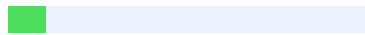




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The application of mathematical model to analyze production system in a manufacturing industry Muhammad Marsudi Faculty of Engineering, Universitas Islam Kalimantan MAB, Jl. Adhyaksa No. 2 Banjarmasin 70123, Indonesia {mmarsudi@uniska-bjm.ac.id) Abstract. Mathematical analysis can be very useful for investigating the performance of production systems. This study describes the production process based on a mathematical model of queuing theory in the manufacturing industry, named Company X. It aims to model the production process by appropriate queuing ¹² model and ¹² determine its performance measures. A field study was conducted and production data was collected through employee self-timing methods. This study then presents the selected production processes in the form of an independent queuing system and describes the various performance measures for each queuing system. The production process was simplified to four independent series workstations, Mixing, Length Cutting, Width Cutting and Packing. The arriving and leaving distribution were determined by the Chi-square goodness of fit test. The performance measures analysis later found that Length Cutting and Width cutting experienced blocking while packing experienced starving. Several suggestions were discussed to improve the queuing performance. Results show that the queuing theory is suitable for to study of production efficiency with some extent of limitations. Keywords: Mathematical Analysis, Manufacturing System, Production Management

1 Introduction Queuing theory, the theory of congestion, is the branch of industrial engineering that explores the relationships between demand on a service system and the ¹⁶ delays suffered by the users of that system. Queuing theory in production processes ² involves the study and simulation of models to predict the behavior of production processes that ² attempt to provide services for randomly arising demands in production workstations. By utilizing the queuing models, ¹¹ we can make decisions about ¹¹ the waiting line which will ¹¹ lead to better productivity. Successful competition today requires the design and production of high-quality products with a broad range of features and on-time delivery. These market requirements lead to manufacturing requirements. The wide range of features leads to smaller lot sizes and on-time delivery leads to a requirement for

reducing the cycle time variability. For this reason, it is important to learn how to control production to minimize cycle time and cycle time variability. Engineers have applied the results of queuing theory to show how cycle time is related to the utilization of machines and the

2 statistics of interarrival times and service times. These analyses provide means for predicting the average cycle time in a steady state for stationary statistics. By knowing the cycle time, work-in-progress inventory can be determined using Little's Law [1]. Based on the discussion above, this paper presents a case study related to the analysis of the production process in a manufacturing industry by using queuing theory.

2 Literature Review

Queuing theory has a wide range of applications, most of which have been well documented in the theory of probability, industrial engineering, operations research and management science. Some examples are telecommunication systems, traffic flow, computer scheduling, patient scheduling and facility design. Other application areas, such as the manufacturing system, have scarcely been touched. Hayashi, Kodashima and Yamaguchi [2] have applied queuing theory in calculating the optimum batch size for their batch processing equipment. In their paper, they have shown the batch size required to achieve short cycle time under different production situations. Hoover and Bartlett [3] in the other hand, have also applied the results of queuing theory to show how cycle time is related to large lot and small lot production. In a large lot production, cycle time is important to determine the amount of work in progress, and it can be determined through the queuing model. However, the study of Hoover and Bartlett has limitations that can only apply to large lot production. Their simulation has shown great fluctuations in cycle time compared to the values predicted by queuing theory. Another interesting application of queuing theory in manufacturing systems is the analysis of plant layout. Wainwright [4] in his paper has developed mathematical models based on queuing theory to enable the performance of each generic plant layout to be assessed on relative costs of work in progress (WIP) and machine idle time. Buzacott and Shantikumar [5] presented the

importance of the analytical model in solving industry problems. Van Dijk [6] has applied on hybrid combination of analytical and simulation to study of queuing system. The most common queuing system in any typical production system is M/G/I, a general service model. Madan and Al-Jararha [7] have studied the time-dependent as well as the steady state behavior of an M/G/I queue with several optional services. They claimed their model is more suitable to be used in analyzing production systems. Choudhury [8] has studied the steady state behavior of Madan and Al-Jararha's results for batch arrival queuing systems. Unlike Choudhury, Madan and Baklizi [9] have developed an M/G/I queuing model with additional second-stage **6 service and optional re-service**. Another common queuing system which suitable to simulate a production system might be a queuing system with scheduled arrival. Chen and Shima [10] have studied this system for an **4 exponentially distributed service time**. Cai, et al. [11] presented a case study on a manufacturing industry by using queuing theory to compare and analyze two optimization strategies. Their **13 research shows that the combination of process analysis and queuing theory can help solve the problems of high cost, low efficiency, and long service time**. Rashid, et al. [12] discussed the **17 application of queuing theory in production-inventory optimization**. In their developed model, demand and production time are considered as stochastic parameters and

3 4 queuing theory is used to calculate long-run inventory costs. Marsudi and Noorazam [13] have examined **1 the use of production capacity of facilities in Fujitsu Components (M) Sdn. Bhd. based on queuing theory**. Their study aims to achieve an appropriate queuing analytical model and determine its performance measures by **analyzing the capacity requirements and estimating manufacturing cycle times**. Vinay [14] examined utilization appertaining to Queuing Theory towards concentrate on impact appertaining to cluster size throughput in enhancing asset use, especially machine assets in an assembling framework. **3 Methodology** This paper aims to illustrate the application of queuing theory in the production process. Our methods start with presenting a brief

description of queuing theory. We then conducted a field study on Company X. The company manufacturing system was studied and data for production was collected by the employee self-timing method. We then model their production process with a suitable queuing model. Next, we determine the queuing performance measures and we review alternative options for improving the systems. To this end, further research suggestions will briefly be discussed.

4 Result and Discussion Company X, is a middle-sized manufacturing firm in Penang, Malaysia. The company's main activity is developing and producing industrial rubber compounding and polymerrelated products. This paper will focus on the production activity of RubClean and Elastowett which are the primary product for the company. The production sequence can be simplified into four workstations in a series arrangement, namely mixing, length cutting, width cutting and packing as these processes pose as the main elements in the production operation. This study will focus only on the queuing phenomena that happened at mixing, length cutting, width cutting and packing. Other assumptions and limitation that need to be taken into account are, that instant scrap recycling are not allowed and transient state queuing will be neglected. Open queuing networks always serve as the best models for analyzing production system [15]. However, the real production environment and practice in Company X make the analyzing by queuing network very difficult. Hence, for simplicity of analysis, the four main processes will be modeled as four isolated queuing systems rather than a single queuing network. The queuing system schematics are illustrated below. Fig. 1. The schematic of Queuing system

4 The arriving pattern and leaving distribution were obtained by using the Chi-square goodness of fit test. The arrival pattern was constructed using Taha's example [16], while the leaving distribution was determined by using Winston's [17].

18 The Chi-square goodness of fit test provided the essential information to mathematically determine the arrival and leaving distribution. The rest of the queue elements however will be determined through observations. The queue seizes and the source from which arrivals are generated

can be considered infinite and the queue discipline are assumed as first come first served with no renege based on actual production practice in Company X. The number of service channel or server in each workstation is one and single stage. The elements and notation for each process **3** are shown in Table 1 [18].

Table 1. Queue's elements

Kendall Notation	Description	Mixing Process	(M/M/1):(FCFS/∞/∞)	Single Server	Unlimited
Markovian Queue Length	Cutting Process	(M/M/1):(FCFS/∞/∞)	Single Server	Unlimited	
Markovian Queue Width	Cutting Process	(M/M/1):(FCFS/∞/∞)	Single Server	Unlimited	
Markovian Queue	Packing Process	(M/M/1):(FCFS/∞/∞)	Single Server	Unlimited	

The industrial common value for queue time is around 80% to 95% [19], and as it **3** is shown in Table 2, the results of this study show that most of the process is within and close to this range, except for the packing process.

Table 2. Queuing Performance of Measures

Work Station	Mean Time for Arrivals Spent in the System, W_s	Mean Time for Arrivals Spent in Queue, W_q	Mean % for arrival spent in queue
Mixing	108 min	95 min	78
Length Cutting	243 min	226 min	92
Width Cutting	382 min	364 min	91
Packing	116 min	103 min	66

However, this industrial common value just served as an indication for common practices in the industry, but not as the performance measure of the queue. Theoretically, queues with short queue time lead to faster production lead time, nevertheless, some workstation might need to have longer queue to prevent it running out of work. If the skill levels of the employees in a workstation vary widely, the queue

5 is also able to provide a variety of potential jobs so that the supervisor can select a job suited to the skill of the individual worker who became available. These values were obtained from steady-state data. As the limit of this study, transient state data was neglected. The cycle time for each process can be determined by subtracting their respective mean time spent in the system, W_s to mean time spent in the queue, W_q . The results **3** are shown in Table 3.

Table 3. Cycle time for each work station

Process	Cycle Time
1 Mixing	13 minutes
2 Length cutting	17 minutes
3 Width cutting	18 minutes
4 Mixing	13 minutes

Blocking occurred in cutting length because infinite numbers of product

batches are always available from the cooling buffer. Cutting width experienced the same blocking problems as both cutting length and cutting width processes are highly interdependent. Another important factor that caused blocking in this two-work station is machinery constrain. Currently, the conventional cutting tool is used to process both cutting length and cutting width. As a result, both workstations were operated ineffectively. The packing process encountered starvation as ⁴ the processing time is faster than widthcutting process, this causes the workstation to often experience earlier shutdown while other workstations are still operating. Queue is always preferable to be controlled within some consistent bounds so that actual lead times are very close to the planned lead time. Hence, ⁴ we can conclude that the packing process is the best among others with the lowest queue time and both cutting processes as the most consistent.

5 Improvement Suggestion 5.1 Cutting Length Work Station Possible improvements for the cutting length workstation are adding an extra parallel cutting length server (Cutting Length Machine) to the existing workstation. Since the arrival and leaving rates still remain the same, the suggested system will become the M/M/2 queuing system. A comparison for measures of performance between single and two server workstations ³ is shown in Table 4.

No of Server	C %Wq
1	92%
2	32%

6 As the comparison indicated, a fraction of waiting time for product batches will reduce from 92% to 32%, which will reduce the work-in-progress inventory stored in the cooling buffer. Another advantage of this solution is capable of improving the queuing stability. The previous analysis showed that for a single server, 3 periods of interval time have a utilization factor of more than 1 ($\rho > 1$, system in transient state), and we would expect, as time goes on, the queue size will grow without bound (assuming no denial of customer entry). By adding an extra parallel server, the queue will guarantee a steady state which is easier to monitor and control. Another area that can help to improve the productivity of this workstation is job control. Operators at this workstation have no job specialization. The job

schedule between pre-cut and cut length is not clear. For instance, operators will first concentrate on the pre-cut process (for certain batches while leaving the length-cutting machine idle), then only switch to cut length (and leave the pre-cut idle). This manner of process will create idle time in one other station whenever the other is in use. To obtain optimal productivity, both pre-cut and cut length should be carried out concurrently. The workforce at the workstation should be assigned to job specialization, i.e., pre-cut operator and cut length operator. Also, for better control, detailed working procedures at each substation need to be created and implemented. Besides fully utilizing the machine available, another advantage is production time can be shortened by the learning curve effect due to repetition.

5.2 Cutting Width Work Station Machinery are the major factor that causes the blocking in this workstation. The best solution is the improvement of technology or on the conservative side, by adding another server to cutting width. Company X has ordered and planned to install a new punching machine to substitute the current machinery. To analyze what can new server and punching machine contribute to the system, we need in essence to make a comparison between the following three situations:

- Current system single-width cutting workstation (M/M/1)
- Proposed parallel width cutting workstation (M/M/2)
- New punching machine (M/G/1)

Table 5. Improvement Comparison for Cutting Width Process

No	Description	%Wq
1	Current system	92%
2	Additional parallel server	27%
3	Single new punching machine	60%

Table 5 shows the improvement comparison for the cutting width process. The result shows that with the parallel server, the waiting fraction would be able to reduce to 27% while a single punching machine would be 60%. Obviously, the parallel server system is more efficient than operating the punching machine. The punching machine too can reduce the waiting fraction. However, the transient state was only able to reduce from 4 interval time (M/M/1) to 3 interval time (M/G/1), compared to M/M/2 system that is capable of providing all steady-state conditions. But, since the company has already

7 ordered the punching machine, the best solution would be to continue running the current

system together with installing a new punching machine. 6 Conclusion The **12** study has shown that queuing theory can be applied in analyzing production systems to determine their characteristics more comprehensively. The capability of the theory to predict the number of work-in-progress, average time for the product batch needed to wait in queue, processing time and cycle time, make it more effective for engineers in planning their production schedule and future improvement. However, this study has also some extend of limitations. The result **3** of this study was established based only on steady-state data, while the actual production environment was a mixture of both transient stage and steady state. The actual transient production system was far too complex and difficult to determine. Hence, the statistical model developed was only applicable to steady-state queuing systems. The accuracy and reliability of this study depend on many things, ranging from the methodology of collecting data to the interpretation of data. The key factor, however, still depends on how we interpret the arriving pattern and leaving distributions. The arriving pattern for this study was found to be Poisson while the leaving distribution was exponential. This is because the production practice in Company X is highly human-dependent. Operator's fatigue, skill level and other human factors cause the variation in processing time and make the arrival distribution random. Automated production systems normally will give general arrivals and general leaving as both processing times can be accurate and easier to control compared to manually operated production systems. The methodology of collecting data is another factor that tends to affect the accuracy of this study. Stop-watch time study always remains the best method but an actual field study that needs continuous data collection all day for a month is impossible to carry out with this method. Therefore, employee self-timing was used. However, this method does not make allowances for inefficiencies or interruptions that might have occurred during the data collection period. Employee self-timing may be not the best method, but taking into account all factors, this is the most practical approach for this study. 7 References [1] Kendall, N.D. (1951). "Some Problems **1** in the Theory of Queues." Journal of the Royal Statistical Society. 13. 151-185. [2] Yoshinobu Hayashi,

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