The Analysis of Manufacturing System Utilization by Using Queuing and Taylor Theories

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Abstract

The manufacturing industry continues to develop rapidly and has since become an important catalyst to the country's economic growth. So, the manufacturing environments are becoming highly competitive. Queuing theory and Taylor theory are analytical models that will be used to analyze capacity usage of manufacturing. This study examines the utilization of production facilities in an automotive industry based on the application of queuing theory and Taylor theory. This study was conducted in machining department and only focused on production of oil pump product. The validation of resulting utilization values, through comparing them with the utilization value, was based on the company database. Based on this validation result, the effectiveness between Queuing theory and Taylor theory in analyzing the utilization of production line can be determined. The finding displayed that the effectiveness of Queuing theory is better than the effectiveness of Taylor theory.

Keywords
Analytical model, capacity, manufacturing system, utilization

1. Introduction

Analysis of several related processes, such as; arriving at the queue, waiting in the queue, and being served by the servers at the front of the queue are important in making engineering, operational and business decisions. Many manufacturing systems can be modeled as network queues, and the use of Queuing theory is one of the alternatives to analyze the performance of these systems. Besides Queuing theory, Taylor theory is also able to analyze the performance of the manufacturing systems. Both theories can be applied to measure the capacity utilization of manufacturing system.

This work is a case study for the application of Queuing and Taylor theories in the multi-stage in the assembly production line. The company produces oil pump, which will be used by a certain automotive industry. There are 9 processes to produce oil pump, which are OP1-plug taper installation, OP2-leak test, OP3-spring plunger cap and pin, OP4-pressure test, OP5-water drying, OP6-stud bolt screw, OP7-rotor installation, OP8-oil seal installation, and OP9-rotor inspection. Oil pump product is shown in Figure 1.

The objectives of this study are:

- Applying Queuing theory and Taylor theory to examine their utilization on an assembly production line.
- Comparing the effectiveness of Queuing theory and Taylor theory in the utilization analysis.

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2. Problem Definition

Due to the increase in the product demand, the company needs to examine the utilization of its assembly line. Increasing the utilization value means increasing the productivity in producing product. Thus, the use of analytical model such as: Queuing and Taylor theories are very helpful to examine this utilization parameter.

Figure 1. Oil pump product

3. Related Work

Bermon *et al*. (1995) used a capacity analysis model for manufacturing line that produces multiple products. From their research, they defined that the capacity is available as the number of operations that a piece of equipment can perform each day. They assumed deterministic demand. In the case of multiple products, the aggregate capacity is divided among these products according to a policy. Their model is directly related to two threads of strategic capacity planning models. Finally they address problems of realistic size and complexity arising in semiconductor industry.

Shantikumar and Buzacott (1981) have provided a comprehensive treatment of queuing models in manufacturing systems, and developed stochastic models that evaluate the performance, and provide an understanding of how different components of a manufacturing system can be coordinated.

Marsudi and Shafeek (2014) discussed the application of Queuing theory in multi-stage production line. The study resulted in 93.80% accuracy between data using queuing theory and standard data in the company.

Taylor and Graves (1991) introduced a system integration strategy called "design to fit an existing environment" (DFEE). In many industries, the success or failure of a new product is largely determined in the design phase of the project. Consequently, manufacturers should strive to develop integrated system design tools to help ensure that new products are readily producible, according to manufacturing or assembly capability. The purpose of this DFEE sub-strategy is to integrate capacity and product mix issues into design strategies to design new products, which are more globally optimal from a systems standpoint. The result of using DFEE is that better product time-to-market targets can be established, and products can be designed to take advantage of existing slack manufacturing capacity, thus balancing assembly flow and reducing capital expenditure.

Sukhotua and Peters (2005) discussed numerous 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 resulted in more accurate results compared to previous methods used in facility design based on numerical comparisons with results of discrete-event simulation.

Marcheta *et al.* (2012) presented an analytical model to estimate the performance (the transaction cycle time and waiting times) for a certain product movement. The model is based on an open queuing network approach. The model effectiveness in performance estimation was validated through simulation. Process analysis is recognized as a major stage in business process reengineering that has developed over the last two decades

Efforts to improve the performance of the manufacturing system have never ended. Utilization is one of the performance parameters, which need to be improved. Previous studies to improve the resource utilization of manufacturing system have been conducted by Walid Abdul-Kader (2006), Seraj Yousef Abed (2008), Hopp and Spearman (2004), Gamberi *et al.* (2008), Marsudi and Shafeek (2013, 2014).

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The use of simulation, as a powerful technique, helps decision maker in solving difficult problems in the design, control, or improvement of complex systems aiming at reducing cost, improving quality or productivity, and shortening time-to-market. However, the technology is still underutilized due to several reasons: (1) simulation modeling is a time-consuming and knowledge-intense 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 an 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 and Taylor theory is better than simulation to analyze the performance of manufacturing system.

4. Methodology

4.1 Data source

Data has been collected from production line of the manufacturing industry (factory). The study also takes into consideration the process sequential, types, and related processing time of workstation, capacity of production line and other information.

4.2 Data collection

The collected data are based on mathematical model of queuing theory and Taylor theory. The data is collected for each machine (process) and it can be described by three parameters. These are failure rate, repair rate, and processing rate. The data is collected starting from the raw material entering to a production line until the final process and delivery. The data collections are only from arrival time and services time distribution.

Briefly, the following steps were conducted in this study:

1. Select a production line to be studied.
2. Collect data for each workstation.
3. Conduct performance measures of each workstation by using equations based on Queuing theory and Taylor theory. The performance measure that was needed to be measured is: the utilization factor (u_j for Queuing theory, or U_{jk} for Taylor theory).
4. Validate the utilization factor values resulted at step (3) by comparing them with the utilization factor value, obtained from the company database.

4.3 Queuing theory equations

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

$$A_j = \frac{m_j^f}{m_j^f + m_j^r} \qquad \textbf{\textit{(1)}}$$

where A_j = availability of a resource at station j, m_j^f = mean time to failure for a resource at station *j*, m_j^r = mean time to repair for a resource at station *j*.

$$t_{ij}^{+} = B_i Y_{ij} t_{ij} + s_{ij} \qquad \textbf{\textit{(2)}}$$

where t_{ij}^{+} = total process time of product *i* at station *j*, B_i = batch size (number of parts) at order release of product *i*, Y_{ij} = cumulative yield of product *i* at station *j*, t_{ij} = mean part process time of product *i* at station *j*, s_{ij} = mean job setup time of product *i* at station *j*

$$x_i = \frac{T_i}{(B_i)(Y_i)} \quad (3)$$

where x_i = release rate of product i, T_i = desired throughput of product i(parts per hour), Y_i = cumulative yield of product *i*.

$$t_j^+ = \frac{\sum_{i \in V_j} x_i t_{ij}^+}{\sum_{i \in V_j} x_i} \quad (4)$$

where t_j^+ = aggregate process time at station *j*, t_{ij}^+ = total process time of product *i* at station *j*, V_j = the set of products that visit station *j*.

$$t_j^* = \frac{t_j^+}{A_j} \quad (5)$$

$$u_j = \frac{t_j^*}{n_j} \sum_{i \in V_j} x_i \quad (6)$$

where t_j^* = modified aggregate process time at station *j*, u_j = utilization of the resources at station *j*.

4.4 Taylor theory equations

The equations based on Taylor theory in this study are as follows:

$$L_j = \left\{ 1 - \left[\frac{MTTR_j}{MTTR_j + MTBF_j} \right] \right\} \quad (7)$$

where L_j = the long-run availability of process j, $MTBF_j$ = the mean time between failures for process j, $MTTR_j$ = the mean time to repair for process *j*.

$$A_{jk} = (L_j)(M_{jk}) \quad (8)$$

where A_{jk} = time available at process *j* in period *k* (hours), L_j = the long-run availability of process *j*, M_{jk} = The number of machine of type *j* available in period *k*.

$$N_{jk} = \sum_{\forall i} \left[\frac{D_{ik} X_{ijk}}{R_{jk}} \right] + \sum_{\forall i} \left[\frac{D_{ik} S_{ijk}}{B_{ik}} \right] + \sum_{\forall i} \left[D_{ik} P_{ijk} \right] \quad (9)$$

$$U_{jk} = \left[\frac{N_{jk}}{A_{jk}} \right] \quad (10)$$

where D_{ik} =demand for product *i* in period *k* (units), X_{ijk} = number of operations required by product *i* at process *j* in period *k*, R_{jk} = run rate at process *j* in period *k* (operations/hours), S_{ijk} = set up time for a batch of product *i* at process *j* in period k (hours), B_{ik} = batch size for product *i* in period *k* (units), P_{ijk} = set up (load/unload) time for each units of product *i* at process *j* in period *k* (hours), and U_{jk} = utilization of process *j* in period *k.*

5. Result and Discussion

5.1 Queuing theory

Figure 2 shows the value of utilzation for each process by using Queing theory. The range of utilization by using Queuing theory is 5% to 45%. The higher utilzation is at machine OP6, which is process to install studbolt and screw. It happens because this process takes more time to install child part. The lower utilzation is at machine OP8 and OP9 where; OP8 is for oil seal installation and OP9 is for rotor inspection. The value of utilization for each machine depends on its processing time.

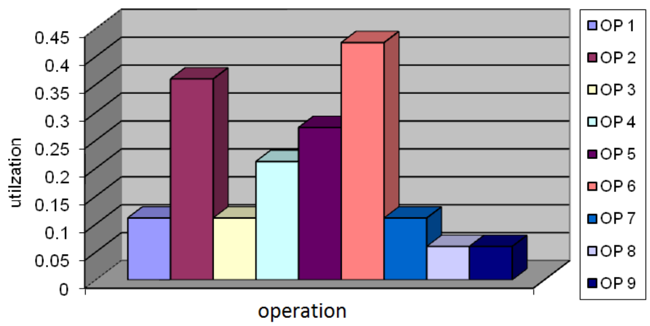

Figure 2. Utilization of each process based on Queuing theory

5.2 Taylor theory

Figure 3 shows the utilization of each process by using Taylor theory. For this analytical theory, their range of utilization is between 50% to 80%. Similar to Figure 2, the highest utilization is also at OP6 which is 80%. But the lowest utilization is at OP1(plug taper installation) and OP3 (spring, plunger, cap and pin installation) which is 53%. Those utization values are infuenced by the processing time at each machine.

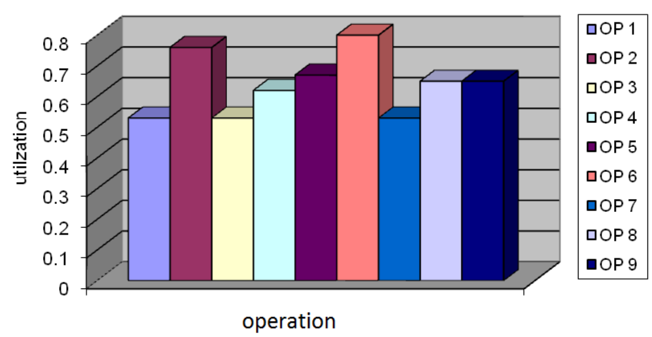

Figure 3. Utilization of each process based on Taylor theory

The resulted data from Queuing theory and Taylor theory used in this study was compared to the standard data in the company to check the validity of both theories. Accuracy between data using Queuing theory and the standard data was 85%. On the other hand, the accuracy of Taylor theory was 55%. The effectiveness of the Queuing theory is better than that of Taylor theory.

Figure 4 shows a comparison between the average utilization percentages for the assembly process using Taylor theory and Queuing theory. Based on the graph, the average utilization percentages using Taylor theory is higher than that using Queuing theory where; Taylor theory resulted in 63 percent average utilization compared to a 19 percent resulting from using the Queuing theory. This happens because Taylor theory is simpler than Queuing theory in its application, and thus its accuracy is lower than that of the Queuing theory. However, both theories require less data and less computational effort compared to simulation models and other analysis techniques.

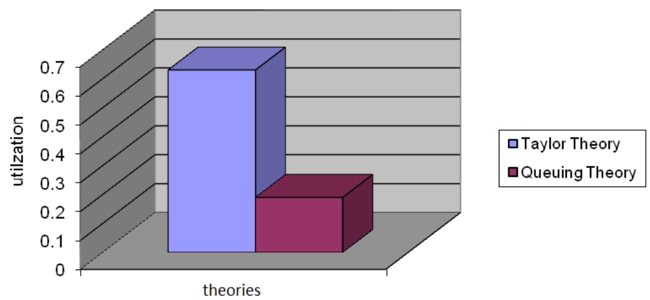

Figure 4. Average utilization for Queuing and Taylor theories

6. Conclusion

This study presented a specific approach that determines how the utilization factor affects the performances of the manufacturing system by using analytical theory. The study showed that Taylor theory and Queuing theory are capable of analyzing the production system. This theory is able to provide system design guidelines, capacity analysis and estimation throughout times. Future research is directed towards using simulation software such as; ARENA to measure capacity utilization in the assembling line.

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Biography

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