



Methodology Development for Calculating Productivity
and Its Losses to Determine Optimization Regime
in Assembly Line

by

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Pengembangan Metode Perhitungan Produktivitas dan Kerugiannya untuk Mendapatkan Optimisasi di Assembly Line

Abstrak

Sistem pembuatan moden memerlukan produktiviti yang tinggi dengan unit cost harga murah untuk mempertahankan daya saing di pasaran global. Untuk mencapai tujuan bersama penyelidikan produktiviti dalam bidang perkilangan terutamanya dalam persekitaran assembly line terdiri daripada dua tujuan utama: (1) Untuk menentukan potensi cadangan produktiviti dalam keadaan pengeluaran yang sebenarnya, dan (2) Untuk memberikan parameter awal untuk perancangan proses penyusunan baru berdasarkan pengalaman dahulu daripada tatacara operasi sebenar. Perhitungan produktiviti itu sendiri mudah harus digunakan untuk pelbagai jenis jenis seperti pemasangan manual, automatik atau hibrida dan mungkin juga merangkumi kompleksitas berbagai model produk yang menghasilkan. Dengan menggunakan analisis chronometric sebagai asas statistik, perumusan untuk pengiraan produktiviti perlu merangkumi semua kompleksitasnya matematik. Hasil perhitungan produktiviti perlu dibandingkan dengan grafik harga per unit di bawah domain yang sama untuk menentukan rejim pengoptimuman. Keputusan akhir merupakan suatu data yang boleh dipercayai penting bagi pengambil keputusan syarikat untuk memilih tatarajah yang optimum antara tatarajah yang paling ekonomis dan konfigurasi yang paling produktif.

Key words : productivity calculation, assembly line, balancing, optimisasi

Methodology Development for Calculating Productivity and Its Losses to Obtain Optimization Regimes in Assembly Line

Abstract

Modern manufacturing system requires high rate productivity with low cost unit price to maintain its competitiveness in global market. To achieve these goal common investigation of productivity in manufacturing especially in assembly line environment consist of two main purposes: (1) To determine potential reserve of productivity in actual production condition, and (2) To provide initial parameter for planning a new process arrangement based on prior experience of actual operating arrangement. The calculation of productivity itself shall easily be applied for various kind of assembly type such manual, automatic or hybrid and also may cover the complexity of various models of products its produces. By using chronometric analysis as the statistical basis, the formulation for productivity calculation must cover all its complexity mathematically. The result of productivity calculation should be compared to graph of price per unit under the same domain to determine the range of optimization regimes. The final result is reliable important data for corporate decision makers to choose the optimum configuration between the most economical configuration and the most productive configuration.

Key words : productivity calculation, assembly line, balancing, optimization

Chapter 1

Introduction

1.1 BACKGROUND OF THIS PROJECT

Productivity is an important parameter in the world of manufacturing but not yet mathematically satisfies formulated comprehensively according to manufacturing basis. There are not many information about these subject in Industrial Engineering fields such as Operational Research Handbook and only available in Macroeconomics fields^[1] but unfortunately productivity explained in different way according to input and output basis.

There are several books and papers discussing productivity calculation to be implemented in manufacturing fields. The influence of economics fundamentals is very strong affecting the basic calculation for manufacturing productivity therefore qualitative paradigm drives mathematical formula into profit orientation^[2]. Hence the manufacturers may produce the same amount of products at the same duration but the productivity might be different according to price ratio of raw material and output products in market place which always fluctuating.

This thesis developed from qualitative paradigm in term of how many products produced in observed time. It doesn't matter the price fluctuation in market place because only focusing on the number of accepted products according to quality control criterion per operation time basis. This perspective acknowledged by economist point

of view as “output rate” not considered as “productivity”.

In common practice nowadays many methods developed to increase productivity levels according to prior experience such Kaizen and Kanban which originally developed in Toyota Motors Corporation. Certainly it has been a proven method capable to reduce losses but still unable to explain the current status of productivity mathematically.

Several concepts developed to increase productivity and quality such Kaizen and Kanban in production line. The purpose of Kanban philosophy is to push process schedule near delivery due date in purpose to reduce inventory cost. Thus Kanban formulated as "Just in Time" concept ^[3] while Kaizen philosophy aims to engage continuity of improvement in all aspects ^[4]. In western hemisphere Six Sigma plays as major techniques to increase productivity with the main purpose to achieve zero mistakes or perfect procedure ^[5].

For many type of manufacturing whether it is machining, foundry, hot and cold working, assembly and others, the main problem is mathematical limitation of production capacity of manufacturing system. The rate of productivity so much depends on machine ability and labor fatigue limit whereas impossible to be exceeded more. From Kaizen point the view it becomes clear where continues improvement will achieve stagnant result when the latest improvement already reached the limits of machine ability or labor fatigue limit. The phenomenon of stagnant improvement will show an asymptotic graph.

Mathematical formulation of productivity is very important to figure out the peak of productivity level which unable to exceed more than its production capacity. This happens because of limitation of technological machine ability or skill of labor in production line. Mathematical formulation must also able to discover various type of losses that might not realized in advance therefore the elimination of losses can be resolved to achieve the higher productivity level.

Hence the knowledge of productivity is very important in manufacturing because investment of high rate expensive machine may become useless if not managed in proper configuration. This might happen because losses may occur anywhere without being realized in advance or early stage of line arrangement processes. In the opposite old or cheaper equipment may provide higher productivity level if the line configuration in serial or parallel set properly on the optimum performance. This condition may achieve higher productivity result in overall manufacturing system.

1.2 MOTIVATION

© The suitable formulation about productivity according to quantitative perspective was explained by Prof. Shaumyana^[6] who originally derived the formula for machining environment purpose. He explained the productivity calculation and its factors mathematically. Hence, the author believes this method should also possible to be mathematically implemented for assembly line environment. Assembling is more complicated in term of activity involved therefore continues balancing process is required as continues improvement for reducing all losses to improve its productivity.

This is actually what Kaizen concept application which nowadays applied almost everywhere.

Assembly line has slight different behavior compared to machining area therefore some modification of mathematical notation should be implemented. For example the notation of machining time should be replaced as assembling time but principally has the same basis of mathematical approach for overall productivity calculation.

Productivity calculation for all of manufacturing type is a fundamental basis to determine the range of optimization level. This research aims to discover the optimization regime of productivity VS assembling cost where the implementation should be able to be applied for typical manufacturing system especially in assembly line environment.

1.3. OBJECTIVE

The objective of the thesis is to develop a new formula for calculating productivity level in assembly line environment base on calculation of productivity in machining environment. Potential reserve of maximum productivity can be obtained by eliminating productivity losses clearly seen according to mathematical point of view. This is the fundamental step to discover range of optimization in assembly line base on productivity versus economics configuration.

The basic example of optimization in machining environment it requires high speed machining process as main consideration to gain economic advantageous. In the other

hands limitation of tool life forced the process engineer to set machining parameter in a certain specific level therefore optimum range of cutting speed to satisfy both economic and tool life can be determined.

This is a challenge to find an optimization range in assembly line area where prior productivity level already described. Considering the same example from machining optimization then it supposed the productivity level increases when the assembling time decreases. Assembly time of a system may decrease by reducing bottleneck by redistributing the work for each overloaded workstation into less activities workstation which is technically called assembly line balancing. The assembly time may also decrease by re-arranging a number of workstation, more workstations being added then less assembly time required and more productivity will be achieved. Expanding the number of workstation cost more infrastructure investment that similar problem with tool life in manufacturing area. This is where drawing the range of optimization regime is important part in this thesis.

From development methods in this thesis shall easily applied to similar industry instead of assembly line as this case study. This method can be mathematical perspective to explain another method developed to increase productivity such Kaizen and Kanban mathematically.

Further step of productivity evaluation is useful for finding the optimization of assembly process. Hopefully this research will be developed into manufacturing standard for calculating productivity and its losses and determine the optimization range for assembly line environment. Furthermore it supposed able to draw the similar

method for productivity calculation in other areas such oilfield production, food industry and so forth.

1.4. ORGANIZATION OF THESIS

This thesis consists of 6 chapters. Chapter 1 is introduction explains about an overview and background of research and expected goal of this result in industry.

Chapter 2 explains about literature reviews. This chapter presents all mathematical background for developing the research. At the beginning explains the difference definition between macroeconomics and manufacturing approach about Productivity calculation. All necessary the mathematical formula for various productivity configurations explained in general therefore can be developed for any material flow configuration. Cost calculation here explained according to several economic points of view to suit the further optimization theory.

Chapter 3 explains about step-by-step procedure in calculating and analyzing productivity at assembly line. Productivity calculation in machining area developed for assembly line to suit new formulation. Regarding to optimization that corresponds with cost therefore necessary formula related with cost item calculation explained in chapter 2 developed to be suitable into assembly line environment.

Chapter 4 explains about actual calculation and analysis in assembly line. This part explains how to calculate the actual productivity and discover the losses. From serial assembly line balancing the productivity may increase by removing previous losses.

From this section the available resource can be use increase productivity level which undiscovered before.

Chapter 5 explains about optimization in assembly line. Optimization of productivity related with production cost. Refer to chapter 3 where formulation of optimization was developed from chapter 2 about tool life against rate of machining process then the similar approach can be use to implement optimization regime in assembly line environment

Chapter 6 briefs a conclusion and perspective according to other methods in improving productivity. The objectives of this research also declared and draw the future work in ERP development.

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Chapter 2

Literature Review

2.1 OVERVIEW

Productivity is a measure of output from a production process, per unit of input. For example, labor productivity is typically measured as a ratio of output per labor-hour, an input. Productivity may be conceived of as a metric of the technical or engineering efficiency of production. As such, the emphasis is on quantitative metrics of input, and sometimes output. Productivity is distinct from metrics of allocative efficiency, which take into account both the monetary value (price) of what is produced and the cost of inputs used and also distinct from metrics of profitability, which address the difference between the revenues obtained from output and the expense associated with consumption of inputs. (Courbois & Temple 1975 ^[8], Gollop 1979 ^[9], Kurosawa 1975 ^[10], Pineda 1990 ^[11], Saari 2006 ^{[12][13]})

According to dictionary of Investing World ^[15] the definition of productivity is the amount of the output per unit of input (labor, equipments and capital). There are many different ways of measuring productivity. For example, in a factory productivity might be measured based on the number of hours it takes to produce a good, while in the service sector productivity might be measured based on the revenue generated by an employee divided by his/her salary

Several productivity issues have been raised recently. For example, Oil and Gas industry is more familiar with term of BOPD (Barrel Oil per Day) to indicate the productivity rate of crude oil output in Oilfields. This is extremely different definition from above in economics point of view as described above.

There are three main objectives on this study. The first is to develop a new productivity assessment framework and methodology capable of identifying and measuring the source of improvement in productivity for industry or a company. The second purpose is to apply the methodology into assembly line operations. The third is to determine the optimum range of productivity in term of economics parameter and productivity rate.

2.2 QUALITATIVE PRODUCTIVITY

Qualitative productivity fundamentals based on economics paradigm on profit oriented indicator. Rolf Fare (1942) and Shawna Groskopf formulated ^[2] productivity as ratio between outputs per input as following equations:

$$\text{Pr oductivity} = \frac{\text{Output}}{\text{Input}} \quad (1)$$

Young Kyo Son and Chan S. Park ^[15] developed formulation for qualitative productivity in advanced manufacturing system derived from equation [1] as following

$$P_C = \frac{O_T}{C_C} \quad (2)$$

Where:

PC: Capital Productivity

OT: Output of products

CC: The service cost of using invested capital

2.3 QUANTITATIVE PRODUCTIVITY

Basic principles of the theory of industrial productivity

1. Each work for its accomplishing requires the expenditures of time and labor
2. Time spent is considered productive it is expended on the working processes. All other time is considered as losses
3. A machine considered ideal if working with high rate productivity produces accepted quality products without no time losses
4. Any technological process should be decomposed into the its components
5. Segmentation of technological process and concentration of its operations is base of design of any automated production machines and systems
6. Any type of automatic machines and systems of any industries have the integrated basis of automation, which is expressed in general laws governing the design, productivity, reliability, effectiveness, etc

Prof GA Shawmyan ^[6], L. Volchkevich ^[7] formulated the actual productivity in machining environment is related to number of products produced in observed time.

$$Q_{ACT} = \frac{Z}{\theta} \quad (3)$$

Where

Q_{ACT} : Actual productivity,

Z : Number of products produced in observed time

θ : Observed time

Losses or inefficiency in observed time might cause by idle times, defect parts, scheduling problems as described in equation [4].

$$Q_{ACT} = \frac{Z}{\theta} = \frac{Z}{\theta_W + \theta_{IDLE}} = \frac{1}{\frac{\theta_W}{Z} + \frac{\theta_{IDLE}}{Z}} \quad (4)$$

Where

Q_{ACT} : Actual Productivity

Z : Number of product produced

$\theta = \theta_W + \theta_{IDLE}$: Observed time that is sum of

θ_W : Work time, and

θ_{IDLE} : Idle time

For simplicity it is necessary divide nominator and denominator from eq. [4] on the number produced parts Z , then

$$\frac{\theta_W}{Z} = T = t_{ass} + t_{aux} \quad (5)$$

Where

T - duration of the cycle time of process,

t_{ass} - duration of the assembling process, and

t_{aux} is duration of the auxiliary motions like fast loading and reloading of parts to assembling area, deliver and withdraw tools from assembling

area, tuning some components of process before assembling, etc. This auxiliary time is property of the discrete production systems. For continuous production processes $t_{aux} = 0$.

An idle time is the sum of any nonproductive time and auxiliary time relatively to the number of parts produced during process in production line formulated in equation [6]

$$\frac{\sum_{i=1}^n \theta_i}{Z} = \frac{\sum_{j=1}^k \theta_{tech.j}}{Z} + \frac{\sum_{l=1}^m \theta_{org.l}}{Z} = \sum_{j=1}^k t_{tech.j} + \sum_{l=1}^m t_{org.l} \quad (6)$$

Where θ_{tech} is idle time due to technical reasons like brakes of conveyor, actuator, and other mechanisms that belong to the assembling equipments, defected assembled units, and brakes of tools for assembling process, etc.

While θ_{org} is idle time due to organizational or managerial problems like absent of parts to be assembled, absent of workers, drop of power, stops of previous sections of assembling line, absent of carts to deliver assembled parts to other production area, etc

© $\frac{\sum \theta_{tech}}{Z} = \sum t_{tech}$ Is time losses due to technical problem referring to one product that reflect the level of reliability of the assembling equipment

$\frac{\sum \theta_{org}}{Z} = \sum t_{org}$ Are time losses due to organizational or managerial problems. These problems refer to production stops that reflect the level of quality of organizational skill

or miss-management.

After substitution all new expressions to Eq. [3] the expression of the actual productivity is given in equation [7] as following [2]:

$$Q_{ACT} = \frac{1}{t_{ass} + t_{aux} + \sum t_{tech} + \sum t_{org}} \quad (7)$$

For production systems where machines are ideal and reliable, and organizational and managerial system are perfect, that is practically impossible to have, however for further analysis it is necessary to have some indicator that reflects production process. In ideal case $\sum t_{tech} = 0$, and $\sum t_{org} = 0$

In such case the productivity of ideal process is presented by equation of cyclic productivity [7]

$$Q_T = \frac{1}{T} = \frac{1}{t_{ass} + t_{aux}} \quad (8)$$

Where Q_T - cycle productivity, T - cycle time, other components presented above.

In industrial areas there are many solutions of production processes or work of machines (here equivalent with assembling process) where there are no auxiliary motions and times spent on this process, i.e. $t_{aux} = 0$. In such case production process or work of machine is described by following equation [7].

$$K = \frac{1}{T} = \frac{1}{t_{ass}} \quad (9)$$

Where, K is technological productivity that reflects the limit or maximum productivity of such process in manufacturing or assembling processes.

According to the result of research in assembly line the average auxiliary time around 20% which statistically the same with average auxiliary time occurs in machining processes. According to these phenomena machining and assembling processes had shown similar behavior.

Ideal assembling process without any managerial and technical losses can be presented as following diagram with sequence of cyclic process of assembling process

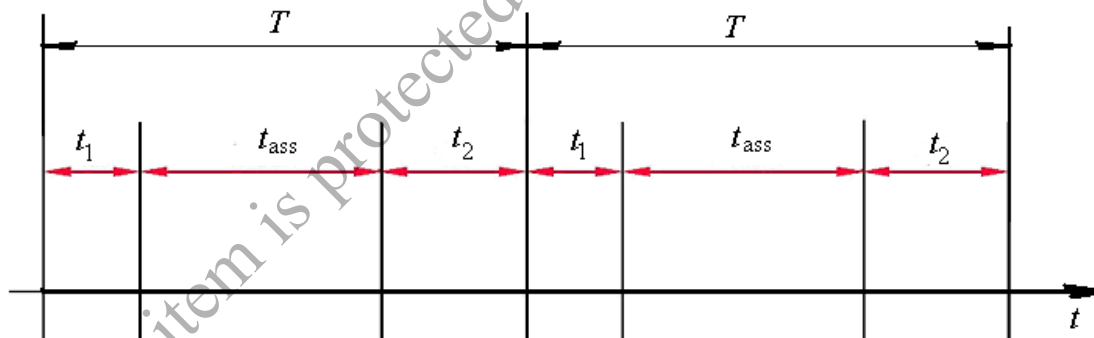


Figure 2.1. Cycle time diagram of assembling process

Where

t_1 = In machining process: load of work piece, clam of work piece, move out arm of robot, move in cutter / preparation

In assembling process: load of workpiece, take and adjust the lightener.

t_2 = In machining process: move out cutter, transfer work piece out of