ANALYSIS OF FACTORS AFFECTING THROUGHPUT RATE IN FLEXIBLE MANUFACTURING SYSTEM WITH AUTOMATED GUIDED VEHICLE SYSTEM

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ABSTRACT

Flexibility is known as one of the competitive keys for manufacturing industries. Flexible Manufacturing System is a complex and expensive system that require an accurate designing phase. By simulation, it is possible to carefully examine the behavior of FMS components to predict the performance of a manufacturing system. Buffer size, mean time to repair, and number of automated guided vehicles are proven as critical factors in FMS which affecting throughput rate significantly. Furthermore, it is found that there are significant interactions between buffer size and MTTR and also between MTTR and number of AGVs.

Key words: *Flexible Manufacturing System, buffer size, mean time to repair, automated guided vehicle.*

1. INTRODUCTION

As the economy grows the demand for goods and services continues to increase. To meet the high demand for goods, manufacturing industries are required to operate on a large scale. Flow shop manufacturing system can accommodate the production of large quantities but in limited variability. Meanwhile, job shop can accommodate consumer demand for product varieties, but resulted in a relatively low-volume production. Flexible Manufacturing System (FMS) is a way to combine the efficiency of flow shop with the flexibility of a job shop to meet the diverse demand for goods at a lower cost (Basnet, 1994).

Flexibility has been known as one of the key competitive for manufacturing companies. Today, consumer involvement in determining the quality and variety of products is becoming increasingly important for manufacturing industries. Market trends are subject to change in a short time led to a shorter product life cycles and a competitive marketplace is forcing manufacturing companies to explore new markets to sell their products. Such market condition raises the urgency for change in the organization of production processes, through automation, computer aided design and manufacturing management, and development of a modern multi-stand machining, such as Flexible Manufacturing System (Yucel, 2005).

2. THEORETICAL BACKGROUND

FMS is a manufacturing technology and also a philosophy (Shivanand, 2006). (Anglani et.al, 2002) and (Yucel, 2005) define FMS as an automated manufacturing system composed of multi-function machines that are connected by a material handling system and controlled by a computer system. Throughput rate is one of the most important parameter in measuring the effectiveness of a manufacturing system, FMS is not an exception, as shown in (Smith, 1986). The definition of the throughput rate is the number of output processes per time unit (Chase, 2006). Thus the throughput rate can be used as a parameter of success that must be carefully considered in designing an FMS.

There are many factors that affect the throughput rate in a manufacturing system. Some authors claim that the flexibility of the route as the most influential factor of an FMS. Several other authors include a tool-slots of workstations in their studies. The number of pallets, buffer capacity, and machine failure are also discussed by many authors as factors that have significant impact on FMS. In 2009, I. Um et al (I.Um, 2009) specifically examined the factors that affect the FMS with AGVs. The number of AGV, AGV speed, AGV deceleration, and pickup time proved to be a factor that greatly affect the FMS. Among the four factors, it appeared that the number of AGV is the factor that most affects the throughput rate.

Regarding the engine failure factor, Chen and Thinphangnga (Chen, 1996) conducted a study that addresses the effect of engine failure on the performance of FMS with emphasis on the comparison of analytical and simulation methods. In addition, there is also a research by Vineyard et al (Vineyard, 1999) which describes the characteristics of failure and repair rate in the FMS, with a case study of a manufacturing plant in the western United States. On the other hand, Selen and Ashayeri (Selen, 2001) used simulation in terms of design of experiments to identify an increase in throughput rate through the buffer capacity management.

FMS is a complex system and spend substantial investment that requires an accurate design phase. In particular, it is important to check carefully the behavior of FMS components to predict the performance of production systems (Anglani et.al, 2002). One of the best ways to do this is by simulation. Through simulation, researchers can see the behavior of the model in a complex system that can not be easily explained through analytical or mathematical models.

3. RESEARCH METHOD

3.1. Model Building

Hypothetical model of FMS which designed by Insup Um et al (I.Um, 2009) is shown in Figure 1.
This model is chosen because it is comprehensive enough in accommodating machinery flexibility, material handling flexibility, and routes flexibility. This model is also found to be more complex than models of other FMS hypothesis which generally consist of 3 to 4 machining centers, so it is expected to describe the likely behavior of the components of FMS in the real world.
The model consists of:

- Six Machining Centers (MC) with input and output buffer
- Automated Guided Vehicle system (AGVs) with a fixed path
- Incoming and outgoing conveyor

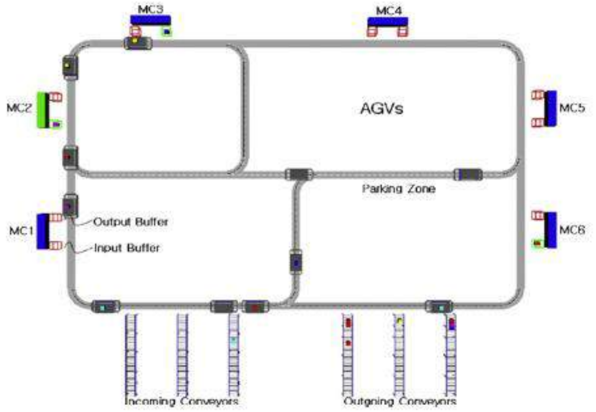

Figure 1. Model from Paper
(Source: I. Um et al, 2009)

Operation of FMS models which simulated in the literature is based on the following assumptions.

- MC, AGV, and conveyor never breakdown; so it is always available for processing and transporting
- Each MC can only process one operation at a time
- No parts were rejected due to quality inspection; therefore, rework is not allowed
- Each type of part, upon entering the system must be processed to completion; the cancellation order is permitted
- The time required to move a part between the buffer input / output to MC ignored
- Input and output buffer capacity is assumed unlimited
- Each AGV can carry only 1 part

This model was rebuild using Tecnomatix Plant Simulation 9.0 as shown in Figure 2. In this study, validation is performed by comparing the resulting throughput with the throughput models made in the author written on the paper, in the following conditions:

- The number of AGV 10 units
- AGV speed 4.8 m / s
- AGV 1 m/s2 acceleration

- Pickup time 3 s
- The simulation is run for 8 hours

Table 1. Model Validation

Model Simulation Result	342
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3.2. Experimental Design

This experimental design is using the General Factorial Design consisting of three factors: the buffer capacity, MTTR, and the number of AGV with each of 3 levels, 2 levels, and 3 levels. Arrival time, processing time, and mean time between failure are stochastic so it needs quite a lot replication in order to obtain the actual mean value, for it to replicate as much as 30 times. So the total observation was 540 (30 x 3 x 2 x 3) times with 8-hour simulation each run and 1-hour interval for each replication.

4. RESULT AND DISCUSSION

To know the magnitude of the effect of each factor and also the interactions that take place, analysis of variance was conducted using Minitab 15. The result is shown in Table 2.

ANOVA is a technique that allows us to examine differences in the influence factor of the sample being taken. In the ANOVA table obtained from the software Minitab 15, we can see which factors are influencing the parameters via the *p*-value indicator. If the *p*-value less than or equal to alpha (α) the influence of these factors are statistically significant or in other words the null hypothesis can be rejected.

Charts of the influence of the main factors of throughput shown in Figure 3. The graph has been given an idea of how the effects of each factor and which factors are more influential. To be more in-depth, analysis of each of the major factors will be discussed one by one as follows.

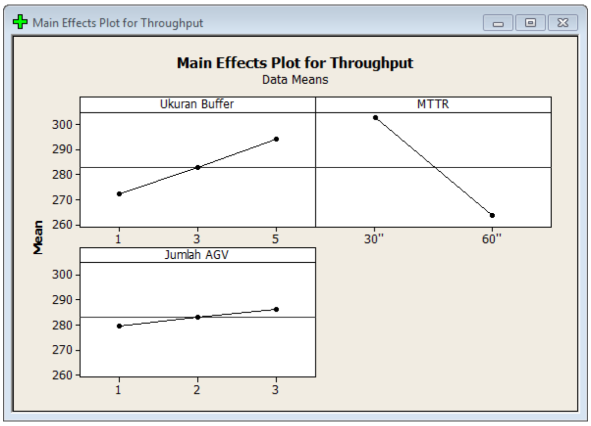

Figure 3. Main Effects Plot

From the ANOVA table we can that the buffer capacity factor has *P*-value <0.001 which means that this factor has a significant effect even at 99% confidence level (α = 0.1). Positive slope indicates that a larger buffer capacity will result in greater throughput.

Buffer can be interpreted as a safety stocks because it reduces the risk of a line stop. If there is a failure on one machine, the production can continue for a period of time by taking parts which available on the buffer. From this point of view, a large buffer capacity should be provided, but on the other side the buffer will use a larger production floor so that would lead to additional costs (Selen, 2001). For this case, the addition of buffer capacity of 1 unit to 3 units can increase throughput by an average of 10 units for 8 hours of simulation, and the addition of an average of 10 units if its buffer capacity is increased into 5 units.

4.1. MTTR Factor

MTTR factor also have a *P*-value <0.001 which means duration of MTTR have an effect on system's throughput. The negative slope of the graph shows that MTTR is inversely proportional to the throughput, ie MTTR 60 minutes produce throughput MTTR less than 30 minutes on this system. Compared to two other major factors, MTTR has the most significant effect, seen from the slope of the graph which larger than the others.

MTTR of 60 minutes represents the engine failure due to human error, such as push a wrong button, giving the wrong weight of oil,

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do not closing the interlockingdoor, or not tightening a bolt. While MTTR of 30 minutes represents the engine failure due to electrical equipment failure such as motors, relays, starters, transformers, and cables. Engine failure due to human error and failure of electrical equipment are two of the three most common types of engine failures in FMS (Vineyard, 1999). Though the fact that engine failure may occur due to several causes at once, it is not addressed in this study.

Engine failure due to human error may be reduced by providing training and creating standard operating procedures. While the engine failure due to electrical equipment failure can be avoided by performing preventive maintenance or routine inspection.

4.2. Number of AGVs Factor

The number of AGV factors also indicate p-value <0.001, which means it has a significant effect on system throughput. Positive slope of the graph shows a directly proportional relationship, which is an increase of number of AGV then system's throughput will be greater too. Although significant at 99% confidence interval, these factors influence the number of AGV at the least compared to the two other factors. The addition of an AGV unit into the system will only provide additional throughput average of 3 units for 8 hours of simulation.

In the FMS with AGVs, material handling costs can include 20-50% of total operating costs (Shirazi, 2010). Therefore, the number of AGV used in an FMS system usually just a little number to reduce costs. At a factory in the west United States, which used as case studies by Michael Vineyard (Vineyard, 1999), there is an FMS consists of four CNC machines with three AGVs. While the PT Dirgantara Indonesia used an FMS consists of four CNC machines and have only one AGV.

4.3. Analysis of Factors Interaction

In addition to the influence of each factor, presumably the system's throughput is also affected by the interaction between the factors. Figure 4 shows that there are some charts that show the interaction between factors, seen from the intersection of lines, but there are also graphs that do not show an interaction, which showed by paralel lines.

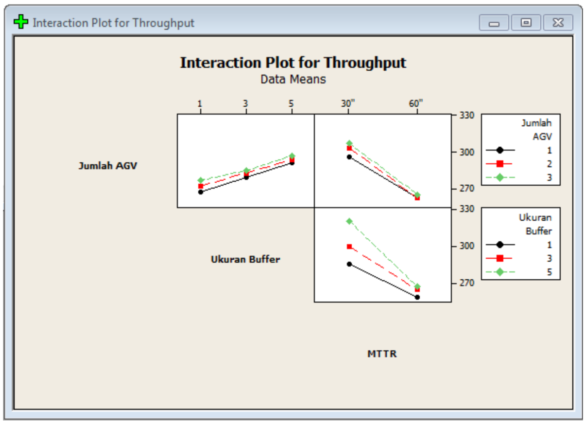

Figure 4.Interaction Plot

4.3.1. Interaction between MTTR and Buffer Capacity

Interaction between these factors has a p-value <0.001 which means there is a significant interaction. Seen that the buffer capacity lines have different slopes to the MTTR. Buffer capacity 5 has the greatest slope, a decrease of 50 units throughput will happen when MTTR increase from 30 minutes to 60 minutes. Whereas in buffer capacity 1, a decrease is only at an average of 20 units for 8 hours of simulation.

Significant interaction means that changes in one factor levels will result in significant changes to the yield, the throughput in this case. On the MTTR of 30 minutes, it is seen that the buffer capacity increase from 3 to 5 add up to an average of 20 throughput. Though at MTTR of 60 minutes, the buffer capacity increase from 3 to 5 only add an average of 2 throughput.

4.3.2. Interaction between Number of AGV and MTTR

P-value of interactions between number of AGV and MTTR is 0.006 which means a significant interaction at 99% confidence level. The graph shows that when MTTR 30 minutes the line slope is firstly large enough at the increase the number of AGV from 1 to 2, namely an increase in average throughput of 10 units, then the slope becomes sligther at increase number of AGV from 2 to 3, the throughput increased an average of 5 unit.

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While at the time MTTR 60 minutes, a small initial slope of the line become larger, so that when these two lines are near the intersection will happen.

So it can be interpreted if an engine failure due to human error (MTTR 60 minutes) can not be avoided then the additional number of AGV will not help much in increasing the number of system's throughput. Otherwise in engine failure caused by electrical failure or MTTR 30 minutes, adding the number of AGV will be sufficient to affect the increased throughput of the system, especially in increasing the number of AGV from one unit into two units.

4.3.3. Interaction between Buffer Capacity and Number of AGV

The interaction between the buffer capacity by the number of AGV has a *p*-value 0.667, which means no interaction between these two factors. In other word, increase the amount of buffer capacity of the AGV at any level will give the same result, ie an average increase of 3 units of throughput for each additional unit AGV.

4.3.4. Interaction between the Three Factors

Interactions between these three factors produces a *p*-value 0.414 or accept null hypothesis which means these three factors have no significant interaction. In other words the change in the level of one factor will give the same value of change to throughput rate at any level of other factors.

5. CONCLUSION

From the results of data processing and analysis, it can be concluded from this study that:

1. These three main factors; the buffer capacity, the mean time to repair, and the number of AGV are shown to have significant influence on the throughput rate in this model of FMS.
2. The factor that has most influence on the throughput rate is the MTTR, followed by buffer capacity and number of AGV
3. Interaction of factors that proved significant are the interaction between the buffer capacity and MTTR and also interaction between MTTR and the number of AGV.
4. The interaction between the buffer capacity and the number of AGV and also the interaction between the three factors proved to be not significant, which means changes in the levels of one factor will give the same value of change to the throughput rate at any level of other factors.

As a suggestion, subsequent studies should also examine other parameters in addition to throughput rate, such as utilization (either on the machine, AGV, or land area), and track density. There are many other factors can also be studied such as tool magazine capacity on machine, pallet number, and vehicle recharging. This study can also be enhanced by adding a financial aspect. In conclusion, the Authors wish this study may be useful in expanding the reader's understanding of the flexible manufacturing system, as well as hoping this research can be refined in further opportunities.

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Attachment

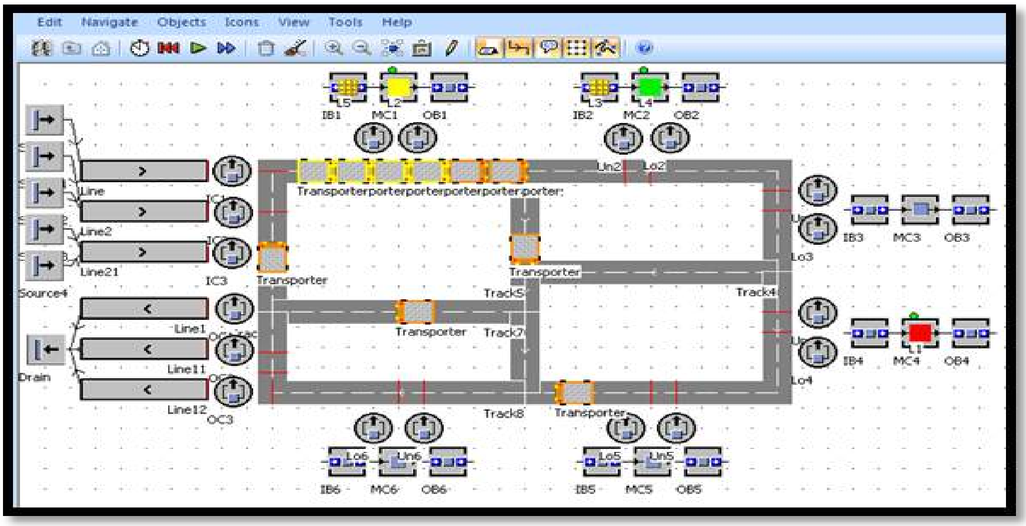

Figure 2. Model Layout

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Table 2. Data Processing Result

General Linear Model: Throughput versus Kapasitas Buffer; MTTR; Jumlah AGV

Factor	Type	Levels	Values
Kapasitas Buffer	fixed	3	1; 3; 5
MTTR	fixed	2	30''; 60''
Jumlah AGV	fixed	3	1; 2; 3

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Kapasitas Buffer	2	43084	43084	21542	129,67	0,000
MTTR	1	204439	204439	204439	1230,58	0,000
Jumlah AGV	2	4155	4155	2078	12,51	0,000
Kapasitas Buffer*MTTR	2	16510	16510	8255	49,69	0,000
Kapasitas Buffer*Jumlah AGV	4	386	386	97	0,58	0,677
MTTR*Jumlah AGV	2	1740	1740	870	5,24	0,006
Uk Buffer*MTTR*Jumlah AGV	4	656	656	164	0,99	0,414
Error	522	86721	86721	166		
Total	539	357692				