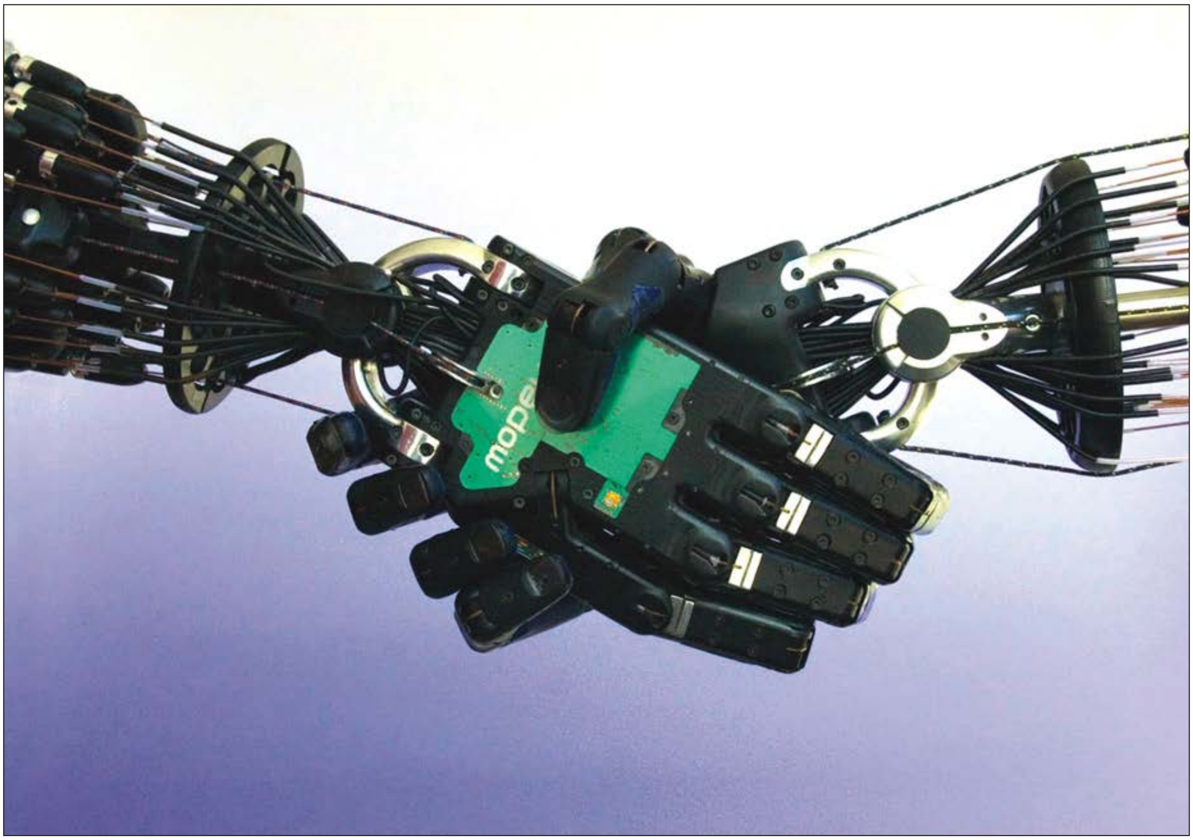

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Case Report
A Study on Effective Production Model for Higher Productivity in Manufacturing Plant

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Abstract
Manufacturing is a highly competitive arena. Many industries and firms, either in perfect competition or monopoly, absorb the costs of production, including the sunk cost and emergence of production capacity within the low labor cost areas in short or long run activities. A significant demand is to operate in optimum or near optimum production conditions. With using methods and techniques, the industries and firms can make a quality of production in term of more profitable. The development of a generic model with line balance technique using computer systems simulation is commonly applied to investigate the effects of statistical variability data. The industries and firms evolve their manufacturing methods and it is significant that production approaches are ready in adapting changes. Consumer's demands are unpredictable and competition affects the production strategies of companies, hence, organizations must attempt to initiate flexible manufacturing methods.

Key words: Generic model, PCB assembly, SRFL, queue graph

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

A system model is an image or object constructed by a person for better understanding on how a real system works. All models have an input of information, a processor and an output of expected outcomes. The key features of a model development will include:

- Boundary conditions
- Initial conditions
- Range of applicability

Typical system models are:

- **Conceptual or generic:** These models aim to highlight important connections to the real world systems and processes. They are normally utilized as a first step towards the creation of more complex models
- **Full:** A full or physical model can be easily examined and manipulated. They have similar characteristics to the key features of more complex system in the real world. These models can help bridge the gap between a real system and the generic model. With the assistance of the other computer applications, more image manipulation and analysis can be constructed. This is done through computer simulation, 2D/3D visualizations and animations, where data and graphics are directly linked
- **Statistical and mathematical:** These are the models used in solving the relevant system equations of where statistical, analytical and numerical parameters are involved. Statistical models are used to identify patterns and relationship between data sets. Mathematical models use equations and numerical manipulation to support the logic of the system

Prior to the full application proceeding, an investigation of the generic model is conducted using all the required functions that can be examined. On the other hand, the full model of a real application is more complex whilst exact data collection for analysis is time consuming. It is, therefore, essential to test the methodology with a generic model before attempting to test it using a real application. Besides, it is time and cost-effective to solve some potential problems before hand. The generic model has a number of simplifications in comparison to the full application model. The significant differences between the two models are:

- Fewer assembly stages
- Fewer source of materials
- Buffer size (bigger or smaller)
- Forklift speed (slower or faster)
- Conveyor speed (slower or faster)

In accelerating the total revenue within the manufacturing industries or firms, the short or long productivity will have to be prearranged. These may be applied in the competitive and monopolize market structure by using many techniques and methods. The techniques and methods have been developed to enhance the reliability and availability of the production lines to become more effective and efficient just to minimize the operational cost, including the sunk cost towards the improvement of quality of production. The lean approach is considered as the tool to reduce and remove waste across the process of production activities[1,2]. On the other hand, it is stated that the lean approach is focused on the stable activities where smooth workflow, stable orders and supplier relations can avoid unnecessary waste or activities. Inventory in production activities is an important element as good planning without surplus it can reduce the operational cost[3,4].

Variability in production activities is likely the main problem in the lean method implementation. As stated by Standridge and Marvel[5], to address some deficiencies in the lean approach, simulation is required. Meanwhile, it has commented that an agile approach is adapted to promote a desirably rapid and cost effective response to unpredictable customer demand[6].

Business Process Reengineering (BPR) and Supply Chain Logistic (SCL) application studied by Ulgen and Upendram[7] are focusing on the automotive body shop design, robotic work cell design and warehousing and supply chain logistics model with production rate. Porras and Dekker[8] have stated that the excess inventory leads to high holding costs and stock output which may have a great impact on operations performance.

Meanwhile, Ferrari *et al.*[9] presented a case study using tool to deal with production planning and control in a multi-cellular flexible automotive line. Spieckermann *et al.*[10], Althinkilinc[11], Gujarathi *et al.*[12] and Longo *et al.*[13] have illustrated more examples using simulation approaches. The significant of using simulation has been stated by Idris[14], where simulation is not only seen as an optimization technique even though it can provide data for experimental analysis or direct inputs to computer based optimization techniques.

The objective of this study is to create a simplified system model which represents a realistic situation. The methodology adopted in creating the generic model was applied in a motorcycle assembly factory. However, the strategy is to develop stages of simpler 'Building blocks' before attempting a more complex case. Initially, a 'Generic' model, that incorporates all the basic functions required in the full practical application is investigated. In order to test the concept of the production flow line, the generic model is required since it has the key features. Nevertheless, duplication of these features should be avoided and in the intervening time, a full model is created based on an actual application.

MATERIALS AND METHODS

Generic model: In representing the essential characteristics of a range for real applications, a generic model is devised. Both automotive assembly and electronics production are chosen as the analysis subject of to represent a good range of Short Run Flow Line (SRFL) applications, with the potential complexity and flexibility. Figure 1 shows a typical flow chart for motorcycle assembly and each assembly station has different characteristics based on its requirements.

Based on the flow chart, during the line-up of parts or processes, the movement of products can be disrupted by a 'Bottleneck'. The disruption will eventually upset the whole performance of the assembly line. The line arrangement is normally made to minimize 'Bottlenecks' or 'Blocking' using 'Line of balance' methods as displayed in Fig. 1.

Table 1 shows the analysis for the basic characteristics of the assembly operation at each station. The families of parts are assembled in the process flow which is based on the Group Technology (GT) principles.

Figure 2 shows the stage is significant to minimize the processing time and at the same time to maximize efficiency. Group technology method, as discussed by Krajewski and Ritzman[15] used in the production because it minimizes the set up times while reducing material waiting times.

Figure 3 shows a typical process flow chart for the Printed Circuit Boards (PCB). The process shown is using Surface Mount Technology (SMT) and is common in an electronics factory. Analysis for the application of GT in electronics production requires comparing the main characteristics of their parts and processes with automotive production.

The PCB's assembly is shown in Fig. 4, where the processes are grouped together. The analysis indicates that both automotive and electronics production share the concept of GT principles and it can transform into a minimum of a three-stage assembly process. A generic model for SRFL is using the same principles and can be represented by a three workstation assembly line as shown in Fig. 5.

Table 1: Analyses of assembly characteristics in SRFL

Classifications	Characteristics of generic model in SRFL
Type of parts	Assembly process starts with main body (chassis), bigger and heavier parts, followed with interiors and exteriors and common and unique parts
Number of parts (BOM)	Number of parts to be assembled in each station depending on quantity, complexity that effects cycle time
Size and weight of parts	Size and weight of parts are equally important. Bulky parts to be considered especially seats and heavy parts (engines). Parts lifter may be required for lifting purposes
Cycle time	Variation in cycle time is determined by line of balance and assembly skills
Movements	Movement or non-movement of assembly worker picking up parts will affect the cycle time
Supply methods	Supply methods using forklift, trolleys or pickers. Interval of supply depends on storage capacity and distance of line to the store
Storage type	Line storage (racking, bins or boxes), intermediate storage (racking) and main store (racking) storage capacity depends on availability and location of parts

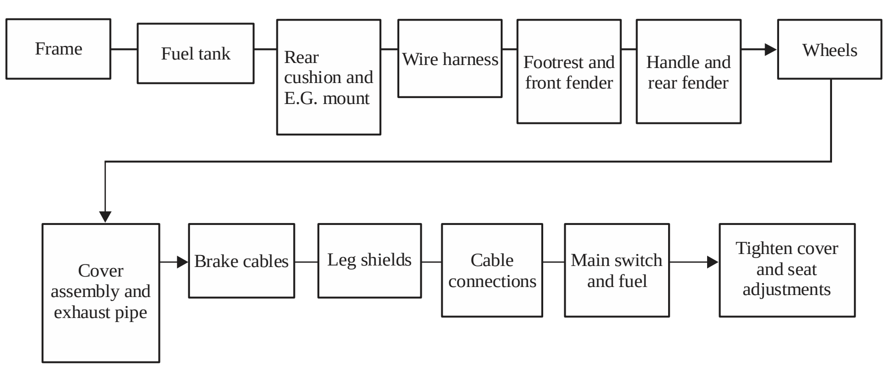

Fig. 1: A typical motorcycle assembly process flow chart

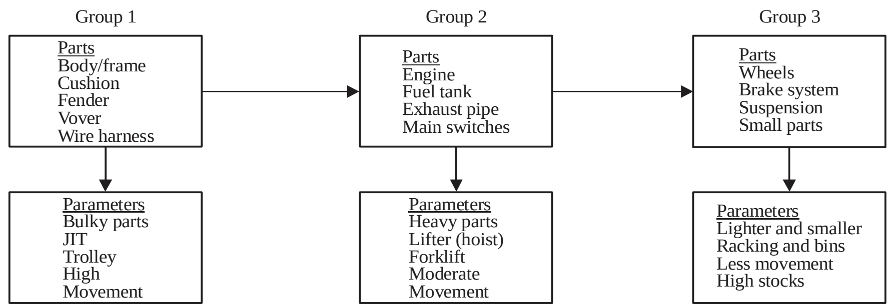

Fig. 2: Automotive assembly process categorized in GT families

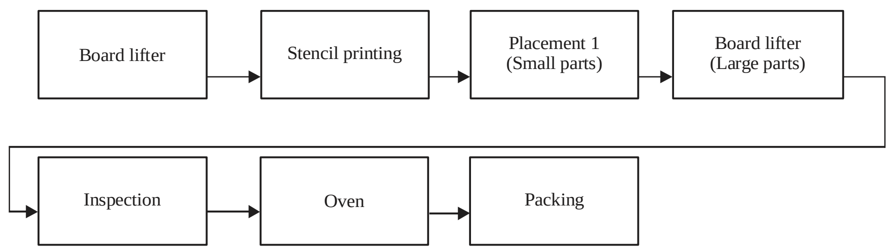

Fig. 3: A typical PCB's assembly process flow chart

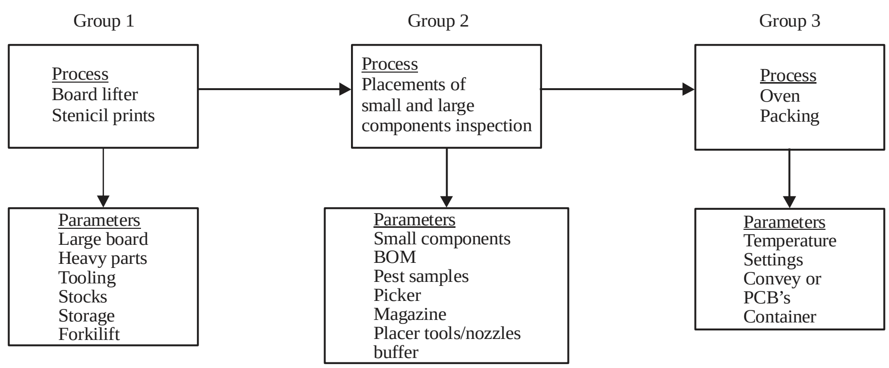

Fig. 4: PCB's assembly

Figure 5 illustrates the newly created flow chart that involves all groupings of parts and supply systems of a generic model. At each station, sufficient operators are required at the continuous assembly processes. The three station generic models represent all the complexities of the actual number of stations and process groups in real applications. Also, at each station, parts within a family group are assembled together in stages. In order to avoid disruptions, buffers are allocated between stations because upon the occurrence of blockage, the buffer is used to avoid further stoppages. The parts are generally supplied from several sources at different time intervals. They need to be correctly delivered to stations and the production normally sed on a fixed batch size. Parts are usually delivered using forklifts, hand pallet trucks, trolleys and pickers.

From Fig. 5, it can be identified that there are three type of storage area which are the main store, intermediate store and line storage. Through the main store, the suppliers deliver parts upon receiving, inspection, storage and distribution and parts are normally delivered to the main store using an MRP ordering system. Usually, small stock quantities of are permitted in the main store to avoid stock-out. This is especially common for high use small parts (i.e., screws, bolts and nuts) which kept in an intermediate store, close to the assembly line. To ensure continuity of supply and minimal worker's movement, this is essential. Line storage is typically designed to maintain minimum number of quantity of parts because of space constraints. This design layout must also ensure the minimum movement of workers in reaching parts. Most of the larger and heavier parts such as in the case of

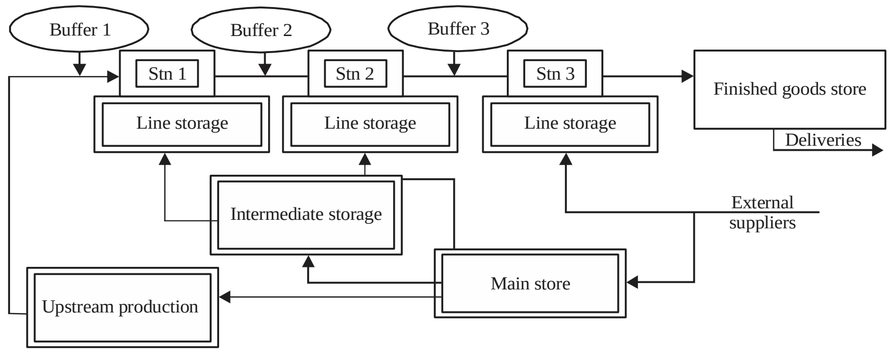

Fig. 5: Generic model of SRFL

Table 2: Parameters in SRFL

Classifications	Production parameters
Demand	Order quantity:
	• Throughput
	• Batch size
	• Product mix
	• Delivery lead time
	• New model
	• Engineering changes
	• Product costs
	• Payments
Work time	Cycle time:
	• Skilled and semi skilled workforce
	• Working hours
	• Work distribution
	• Line balancing
	• Absenteeism
	• Over time work
	• Down time
	• Conveyor down
	• Machine down
	• Faulty tools
	• Power failure (facilities down)
	Set-up time:
	• Model change
	• Quick changeover
	• Common tools concept
	Material arrival time:
	• Storage capacity
	• Replenishment quantity/frequency
	• Transportation
	• Handling/forklift
	• Butter size
Quality	Rejection rate (U):
	• Process quality
	• Parts quality
	• Rework

automotive line like body or frames and engines are delivered periodically to the line using JIT concepts. However, the upstream production is relatively common with SRFL, where it refers the critical processes required (i.e., fabrication, welding, painting or sub-assembly) for main parts of a product are prepared before entering the assembly line. These processes have to be efficient and well-coordinated in order to avoid disruptions in the main line production. Consequently, the main store usually maintains adequate stock for upstream activities in order to support the main line. Products are scheduled sequentially into the production line with a fixed batch size. Customer demand, model availability, production downtime and inventory control are typical factors that contribute to production variability in Short Run Flow Line (SRFL).

Parameters model: Table 2 shows typical parameters in SRFL where the key features could be built using either the generic and/or the full industrial application models.

Based on the parameters shown in Table 2, the variables which are likely to be the main source of production variability in SRFL can be grouped into two categories:

- **Variables that effect throughput:** Downtime (breakdown), set up time, stock-outs maximum cycle time and cycle time variability
- Variables that effect either work-in-progress or overhead costs

Transport distance and level of stock held/replenishment interval. It should be noted that the batch size effects both throughput and overhead costs.

Simulation model: In order to create a simulation model layout, a system flow-chart must be established. There are four basic elements in the which are namely the source, queue, server and sink. These Enterprise Dynamics (ED) atoms were built as representations of simplified processes in the generic model from Fig. 6. The functions and symbol

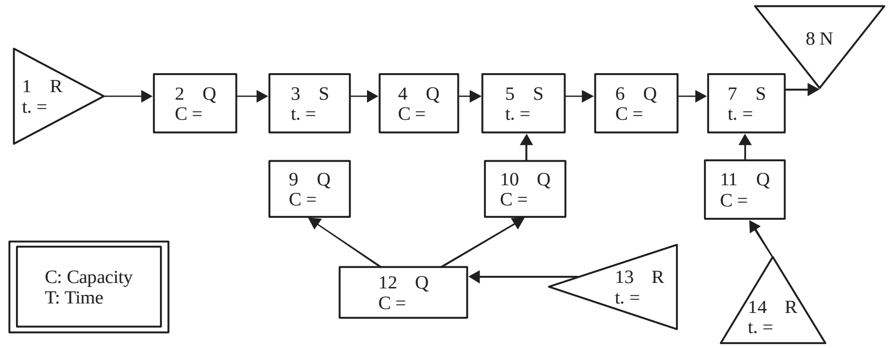

Fig. 6: ED format based on a generic model

for these atoms are allowed: Source, R: this atom is to generate products into the model:

- Queue, Q: This atom is a waiting area or store
- Server or Assembler, S or A: This atom operates on assembled parts
- Sink, N: This atom is for the product to leave the model

Figure 6 shows the flow chart of the system in ED format. After the block ED model is established, the variables for each activity are determined. The input parameters required for processing materials into finished goods (throughput) are as follows:

- Cycle time (t)
- Material Inter-arrival time (e)
- Material storage capacity (c)
- Batch size (b)
- Downtime/mean time between failure (MTBF)
- Downtime maintenance/mean time to repair (MTTR)
- Setup time (s)
- Material replenishment interval (f)
- WIP buffer size (u)
- Rejection rate (r)

RESULTS AND DISCUSSION

This study uses simulation techniques to model the real complexity of a SRFL. The simulation outputs are used to measure, identify, test and predict the performance of the variables. There are three main experiments carried out. They are:

- Using simple model:
  - **Experiment 1:** Simple flow line model without variability
  - **Experiment 2:** Simple flow line with variability. Using generic model
  - **Experiment 3:** SRFL

Experiment 1: In production, the normal calculation used to measure the throughput, Tp is by dividing working hours, Wh by cycle time, Ct. This can be shown as follows:

Assume:

- Simple model: Key features and complexity of model are simplified with 3 stations and 3 storage areas
- Working hours (Wh) = 400 h (1440000 sec, 8 h per shift day)
- Material inter-arrival time, At = 10 sec
- Assembly cycle time, Ct = 60 sec (per product)
- Queue capacity, Q = 100 unit (storage)

Hand calculation gives, Throughput:

$$\begin{aligned} Tp &= Wh/Ct \\ &= 1440000/60 \\ &= 24000 \text{ U} \end{aligned}$$

When using single run simulation Fig. 7 for 400 h (3 months production), Throughput, Tp1a = 23997 U.

If using experiment atom Fig. 8 for 400 and 10 h warm up periods with 30 observations (30 runs), Average throughput, Tp1b = 24000 units (95% confidence interval). Experiment 1 indicates an output of 100% utilization rate. The result gives the same value as obtained with manual calculations. This suggests that the simulation model is accurate and capable of producing a reliable data for further experiments.

Experiment 2: Thus experiment established the significant effect of the variability on the model. In real assembly line, production variability occurs mainly due to man, machine,

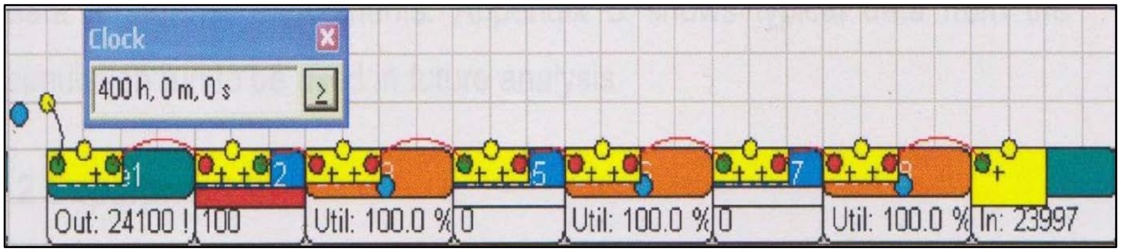

Fig. 7: Experiment 1 using single run

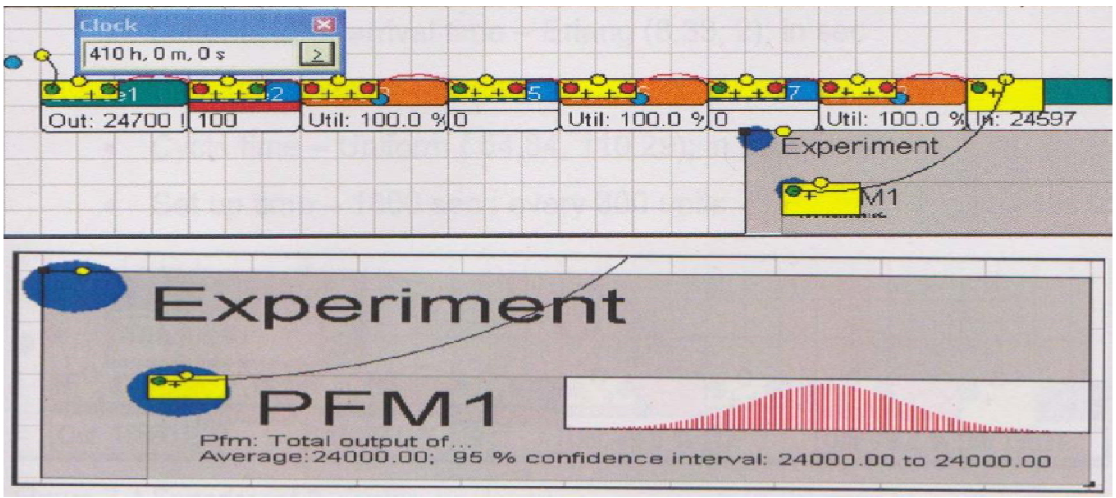

Fig. 8: Experiment 1 using atom

method and material. The following variability factors were considered during data collection in the factory, which will be used in the experiments:

- Material inter-arrival time: Erlang (8.33 and 2 sec)
- Storage capacity: 20 U
- Cycle time: Uniform (54.84 and 110.29 sec)
- Set up time: 1800 sec, every 300 U
- Line breakdown-gamma (74.60 and 2.80)

Observation of simulation runs reveals that the utilisation rate for each station drops from 100% (in experiment 1) to 79% due to variability factors as shown in Fig. 7. This indicates that 21% of assembly operation times are lost by various blocking factors as a result of uncertainties. Now, considering how many products are produced. In a single run simulation (Fig. 9), Throughput, Tp2a = 13831 U.

Whereas, simulation with 30 observations gives (Fig. 10) throughput, Tp2b = 13879.40 (95% confidence interval) by subtracting the throughput, Tp1b-Tp2a = 24000-13879 = 10121 U.

As a result of the blocking factors, the throughput has been reduced by 42% from the potential yield of 24000 U. Although, daily production loss times are recorded, they were not added in order to calculate as they vary. Therefore, simulation provides a useful tool that makes full use of the production data by incorporating the variability factors, to test the effect of the parameter settings and predict the potential throughput.

Experiment 3

SRFL: The generic model consist of all key features of a motorcycle factory. The parameter used are similar to experiment 2. In addition, there is more complexity established in the simulation model o reflect the real world. They are:

- Mixed model line, i.e., A. B, C, D; where there are 4 main models produced in the assembly line. Each model has different specification and customer's requirements, which contribute to the further complexity

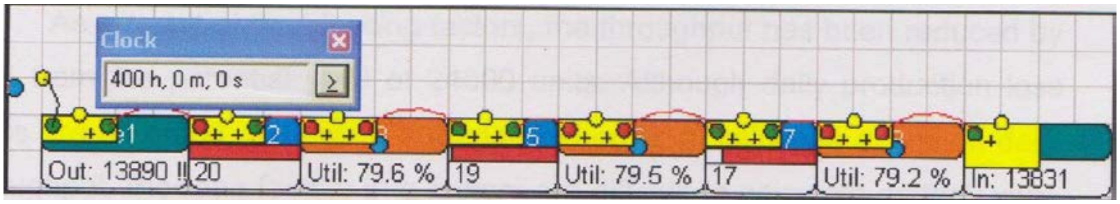

Fig. 9: Experiment 2 using single run

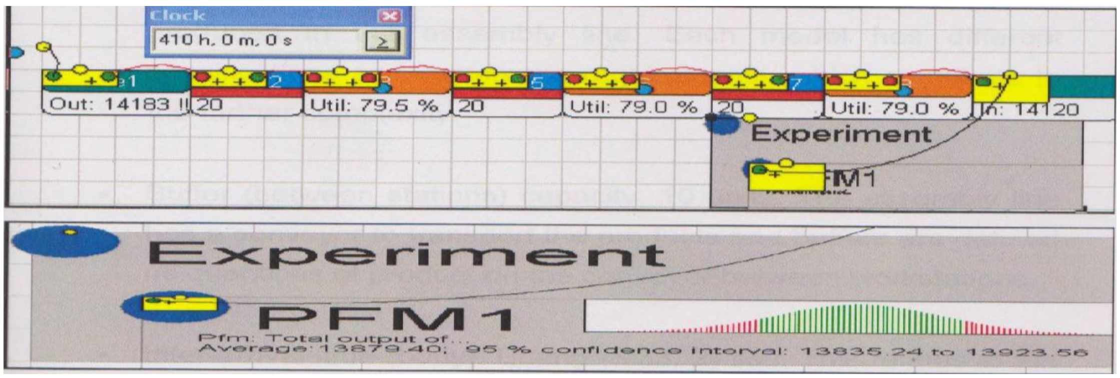

Fig. 10: Experiment 2 using experiment atom

- Buffer (between stations) capacity, 10 U. The assembly line has a conveyor to transport the products and buffers are defined as quantities of product on the conveyor between workstations
- Inter-arrival time (body), Erlang (8.33 and 2 sec). This relates to the distribution of time for picking up the motorcycle body and placing it on conveyor
- Inter-arrival time (materials), Erlang (8.33 and 2 sec). This relates to the distribution time for arrival of the materials in the store. This is based on parts distribution in the store
- Main storage capacity, 300 U. This is the average store capacity measured in vehicles sets or number of complete units
- Forklifts, 0.03 m sec^{-1}, this relates to the replenishment interval of parts to the assembly line
- Handling time, lognormal (200 and 20 sec). This is the time taken to load and unload materials from store to the production line
- Repeat time/replenishment frequency, 2 h transportation arrivals for supplying material to the main store
- Bill of materials, BOM. This relates to the required number of parts to be delivered per station
- Line storage (Racking) capacity, 20 U. This is the storage capacity in the special racks at the production line and measured in vehicle sets
- Kanban bin, 20 U (JIT-continuous). This is used in a continuous supply system based on a JIT or pull system
- Parts shortage, 2%. This is effect on part shortage in the line
- Rejection rate, 10%: A typical daily rejection rate for the motorcycle. Defective products need to be reworked at offline stations

Rework cycle time, Weibull (1800 and 200 sec). The rework cycle time based on a weibull distribution.

Figure 11 is a generic model of SRFL after transformation into an Enterprise Dynamic (ED) layout. The atoms are placed at specific locations as a representation of a real factory. The simulation runs for 400 h, with a 10 h warm up periods using observations (20 runs). Throughput, Tp3 = 9010 U on average, the total production for 3 months is around 9000 U; dropped more than half (62%) compared to the simple model, which was running without blocking factors as depicted in Fig. 12 despite an effort to reduce variability, in a competitive situation, it is sometimes unavoidable.

Higher throughput is difficult to achieve when variability is increased. It is also not an indication for higher profit. When other costs increase with higher output, the profit margin may decrease. There is no simple method to reduce variability in production and it has been everyone's tasks to achieve it.

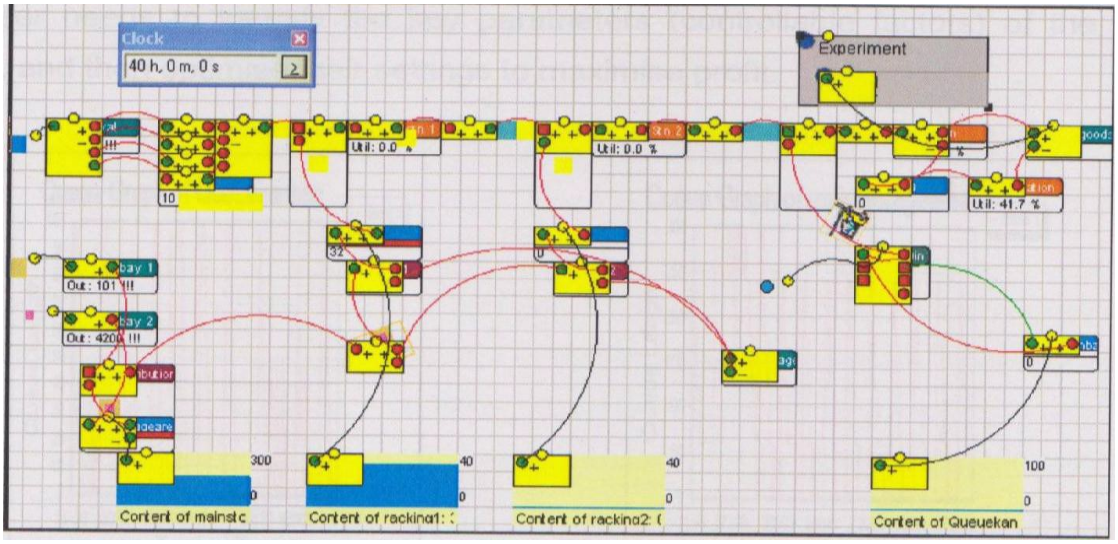

Fig. 11: Experiment 3 model layout

Fig. 12: Average output

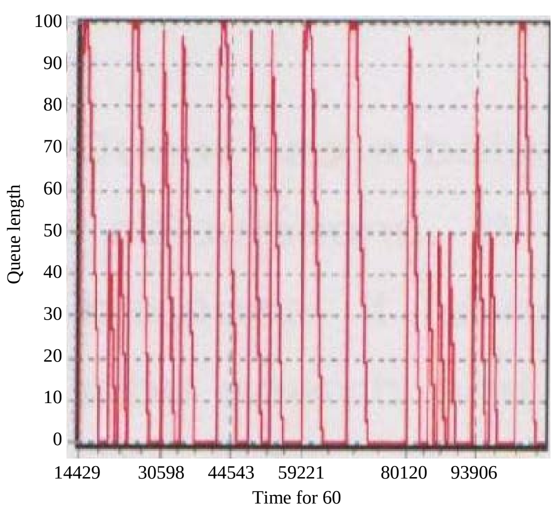

Fig. 13: Queue graph of queue kanban bin

Therefore, an engineer needs to identify the key parameters (controllable factors) of the SRFL and then optimize their settings to maximize profit.

Figure 13 and 14 show the relationship between waiting time and storage capacity (queue length). They indicate that larger storage requires longer waiting time for materials to be processed. This will increase the storage costs. When storage is reduced, replenishment frequency is increased, adding to the stock out, transportation and handling costs. Figure 15 and 16 illustrate racking capacity with minimum waiting time but increased replenished frequency.

In summary, both experiment 1 and 2 demonstrate the need to understand the variation in production ,their causes and their effect on the profiftability. In experiment 3 uses a generic model to reperesent the real plant set up parameters values based on the probability distributions produced from the real data introduced in experiment 2. However, more variations are included in this model that has been deduced from detailed observations and the previous author. They are stock-out element, assembler atoms (BOM), conveyer speed, replenishment frequency, shortages and reject. The simulation result reveals that the throughput had dropped from 13879-9010 U (10 weeks) or 901 U week^{-1}. Production

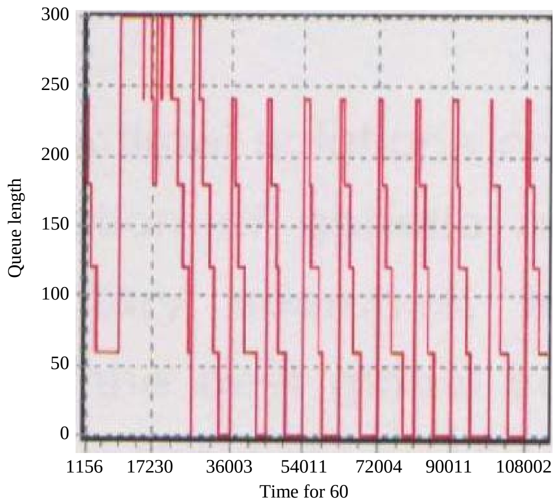

Fig. 14: Queue graph of main storage area

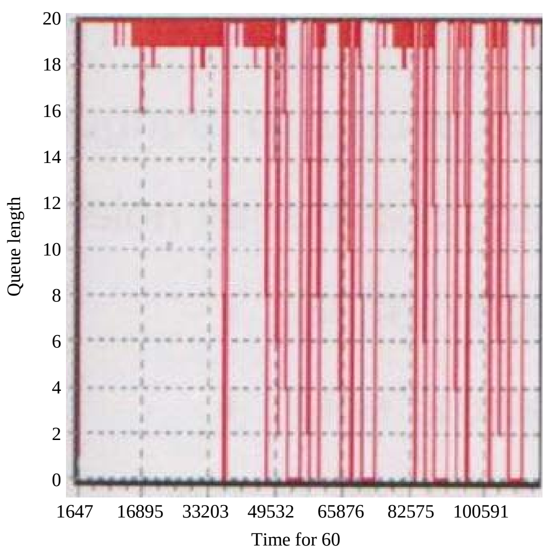

Fig. 15: Queue graph of racking 1

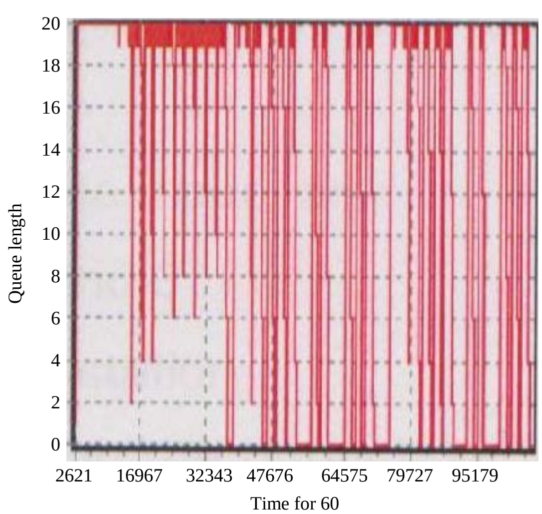

Fig. 16: Queue of racking 2

variations involving stochastic problems are not easy to deal with using conventional methods. However, the proposed methodology, using simulation and optimization will help managers to have a clear understanding and visibility in order for them to indentitify the key parameters that effect productivity.

CONCLUSION

Implementation of a model and technique is most important in order to reduce cost and remove waste came across in production activities. The manufacture can gain profit by implementing typical systems model such as conceptual or generic because it is an important connection to the real world systems and process. They are normally used as a first step towards the creation of more complex models. A full or physical model can be easily seen and manipulated. They have characteristics of the key features of more complex system in the real world. These models can help bridge the gap between a real system and generic model. With the help of other computer applications, more image manipulation and analysis can be made in statistical and mathematical models. These are the models used in solving the relevant system equations of where statistical, analytical and numerical parameters are involved. Statistical models are used to identify patterns and relationship between data sets. Mathematical models use equations and numerical manipulation to support the logic of the systems.

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