Discrete-event simulation and data analysis for process flow improvements in a cabinet manufacturing facility

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Abstract: Project uniqueness and high degrees of customisation have always been challenging characteristics of construction projects and many related operations. This paper describes the simulation of a production line in a cabinet manufacturing facility carried out with the aim of better understanding and improving the production processes particularly associated with mass customisation. Discrete-event simulation (DES) using Simphony.NET, a simulation modelling tool developed at the University of Alberta, is used to investigate and analyse processes in an existing facility. The purpose is to optimise productivity, reduce work-in-progress, and decrease idle time. The cabinet manufacturing factory in the presented study operates multiple production lines, produces different product types, and uses varying materials and finishings. In this specific case study, the simulation model is used to explore the challenges associated with increasing production to satisfy the rising demand of customised products. The result of the simulation study provides valuable information to achieve this goal.

Keywords: discrete-event simulation; DES; cabinet manufacturing; mass customisation; construction manufacturing; workflow improvement; modelling; simulation; data analysis.

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1 Introduction

A construction project can be thought of as a one-of-a-kind product. In the past few decades, the construction industry has been adopting techniques and methods to reduce process waste, increase productivity, improve quality, and ensure the timely delivery of projects. One developed and effective approach is the application of manufacturing principles and techniques to the construction industry: a paradigm associated with the industrialisation of building-construction through offsite construction and modularisation.

In a modular construction approach, building components are built in a well-controlled factory environment. Components are then delivered in sequence to the construction site for installation and assembly by site crews. Reduced construction wastes, higher-quality buildings, shorter onsite execution time, and minimised onsite safety incidents are a few direct advantages of adopting a modular construction approach (Koskela, 1992; Mohsen et al., 2008). Despite these advantages, offsite construction is associated with numerous challenges with respect to the customised nature of construction projects. The coordination between factory operations and onsite activities, and the need for the seamless flow of information (beginning at the design stage, proceeding to the production lines, and finishing at site-delivery and installation) are just a sample of the many challenges taken into consideration. Successful projects completed in this manner rely greatly on the design and implementation of efficient and agile manufacturing processes that adapt to a wide range of product designs.

In this study, factory operations of a kitchen cabinet manufacturing facility (hereafter referred to as 'the facility' or 'the manufacturer') are analysed and simulated. The facility provides complete cabinetry solutions, including kitchen cabinets, bathroom vanities, and hutches to individual customers, home builders, and trade contractors. Contending with rapidly broadening product-demand, the manufacturer is facing various operational and customer-satisfaction challenges related to quality, order fulfilment, supply chain management, material handling, and labour productivity and stability. The goal of the research presented in this paper is to analyse current-state operations and to propose sites for improvement based on models of floor operations using a discrete-event simulation (DES) approach.

2 Literature review

2.1 Mass customisation

Rapidly changing market conditions and an increased demand for customised products have changed the approach we use to conduct and manage businesses. Customers require more customised dwellings to reflect their personal preferences. Cabinets at home or otherwise constitute a portion of the visible customisation in which customers are interested.

Mass customisation is the process of delivering a large quantity of products that are modified to satisfy specific customer needs (Phuluwa et al., 2013). Mass customisation is a marketing and manufacturing technique that combines the flexibility and personalisation of custom-made products with the low unit costs associated with mass production (Pine, 1993). Kotha (1996) concluded that several external and internal conditions are essential for the successful implementation of mass customisation, which include, but are not limited to the following:

1 the close proximity of suppliers
2 industry-wide increases in the number of products
3 the development of an information network within a selected group of retailers
4 investment in manufacturing and information technologies and human resources
5 knowledge creation to develop manufacturing capabilities
6 marketing efforts to promote individualised products.

In the housing industry, Benros and Duarte (2009) developed a framework seeking to accomplish customisation by combining flexible design, data communication, and industrialisation of building processes. Duray et al. (2000) suggested that two variables are key in mass customisation: the point in the production cycle where the customer is involved in specifying the product, and the type of modularity used in the product. Customer-driven design and manufacturing are the core of mass customisation systems. Jagdev and Browne (1998) defined this business practice as to actively consider, in general, the market trends and, in particular, individual customer requirements during the design, manufacturing, and delivery of the products.

2.2 Process-based simulation

Experimenting with different scenarios and analysing the effects of ‘what-if’ cases in order improve the manufacturing of building components is highly valuable. Over the past few decades, process-based/DES has been widely used in the construction and manufacturing industries to model the various activities and processes of real-world systems. Tremendous amounts of research have been conducted in simulation language development, simulation model design, model optimisation, and combining statistical design-of-experiment techniques with simulation modelling (Callahan et al., 2006). AbouRizk (2010) provides an overview of advancements in construction simulation theory and its applications in the construction industry.

Altaf et al. (2014) applied DES using Simphony.NET for the purpose of investigating various resource allocation strategies at a panelised construction factory. Moreover, Altaf et al. (2015, 2017) developed an online simulation-based production control system in a wall panel prefabrication factory using RFID technology. This system evaluates production performance based on real-time data acquired by the RFID system. Mohsen et al. (2008) utilised Simphony.NET to examine the onsite assembly aspect of the modular construction process. This process was used to build five dormitory buildings where building modules were treated as the model entities processed by different resources. Simulation output matched the actual onsite measures, with only slight variation in completion time. Ismail et al. (2017) adopted a simulation technique to support construction project planning using a construction simulation toolkit and ProSIM, a web-based collaboration platform that applies a multi-model data integration approach. Automated construction simulation modelling for aggregate crushing plant operations and for earthmoving operations is discussed by AbouRizk et al. (1995). Golabchi et al. (2018) propose an integrated approach to design, and evaluate safety and productivity of labour operations in construction using simulation modelling and visualisation.

Kamaruddin et al. (2011) used the WITNESS simulation package to examine the performance of different layout designs relating to model variability and headcount variability. They concluded that these two factors impact the performance measures of the flow line, job shop, and cellular layout. Sharma et al. (2007) used simulation to quantify the impact of proposed changes on existing workflow and resource allocation as part of a broader initiative to study and optimise the service-management processes in selected hospitals in Germany. In another field, Longo et al. (2012) and Bruzzone and Longo (2013) used simulation-based approach to support decision making in the food industry. They developed an advanced Java-based simulation model using AnyLogic software to assist production managers with the investigation of various production scenarios in a hazelnut processing facility.

Simulation models are traditionally built based on assumptions and approximations of input data. Chung et al. (2006) applied Bayesian updating techniques to improve the quality of input parameters to a simulation model based on actual data of a tunnelling project, the North Edmonton Sanitary Trunk, in Canada. These updates can mitigate simulation uncertainty and enhance prediction accuracy. Hu and Mohamed (2012) used simulation experiments with embedded artificial intelligence (AI) planning tools to identify the optimal fabrication sequence of pipe spools. They concluded that shop productivity could be improved by changing the spool fabrication sequence. Jahangirian et al. (2010) conducted an extensive literature review (wide coverage of simulation techniques, and a focus on real-world applications) of simulation application within the manufacturing and business sectors between 1997 and 2006.

Applying mass customisation principles, together with underlying lean techniques, can benefit offsite construction companies. In this regard, offsite construction enterprises producing wall panels, complete modules, or specific portions of buildings (e.g., cabinets, doors, windows, etc.) can greatly improve operations by developing simulation models for investigating the application of mass customisation, lean principles, and knowledge discovery in data. Significant contributions to both academia and industry can result from the application of data mining techniques and mass customisation philosophy to production systems using simulation and various data acquisition tools. It is anticipated that the present research will thus offer numerous benefits to the cabinet manufacturing industry at large, as the current research contributions in this area are limited.

Production planning and scheduling is one of the challenging aspects in mass customisation. Several research articles discussed scheduling or evaluation of scheduling using DES. For example, Son et al. (2002) used DES as a task generator to create data for real-time scheduling. They modified the Arena™ simulation tool to queue tasks and the event calendar to handle both internal and external system delays. Kádár et al. (2004) applied the simulation model as a schedule generator. In the first step, the DES model uses production database and scheduling data to initialise both the simulation and the evaluation of the plan. In the second step, the model provides feedback for scheduling based on evaluation criteria and the results of the evaluation process. Venkateswaran and Son (2005) applied a framework architecture with two types of simulation for production planning: a system dynamics (SD) simulation model for higher level decisions and a DES model for the shop-level including more detail about operation processes, flow of parts, inventory, WIP, and cycle times. On the other hand, Bang and Kim (2010) used linear programming for production planning at the higher level, and a rule-based scheduling method for generating shop-floor scheduling at the lower level. They used DES for estimating the feasibility of the production plan and scheduling evaluation. The DES result is used as feedback for linear programming to optimise the production schedule. Ehrenberg and Zimmermann (2012) developed and described an optimised baseline schedule for production planning based on processing times and production system configuration. The baseline schedule is used both as an input to the DES model, and also to update the schedule based on the simulation results.

3 Model development

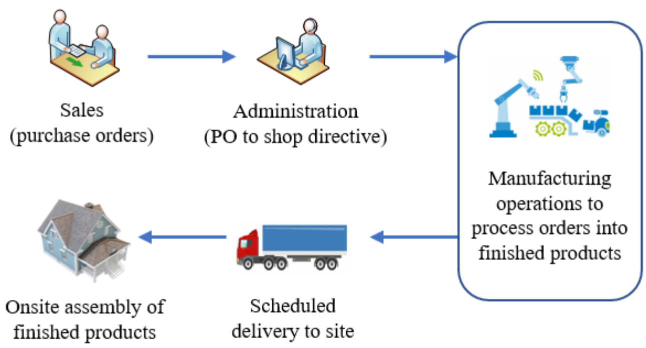
In this section, we describe how the simulation experiment was carried out by outlining the study methodology, the underlying assumptions used to build the simulation model, and our interpretation of the results.

3.1 Methodology

The simulation study started by observing the daily operations at the cabinet manufacturing facility to identify boundaries of the system and abstract its relevant processes.

Figure 1 shows a high-level overview of the business processes that begin when a customer places their order and end when the site installation is complete. The problem domain in this study is restricted to the production lines of regular and custom kitchen cabinets. A workflow diagram is developed upon which the pseudocode in Figure 2 is used to build the simulation model. The pertaining assumptions and requirements upon which the conceptual model was built are summarised and documented in Section 3.2.

Figure 1 High-level business workflow in a cabinet manufacturing facility (see online version for colours)



A DES model was created using Simphony.NET, a simulation modelling tool developed at the University of Alberta. Experimentation with the model through 'what-if' analysis, as well as verification and validation, was performed throughout development until satisfactory results were obtained. Results and a summary of the validation approaches used are presented in Sections 5 and 6, respectively.

3.2 Assumptions

In the model, the basic entity simulated is a kitchen cabinet purchase order. Each order is associated with one project. Days are the employed time unit. The database used in the simulation model is created using information provided by the manufacturer. The main characteristics of the orders used in the simulation are the number of cabinets and the type of material used in cabinets. In this context, we refer to an unfinished product as a 'box'; a finished product, which has the box assembled together with its drawers and doors, is referred to as a 'cabinet'. Each project consists of several cabinets that make up the kitchen; the simulation is based on an order size of 14 to 22 cabinets. Each cabinet consists of the following three main components:

- the cabinet box, which is the skeleton of the cabinet
- the cabinet doors, which may be supplied or manufactured in-house
- the cabinet and kitchen components that are referred to, here, as accessories.

Each of these components is routed to its corresponding department once the raw material has been cut using one of two available saws. The following is a summary of the assumptions used to build the simulation model:

- Approximately 80% of the cabinets are regular, non-custom types, and 20% are custom cabinets. Custom cabinets require approximately three times the duration to assemble.
- The availability of raw materials is not a constraint, meaning that orders are infinitely flowing into the model as they occur with no shortage of supply. In a simulation model, this entails creating a large number of entities at the beginning of the simulation.
- Task durations are based on the historical data available. When such data is not available, the durations are fit into triangular distributions based on observations. These observations include the minimum, maximum and most likely durations required to complete a task. Triangular distribution has been used to model the duration time for the activities performed in the shop because the distribution parameters can practically be obtained from existing data and from expert knowledge. Moreover, triangular distribution has widely been used for practical applications in the literature (Hajdu and Bokor, 2016; Yang, 2005; Wing, 1995).
- Orders in the database are generated randomly based on the wood type with the same probability; cabinets are categorised under four main wood types: hardwood, melamine, paint-grade (PG), and veneer.

3.3 Analysis of NCR data

Non-conformance reports (NCRs) are generated when there is a defect in a product that requires a repair or rework. Based on the analysis of the available NCRs over a period of two years (2016–2017), it is found that approximately 13% of products passing through the quality control (QC) stations will require a rework. This percentage represents the probability (A) that an order will require a repair or rework. Moreover, it is observed that the 13% of rework orders are distributed based on the wood type as shown in Table 1.

Figure 2 Pseudocode of cabinet manufacturing operation

```
Initialization
  While Database != empty:
  Set order arrival time == Exponential(35)
  Set order start time == current Sim. time
  Split the order into two parts:
    1) cabinet box materials go to "north saw"
    2) If wood type == "hardwood":
         material go to "door shop operations"
       Else  # wood type != "hardwood"
         material go to "accessories operations"
       End if
  @ "north saw operations":
  Cut wood panels at north saw then drill holes
        using CNC machine
  Band the edges of box parts before assembly
  If cabinet type == "regular":
     Route material to "regular assembly"
   Else  # the case of "custom cabinets"
     Route material to "custom assembly"
  End if
  Merge "regular" & "custom" boxes and wait for
       "doors" and "accessories"
  @ "doors shop operations":
  Cut "hardwood" for door panels & frames
  Assemble door panels & frames
  Perform auto/manual sanding operations
  Randomly assign rework probability as
       P(A="hardwood" ∩ B="rework") == 6%
  If P(rework) == 6%:
     Reroute for rework @ Sanding
   Else  # the case where door passes QC
     Reroute to "finishing operations"
  End if
  Reroute "finished doors" and merge with
       completed cabinet boxes
  @ "accessories operations":
  Cut material at south saw and band the edges of
       accessories
  If material == "melamine":
     Merge accessories with completed boxes
     Else  # the case of "veneer" or "PG wood"
     Process at "wood preparation"
     Perform sanding operations
     Randomly assign rework probability as
            P(A="PG" ∩ B="rework") == 3%
     If P(rework) == 3%:
         Reroute for rework @ WP
       Else  # the case where no rework required
         Reroute to "finishing operations"
     End if
  End if
  Reroute "finished accessories" and merge with
       completed cabinet boxes
  Perform "final assembly" when all parts (boxes,
     doors, accessories) are ready
  Calculate finish time
  Count number of completed cabinets
End While
```

Table 1 Reworks/repairs as percentages of total NCRs based on the type of wood

	Hardwood	*Melamine*	*PG*	*Thermo.*
Of total rework	41%	21%	19%	19%

Using the probability formula of two dependent events happening together:

$$P(A \cap B) = P(A)\, P(B|A) \tag{1}$$

where P(A) is the probability that the cabinet will require a rework; and P(B | A) is the probability of the type of wood given a rework is required. When developing the simulation model, this formula is used to determine the branching probabilities at QC stations where reworks or repairs are to occur. Modelling the operations in this way will make it easier and more efficient for debugging the model as well as revising it as updated information become available.

4 Model layout and description

4.1 Facility layout and process description

The manufacturer operates kitchen cabinet production lines that produce cabinets and transport them for in-home assembly. An order consists of number of cabinets and each cabinet has mainly three parts: boxes, doors, and accessories. The manufacturing process, therefore, consists of three lines: accessories, doors, and cabinet boxes.

The accessories-line process begins with the cutting task, which is performed by the south saw. The saw can simultaneously cut an average of eight panels at a time. Accordingly, panels are batched into average groups of eight and cut into pieces at once by the south saw. After cutting, pieces are routed to the edge banding station, where they are edge-banded one at a time. Since each element requires a different type of edge banding, setup time is allocated for this task and is incorporated into the duration of the task. The cabinets with melamine material type do not need sanding and painting, so they will skip sanding and painting stations. If the material type is veneer or PG wood, however, pieces are routed for wood preparation and sanding. After sanding, the prepared accessories wait for their corresponding door parts, which are simultaneously being processed in the door manufacturing line. Because there is no need for preparing or sanding melamine type boards, such pieces skip wood-preparation and sanding, proceeding directly to final assembly. Melamine boards account for approximately 20% of the company's orders.

In the doors-manufacturing line, however, veneer and melamine account for almost 40% of the material, while hardwood only accounts for 40%; the remaining 20% are of PG wood type. If the material-type is veneer or melamine, the panels proceed to the accessories-production line to be cut and edge-banded before proceeding to the final assembly line. For hardwood types, the panels go through the doorframe and door panel processes before being routed to the finishing station, and then to the final assembly line. The doorframe process includes outer and inner edge profiling, while the door panel process includes cutting, gluing, clamping, raised panel cutting, and thickness sanding for raised panels. The panels from the doorframe and door panel lines then converge at the automatic and manual sanding stations. A quality-control station (immediately downstream from the sanding stations) flags approximately 6% of the pieces for failing to pass the quality check. The sanding operation is prone to account for the majority of the defects identified. The hardwood doors merge with their corresponding pieces from the accessories line and proceed to the finishing area where they are painted. The second QC station is located after the finishing station. Approximately 8% of the pieces are returned to the finishing station for failing to pass the quality-control check, while the remaining pieces wait for their corresponding pieces from the box-production line to arrive.

Table 2 Distributions of activity durations

Operation station	*Activity*	*Duration (minutes)*
North saw	Cutting	Triangular (0.3, 0.4, 0.35)
South saw	Cutting	Triangular (0.2, 0.35, 0.25)
Accessories edge banding	Edge banding	Triangular (0.5, 1.10, 0.8)
Edge-banding of boxes	CNC router/drilling Edge banding	Triangular (1.6, 2.1, 1.7)
Sorting	Staging and sorting	Triangular (0, 0.75, 0.5)
Final assembly	Drawer storage Door staging Press door hinges	Triangular (0.3, 1.0, 0.5)
Regular assembly	Sort Case clamp	Triangular (2, 3, 2.25)
Custom assembly	Assembly station Case clamp	Triangular (6, 9, 6.75)
QC	Quality check	Triangular (0.4, 1, 0.7)
Door sanding	Sanding machine Manual sanding	Triangular (0.65, 1.15, 0.9)
Accessories sanding	Sanding machine Manual sanding	Triangular (0.9, 1.65, 1.1)
Finishing	Finishing kitchen parts and cabinet parts	Triangular (8, 10, 8.5)
Door frame	Sized lumber for door frames Cutting and profiling for door frame	Triangular (0.5, 1.1, 0.8)
Door panel	Flat panel saw Cutting lumber to width Cutting lumber to thickness Sized lumber for raised panel Gluing station Clamping machine for raised panels Raised panel saw	Triangular (0.8, 1.2, 1.0)
WP	Wood preparation	Triangular (0.5, 0.9, 0.65)

Seven days after an order arrives at the factory, cabinet box production begins at the box-production line. The first station in the box-production line is the north saw: the panels are cut in maximum groups of eight. At the next station, pieces are drilled with a computer numerical controlled (CNC) machine, then edge banded.

As with the accessories line, pieces on the box-production line are edge-banded one at a time. The pieces are then sorted as either 'regular' or 'custom', and are routed to their respective partial assembly lines. The partial assembly line consists of the assembly of boxes and clamping. The last step is the final assembly line, in which all parts of an order converge and are assembled. Table 2 lists the durations of each activity wherein the durations are approximated using triangular distributions. The durations listed for each activity are for operating on a single cabinet, except for the finishing activity, which represents a batch of eight cabinets.

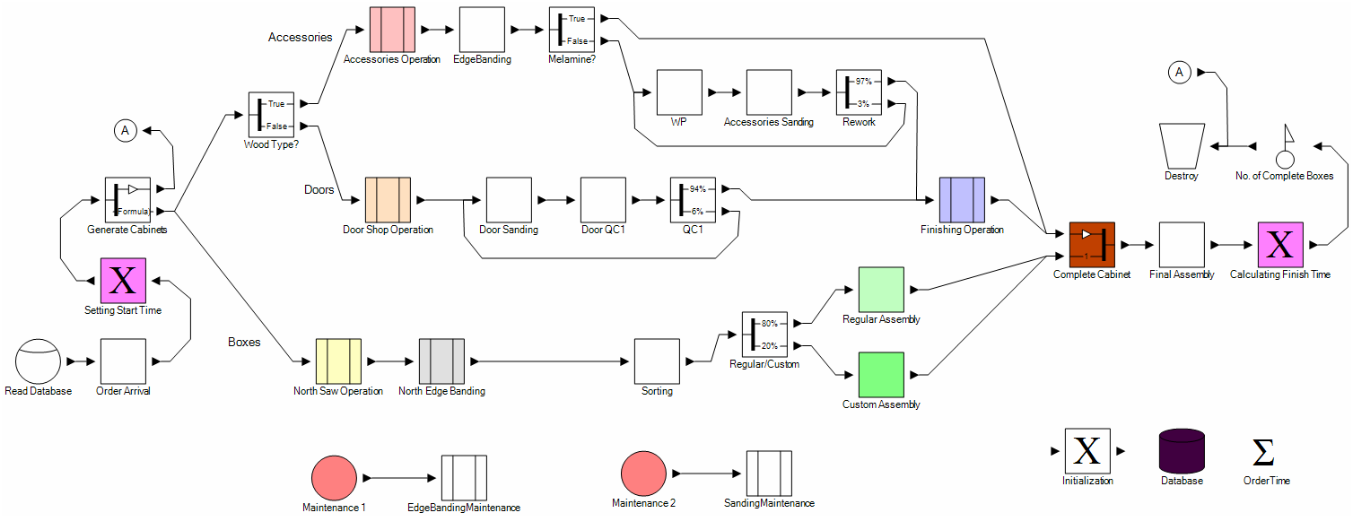
4.2 Simulation model

A detailed simulation model of the cabinet manufacturing production line (shown in Figure 3) is developed in Simphony.NET. In the simulation model, orders are the model entities where all attributes, such as priority, number of cabinets, number of custom cabinets, and type of wood, are extracted from the database at the beginning of each simulation run. Each entity goes through different task elements based on its attributes. A task element represents a work package or a group of work packages in a workstation such as 'door panel', 'door frame', or 'finishing'. Each piece of machinery (e.g., north saw, CNC machine, sanding machine, edge-banding machine) is defined as a resource in the simulation model.

The database contains 1,000 records of orders with randomly-generated attributes. These orders are created based on an exponential distribution with the mean-value of 35 minutes. The orders then go through the 'generate' element, creating cabinets based on the 'number of cabinets' attribute of each order. The conditional branch separates the different types of materials, routing non-hardwood materials to the accessories line for further processing. Given that the south saw in the accessories line can cut several panels simultaneously, an average of eight panels are batched together and cut at the same time. Since some orders have a higher priority than others, the captured resource elements with higher priority are used for each task. This results in the work on the current order being stopped and switched to those with higher priority.

In the box manufacturing line, after passing the north saw and north edge banding stations, the boxes are sorted and divided to regular and custom assembly lines. The ratios for regular and custom cabinets are 80% and 20%, respectively. After the initial assembly, all the parts for each order are collected based on a unique order ID and routed to the final assembly station.

Figure 3 Simulation model of the cabinet manufacturing factory in Simphony.NET (see online version for colours)



5 Simulation results

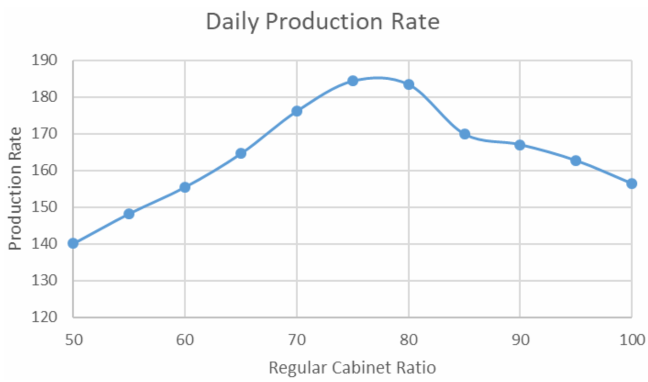
Based on actual performance without unexpected delays, the company produces an average of 170 to 220 cabinets per day. To maintain the company's confidentiality, data are masked by being multiplied by an arbitrary number.

The results derived from the simulation indicate that an average of 38,757 minutes or 81 days (assuming a work shift of eight hours/day) are required to produce 17,317 cabinets. The rationale for choosing a large number of entities is to generate valid results by ensuring that all stations are fully loaded. As there will not be any cabinets produced until day 14 (due to the lead time of placing the first order until the time it is promised to be ready), 14 days are subtracted from the final number of days shown in the results. The simulation estimates a production rate of 179 boxes per day, which is within the range of actual performance. The simulation is run for 30 times to analyse the stochastic nature of activity durations. The average daily production rate remains at 179 with minimal variance. It is noted that the north CNC and edge-banding stations as well as the regular assembly line are the bottlenecks of the whole process owing to over utilisation at 86% and 89%, respectively.

Several scenarios have been examined to mitigate this issue. One proposed solution is to double the number of resources at these stations. Implementing this proposed change will increase the average production rate to 197 cabinets per day and resolve the bottlenecks identified in the model.

On another note, cabinets belonging to the same order can either be of 'regular' or 'custom' type. Assembly of custom cabinets takes three times longer than regular cabinets to complete. To examine the effect of cabinet-type mix on the production rate, different percentages of regular versus custom cabinets were assigned for each order. Figure 4 demonstrates that, to reach the maximum simulated production rate of 179 cabinets per day, total orders should consist of 75–80% regular cabinets and 25–20% custom cabinets.

Figure 4 Daily production rate based on cabinet type (regular vs. custom) (see online version for colours)



6 Model validation

Several model verification and validation approaches are used to ascertain the accuracy and reliability of the proposed simulation model. Conceptual model validations are used to evaluate the system's logic. The input, process, and output of each production line, as well as the assumptions described above, were analysed and confirmed by subject-matter experts. In addition, the results of the computerised model were compared to the historical data of the company. Sensitivity analysis is used to determine the responsiveness of the model to various scenarios. As evidenced in Figure 4, the maximum production rate of 186 cabinets per day occurs when regular boxes represent 75–80% of total cabinets produced which is consistent with the actual percentage used at the factory floor.

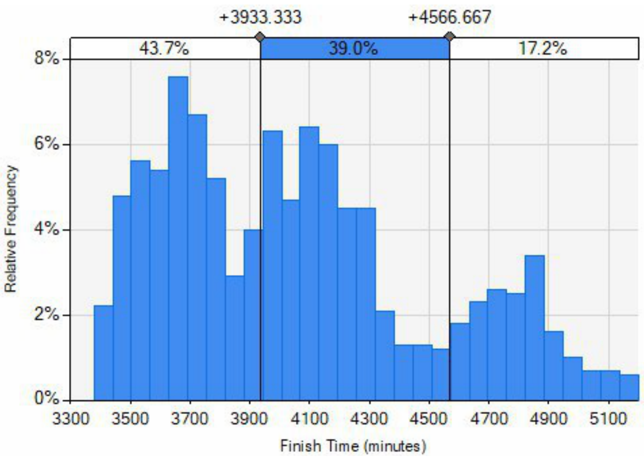
In this study, the simulation model is validated at two levels:

1 time to complete one order

2 daily production rate (cabinets/day).

In order to validate the duration of each completed order, two variables are used. The first variable is time, calculated by recording the start and finish of an order based on its unique ID. The second variable is the number of cabinets in each order. The finish time for each order is calculated when the number variable reaches its limit, i.e., the number of cabinets in that order. The time to complete an order is set to be approximately 14 days; this is the duration promised to the customer. As Figure 5 shows, the duration of completion is approximately 4,566 minutes for 82.8% of the orders (almost equal to ten days). The duration derived from the simulation considers only working days. After adding weekends to the duration, the actual wait-time would be 12–14 days. This timeframe is within the actual acceptable duration promised by the cabinet manufacturing facility.

Figure 5 Distribution of complete order times over all simulation runs (see online version for colours)



For validation of the daily production rate, historical data are compared to simulation model output. The output of the model (approximately 179 box/day) is found to be within the historical data range of daily production (170 to 220), thereby validating the simulation model. The average daily production rate derived from the simulation is 186 cabinets/day which is within the acceptable range of 170 to 220. There are a few possible explanations to account for deviations from the model output from actual data. Breakdown activities of less critical machines, the effect of labour absenteeism, and fine details of custom cabinet operations are not fully incorporated in the proposed simulation model. The results are based on our previously listed assumptions and the available historical data, collected over an observable period of time.

7 Conclusions

In this paper, a simulation study of the production line in a kitchen cabinet manufacturing facility is carried out. A simulation model illustrating the current production process of the facility is developed using the DES approach using Simphony.NET, a simulation environment developed at the University of Alberta.

The proposed simulation model is found to be capable of producing reliable results that are representative of the actual system. Moreover, the simulation model uncovered potential scenarios that are anticipated to improve the production process, reduce wait times, and increase productivity. The model is validated by comparing the total order completion time, as well as the average daily production rate obtained by the simulation model and historical data. Data analysis of NCRs is used to estimate the probabilities of reworks and repair based on the wood type of the cabinet, which form an important component of the simulation study. Generated results are comparable to historical data. One of the most important findings of the simulation result is the recognition of bottlenecks. Based on the utilisation report, the regular assembly line and the north edge-banding station are determined to be the bottlenecks of the process. Several 'what-if' scenarios are examined to determine what improvements are applicable. Doubling the number of resources at the regular assembly line and the north CNC and edge-banding stations is anticipated to increase the average daily production rate by approximately 10%. This improvement needs to be further investigated to decide if it is financially feasible to adopt. This study demonstrates the advantage of utilising simulation models to experiment with real-world systems, and using simulation to investigate the impact of various 'what-if' scenarios before deploying conceptual solutions into practice.

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