A DEVELOPMENT OF OPTIMAL BUFFER ALLOCATION DETERMINATION METHOD FOR μ-UNBALANCED UNPACED PRODUCTION LINE

by

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LIST OF ABBREVIATIONS

μ	Mean process time of each work station
C_v	Coefficient of variation for each station's μ
X	Throughput rate (efficiency) of the production line
E	Number of extra buffer (buffers) after allocating the buffers equally among the buffer slots.
6 Steps OBA	Six mathematical steps developed by this research to get the OBA for the μ-unbalanced production line.
OBA Determination Flow	An easy (simple) flow developed for a management guidance on how to determine *OBA* for the production line.
pdf	Probability Density Function, a type of probability function for continuous random variables.
Unpaced	A production line where the material is not pulled by demand but in a push mode. No conveyor belt is used.
MODAPTS	*Modular Arrangement of Predetermined Time Standard,* a standard method used to determine time for doing a particular process using work study analysis.
SST	Standard Time, standard working time based on calculation from *MODAPTS* method
OBA	Optimal Buffer Allocation, the optimum number of buffers to be allocated in buffer slots for maximum throughput rate of the production line
Buffer	Work In Progress, inventory that is currently being processed in an operation or inventory that has been processed through one operation and is awaiting another operation.
Buffer slot	place to put buffer between stations.
Total buffer Size (*B*)	Total number of buffers allowed by management to be allocated in intermediate buffer slots between the workstations.
WIP	same meaning as buffer

FMEA	Failure Mode and Effect Analysis, a systematic technique which identifies and ranks the potential failure modes of a design or manufacturing process in order to prioritize improvement actions.
DOE	Design of Experiment, the complete sequence of steps taken ahead of time to ensure that the appropriate data will be obtained, which will permit an objective analysis and will lead to valid inferences regarding the stated problem.
SS	Six Sigma method, a set of techniques focused on business process improvement and quality.

PEMBANGUNAN KAEDAH PENENTUAN PERUNTUKAN PEMAMPAN OPTIMUM UNTUK TALIAN PENGELUARAN TIDAK MELANGKAH KETIDAKSEIMBANGAN-μ

ABSTRAK

Kajian ini membincangkan masalah peruntukan pemampan di dalam talian pengeluaran tidak melangkah dengan ketidakseimbangan-μ. Talian pengeluaran tidak melangkah adalah merujuk kepada satu talian pengeluaran dengan stesen kerja yang beroperasi secara bebas dan bahan tidak ditarik secara paksaan tetapi di dalam mod tolakan. Di dalam kajian ini, talian pengeluaran adalah tidak melangkah, ketidakseimbangan-μ tetapi boleh diharap. Peruntukan pemampan optimum (*OBA*) perlu dicari untuk talian pengeluaran seumpama ini. Subjek ini penting kerana kini syarikat dengan produk bersaiz kecil dan sederhana menggunakan talian pengeluaran tidak melangkah dan kaedah sesuai penentuan *OBA* diperlukan. *OBA* adalah merujuk kepada bilangan optimum pemampan yang diperuntukkan di dalam slot pemampan perantaraan di antara stesen untuk membolehkan kadar kecekapan (*throughput*) dapat dimaksimakan dan bilangan *kerja dalam proses* (*WIP*) di dalam talian dapat dioptimumkan. Kajian ini dibahagikan kepada dua fasa utama. Di dalam fasa 1, kaedah carian digunakan untuk mendapatkan kadar kecekapan untuk suatu set bentuk peruntukan pemampan yang diberikan di dalam talian pengeluaran menggunakan perisian simulasi *Arif's algorithm*. Beberapa *Konsep Asas OBA*

(BOC) yang mewakili ciri-ciri OBA disimpulkankan daripada kaedah carian. Dengan mengaplikasikan *BOC* ini, perkembangan *Aliran Penentuan OBA* dilakukan di dalam fasa 2. *Aliran Penentuan OBA* yang menggunakan perkakas *6 Langkah OBA* diaplikasikan untuk panduan pihak pengurusan di dalam memperuntukkan pemampan semasa merekabentuk susunatur, berdasarkan μ untuk setiap stesen di dalam talian pengeluaran tersebut. *Aliran Penentuan OBA* ini dihasilkan bagi meringkaskan aliran untuk mendapatkan *OBA* bagi talian pengeluaran seimbang dan ketidakseimbangan-μ. Dua kajian kes sebenar dengan bilangan stesen yang berbeza dijalankan di sebuah syarikat elektronik multinasional di kawasan utara Semenanjung Malaysia untuk membuktikan keputusan daripada *Aliran Penentuan OBA* yang dikembangkan. Daripada kajian kes yang dijalankan, terbukti *OBA* yang diperolehi menggunakan kaedah yang dikembangkan memberikan kadar kecekapan (produktiviti) yang tertinggi untuk talian pengeluaran. Secara umumnya, *Aliran Penentuan OBA* yang dibangunkan sesuai digunakan sebagai kaedah penentuan *OBA* untuk aliran pengeluaran tidak melangkah ketidakseimbangan-μ.

A DEVELOPMENT OF OPTIMAL BUFFER ALLOCATION DETERMINATION METHOD FOR μ-UNBALANCED UNPACED PRODUCTION LINE

ABSTRACT

This research deals with a buffer allocation problem in an unpaced (asynchronous) μ-unbalanced production line. Unpaced line is referred to a line with workstations act independently and the material is not pulled by demand but in push mode. In this research, the production line is considered unpaced, μ-unbalanced but reliable. The optimal buffer allocation (*OBA*) needs to be determined for this particular type of production line. This subject is importance since recently many small and medium sizes products' companies are utilizing unpaced production lines and a convenient method of determining *OBA* is required. *OBA* is referred to the optimum number of buffers to be allocated in the intermediate buffer slots between the workstations so that it can maximize throughput rate and optimize total number of *work in progress* (*WIP*) on the line. This research's problem statement is divided into two main phases. For phase 1, a searching method using *Arif's algorithm* simulation software is carried out to simulate the throughput rate for a given sets of buffer allocation shapes in the production line. Few *Basic OBA Concept (BOC)* represented the characteristics of *OBA* for a production line was summarized from the searching method. By applying these *BOC*, a development of *OBA Determination Flow* is carried out in phase 2. *OBA Determination Flow* which utilized *6 Steps OBA* tool is used to

guide the management in allocating the buffer during designing a line layout, with reference to the μ of each station in the production line. This *OBA Determination Flow* will summarize the flow of determining *OBA* for both fully balanced and μ-unbalanced line. Then, two actual case studies with different numbers of stations carried out in one of the multinational electronic company in north region of Peninsular Malaysia to validate the result from *OBA Determination Flow* developed. From the case studies, it is proven that the *OBA* decided by using the flow established giving the highest performance to the production line. Generally, *OBA Determination Flow* developed could be utilized as an *OBA* determination method for μ-unbalanced unpaced production line.

CHAPTER 1 : INTRODUCTION

1.1 Background

Recently, there are many researches that have been carried out in improving the production line from the work in progress *(WIP)* perspective. This is due to a demand from a company's management to lead the global competition among manufacturing companies. One of the areas that focused by researchers is a study to maximize the production line throughput rate (efficiency), X and productivity. Throughput rate could be defined as an efficiency of the production line to produce one unit of completed product in a specified time period. Dennis (2001) defined line's throughput rate as the average number of jobs per unit time that can flow through a production line while station's throughput as the number of jobs the station can produce per unit time, taking account of failures. Fully efficient production line is said to be achieved when the throughput rate is equal to 1.00. For a few of the companies, sometimes the efficiency of the production line is determined by line productivity. Basically, line productivity is defined as a percentage of total units output produced in specified working hours and number of manpower in a calculated total standard time (*SST*). The line is said to be good if it achieves 100% productivity. However, it is quite a challenging task for a line to achieve more than 100% productivity.

The management is fighting for a better efficiency of their production lines due to a demand for manufacturing industries. It has become a challenge to a management to design the best and perfect production line layout that can maximize the output with the lowest investment. At the same time they also need to consider the space availability during designing the line layout, optimize manpower usage and selection of good machines and equipment to minimize (or even avoid) any downtime related to machine failure. Nowadays, unpaced production line (sometimes called cell line concept) is one of the direction for the management to reduce the investment cost during new product introduction. This line concept is suitable for small and medium size products such as computer peripheral and accessories products, home appliances products and small electrical products. Many multinational companies are using the cell line concept for their product assembly line.

In the real world, it is impossible for unpaced production line to achieve 100% perfect balance and reliable lines. This is due to many factors causing the lines to become unreliable and unbalance. The sources of unbalanced are mean processing time (μ), coefficient of variation (C_v) and buffer allocation that need to be considered for balanced production line. In an actual unpaced production line, μ for each station is difficult to be set at a perfectly balanced or distributed uniformly. As for an unreliable line, more factors need to be taken into consideration such as failure rate, machine downtime and repair rate.

One of the possible methods to optimize the line efficiency is by identifying the optimal buffer allocation (*OBA*) of the line. Buffer allocation is an important, yet intriguingly difficult issue in planning the physical layout and location of the production line layout. Optimal buffer allocation can optimize production line performances such as minimizing buffer (work in progress, *WIP*), cycle time, blocking probability and maximizing throughput rate.

There is a necessity between researchers, industrial engineers and managements to synchronize their understanding in buffer allocation at the actual production line. Therefore, the *OBA Determination Flow* need to be developed as a guideline for a management to set up a production line with the optimum buffer allocation, hence could lead to the best line efficiency.

1.2 Problem statement

As has been discussed in previous section, nowadays a majority of companies in Malaysia are practicing a cell line concept (unpaced line) particularly the manufacturing companies that produce small and medium size products. The production line in these companies usually is considered unpaced or asynchronous line, reliable but with μ unbalanced. The company's management unquestionably will put a goal of getting 100% reliable line. A good manufacturing company must move to a nearly perfect (reliable) production line. Generally, a reliable line is achieved by selecting good machines and well trained operators. There are also zero failure rates for the assembly process and inspection station which would be achieved by good equipment maintenance and a good support of engineering knowledge to avoid line machine's downtime and product (process) failures. Once a failure occurred, it must be fixed and repaired (corrected) as soon as possible. In addition to that it has become a norm in any manufacturing company to have a goal in maximising the production line's throughput rate (Efficiency), *X* and productivity. Even though various concepts and solutions have been proposed for realizing the goals stated such as lean concept, quality improvement methods and so on, still there is opportunity for better and simple solutions. As an example, one of the solutions is in identifying the accurate buffer in term of the quantity and the size to be used on the production line.

Therefore, it will be a revolution for companies especially in Malaysia to adopt the concept of arranging the correct number of buffers known as optimal buffer allocation (*OBA*) between the stations in the production line in order to achieve the best line's throughput rate, *X* and productivity. Even though various number of research has been carried out over the years relating to the *OBA* but most of the findings is convoluted to be adopted in real world. One of the possible reasons for the company management not to practice the *OBA* is due to an unavailability of easy guidelines to adopt the concept.

Hence, a better optimal buffer allocation *(OBA)* is needed to be developed for this particular type of production line so that it can maximize *X* and minimize (optimize) total number of buffer (*Work In Progress* (*WIP*)) on the line (both on workstation and on buffer slot). In addition to that there is a challenge for the researchers to convince the company management to adopt the findings from the concept of identifying the *OBA* of the production line. As a result a direct guidance to management on how to apply the *OBA* to the production line needs to be developed as well.

1.3 Research objective

The main objectives of this research are as follows:

a) To categorize the unpaced production line in order to have a better understanding of the criteria and characteristics of this production line. It will be achieved by reviewing the relevant literatures related to this subject matter.

b) To develop a methodology and a flow to determine the OBA of the μ-unbalanced unpaced production line. The flow is called *OBA Determination Flow*. This will be achieved by adopting and improving the previous work done by various authors identified in the literatures. Simulation, searching and mathematical approaches will be used during developing this flow.

c) To validate the findings concluded in the *OBA Determination Flow*. This flow will be tested in an actual unpaced production line at one electronics manufacturing company in the northern area of Peninsular Malaysia. Two different products (with different μ-unbalanced shapes, number of stations and buffers) produced by this company will be selected for the verification and validation purposes.

1.4 Layout of Thesis

This thesis is organized as follows. In chapter 2, all the literature review findings related to the discussed topic were highlighted. There are various papers discussing the combination between unbalanced, balanced, unreliable and reliable production line conditions. Each paper was studied in order to understand previous researchers' scopes, findings and limitations. Based on the literatures, there is still no any single study carried out to discuss the management guide to allocate buffer in the production line. Therefore this research will focus on the easy method to determine the *OBA* of the production line, once the total number of stations and buffers are decided.

Then in chapter 3, the production line model selected, methodology and approach used to complete the research was explained. The methodology used is broken down into two major phases; Phase 1 and Phase 2. In phase 1, searching method is used to find out few *Basic OBA concept (BOC)* which need to be followed during determining *OBA* of the production. Next in phase 2, based on the *BOC* results, *OBA Determination Flow* using a tool called *6 Steps OBA* is developed. The *OBA Determination Flow* concluded the finding as a management guidance to get *OBA* of the production line.

In chapter 4, details of findings in two different case studies were discussed. These case studies were carried out in actual production line for two different product models in one multinational company in northern Peninsular Malaysia. The purposes of these case studies are to confirm whether the method and approach developed would be applicable to the real world. The results (output) between *OBA Determination Flow* and actual production line throughput rate are compared in details. The two different models and conditions of production line layouts tested in a separate time frame. Case study 1 was tested for unpaced μ-unbalanced production line with eight stations line while case study 2 for 17 stations line. Chapter 4 will give detailed results of the case studies.

Finally, chapter 5 concludes the research besides indicating the proposed future works on the relevant topics.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

The literature review of this research revolved around Optimal Buffer Allocation (*OBA*) for a few combinations of unpaced production line conditions either it is fully balanced, mean process time (μ) unbalanced or coefficient of variation (C_v) unbalanced, reliable or unreliable. The overview of production line's throughput, unpaced production line, balanced and unbalanced production line was also elaborated in the next sections.

2.2 Production Line's Throughput Rate

Production line's throughput rate could be defined as an efficiency of the production line to produce one unit of completed product in a specified time period. It is widely used by management as a performance index of the production line. The highest performance for the production line is achieved when throughput rate value is equals to 1.0 . Dennis (2001) derived the equations to determine production line's throughput rate for two stations arranged in series (with buffer). The parameters involved are the speed (service rate) of a stn i (i=1,2) (jobs per unit time) (*S*), buffer size (number of jobs that can be held in the buffer) (*B*) and the throughput rate of the line (jobs per unit time) (*P*). The production line were assumed as follows :

(i) processing time at station-i are independent and exponentially distributed (with mean $1/S_i$, i =1,2)

(ii) stations are not subject to failures.

Then, the throughput rate of the line (average number of jobs per unit time) is given by :

$$P = S_1 S_2 \left(\left(S_1^{B+2} - S_2^{B+2}\right) / \left(S_1^{B+3} - S_2^{B+3}\right) \right) \quad (1)$$

In a special case of identical stations ($S1 = S2 = S$), this throughput result reduces to

$$P = \left((B+2) / (B+3) \right) S \quad (2)$$

Elsayed (1994) represented line's throughput rate as line's efficiency (LE) which was defined as the ratio of total station time (ST) to the cycle time (CT) multiplied by the number of workstations (N). In equation, it was given by:

$$LE = \frac{\sum_{i=1}^{N} ST_i}{(N)(CT)} \quad (3)$$

Station time (ST) is the sum of the times of work elements that are performed at the same workstation. Cycle time (CT) the time between the completion of two successive assemblies, assumed constant for all assemblies for a given speed. It is obvious that the station time (ST) should not exceed the cycle time (CT). The minimum value of the cycle time must be greater than or equal to the longest station time. Then, delay time of a station is the difference between the cycle time (CT) and the station time (ST) (that is the idle time of the station = *CT-ST*). In designing an assembly line, the following restrictions must be imposed on grouping of work elements:

i) Precedence relationship

ii) The number of work stations, cannot be greater than the number of work elements (operations) and the minimum number of work station is 1 ($1 \leq N \leq W$) where W = number of work elements to complete the assembly.

iii) The cycle time is greater than or equal to the maximum time of any station time and of any work element, T_i. The station's time should not exceed the cycle time ($T_i \leq ST_i \leq CT$).

Arif and Zahid (2003) defined throughput rate (X) as total number of items produced from the production line in a specific time. This is as stated in the *Arif's Algorithm* simulation software. The *Arif's Algorithm* was also utilized during completing methodology section in chapter 3.

2.3 Unpaced production line

A production line is an assembly line in which material moves continuously at a uniform average rate through a sequence of workstations where assembly work is performed. Elsayed and Thomas (1994) mentioned that an arrangement of work along the assembly line will vary according to the size of the product being assembled, the precedence requirements, the available space, the work elements, and the nature of the work to be performed on the job. There are two main problems in assembly lines; to balance the workstations and to keep the assembly line in continuous production.