The Analytical Approach to Improve Utilization of Production Line

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Abstract: The manufacturing industry has to strive continually in order to increase efficiency in product development so as to stay competitive and sustainable. This situation is forcing the manufacturing industry to optimize the utilization of existing manufacturing system to enable the development of mixed products as a combination of existing and new products. A manufacturing system capable of processing mixed products normally has a complex structure due to its multi-stage production lines, e.g. automotive, pharmaceutical and petroleum industries. The production capacity of this type of manufacturing system has to be optimized in order to optimize utilization of multi-stage product lines. This study will use an analytical approach, which is validated by Arena simulation, to develop a model for production line optimization. Based on the findings, it is clear that the analytical approach can play an important role in the optimization of multi-product, multi-stage production lines.

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1. Introduction

The efforts to improve performances of manufacturing system have never ended. These improvement efforts could be in terms of cycle time, resource utilization, WIP, throughput of the system, or also for other performance parameters. Some previous studies to improve cycle time was conducted by Szenrovits (1975), Baker (1987), Baker and Pyke (1989), Dobson *et al.* (1987), Potts and Baker (1989), Steiner and Truscott (1993), Griffin (2002), Johnson (2003), and Villarreal and Alanis (2011). Burgess *et al.* (1993), Hopp and Spearman (2004), Chung *et al.* (2006), Walid (2006), Gamberi (2008), Marvel *et al.* (2008) and Seraj (2008) presented their studies to improve the resource utilization of manufacturing system.

Manufacturing system has many variations in term of number of stage and number of product processed. The combination of these variations will result many type of manufacturing system exist. These types are single-stage single-product, single-stage multi-product, multistage single-product, and multistage multi-product. And especially for multistage manufacturing system, it can be categorized further into two types which are with buffer or without buffer. There are many studies related to single–stage manufacturing system (Baker, 1987; Baker and Pyke, 1989; Dobson *et al*., 1987; El-Najdawi, 1992, 1994; El-Najdawi and Kleindorfer, 1993; Halim and Ohta, 1993) and multistage manufacturing system (Goyal, 1977; Szendrovits, 1983; Truscott, 1985; Tatwawadi *et al*., 2010).

There are many parameters of manufacturing system needed to be measured. Those parameters named performance measure of manufacturing system, and some of them are utilization, throughput, and WIP. There are two methods commonly used to evaluate performance of manufacturing system which are analytical method and simulation method.

Walid (2006) addressed the issue of capacity estimation and improvement in a multi-product unreliable production line with finite buffers. The procedure allowed for the enumeration of the defined states that a station may have while processing the mix of products. Durations of service interruptions or downtimes were taken into account as the mean time to repair the failed. This approach complements a linear programming model by altering the production sequence and inserting fictive product at appropriate positions in the sequence. The modified model provided the expected cycle time of the unreliable production line.

Gamberi (2008) presented the evaluation of the implementation of a manufacturing line by comparing different layouts. His studied was focused on analytical model for multi-stage multiproduct production line without buffer. In particular, the proposed approach involves both a preliminary choice considering the production capacity utilization rate, and then an in-depth analysis evaluating the total cost per unit; the selection of the least-cost set-up policy by analyzing four set-up strategies which were the sequential execution on each machine, the paralleling of stations, the paralleling of machines, and the execution in a predefined period of time.

Su and Chandra (1995) developed an efficient analytical approximation method for modeling and analyzing n-machine production lines. The results obtained using the method was compared with those obtained from an existing method. The simulation experiments were also run to validate the analytical approximation method. It was shown that the analytical approximation method works very efficiently and satisfactorily, and the results obtained using the method achieved an acceptable error level.

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 relative error was 10%.

Frank and Satanapa (1996) reported that the percentage difference between the average part flow time derived from an analytical model and from a simulation model was relatively small (less than 12%) for almost all data sets tested. This indicated the general robustness of the analytical model. This study provided a rather effective way of measuring Flexible Manufacturing Systems performance by quickly producing an acceptable result when compared to the simulation result.

Reza and Panagiotis (1999) presented that the design of component assembly lines in Printed Circuit Board (PCB) manufacturing environments is a challenging problem faced by many firms in the electronics industry. In their paper, they discussed the operational trade-offs associated with these design alternatives and presented a mathematical programming framework that captures relevant system design issues. Each of the design alternatives can be viewed as a special case of the stated mathematical programming model. They developed effective algorithms to solve these mathematical programs.

Marsudi and Noorazam (2010) examined the use of production capacity of facilities in Fujitsu Components (M) Sdn. Bhd. based on queuing theory. The aim of their study was to achieve an appropriate queuing analytical model and determine its performance measures by analyzing the capacity requirements and estimating manufacturing cycle times. Results for their study clearly showed that queuing theory is very useful and practical in evaluating the capacity requirement of the production system facilities.

Papadopoulos (1996) used the holding time model method for analyzing and evaluating the performance measures of production lines. An approximate analytic formula was derived for calculating the average throughput of any K-station production line with no intermediate buffers between adjacent stations, and exponential service times.

Tan (1998) presented a method to determine the mean and the variance of the amount of materials produced in a fixed time interval by a continuous materials flow production system with N stations in series and M stations in parallel and no inter-station buffers. The analytic result derived in this study determined the asymptotic distribution of the amount of products processed in a fixed time interval. By using this asymptotic distribution, other performance measures such as the probability of meeting a customer order on time can be derived. These results can be used both in the design and also in the control of manufacturing systems.

Hajji, *et al.* (2011) described the analytical approach with an experimental approach based on simulation modeling, design of experiment and response surface methodology. Their findings were interesting to note that the simulation based approach offers a versatile procedure to control manufacturing systems at the operational level as it was capable of handling more general non-exponential machines than allowed by the analytical method.

Fariaa, *et al.*(2006) presented a reliability analysis method that will help managers in the design of the working process buffers. Existing methods and tools for the analysis and performance evaluation of production systems often impose severe restrictions on the structure and behavior of the systems that limit its application to relatively simple systems.

Shi and Gershwin (2009) presented an accurate, fast, and reliable algorithm for maximizing profits through buffer space optimization for production lines. In the cost function, they considered both buffer space cost and average inventory cost and assign different cost coefficients to different buffers. In addition, they included a production rate constraint in their problem. A nonlinear programming approach was adopted to solve the problem.

Colledani and Tolio (2009) proposed a new analytical method for evaluating the performance of production systems monitored by statistical process control and off-line inspection.

This paper reports our study of a multi-stage multi-product batch flow production system at

Company Z in Malaysia. Company Z, which is located in the town of Nilai, produces door-sashes for the Proton Wira, a car manufactured by Malaysian carmaker Proton. The door-sashes that consist of the front door-sash and rear door-sash produced at the company Z are depicted on Figure 1.

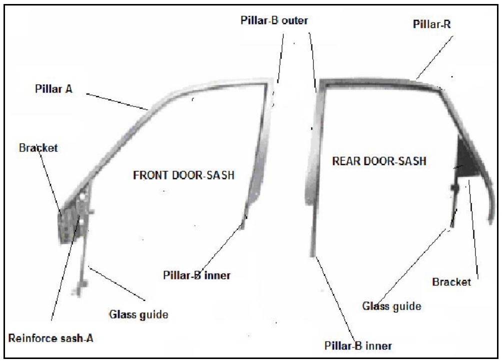

Figure 1. Front door-sash and rear door-sash of Proton Wira

The manufacturing system to produce door-sash in this company consists of two principal stages of module production and system assembly. Both front door-sash and rear door-sash are produced at the same production line named Production Line A at the system assembly stage. To anticipate the increasing demand of their products, the company plans to increase its production capacity by firstly examining the resource utilization at Production Line A. The management of the company also needs quick decision related to this Production Line A. To address this problem, we introduce an analytical approach solution. It is possible to use certain simulation software to analyze resource utilization but the use of software needs more input data compared to the analytical approach.

In the following sections, we provide a description of the company's manufacturing process, a discussion of analytical approach, and a description of the experimental procedure. Next, we present and discuss the analytical approach results. Finally, we discuss the validation of the analytical approach results by comparing them with the Arena simulation results.

2. Company Background

As mention above, there are two principal stages to produce door-sash in Company Z. Clearly, the operations system for the company as shown in Figure 2 consists of three stages:

- Raw material purchasing
- Manufacturing which consists of module production and system assembly
- Sale and service.

Table 1 shows the process planning for two door-sash modules at production line A. This process is categorized as multi-product at multi-stage processes by front door-sash Wira as product 1, and rear door-sash Wira as product 2. Figure 3 shows the process flow for front door-sash Wira. Pillar B, Pillar A, and Bracket are product components which are produced at the front door-sash module production.

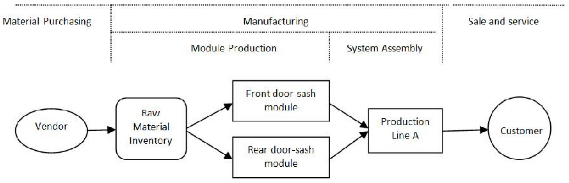

Figure 2. Operations system in Company Z

Table 1. Process planning for products in company Z

Product 1		Product 2	
No.	Process	No.	Process
1	MS cutting	1	MS cutting
2	OP cutting	2	PLW (S)
3	PLW (S)	3	Knocking
4	Knocking	4	PLW (B)
5	PLW (B)	5	CO2 welding
6	CO2 welding	6	Die matching
7	Manual welding	7	Finishing 1
8	Die matching	8	Finishing 2
9	Finishing 1	9	Inspection
10	Finishing 2	10	Anti-rust oil spray
11	Inspection		
12	Anti-rust oil spray		

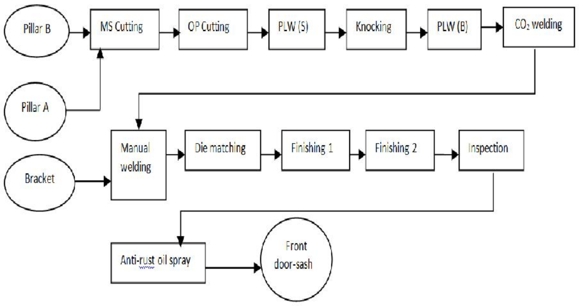

Figure 3. Process flow for front door-sash of Proton Wira

Setup time (s_{ij}) and processing time (t_{ij}) for each workstation for both type of product is shown in Table 2 which is as follows:

Table 2. Setup time and processing time at each workstation for Product 1 and Product 2

Workstation (WS)	s_{ij} (seconds)		t_{ij} (seconds)	
	Prd.1	Prd. 2	Prd.1	Prd.2
MS cutting	735.3	702.0	25.3	23.8
OP cutting	183.4	0	1.0	0
PLW (S)	501.6	529.8	29.1	29.8
Knocking	120.4	121.4	1.4	1.6
PLW (B)	346.4	389.0	20.3	25.6
CO2 welding	807.5	806.5	33.3	21.8
Manual welding	272.0	0	8.7	0
Die matching	186.5	191.6	5.6	6.5
Finishing 1	382.3	383.3	26.8	28.8
Finishing 2	428.4	434.0	24.7	19.6
Inspection	44.2	44.2	1.5	1.5
Anti-rust oil spray	443.9	383.4	34.3	34.3

3. Analytical Approach

This section summarizes analytical approach that used in this study to estimate resource utilization and manufacturing cycle time. To make clear the formula used, multi-product multi-stage production line with buffers can be sketched as Figure 4.

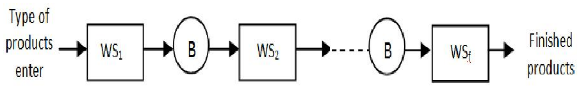

Figure 4. Multi-product multi-stage production line with buffer between workstations

More than one type of product enter at workstation 1 (WS$_1$) and exit from the last workstation (WS$_f$) as indicated by the arrows in Figure 4. In this case, the type of products entering to the production line is in the form of a batch. Each workstation *j* (*j* = 1, 2, . . . , *f*) has different with the other workstations for both its setup time and processing time related to each product type *i* (*i* = 1, 2, ….., *c*). The capability of each workstation to produce 'good' product is the yield of that workstation. In general, the yield can be defined as the percentage of product which is good or acceptable from the percentage of product components that are processed through a workstation. The cumulative of yield in workstation *j* is the number of multiplication that all of the results resulted in each workstation that precedes workstation *j*. Another issue in production line is throughput. User-measured processing speed of a machine expressed as total output in a unit period (usually an hour) under normal operating conditions. It includes operator caused delays and therefore differs from the machine vendor's rated speed which is often the machine's best output capability under optimum operating conditions.

The following equations are developed by Herrmann and Chincholkar (2001) for multi-product multi-stage production line without considering any buffer between workstations.

$$Y_i = \prod_{k\in R_i} y_{ik} \quad \text{....(1)}$$

where, Y_i is yield cumulative of product i through R_i, and R_i is the sequence of workstations that product *i* must visit.

$$x_i = \frac{T_i}{(B_i)(Y_i)} \quad \text{....(2)}$$

where, x_i is release rate of product *i* (jobs per hour), T_i is throughput of product *i*, and B_i is batch size of product *i* at release.

The time spent by a job at station *j* consists of the element of the part processing times, the setup time, and also the variance of these both times. Therefore, the equation (3) is used for a certain workstation.

$$t_{ij}^{+} = \sqrt{\frac{B_i Y_i t_{ij}^2 c_{ij}^t + s_{ij}^2 c_{ij}^s}{c_{ij}^{+}}} \quad \text{....(3)}$$

where, t_{ij}^{+} is total process time of product *i* at workstation *j*, t_{ij} is mean part process time of product *i* at workstation *j*, s_{ij} is mean job setup time of product *i* at workstation *j*, c_{ij}^t is squared coefficient of variation (SCV) of the part process times, c_{ij}^s is SCV of the job setup times, and c_{ij}^{+} is SCV of the total process times.

The performance measure of interest is u_j (the utilization of the resources at workstation *j*), and the equation is as below.

$$u_j = \frac{\sum_{i\in V_j} x_i t_{ij}^{+}}{A_j n_j} \quad \text{....(4)}$$

where, V_j is set of products that visit workstations *j*, n_j is the number of resources in workstation *j*, and A_j is availability of a resource at a workstation *j*.

$$A_j = \frac{m_j^f}{m_j^f + m_j^r} \quad \text{...(5)}$$

where, m_j^f is mean time between failure for a resource at a workstation *j,* and m_j^r is mean time to repair for a resource at a workstation *j.*

If any buffer exists between one workstation to another workstation, Blumenfeld and Li (2005) derived the following approximate equation for throughput parameter.

$$x_i = \frac{T_i}{1+(m_j^r/m_j^f)+\{(M-1)m_j^r/m_j^f\}/\{1+(M/4)(1+2m_j^r/m_j^f)+B(m_j^f)/x_i\}}$$

… (6)

where, *M* is number of workstations in production line, and *B* is buffer size (number of jobs).

Based on the equations (2) and (6), we can derive the new equation for release rate of product (x_i) as shown in the equation (7).

$$x_i = \frac{\{B_iY_i - 1 - (m_j^r/m_j^f)\}(M/4)\{1+2(m_j^r/m_j^f)\}(B)(m_j^f)}{(M-1)(m_j^r/m_j^f) - \{(B_iY_i - 1 - (m_j^r/m_j^f)\}}$$

… (7)

The analytical model discussed above is also based on the following assumption about the system:

- The sizes of buffers are equal.
- The buffer does not fail, and jobs flow through it with zero transit time.
- The first station is never starved and the next stations are never blocked.
- Operating systems between failures at a station *j* are exponentially distributed (with mean $1/m_j^f$).
- Repair times at a station *j* are exponentially distributed (with mean $1/m_j^r$).

4. Experimental Procedure

Based on the discussion on the analytical approach above, the experimental procedure in this study can be figured out on Figure 5.

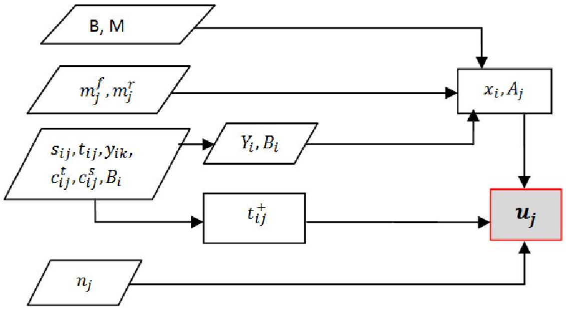

Figure 5. Experimental procedure flow-chart

In this study, we first analyzed the existing manufacturing process of the company to identify the current utilization and its manufacturing cycle time at Production Line A. And then to improve utilization parameter, we modified parameter inputs of B_i and B. It is possible to change other parameter inputs (such as s_{ij}, n_j, and so on) but these other inputs are more related to improve or to buy the new of the production resources (machines and production equipments).

Clearly, the algorithm or procedure to improve utilization discussed on this paper is by trial and error process until the optimum utilization can be achieved. The process is shown in Figure 6.

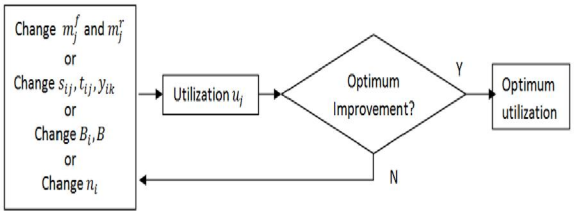

Figure 6. Procedure to improve utilization

5. Industry Application Results

Firstly, the discussion in this section related to the findings found from the existing process, and then the discussion is related to the findings after B_i parameter has been modified.

The input parameters of mix-product process for batch size and buffer size are shown in Table 3. Other input parameters which are setup time and processing time at each workstation is shown in Table 2, and the yield cumulative of product data which was gathered from the company is 84.67%.

Table 3. Input parameters for mix-product process (existing process)

Parameter	Mix of front and rear door-sash	
	Front	Rear
Batch size (unit/batch) Buffer size (number of jobs)	8 5	8 5

Based on these inputs, the analysis result is shown in Table 4 which is very clear that the utilization at workstation CO_2 welding (i.e. 84%) is higher compared to other workstations. Anyway, this utilization value is still not maximum value yet and it can be improved by increasing the value to the nearly of 100%.

The input of batch size parameters for modified manufacturing process is shown in Table 5. In this case, we changed the batch size of front door-sash and rear door-sash from 8 and 8 to 10 and 10, respectively. The results of modified process is shown at Table 6.

Table 4. Utilization values at each workstation (existing process)

Workstations	*j*	n_j	u_j
MS Cutting	1	1	0.75
OP Cutting	2	1	0.04
PLW (S)	3	1	0.76
Knocking	4	1	0.07
PLW (B)	5	1	0.58
CO_2 welding	6	1	0.84
Manual welding	7	1	0.14
Die matching	8	1	0.19
Finishing 1	9	1	0.68
Finishing 2	10	1	0.59
Inspection	11	1	0.07
Anti-rust oil spray	12	1	0.75

Table 5. Input parameters for mix-product process (modified process)

Parameter	Mix of front and rear door-sash	
	Front	Rear
Batch size (unit/batch)	10	10
Buffer size (number of jobs)	5	5

Table 6. Utilization values at each workstation (modified process)

Workstations	*j*	n_j	u_j
MS Cutting	1	1	0.87
OP Cutting	2	1	0.05
PLW (S)	3	1	0.89
Knocking	4	1	0.09
PLW (B)	5	1	0.68
CO_2 welding	6	1	0.98
Manual welding	7	1	0.16
Die matching	8	1	0.22
Finishing 1	9	1	0.79
Finishing 2	10	1	0.69
Inspection	11	1	0.07
Anti-rust oil spray	12	1	0.88

As a whole for processing of two combined products, utilization value at workstation CO_2 welding in production line A is almost maximum, namely 98 %. Therefore by quantity of 10 units/batch (front door-sash) and 10 units/batch (rear door-sash) and use buffer size at 5 for both of them, the combination of two products process has nearly achieved the optimum condition although some of workstations in production line A are still not optimum yet, and therefore production line A is needed to increase their utilization values. Anyway if the utilization values of these not optimum workstations are tried to be increased, the utilization value at workstation CO_2 welding will be more 100% or to be over-utilization. This situation led to workstation CO_2 welding to be as a 'bottleneck' or to be as a critical workstation in the case of effort to optimize the utilization parameter. Figure 7 explains in the form of graph the condition before and after modified batch size input for utilization values at each workstation.

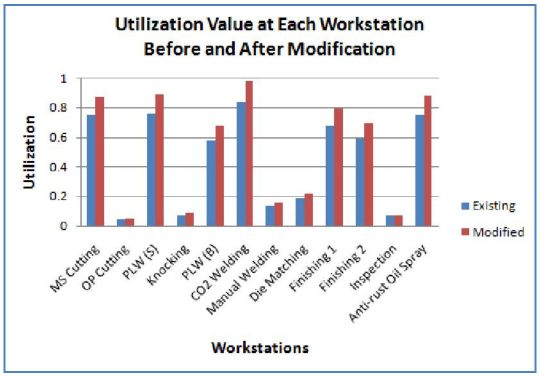

Figure 7. Utilization value at each workstation

6. Model Validation

Arena is one of the most powerful softwares for simulation. In this study, the results based on the analytical approach will be compared to the results based on Arena simulation. In other words, validation of the analytical approach was done by comparing its utilization output with the utilization output of Arena simulation.

The nature of this production system is a steady state because it runs continuously for 24 hours a day and 7 days a week. For this reason, the simulation model should be warmed-up to get steady state before collecting any statistics to get good unbiased results. In this study, the warm-up period was 10,000 time units with number of replication were 20. The warm-up period was determined by Arena Output Analyzer on the basis of the MS Cutting utilization. Table 7 shows the results based on the analytical approach and the simulation approach.

Data in Table 7 shows that the maximum relative error for both two cases (existing and modified processes) is 0.03 or 3%, far below the limit value 10% suggested by Koo *et al.* (1995) and 12% suggested by Frank and Satanapa (1996). This finding proves that the validity of analytical approach is good enough and valid to be applied.

Table 7. Comparison of utilization values between analytical and simulation approaches

Workstations	Utility (existing process)			Utility (modified process)		
	Ana.	Sim.	Rel. Err.	Ana.	Sim.	Rel. Err.
MS Cutting	0.75	0.76	0.01	0.87	0.89	0.02
OP Cutting	0.04	0.04	0.00	0.05	0.05	0.00
PLW (S)	0.76	0.78	0.02	0.89	0.91	0.01
Knocking	0.07	0.07	0.00	0.09	0.09	0.00
PLW (B)	0.58	0.59	0.01	0.68	0.68	0.00
CO_2 welding	0.84	0.82	0.02	0.98	0.95	0.03
Man.welding	0.14	0.12	0.02	0.16	0.15	0.01
Die matching	0.19	0.19	0.00	0.22	0.21	0.01
Finishing 1	0.68	0.67	0.01	0.79	0.76	0.03
Finishing 2	0.59	0.57	0.02	0.69	0.66	0.03
Inspection	0.07	0.07	0.00	0.07	0.05	0.02
Anti-rust oil spray	0.75	0.72	0.03	0.88	0.85	0.03

7. Summary and Conclusion

The analytical approach based on mathematical model that has been developed in this study is intended to analyze the production system of multi-product multi-stage production line. The study has shown that the developed model is able to be applied to analyze production system comprehensively. The validation of developed model was done by comparing it to Arena simulation model. The capability of the developed model to identify resource utilization makes it more effective for process planners in planning their production schedule and future improvement.

We studied the manufacturing system of Company Z, a Malaysian manufacturer of door-sash for Proton car. A major concern of Company Z management was to anticipate the increasingly demand of its products. Related to this concern, we analyzed the most important parameter of its manufacturing process which was the utilizations at Production Line A. By using the developed analytical approach, the current utilization at Production Line A was evaluated first, and then by modifying batch size input, the next evaluation has been conducted.

Based on the result of this study, the resource utilization at production line has been improved from the current condition to the modified condition. For example, after the modification, the utilization at workstation 'CO2 welding' changed from 84% to 98 %.

The results of our study have very important implication for the company. In terms of the major concern of the company, the study shows a direction that would lead the company to improve its resources utilization.

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