

The Application of Queuing Theory in Multi-Stage Production Line

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Abstract

The purpose of this paper is to carry out queuing analysis to examine multi-stage production line performance to facilitate more realistic resource planning. It is one of a few such studies to improve the performance of multi-product multi-stage production lines. This work aims to help managers in improving the efficiency, effectiveness and selecting the most suitable policy for assembly systems. The paper adopts an analytical approach based on real life data from an international battery company producing battery covers for camera model EC-196. The battery production line consists of six independent workstations namely injection molding, first color spray, second color spray, ultra-violet (UV) station, assembly station and a packing workstation. The relevant data for each workstation was collected and the chi-squared goodness test was applied to determine the arriving and leaving distributions data of processing parts. Queuing analysis reported in this work provides a basis for estimating and analyzing production systems by measures such as utilization, percentage of idle workstation, number of batches in system, number of batches in queue, expected time spent in queue, and expected time spent in system. The comparison between results and standard data in the company showed an accuracy of 93.80%.

Keywords

Case study, manufacturing, performance measurement, production line, queuing theory

1. Introduction

Queuing Theory in manufacturing process involves the study and simulation of models to predict the behavior of a manufacturing process which attempt to provide services for randomly arising demands in manufacturing work station. By utilizing queuing model, we can make decisions about the waiting line which lead better productivity. Engineers have applied results of queuing theory to show how cycle time is related to utilization of machine and statistic of inter-arrival time and service. These analyses provide means and predicting the average cycle time in steady state condition. By knowing the cycle time, work in progress can be determined.

The main purpose of application Queuing Theory that related in manufacturing industries having an assembly processes is to model the assembly process in manufacturing plant by using an appropriate analytical model of Queuing Theory. Certain importance measures of this model will be derived and can serve as comparison with the standard data available in the company. Important performance of queuing model will be determined as a guide to increase efficiency of each workstations and suggestion to increase the performance of each work station.

This paper discusses a case study about the application of Queuing Theory in Company Z. The company produces Canon B. battery lid (CD3-3836-00) as a cover to place battery in camera. Because of the increasing of its product demand, the company needs to examine the efficiency and other parameters of production line to produce Canon B. battery lid product. Based on this reason, the objectives of this case study are:

- To model a production line of assembly process in manufacturing plant by using an appropriate analytical model of Queuing Theory.

- To examine the important performance of production line by using the developed queuing model, so that the performance improvement of production line can be achieved.

To give information about the studied production line in this case study, Figure 1 shows the process flow to produce Canon B. battery lid.

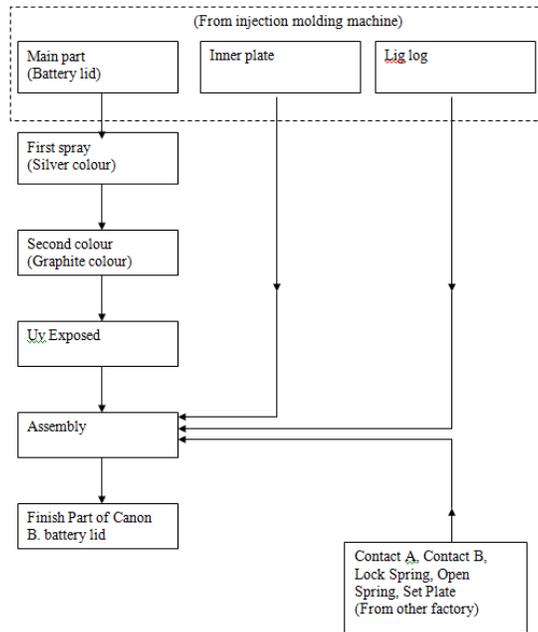


Figure 1: Process flow to produce Canon B. battery lid

There are three parts produced in injection molding machine. These parts are battery lid, inner plate, and lig log. Battery lid needs more treatments and processes through the first colour spray, the second colour spray, and ultra-violet spray before this battery lid are combined with other parts to become a product named ‘Canon B. battery lid’. As shown in Figure 1, the other parts those need to be combined with battery lid are inner plate, lig log, contact A, contact B, lock spring, open spring, and set plate. Canon B. battery lid product is shown in Figure 2.



Figure 2: Canon B. battery lid product

2. Related Work

Queuing Theory was developed to provide models to predict behavior of systems that attempt to provide service for randomly arising and not unnaturally demand. The earliest problems studied were those of telephone traffic congestion (Syski 1986). Mital (2010) carried out queuing analysis to analyse patient load in outpatient and inpatient services to facilitate more realistic resource planning. Queuing analysis reported in his case study provides a basis

for estimating medical staff size and number of beds, which are two very important resources for outpatient and inpatient services in a large hospital, and all other hospital resources in one way or another depend on them.

As discussed by Hideaki Takagi (1993), Hayashi, Kodashima and Yamaguchi presented a new approach in designing of semiconductor equipment based Queuing Theory to reduce cycle time. They applied Queuing Theory in calculating optimum batch size for their processing equipment. They have showed the batch size required to achieve short time under different production situations. As presented by Cooper (2000), Hoover and Bartlett have also applied the results of Queuing Theory to show how the cycle time is related to large and small production. In large production, cycle time is important to determine the amount of work in progress, and it can be determined by using Queuing models. However, their study had limitation which it can be applied only in large production. Their simulation has showed greater fluctuations in cycle time compared to the value predicated by Queuing Theory.

Ullah (2011) presented a comparison between Petri net (PN) and queuing network tools to determine the optimum values for flexible manufacturing system (FMS) measures of performance. A queuing theory was presented by Tsarouhas (2011) to calculate the total processing time for the processing time per pizza line at workstation in food production lines. McGuire (2010) proposed and tested a model which defines the psychological processes that mediate the relationship between perceived wait duration (PWD) and satisfaction. Caputo and Pelagagge (2011) reported that of the scarce literature existing on modeling material delivery to assembly lines, kitting has received the greater attention. However, most available models utilize queuing theory to analyze dynamic performances of kitting systems and kit-replenished assembly systems. Mehmood and Lu (2011) reported that Markov chains and queuing theory are widely used analysis, optimization and decision-making tools in many areas of science and engineering. Real life systems could be modeled and analyzed for their steady-state and time-dependent behavior. Diaz (2010) presented financial engineering derivative interest rate swap as well as new scheduling applications including inventory management and queuing models. Gudmundsson and Goldberg (2007) developed a model to study a commercially available industrial part feeder that uses an industrial robot arm and computer vision system. The problem of optimizing belt speeds and hence throughput of this feeder are addressed that avoid starvation, where no parts are visible to the camera and saturation, where too many parts prevent part pose detection or grasping. There have been a number of books focusing on the application of queuing theory on manufacturing systems, such as those by Papadopoulos *et al.* (2013), Smith and Tan (2013), Guy *et al.* (1997), Gershwin (1994), Yao *et al.* (1994), Buzacott and Shanthikumar (1993) and Narahari (1992).

Koo *et al.* (1995) proposed a manufacturing system modeling approach using computer spreadsheet software, in which a static capacity planning model and stochastic queuing model are integrated. Most stochastic performance measures such as throughput time or work in process as well as deterministic measures can be captured directly from the proposed model. Several special manufacturing features such as machine breakdown and batch production can be included in the model. The performance of the proposed model was evaluated by comparing its results with those obtained from other existing approaches. Their finding for this comparison stated that the maximum allowed a relative error was 10%. Sukhotua and Peters (2005) discussed a number of approaches in the facility design for modelling material flow using queuing networks. In these approaches, Poisson arrival or Markovian job routing assumptions were used. However, for many manufacturing environments, these assumptions lead to an inaccurate estimation of the material handling system's performance and thus lead to poor facility designs. The proposed modelling approach has showed to provide more accurate results than previous methods used in facility design based on numerical comparisons with results from discrete-event simulation. Marcheta *et al.* (2012) presented an analytical model to estimate the performances (the transaction cycle time and waiting times) for product tote movement. The model is based on an open queuing network approach. The model effectiveness in performance estimation was validated through simulation.

The use of simulation in improving cycle time had been discussed by many researchers (Sivakumar and Chong 2001, Domaschke and Brown 1998, Wang *et al.* 1993, Toh *et al.* 1995). Based on their study on many manufacturing systems, they concluded that simulation can improve cycle time varies from 15% to 45%. The use of simulation is a powerful technique that helps decision maker to solve difficult problems in the design, control, or improvement of complex systems to reduce cost, improve quality or productivity, and shorten time-to-market. However, the technology is still underutilized due to several reasons: (1) simulation modeling is a time-consuming and knowledge-intensive process that requires knowledge not only about simulation but also application and implementation tools; (2) most simulation models developed with current technology are customized "rigid" ones that cannot be reused or easily adapted to other similar problems; and (3) transforming related knowledge and

information from application domain to simulation is a unstructured or ill-defined process dependent on the skill and experience of individual modelers (Zhou *et al.* 2010). Based on these facts, the use of analytical approach such as Queuing Theory sometimes is better than simulation to analyze the performance of manufacturing system.

3. Methodology

To accomplish the objectives of this study, the following steps were used.

1. Select a production line to be studied.
2. Collect data for each workstation. The data are throughput rate, number of operator, and number of parts that arrives and leaves during part processing. Data for the number of parts that arrives and leaves are collected at least at amount of ten samples to make the data is possible to be analyzed by Chi-Squared Goodness Test.
3. Analyze the arriving and leaving data by Chi-Squared Goodness Test to determine its variable distribution (Exponential or Poisson distribution).
4. Conduct performance measures of each workstation by using equations based on Queuing theory. The performance measures need to be measured are: utilization factor (ρ), percentage of workstation idle time, number of parts in system (L_s), number of parts in queue (L_q), waiting time spent in queue (W_q), waiting time spent in system (W_s), and task time.
5. Determine the efficiency of each workstation.
6. Make validation of the task time value resulted at step (4) by comparing it with the task time value based on the company database.

The equations based on Queuing theory that is used in this study can be described as follows:

$$\rho = \frac{\lambda}{\mu} \quad (1)$$

where, ρ is utilization factor, λ is average number of parts arriving in one unit of time, and μ is service rate to parts in one unit of time.

$$\text{Percentage of idle workstation} = (1 - \rho) 100\% \quad (2)$$

$$L_s = \frac{\lambda}{\mu - \lambda} \quad (3)$$

where L_s = number of parts in system

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} \quad (4)$$

where, L_q = number of parts in queue

$$W_q = \frac{L_q}{\lambda} = \frac{L_s}{\mu} \quad (5)$$

where, W_q = waiting time spent in

$$W_s = W_q + \frac{1}{\mu} \quad (6)$$

where, W_s = waiting time spent in system

$$\text{Task time} = \frac{1}{\mu} \quad (7)$$

$$\text{Total task time} = \text{setup time} + \text{inspection time} + \text{task time} + \text{waiting time in queue} \quad (8)$$

$$\text{Cycle time} = \frac{\text{production time available per day}}{\text{demand per day or production per day}} \quad (9)$$

$$\text{Efficiency, } e = \frac{\sum \text{task time}}{(\text{number of operator}) \times (\text{assumed cycle time})} \times 100\% \quad (10)$$

$$\text{Maximum number of operator} = \frac{\sum \text{cycle time for task } i}{\text{cycle time}} \quad (11)$$

4. Result and Discussion

Some performance parameters for a certain process resulted in this study are shown in Table 1. These results are based on the queuing theory analysis.

Table 1: Performance parameters for a certain process

Process	Performance Parameter			
	Arrival distribution (unit/hour)	Leaving distribution (unit/ hour)	Task time (seconds)	Number of operator (persons)
Injection molding:				
a) Main part	-	2500	6	4
b) Inner plate	-	1000	15	4
1 st colour spray	2547	2476	4.38	8
2 nd colour spray	2430	2338	3.42	8
UV spray	2172	1810	4.76	10
Assembly	1787	1826	19.53	16
Packing	1876	1828	5.2	5

To make validation for queuing theory model used in this study, all the task time values found by using queuing theory, as described in Table 1, were compared to the existing standard task time values in database of the company. This comparison is shown in Table 2. Accuracy between data using queuing theory and standard data in the company is 93.80%. Based on this data, it can be stated that queuing theory is valid to be used in this case study.

Table 2: Task time values based on queuing theory and standard data

No.	Process	Task time by queuing theory analysis	Standard data available in IPC
1	Injection Molding a) Main Part b) Inner plate	6s 15s	7s 16s
2	1 st colour spray	4.38s	3s
3	2 nd colour spray	3.42s	4.9s
4	UV spray	4.76s	4.50s
5	Assembly	19.53s	35.7s
6	Packing	5.2m	5.3m
	Total	365.09s ~ 6.085 minutes	389.1s ~ 6.485 minutes

Total production time to produce each part of Canon B. battery lid can be determined by adding the total task time in each workstation. As shown in Table 3, the total production time is 42.79 minutes. The efficiency in each workstation is also shown in Table 3.

Table 3: Total task time and efficiency in each workstation

No.	Process	Total task time	Efficiency
1	Injection Molding a) Main Part b) Inner plate	6s 15s	30.25%
2	1 st colour spray	15.43 s	54.85%
3	2 nd colour spray	22.42 s	39.11%
4	UV spray	13.10 s	67.97%
5	Assembly	35.30 s	80.98%
6	Packing	41.00 m	37.38%
	Total	2567.25 s ~ 42.79 minutes	

Packing process is the last process to produce Canon B. battery lid and it suffered the most in queue time. The process production is performed by batch process, once in ten days. This happened because the time to pack single part is less than the time in previous workstation (assembly workstation). In a single day, average part leaving assembly workstation is only 13500 units a day, but in packing workstation the total part can be packed is 14625 units for an hour.

Process in this packing workstation is handled manually by five operators and the average value of queuing time is 76%. This value is higher than the values in other workstations which have range between 20 – 42%. Value of 76% of queuing time is equal to 36 minute per carton. In each carton, there is 1000 pieces of parts. This estimated queue time is very high and will increase the total task time. As time goes on, the queue size will grow unlimited and it is difficult to control and monitor. It will also create a problem in storing the parts.

To reduce the queuing time and increase the efficiency, any possible improvement should be done. One possible action is by increasing the number of operators that manually operate this workstation. Based on the analysis, we found out that the efficiency of this workstation was only 37.78% when it was operated by five operators and it increased to 99.94% when it was operated by ten operators. Therefore, it is better for the company to hire at least ten operators to get a maximum efficiency. As informed before, currently there are 5 workers. To get a maximum efficiency, the company should hire:

$$\text{Maximum number of operator} = \frac{\text{Total time for task } t}{\text{cycle time}} = \frac{41 \text{ min} \times 60}{246.13} = 9.99 \approx 10$$

From this data we can derive the efficiency of packing workstation:

$$\text{Efficiency, } e = \frac{41 \text{ min} \times 60}{(10) \times (246.13)} \times 100\% = 99.94\%$$

5. Conclusion

This study examined the production line performance by using queuing theory at the company producing Canon B. battery lid product. The study has shown that queuing theory is able to analyze production system such as utilization (ρ), percentage of idle workstation, number of batch in system (L_s), number of batch in queue (L_q), expected time spend in queue (W_q), and expected time spent in system (W_s).

This study was based on independent queuing system and it was simplified into 6 independent workstations. The workstations were injection molding, first colour spray, second colour spray, Ultra-violet, assembly and packing workstation. Arrival and leaving distribution was determined by using analysis of Chi Squared Goodness of fit test to determine whether it was in Poisson or Exponential distribution. The resulted data by queuing model used in this study was compared to the standard data in the company to check the validity of queuing model. Accuracy between data using queuing theory and standard data in the company was 93.80%.

This study is very valuable for the company, because by knowing all information related to the performance of its production line, it is more effective and easier for the management of company to plan their production in the future. This study is also important because it examines multi-stage production line in a manufacturing industry by queuing theory approach, as such it is one of a few such studies to improve the performance of multi-product multi-stage production lines.

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Biography

Muhammad Marsudi is an Assistant Professor in Industrial Engineering, Faculty of Engineering (Rabigh), King Abdulaziz University, Jeddah, KSA. He obtained his PhD in Industrial Engineering from the National University of Malaysia, MSc in Computer Integrated Manufacturing & its Management from the University of Huddersfield (UK), and BSc in Mechanical Engineering from Gadjah Mada University, Indonesia. He started his career as a lecturer at Lambung Mangkurat University (Indonesia) in 1989, and as a visiting lecturer on University Tun Hussein Onn Malaysia (UTHM) from 2001 until 2011. He joined King Abdulaziz University since 2011. Muhammad Marsudi has had about 24 years experience of teaching in higher education in Lambung Mangkurat University, UTHM, and King Abdulaziz University which involve teaching in Operation Research, Industrial System Simulation, Industrial Quality Control, IE Seminar, and so on. He has published journal and conference papers. His research interests include simulation and modeling, optimization, and quality control.

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The main purpose of application Queuing Theory that related in manufacturing industries having an assembly processes is to model the assembly process in manufacturing plant by using an appropriate analytical model of Queuing Theory. Certain importance measures of this model will be derived and can serve as comparison with the standard data available in the company. This study is also important because it examines multi-stage production line in a manufacturing industry by queuing theory approach, as such it is one of a few such studies to improve the performance of multi-product multi-stage production lines. References. Altiook ,T., Performance Analysis of Manufacturing Systems, New York:Springer,1997. View Queuing Theory Research Papers on Academia.edu for free. Layout constraints, reworking constraints and inflexible product schedule in multi product lines, needs a precise planning to reduce volume of line stock. In this article, by analyzing real queue systems with layout constraints and by using concepts and principles of Markov chain in queue theory, a hybrid model has presented. This model can be a base to assess queue systems with probability parameters of service. Here by presenting a case study, the proposed model will be described. To do this, with Optimization the layout of production lines of a home application manufacturer, results will be