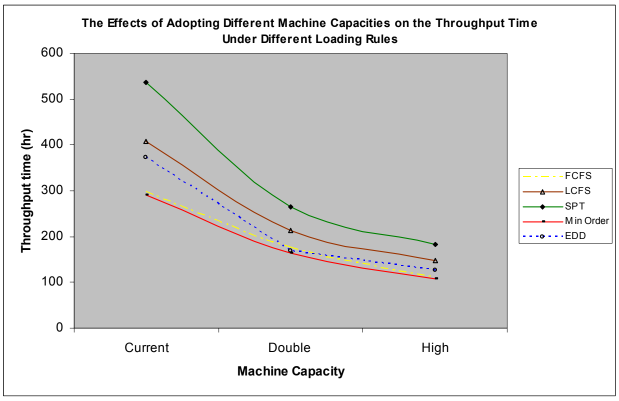

Figure 5. The effect of adopting different machine capacities on the throughput time under different loading rules.

Figure 5 reveals that the Min Order rule shows minimum throughput time besides FCFS loading rule. At high capacity, the minimum throughput time is achieved for both Min Order and FCFS rules, the Min Order loading rule shows a better minimization of throughput time than the FCFS loading rule. (See figure 6)

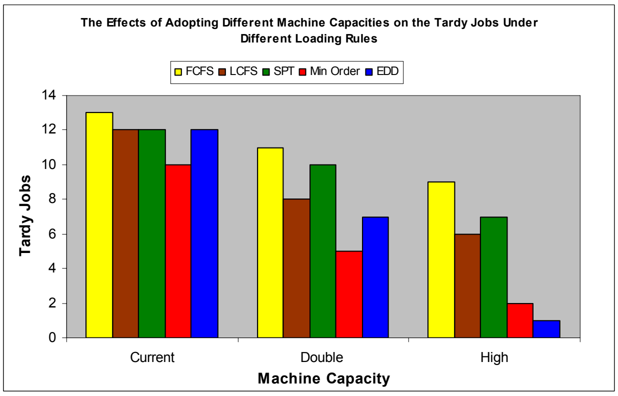

Figure 6. The effect of adopting different machine capacities on the number of tardy jobs under different loading rules.

The minimum number of tardy jobs is achieved by using EDD rule at high capacity.

The second best loading rule is Min Order rule, which gives an acceptable number of tardy jobs, as opposed to other loading rules. Evaluating of machines utilisation under different loading rules have also been identified in order to detect the bottlenecks and to discover if there is a necessity for using high machine capacity or not. (Figures 7-11 depicts the utilisation rates)

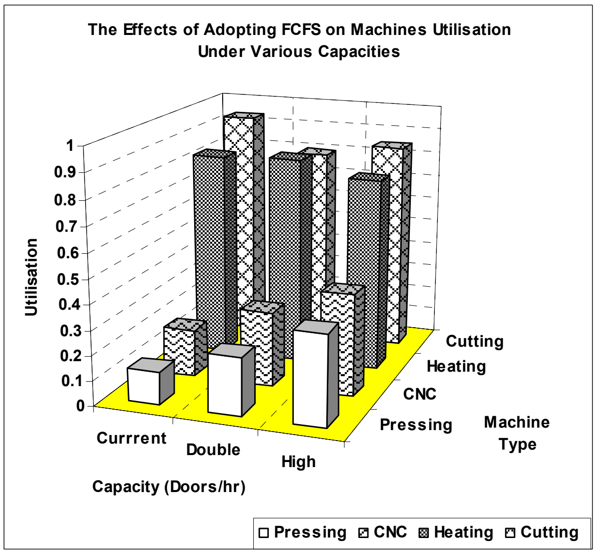

Figure 7. The effects of adopting FCFS on machines utilisation under various capacities.

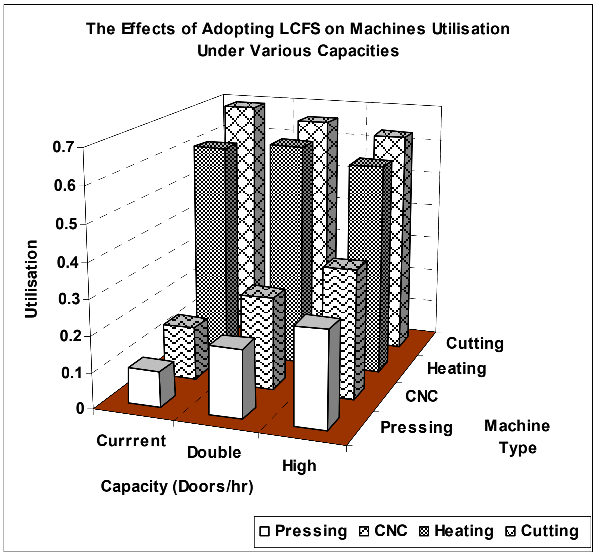

Figure 8. The effects of adopting LCFS on machines utilisation under various capacities.

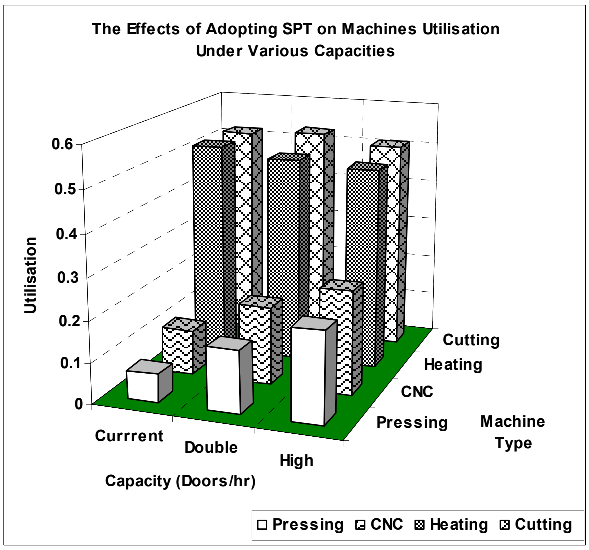

Figure 9. The effects of adopting SPT on machines utilisation under various capacities.

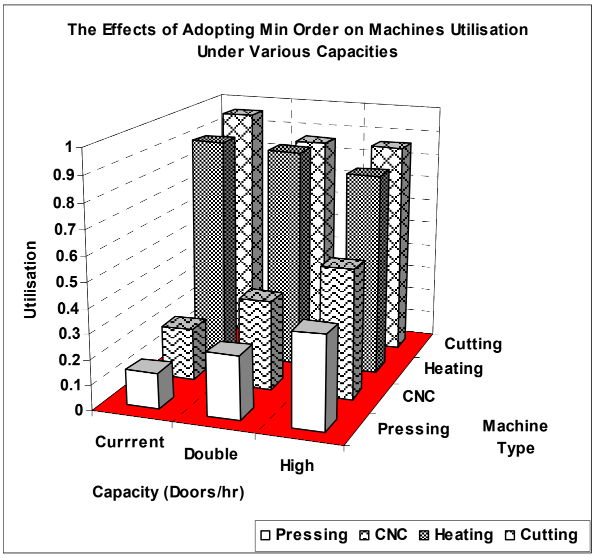

Figure 10. The effects of adopting Min Order on machines utilisation under various capacities.

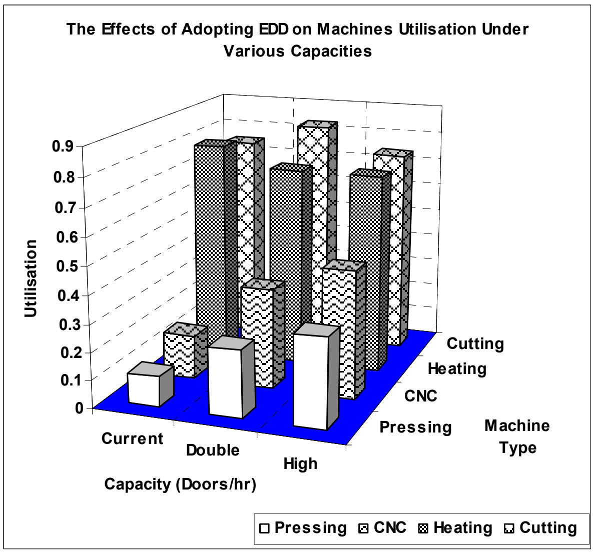

Figure 11. The effects of adopting EDD on machines utilisation under various capacities.

By adopting Min Order loading rule, maximum utilisation for the bottlenecked machines could be achieved as follows: 86% for the cutting machine, 52% for the CNC machine, 81% for the heating system, and 37% for the pressing machine. While the worst scenario occurred when applying the SPT rule as follows: 25%, 51%, 49%, and 22% for CNC, cutting, heating, and pressing machines respectively under high capacity.

7 ANALYSIS AND INTERPRETATION

Simulation using DOORSSIM model for 15 orders with 800 of different types of doors under different scenarios revealed a collection of notes, which needed to be investigated and interpreted in details as follows:

(1) Throughput time

Using of different machines capacities under various loading rules have greatly effects on the performance of the doors manufacturing supply chain by reducing significantly the total throughput time as in the following table:

Table 1. The throughput time yield by adopting various machines capacities under different loading rules.

Loading Rule	Both Cutting & Heating Capacities		
	Current	Double	High
FCFS	296.81	175.09	109.68
LCFS	406.96	212.24	148.16
SPT	535.93	264.87	183.22
Min Order	291.21	162.93	108.71
EDD	373.78	168.35	125.81

By subtracting, the throughput time, yielded by adopting the new capacity from the throughput time yielded by the old capacity adoption divided by the throughput time yielded by the same old adoption capacity, table 2 could be calculated which shows the trend and the percentage of the throughput time changing under various capacities.

Table 2. The effects of adopting various machines capacities under different loading rules on the total throughput time. ("+" means increasing, "-" means decreasing).

Loading Rule	Both Cutting & Heating Capacities		
	Current→ Double	Current→High	Double→High
FCFS	-0.70	-1.70	-0.60
LCFS	-0.92	-1.75	-0.43
SPT	-1.02	-1.92	-0.45
Min Order	-0.79	-1.68	-0.50
EDD	-1.22	-1.97	-0.34

For all loading rules, the significant reduction in the throughput time will be achieved by using high-capacitated machines of both cutting and heating systems.

Min Order rule will provide a minimum throughput time 108.71 hr. under high-capacitated machines while the maximum throughput time is yielded by using SPT loading rule under the current machine capacity 535.94 hr.

Adopting high-capacitated machines instead of current used capacity will have a highly effect on the reduction of the total throughput time. (See, "Current→High" shaded column, Table 2)

(2) Number of tardy jobs

The second performance indicator, which has been adopted, is the number of tardy jobs. Obviously, the performance of the doors manufacturing supply chain could be improved by minimizing of number of tardy jobs to satisfy the commitments of delivering orders by their due date.

Table 3. The effects of adopting various machines capacities under different loading rules on the number of tardy jobs.

Loading Rule	Both Cutting & Heating Capacities		
	Current→ Double	Current→High	Double→High
FCFS	13	11	9
LCFS	12	8	6
SPT	12	10	7
Min Order	10	5	2
EDD	12	7	1

Table 3 shows that, by experimenting with all loading rules under different machines capacities, the significant reduction in Tardy jobs is obtained on the high capacity.

EDD loading rule is providing the minimum number of tardy jobs by satisfying 14 jobs on their due date with throughput time equal to 125.81 hr. while the application of Min Order loading rule will give just only 2 tardy jobs with minimal throughput time equal to 108.71 hr.

(3) Machines utilisation

As the third performance measurement criterion, machine utilisation will be considered as an important criterion that will be used to evaluate the performance of the doors supply chain simulator.

The same procedure that is applied in calculating the trend and the percentage of the throughput time changing under various capacities will be applied in machine utilisation in order to detect the trend and the percentage of the bottlenecked machines utilisation improvements.

Table 4. The effects of adopting various machines capacities under different loading rules on machines utilisation. ("+" means increasing, "-" means decreasing)

Loading Rule	Both Cutting & Heating Capacities			
	Machine	Current→ Double	Current→High	Double→High
FCFS	CNC	+0.37	+0.54	+0.27
	Cutting	-0.18	-0.11	+0.06
	Heating	+0.01	-0.06	-0.08
	Pressing	+0.44	+0.64	+0.36
LCFS	CNC	+0.42	+0.58	+0.28
	Cutting	-0.05	-0.10	-0.05
	Heating	+0.03	-0.03	-0.07
	Pressing	+0.47	+0.63	+0.30
SPT	CNC	+0.42	+0.56	+0.24
	Cutting	+0.02	-0.02	-0.04
	Heating	-0.04	-0.06	-0.02
	Pressing	+0.53	+0.68	+0.32
Min Order	CNC	+0.42	+0.60	+0.31
	Cutting	-0.12	-0.12	0.00
	Heating	-0.02	-0.11	-0.08
	Pressing	+0.44	+0.62	+0.32
EDD	CNC	+0.47	+0.60	+0.25
	Cutting	-0.01	-0.01	-0.09
	Heating	+0.01	-0.01	-0.01
	Pressing	+0.50	+0.63	+0.25

For the results given in table 4, we can conclude that for all the loading rules under high machine capacity, the pressing and CNC machines utilisation will be increased in order to improve the performance and reliability of the doors manufacturing supply chain. The best increment was achieved by adopting EDD loading rule under high capacity.

The utilisation of pressing and CNC machines is increased by overcoming the bottlenecks in both cutting and heating systems, i.e. the increased utilisation in both pressing and CNC machines are highly related to the flow work at cutting and heating machines.

8 CONCLUSIONS

This study underlined the value of the simulation for evaluation of the performance of doors manufacturing supply chain. In addition, it shows the effectiveness of adopting the double impact of the used loading rule and machine capacity on the performance of the doors supply chain.

The simulation model DOORSSIM identified the bottlenecks in both cutting machine and heating system and has showed the effects of those two machines on the workflow especially the cutting processes .

The model is used to evaluate the performance of the doors supply chain under different operational conditions such as machine capacities and various loading rules. Both Cutting machine and the heating system have a significant effect on the Pressing and CNC machine utilisation and on the workflow in general.

The results have showed that the performance of doors supply chain could be improved by using of high capacity machines (in particular cutting and heating area) and adopting the right loading rule (Min order or EDD) in this type of manufacturing industry.

9 FUTURE WORKS

Some intelligence will be added to the current DOORSSIM model by developing an evolutionary metaheuristic searching methodology such as "Genetic Algorithms" integrated with our simulation-based planning and scheduling system in order to improve the performance of the Doorsets supply chain. This development enables to test more combinations and discover the effects of increasing other manufacturing machines capacities with additional loading rule on the performance of the current supply chain.

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