VARYING LOT SIZE MODEL WITH EQUAL AND UNEQUAL SIZED BATCH AND VARYING NUMBERS OF BATCHES FOR MULTI-STAGE PRODUCTION IN PALM OIL MILL

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2013

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by

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Thesis submitted in fulfilment of the requirements for the degree of

Master of Science

August 2013

ACKNOWLEDGEMENTS

This research would not have been possible carried out without the guidance and help of several individuals, who in way or another have extended their valuable assistance in helping me to complete all of my studies successfully.

First of all, I wish to express my gratitude to God for granting me a good health and wisdom to complete my research. I wish to express my appreciation to my supervisor, Associate Professor Adam Baharum who is very helpful in providing invaluable assistance, support and guidance throughout my study. I have gained invaluable knowledge and analytical skills from him throughout the period of this study.

I would also like to thank the Dean of the School of Mathematical Sciences, Universiti Sains Malaysia (USM), Professor Ahmad Izani Md. Ismail, lecturers and staff of the department for the generous provision of facilities and space to complete this research work. My obliged thanks also go to the two laboratory technicians, Ms. Hartini Ahmad and Mr. Syed Mohamad Hussein Syed Osman for their patience and kindness in assisting me with a laboratory to run my computer programs.

My deepest gratitude goes to my family members for giving me the opportunity to further my study. Their moral support and inspiration throughout the period of this research have encouraged me to work hard in completing all the tasks required in this study. I would like to express my special thanks to my mother, who has always respected and supported my decisions, my belated father who had inspired me to stay strong despite any difficulties, my uncle who has provided me the information and knowledge regarding palm oil industry as well as connections between palm oil millers to collect the data.

I wish to extend my thanks to all of my beloved friends, especially Dr. Kwan Wai Hoe, Ms. Chin Wen Sim, Ms. Ng Kah Pin, Ms. Kang Miew Ying and Ms. Kang Pei Yi for sharing their knowledge in the literature study and providing invaluable assistance and encouragement. Not forgetting, my sincere thanks to my best friends who are always offering help at any time.

Last but not least, I would like to convey my thanks to the Institute of Postgraduate Study for providing me with the USM Fellowship scheme giving financial aid in tuition fees and monthly allowance. At the same time, appreciations are dedicated to Associate Professor Adam Baharum for supporting me in financial way from his Research University Grant, number 1001/PMATHS/823005, to carry out the data collection in Sabah.

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ABSTRAK

Dalam industri minyak kelapa sawit, kos pemprosesan minyak kelapa sawit mentah berubah dari semasa ke semasa. Oleh itu, keputusan yang tepat terhadap jumlah dan masa pemprosesan adalah kritikal. Ini boleh dijalankan dengan pengaplikasian model-model inventori ke dalam industri minyak kelapa sawit supaya dapat mengenalpasti faktor-faktor kos pengaruh utama serta kos unit khas dalam pemprosesan minyak kelapa sawit mentah. Ini bukan sahaja membantu pengurus kilang minyak kelapa sawit untuk membuat keputusan yang tepat malahan menjimatkan kos pemprosesan ke tahap optimum. Walau bagaimanapun, jurang dalam pengetahuan tentang pengamalan model-model inventori terhadap industri minyak kelapa sawit adalah besar. Penyelidikan ini cuba mengenalpasti model-model inventori yang boleh dimuatkan ke dalam industri minyak kelapa sawit. Model yang paling sesuai digunakan untuk mengenalpasti polisi operasi terbaik yang boleh dilaksanakan ke dalam kilang minyak kelapa sawit. Kos-kos komponen utama yang terdapat di dalam model adalah kos unit pegangan inventori, penyediaan, belian dan pengangkutan. Ujian keserasian terhadap teori-teori inventori dengan industri semasa dijalankan supaya menentukan praktikal model-model inventori dalam industri minyak kelapa sawit. Pada peringkat awal penyelidikan ini, model-model inventori yang berkenaan dan ciri-ciri industri minyak kelapa sawit dikaji sebelum pengumpulan data. Model-model inventori yang sesuai dikenalpasti dengan merujuk kepada kriteria-kriteria dan amalan-amalan kilang minyak kelapa sawit; isitu, saiz kolompok yang berbeza, nombor kolompok yang berbeza, dan pemprosesan pelbagai peringkat. Data dikumpul dengan cara temuduga berhadapan pengurus kilang minyak kelapa sawit dari kilang minyak kelapa sawit khas di Sabah. Eksperimen berangka dijalankan antara kedua-dua model (pengangkutan inventori bagi saiz kolompok yang malar serta saiz kolompok yang malar dan berbeza antara peringkat-peringkat). Model yang dapat menghasilkan kos pemprosesan minyak kelapa sawit mentah yang terbaik dipilih. Perbandingan kos juga dijalankan antara kedua-dua model dengan praktis sebenar. Keputusan daripada model pengangkutan inventori bersaiz kolompok yang malar dan berbeza adalah RM 232 – 246 per ton metrik bagi minyak kelapa sawit mentah, memberi pemajuan sebanyak 5% hingga 10% berbanding dengan model yang bersaiz kolompok malar. Keputusan-keputusan yang ditunjukkan adalah serasi dengan industri, iaitu dalam lingkungan RM 45 – 50 per ton metrik bagi bijian kelapa sawit, bersamaan dengan RM 225 – 250 per ton metrik bagi minyak kelapa sawit mentah. Kos-kos komponen utama termasuk kos penyediaan, pegangan inventori dan pengangkutan serta sumbangan peratusan adalah 25%, 50% dan 25% masing-masing. Ini menunjukkan kos pegangan inventori ialah faktor kos pengaruh utama dalam kilang minyak kelapa sawit. Oleh itu, pengusaha kilang minyak kelapa sawit seharusnya menumpu perhatian terhadap pengurangan kos dalam pegangan inventori.

VARYING LOT SIZE MODEL WITH EQUAL AND UNEQUAL SIZED BATCH AND VARYING NUMBERS OF BATCHES FOR MULTI-STAGE PRODUCTION IN PALM OIL MILL

ABSTRACT

In palm oil industry, production cost for crude palm oil varies from time-to-time. Therefore, accurate decisions on production volume and timing are critical. This can be done by adopting inventory models into palm oil industry to identify the major cost influencing factors as well as the specific unit cost involve in production of crude palm oil. This will not only help the palm oil millers to make accurate decision but also to save the production cost to optimum. However, there is a large gap of knowledge present on the adoption of inventory models in palm oil industry. This research attempts to identify the inventory models that can fit into palm oil industry. The best fitted model is used to determine the best operating policy that can be implemented into palm oil mills. The major costs components in the models are unit inventory holding, setup, purchasing and transportation cost. The examination of compatibility of inventory theories with current industry was done so as to determine the practicality of inventory models in palm oil industry. In the preliminary stage of this research, relevant inventory models and characteristics of the palm oil industry were studied before data collection. Suitable inventory models were identified with reference to the criteria and practices of palm oil mills; namely, varying batch sizes, varying numbers of batches and multi stages production. The information was collected directly from the mill managers from the specific palm oil mill in Sabah. Numerical experimentation was done among two models (equal batch size as well as equal and unequal batch size shipment between stages). The model that can produce the best production cost for crude palm oil were selected. Cost comparisons are also done between the models and real practice. The results from the model with equal and unequal batch sized shipment were RM 232-246 per metric ton of crude palm oil, gave 5 % to 10% improvement in production cost compared to the model with equal batch sized shipment. The results shown are compatible with the industry where they are in the range of RM 45 – 50 per metric ton in terms of fresh fruits bunches, which is also equivalent to RM 225 – 250 per metric ton of crude palm oil. The cost components in CPO production cost include setup, inventory holding and transportation cost and the percentages of contribution are 25%, 50% and 25% respectively. These showed that inventory holding cost is the major cost influencing factor in palm oil mills. Thus, palm oil millers should focus on reducing cost in unit inventory holding cost.

CHAPTER 1 INTRODUCTION

1.1 Introduction

The palm oil industry heavily depends on world market. The consumption of world palm oil increases over the years. Asian countries contribute a large number in the palm oil industry and Malaysia is one of the world's largest palm oil producers and exporters. Palm oil industry is one of the leading contributors towards the Gross Domestic Product (GDP) in Malaysia. In 2011, agriculture sector contributed 7.3% towards GDP and it was mainly contributed by production of crude palm oil (CPO) (Lindsay, 2012). Agensi Innovasi Malaysia (AIM) targeted palm oil sector contributes RM 60 billion towards the national GDP of Malaysia by 2020 (Shanmuganathan, 2012). Therefore, it can be seen that the palm oil industry in Malaysia is very competitive and important.

There are a lot of procedures involve in producing CPO. It includes collecting fresh fruit bunches (FFB) from own and other plantations, sterilizing and threshing bunches to free palm fruits, mashing and pressing fruits to release oil, and finally purifying the CPO for storage and dispatch. Appropriate amount of FFB to be processed can avoid fruits degradation and thus to ensure the quality of CPO. Appropriate dispatch frequencies can control the quality of CPO from being deteriorated. These incur cost for storage and quality control of CPO.

Due to massive production of CPO in palm oil mills (POMs), each decision making is very critical as it encounters huge risk that will determine the profit and lost. Often palm oil miller asked two questions: when should an order be placed and how large should each order to be. Inventory models always answer these questions. There are four main costs in all inventory models; namely, ordering or setup cost, unit purchasing cost, holding or carrying cost, and shortage cost. Companies often keep on hand stock that is waiting for sale to meet demand on time. There are four types of inventory; namely, buffer inventory, cycle inventory, anticipation inventory, and pipeline inventory. Yet, these can decide the level of inventory in all companies. A good model should able to balance the costs that are associated with holding inventory and placing orders, to meet customer demand.

Different POMs practice different principles. Some POMs allow back order and some of them allow quantity discount if buyers purchase in massive volume where some POMs have its own plantation to supply FFB and so on. Nevertheless, inventory control models can determine optimal order quantity based on existing demand. Palm oil millers can either find suppliers in advanced with the aiding of inventory control models in order to ensure smooth operation of POMs. Besides, palm oil millers also can avoid receiving excessive FFB as it would incur extra cost. For example, further enzymatic process, over time expenses to process FFB, storage and cost of quality control for excessive CPO produced are the causes responsible for it.

1.2 Problem Statement

The price of the CPO is fluctuating over the time as well as its production costs due to the seasonal harvesting of FFB. Therefore, it is crucially important to identify the major cost influencing factors on the CPO production. To have higher degree of accuracy in controlling the production cost, adopting inventory control theories is one of the effective measures. However, the literature materials on this matter is relatively scarce. Thus, this study is conducted to bridge over this gap of knowledge.

In the current scenario, POMs receive the FFB from the estate daily, and in large quantity. The received FFB will stockpile in an open area and subject to the weathering effects which will resulting in deterioration. Therefore, all received FFB must be processing within the same day in order to minimize the losses. The problem arises whether it should be processing the FFB in equal batch sizes or in equal and unequal batch sizes. By comparing the best fitted models, it can provide a definite answer.

1.3 Objectives

The main aim of the research is to find out the best policy for the palm oil millers whether they should process the FFB in equal batch sizes or equal and unequal batch sizes. In order to reach the aim, the following measureable objectives should be achieved in stages:

1. To find out the best fitted models that can comply with the characteristics of the POM industry.

2. To find the best policy by determining and comparing the production cost incur from the best fitted model.

3. To recommend the major cost influencing factors of CPO production cost.

4. To examine the theories in inventory control models and their compatibility and/or practicality of the models in POMs.

1.4 Scope of Study and Limitations

The present investigation is designed to find out the best policy from the best fitted inventory model in POMs. Characterisation of POMs is done at the initial stage. Criteria and assumptions such as constant demand, backlog is not allowed, capacity of manufacturing is not limited, and so on are used as the guidelines to find the relevant models. Only the model that can fulfil all of the aforementioned criteria or assumptions is considered as best fitted model. Data collection is carried out by case study method on specific POM that can provide the required data for the selected models. Therefore, the research focuses on palm oil industry and the respondent only target on POM when case study is carried out.

1.5 Research Methodology

Critical review was implemented at the initial stage of the study. In this stage, characteristics of POMs were identified as well as figure out the models that are relevant to the POMs. Next, the required data was collected through the industrial collaborators from Sabah. Case study method was employed during the data collection stage. Face to face interview was carried out with the mill managers and also to obtain full set of audited data from the account department. The best fitted models which their assumptions are complying with the practices of the POMs were identified. The production cost were also calculated and ensured that it was tally with the real practices. Otherwise, the selected models would be rejected. Consequently, the best policy was determined from the remaining models. Meanwhile, major cost influencing factors of the CPO production were also being identified. Figure below illustrates the flow of study.

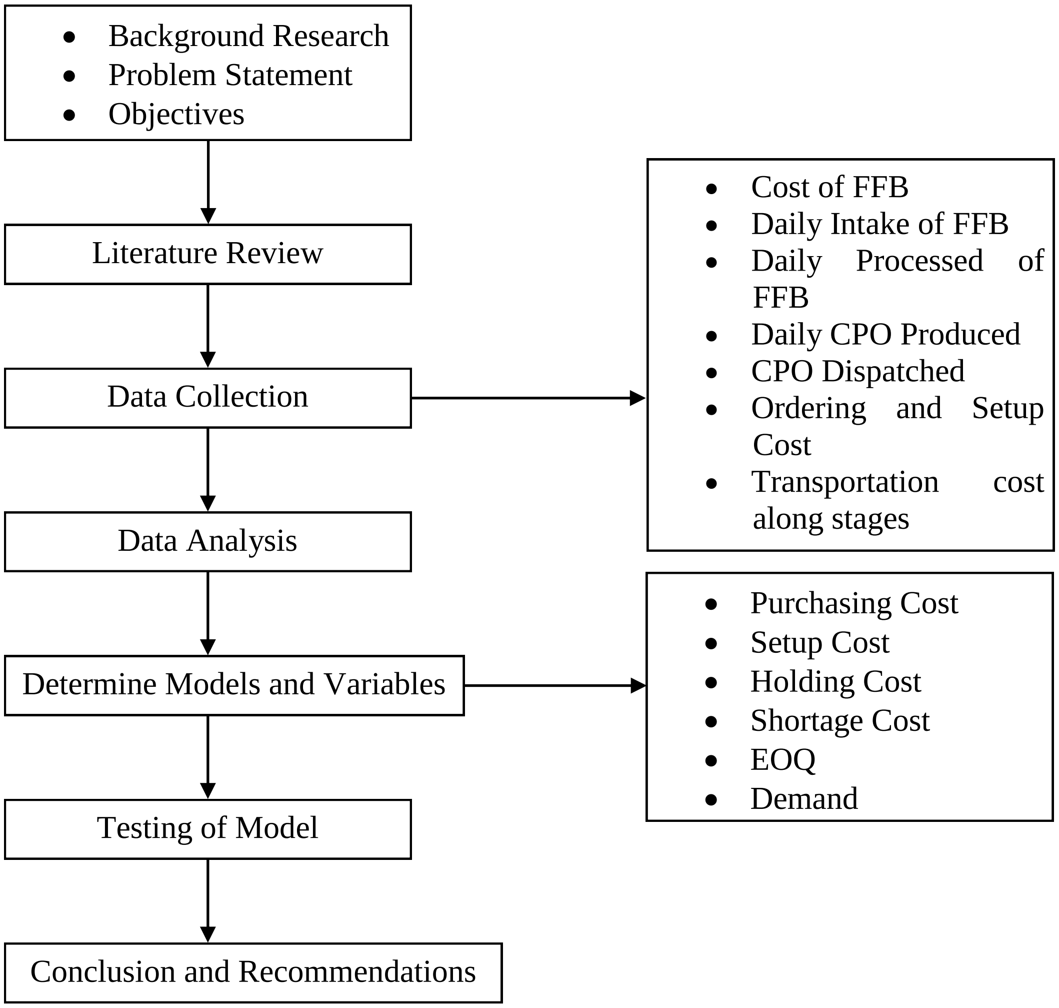

Figure 1.1 Programme of study

1.6 Research Significant

The practicality of the theories in reality is crucially important. With the best policy from the best fitted models, the palm oil millers can benefit from the followings:

1. To introduce the best fitted models into POMs.
2. To determine the best policy that can give optimum order quantity of FFB and production cost of CPO.
3. To recommend the major cost influencing factors so that to allow palm oil millers establish pessimum amount of cash flow for the business operations and maximize the profits by doing short term or long term profitable investments.

1.7 Layout of Thesis

This thesis contains five chapters.

Chapter one sets up a proposal of this research. The background of inventory control and palm oil industry and also the relationship between them are discussed briefly. The scope of study, aims and objectives of the research are outlined.

Chapter two presents literature reviews on basic inventory models as well as palm oil industry in Malaysia. Definitions of purchasing costs, setup costs, inventory holding costs, transportation costs, shortage costs, demand patterns as well as some relevant models are discussed thoroughly. Review is also done on the milling process of FFB until CPO and palm kernel (PK).

Chapter three clarifies the research methodology for this study. Method of collecting data and filtrations of models which gives the solutions that are tally with industrial are discussed thoroughly.

Chapter four reports the data analysis and discussion choice of the models. The major cost influencing factors for CPO production cost are identified. The computation of FFB price in MPOB is discussed as well. The prediction of CPO production costs is carried out to test the compatibility of the model with the current industry.

Chapter five summarizes the conclusions from the study and provide recommendations for further study are also part of the content in this chapter.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter reviews the basic inventory control theory and the characteristics of demand. Two inventory models, constant batch sizes as well as equal and unequal batch sizes shipment, which are relevant with the palm oil industry, are also discussed in detail. The review on palm oil industry covers palm oil in Malaysia as well as palm oil milling process. The chapter ends with a critical summary which highlights the importance and the rationales of the research. It also summarized the characteristics of palm oil milling process which are used to select the best policy from the best fitted model.

2.2 Inventory Control

Inventory model dealt with determining level of commodity to ensure smoothness of an operation. Storing certain level of inventory is at high risk for an operation because of deterioration, obsolescence or being stole. Furthermore, inventory takes up space for storage and there is some uncertain environment. The basis decision of inventory model is to balance the cost resulted from holding too much inventory against the penalty cost resulted from inventory shortage (Taha, 2006). Two basic results which are volume and timing decisions can be obtained by optimizing the following cost function:

$$\begin{array}{ccccccccc} \text{Total inventory} & = & \text{Purchasing} & + & \text{Setup} & + & \text{Holding} & + & \text{Shortage} \\ \text{Cost (TC)} & & \text{cost} & & \text{cost} & & \text{cost} & & \text{cost} \end{array} \quad (2.1)$$

(Taha, 2006)

1. Purchasing cost is the price of purchasing a unit inventory. Typically, this cost includes labour cost, overhead cost, raw material cost, and production cost for

the case when goods are self produced. If inventory is ordered from an external source, purchasing cost may include shipping cost. When an order is placed, discount offers for bulk quantities purchasing is a factor of volume decision (Wayne & Jeffrey, 2004).

2. Setup cost is also known as ordering cost. This cost is incurred by placing an order regardless the size of the order. Increasing the number of orders results increasing of ordering cost and vice versa. It will be appropriate to increase order quantity so that to reduce paperwork and billing associated with an order. However, this action increases average inventory level as well as cost of capital. So, inventory model balances both costs. Labour cost for goods producing is included into setup cost if the product is made internally. Inventory system bases on periodic review or continuous review. Periodic review refers to place new orders at each starting period while continuous review refers to place new orders when the inventory level drops to a reorder point (Wayne & Jeffrey, 2004).
3. The cost associated with carrying or maintaining unit inventory for a time period is referred as the holding cost. Holding cost usually comprises of storage, insurance, taxes, possibility of obsolescence or theft (Wayne & Jeffrey, 2004).
4. When demand is not met on time, shortage is said to occur. This causes backlog demand or lost sales. If back order is allowed, extra costs such as overtime production and compound interest charged by customers are included. Besides, there are non-computed costs such as losing goodwill when customers source out new suppliers to meet current and future demands (Wayne & Jeffrey, 2004).

Demand can be categorized into four types: deterministic and constant with time, deterministic and variable with time, probabilistic and stationary over time, and finally probabilistic and non-stationary over time. Silver, Pyke and Peterson (1998) recommended following computations to be done in order to determine the nature of demand.

1. Estimate $\bar{d}$, the average demand per period

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{i=n} d_i$$

2. Estimate var D, variation of demand

$$\text{var}\, D = \frac{1}{n}\sum_{i=1}^{i=n} d_i^{\,2} - \bar{d}^{\,2}$$

3. Estimate VC, variability co-efficient

$$vc = \frac{\text{var}\, D}{\bar{d}^{\,2}}$$

Table 2.1: Characteristics of demand in the development of inventory models (Wayne & Jeffrey, 2004)

Roles of Demand	*vc*	Demand
Deterministic and constant	< 0.20	Constant
Deterministic and variable	<0.20	Varied appreciably
Probabilistic and stationary	>0.20	Constant
Probabilistic and non-stationary	>0.20	Varied appreciably

Table 2.1 shows the classification of demand patterns in industry. This classification assumes the available data represents future demand. If the average monthly demand is approximately constant for all months and *vc* is relatively small, which is less than 20%, the demand may be considered as deterministic and constant. If the average monthly demand varies appreciably among all months but *vc* remains relatively small, the demand is considered as deterministic and variable. If *vc* is relatively high, which is more than 20%, but demand approximately constant, then the demand is categorized as probabilistic and stationary. The case probabilistic and non-stationary demand occurs when the means and *vc* vary appreciably over time. The information from the table allows adoption of inventory models into POM based on the availability of data from POM. The future demand of POMs can be predicted as well.

2.3 Optimizing Multi-Stage Production with Constant Lot Size and Varying Numbers of Batches

The model upholds some characteristics such as a single setup at each stage without interruption to produce a uniform lot size through all stages in serial manufacturing system (Szendrovits & Drezner, 1980). The model also assumes transporting equal sized batches from one stage to the next upon completion of a batch before the lot is finish. Thus, different number of equal sized batches can be produced at different stages. The multi stage model replaces the single stage model in order to have dramatic savings. In multi stage model, priorities are given to products that must follow the process flow in order to ensure that sufficient space is always available to manipulate the schedule for production line since the products do not occupy all empty spaces.

Some other assumptions in this multi-stage model are as follow:

1. Deterministic and constant demand and production rates.
2. Fixed setup cost and linear inventory holding cost over an infinite time horizon.
3. Shipment of batches from one stage to the next incurred transportation cost and size must not exceed capacity of transport equipment.
4. Holding cost incurred by holding physical inventory on each stage.
5. Unrestricted capacity in the manufacturing process.
6. Ignore setup and transportation time.
7. Back-logging is not allowed.
8. Lot size and batch size are infinitely divisible.
9. Production stages, i = 1,..., n where n represents final stage.

The following notations are used in computing the model.

D = demand rate of final product;

P_i = production rate at stage i;

F_i = fixed setup cost per lot at stage i;

T_i = transportation cost of a batch from stage i to stage $i+1$;

c_i = unit inventory holding cost at stage i;

y_i = number of equal sized batches at stage i (y_i is an integer);

Q = uniform lot size;

$x_i = \dfrac{Q}{y_i}$, size of one batch at stage *i*.

"Lot" in the models denotes the production quantity with single set up at a stage and "batch" denotes the transported portion of a lot to the next stages.

The model relaxes constraint on the size of batches which must be equal at all stages. This can be done when different numbers of batches at different stages are allowed. Eventually, the work-in-process and total cost of production can be reduced.

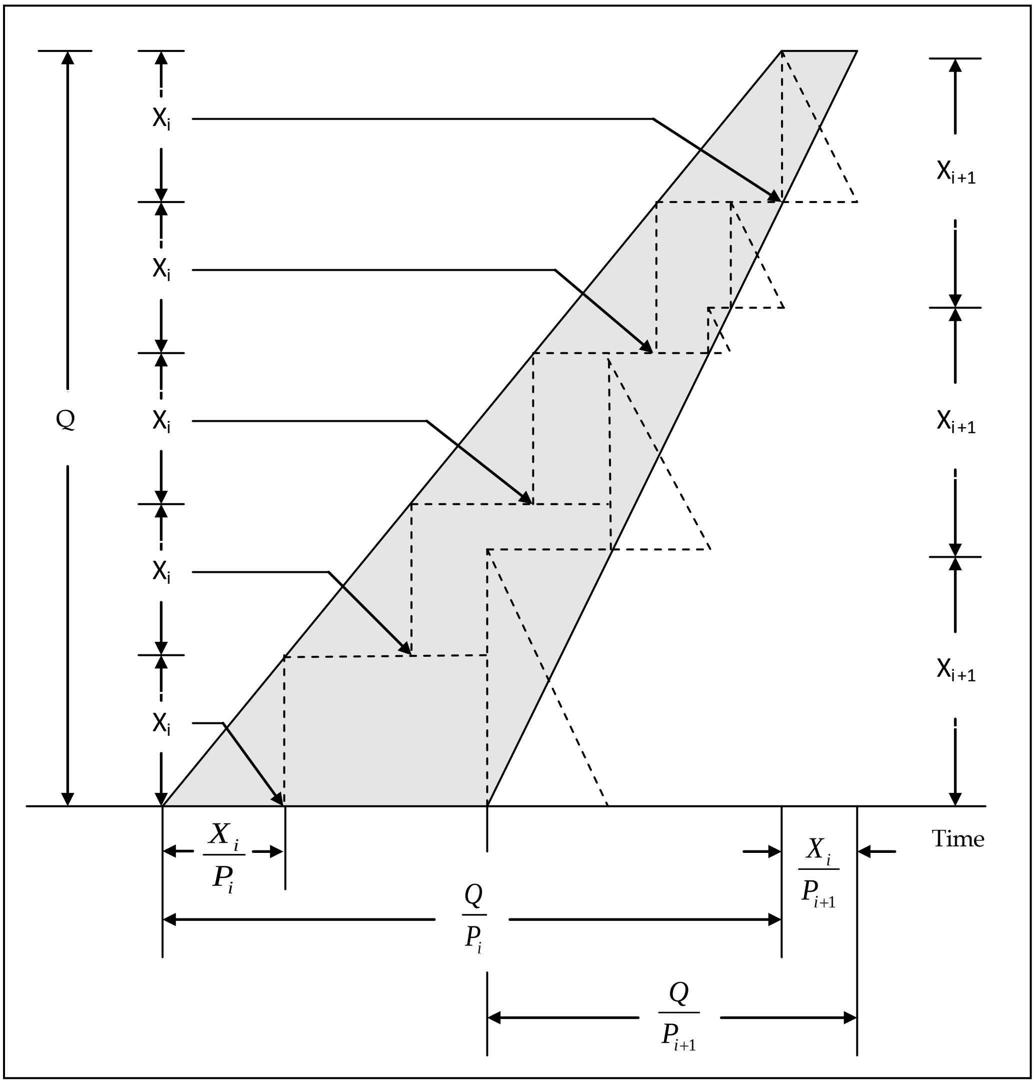

Figure 2.1: Time-weighted inventory at stage *i* for equal batch sizes when $P_i < P_{i+1}$ (Szendrovits & Drezner, 1980)

Figure 2.1 shows the inventory level over time at stage *i* for equal batch sizes when $P_i < P_{i+1}$. A lot, Q is divided into batches, x_i. The batches are transferred to the next stage upon completion. The area of trapezoid (shaded area) represents inventory level. For $P_i < P_{i+1}$, inventory level is $\frac{Q}{2}\left[\frac{x_i}{P_{i+1}}+\left(\frac{Q}{P_i}+\frac{x_i}{P_{i+1}}-\frac{Q}{P_{i+1}}\right)\right]$. Simplify the equation become

$$Q\frac{x_i}{P_{i+1}}+\frac{Q^2}{2}\left(\frac{1}{P_i}-\frac{1}{P_{i+1}}\right). \tag{2.2}$$

For $P_i \geq P_{i+1}$, inventory level is $\frac{Q}{2}\left[\frac{x_i}{P_i}\left(\frac{Q}{P_{i+1}}+\frac{x_i}{P_i}-\frac{Q}{P_i}\right)\right]$. Simplify the equation become

$$Q\frac{x_i}{P_i}+\frac{Q^2}{2}\left(\frac{1}{P_{i+1}}-\frac{1}{P_i}\right). \tag{2.3}$$

From notations, $x_i = \frac{Q}{y_i}$ can be applied into (2.2) and (2.3) to form a general expression for time weighted inventory at stage *i*,

$$Q^2\left(\frac{1}{y_i \max\{P_i, P_{i+1}\}}\right)+\frac{1}{2}\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|. \tag{2.4}$$

Then, equation (2.4) is multiplied by c_i and the number of inventory cycles per unit time, $\frac{D}{Q}$ to obtain average inventory holding cost

$$D\sum_{i=1}^{n} c_i\left(\frac{Q}{y_i}\frac{1}{\max\{P_i, P_{i+1}\}}+\frac{Q}{2}\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|\right). \tag{2.5}$$

The fixed setup and transportation cost is

$$D\sum_{i=1}^{n}\left(\frac{F_i}{Q}+\frac{y_iT_i}{Q}\right). \tag{2.6}$$

Summing (2.5) and (2.6) to obtain total cost for the system per unit time

$$C(Q,Y)=D\sum_{i=1}^{n}\left(\frac{F_i}{Q}+\frac{Qc_i}{2}\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|\right)+D\sum_{i=1}^{n}\left(\frac{T_i}{Q/y_i}+\frac{Q}{y_i}\frac{c_i}{\max\{P_i,P_{i+1}\}}\right) \tag{2.7}$$

where $Y=\{y_1,y_2,...,y_n\}$, y_i are positive integer and P_{n+1} is demand of the system.

Re-arranging the total cost function (2.7) to get

$$C(Q,Y)=D\sum_{i=1}^{n}\frac{c_i}{2}\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|Q+\frac{D\sum_{i=1}^{n}F_i}{Q}+\sum_{i=1}^{n}\left[\left(\frac{DT_i}{Q}\right)y_i+\frac{\frac{Dc_i}{\max\{P_i,P_{i+1}\}}Q}{y_i}\right].$$

The objective function (2.7) can be summarized as follow:

$$C(Q,Y)=AQ+\frac{B}{Q}+\sum_{i=1}^{n}\left[\left(\frac{b_i}{Q}\right)y_i+\frac{a_iQ}{y_i}\right] \tag{2.8}$$

where $Y=\{y_1,y_2,...,y_n\}$, $y_i=$ positive integer;

$$A=D\sum_{i=1}^{n}\frac{c_i}{2}\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|;$$

$$B=D\sum_{i=1}^{n}F_i\,;$$

$$a_i=\frac{Dc_i}{\max\{P_i,P_{i+1}\}};$$

$$b_i = DT_i;$$

$$P_{n+1} = D;$$

$$A, B, a_i, b_i > 0.$$

In order to optimize the objective function (2.8), two phases, heuristic solution and optimal solution, are carried out. Heuristic solution is found in first phase by attaining a finite number of iterations. Although the algorithm converges very fast but the solution is only an upper bound of the optimal solution. The results from the first phase are used in second phase to obtain lower bound and upper bound. Optimal cost lies between these boundaries. Scanning process for optimal solution is carried out to ensure the maximum number of iterations in algorithm is relatively small. Same batch sizes at each stage add flexibility and results in lower cost. The cost resulted from this system is lower than the cost generated by other model with same batch sizes but no batch shipment is warranted at any stage. The significance of the cost difference between these inventory policies increases when the variation among transportation costs for a batch at various stages increases (Szendrovits & Drezner, 1980).

2.4 A Constant Lot Size Model with Equal and Unequal Sized Batch Shipments between Production Stages

Among a number of models, the model with batch shipments are allowed in uniform lot size results lower cost. The cost saving becomes more significant if the number of stages are increased (Szendrovits & Golden, 1984). Goyal (1977) has suggested the model using unequal batch sizes and the smallest batch size fluctuated according to a geometric series. The two stages model gives the lowest cost among uniform lot size models. A two stages system with load capacity of transport equipment at least equal to the largest batch size was introduced by Szendrovits (1978). However, the model is under-utilized for smaller batch sizes. Therefore, Goyal (1978) has improved the model to overcome the situation.

Based on the advantages of two aforementioned models, Goyal and Szendrovits (1986) have proposed another new model. The new model relaxes the constraints of equal sized batches in Section 2.3 as well as unequal batch sizes in Szendrovits (1978). While allowing the application to unrestricted number of stages, the model gives lower inventory costs. Thus, it allows incorporation of equal and unequal batch sizes shipment at particular stage so that the equal batch size will always appears as the largest.

The assumptions in this model are similar with those in the Section 2.3. The notations are as follow:

Variables: Q = uniform lot size and infinitely divisible;

m_i = total number of batches;

$M = \{m_1, ..., m_n\}$, a vector;

e_i = number of unequal sized batches;

$E = \{e_i, ..., e_n\}$, a vector;

z_i = smallest batch size;

$m_i, e_i \geq 1; m_i \geq e_i$.

Parameters: D = demand rate of final product;

P_i = production rate at stage i;

F_i = fixed setup cost per lot at stage i;

T_i = transportation cost of a batch from stage i to stage $i+1$;

g_i = capacity of the transport equipment;

c_i = unit inventory holding cost at stage i;

k_i = ratio of production rates, $\max\left\{\frac{P_i}{P_{i+1}},\frac{P_{i+1}}{P_i}\right\}$;

$T_i \geq 0$; $P_i \geq D$; $P_{n+1} = D$.

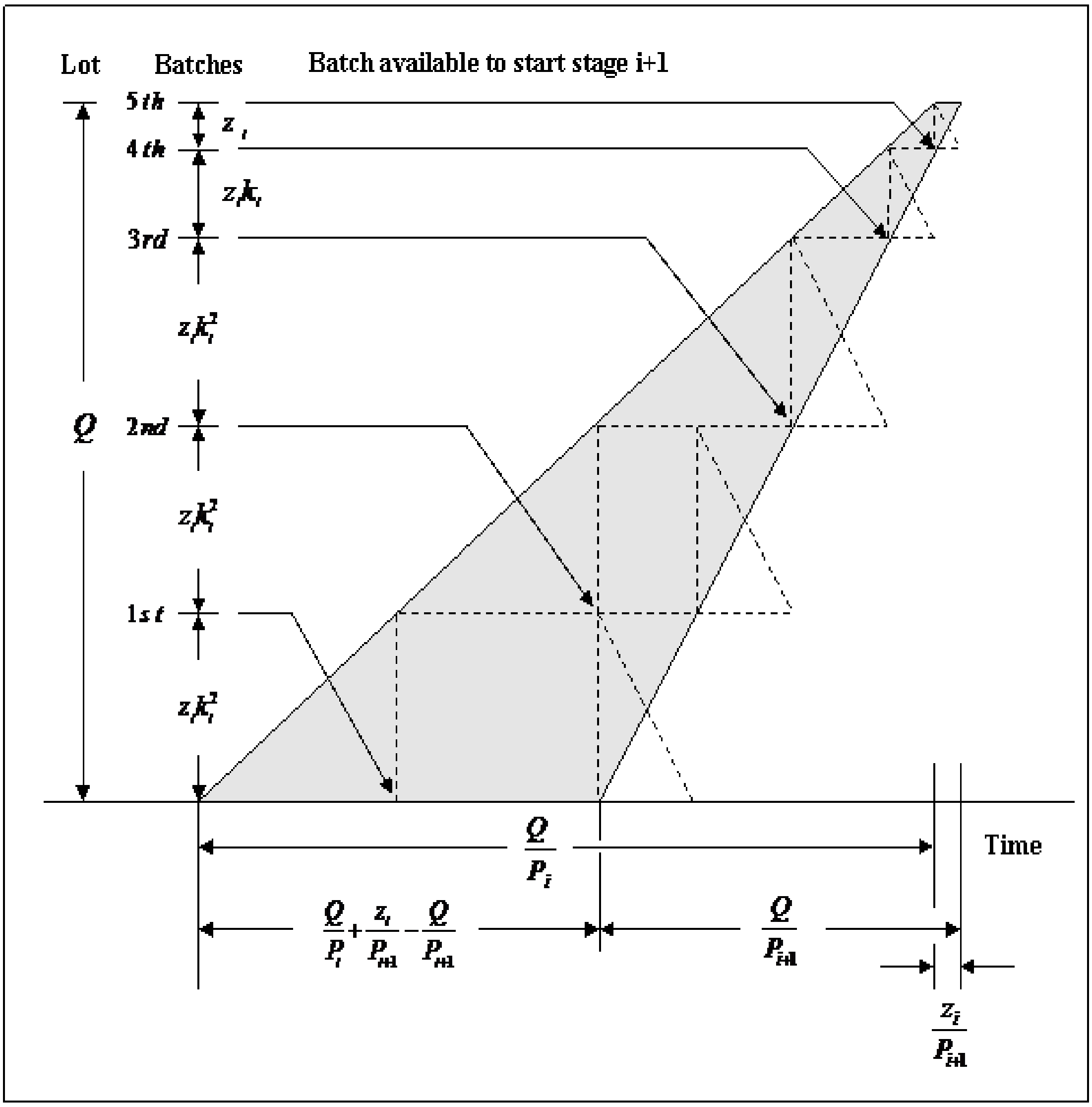

Figure 2.2: Time-weighted inventory at stage *i* for unequal batch sizes when $P_i < P_{i+1}$ (Goyal & Szendrovits, 1986)

Figure 2.2 shows the level of inventory per unit time at stage *i* for unequal batch sizes shipment when $P_i < P_{i+1}$. The area of trapezoid (shaded region) enclosed by solid lines represents inventory level and it can be shown by

$$\left(\frac{Q}{2}\right)\left(\frac{z_i}{P_{i+1}}+\frac{Q}{P_i}+\frac{z_i}{P_{i+1}}-\frac{Q}{P_{i+1}}\right). \tag{2.9}$$

When $P_i \geq P_{i+1}$, the inventory level is

$$\left(\frac{Q}{2}\right)\left(\frac{z_i}{P_i}+\frac{Q}{P_{i+1}}+\frac{z_i}{P_i}-\frac{Q}{P_i}\right). \tag{2.10}$$

Multiplying the combination of (2.9) and (2.10) with c_i to obtain

$$\frac{c_i Q z_i}{\max\{P_i, P_{i+1}\}}+c_i\left(\frac{Q^2}{2}\right)\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|. \tag{2.11}$$

The smallest batch size is z_i and it increases according to a geometric series. Let k_i be the multiplier, the unequal batch sizes are $z_i, z_i k_i, z_i k_i^2, ..., z_i k_i^{e_i-1}$ where $z_i k_i^{e_i-1}$ is the largest and $e_i > 1$. Largest batch size is produced first if $P_i < P_{i+1}$ while smallest is produced first if $P_i > P_{i+1}$. When $P_i = P_{i+1}$, all batches are of equal size. There are m_i equal sized batches, z_i when $e_i = 1$. The complete lot is transported to the next stage if $m_i = 1$ where $z_i = Q$. Since summation of batch sizes equal to lot size, thus

$$z_i + z_i k_i + z_i k_i^2 + ... + z_i k_i^{e_i-1} + (m_i - e_i) z_i k_i^{e_i-1} = Q \ . \tag{2.12}$$

Hence, the smallest batch size in term of Q, m_i and e_i is

$$z_i = \frac{Q}{(m_i - e_i) k_i^{e_i-1} + \sum_{r=0}^{e_i-1} k_i^r}. \tag{2.13}$$

Substitute (2.13) into (2.11) and then multiply with $\frac{D}{Q}$ to obtain inventory holding cost of all stage,

$$D\sum_{i=1}^{n}\left\{\frac{Qc_i}{\left[(m_i-e_i)k_i^{e_i-1}+\sum_{r=0}^{e_i-1}k_i^r\right]\max\{P_i,P_{i+1}\}}+Q\frac{c_i}{2}\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|\right\}. \tag{2.14}$$

The single setup cost, F_i and the transportation cost, m_iT_i are multiplied by $\frac{D}{Q}$ and give

$$D\sum_{i=1}^{n}\left(\frac{F_i}{Q}+\frac{m_iT_i}{Q}\right). \tag{2.15}$$

Summing both (2.14) and (2.15) to form the cost function of the system

$$C(Q,M,E)=AQ+\frac{B}{Q}+\sum_{i=1}^{n}\left(\frac{m_ib_i}{Q}+\frac{Qa_i}{(m_i-e_i)k_i^{e_i-1}+\sum_{r=0}^{e_i-1}k_i^r}\right) \tag{2.16}$$

where $A=D\sum_{i=1}^{n}\left(\frac{c_i}{2}\right)\left|\frac{1}{P_i}-\frac{1}{P_{i+1}}\right|;$

$B=D\sum_{i=1}^{n}F_i\ ;$

$a_i=\frac{Dc_i}{\max\{P_i,P_{i+1}\}}\ ;$

$b_i=DT_i\ ;$

$P_{n+1}=D\ ;$

subjects to $$e_i(k_i-1)+\left(\frac{1}{k_i}\right)^{e_i-1}\le(k_i-1)\left(m_i-\frac{Q}{g_i}\right)+k_i\text{, for } i=1,\dots,n \tag{2.17}$$

for which the capacity of transport equipment must exceed the largest capacity batch size.

In order to optimize objective function (2.16), an algorithm for the heuristic search is carried out. The cost resulted from the model is lower than the cost in Section 2.3 which the model requires equal batch sizes shipment at any particular stage. This phenomenon due to the model is applicable to an unrestricted number of stages by allowing both equal and unequal batch sizes.

2.5 Oil Palm

This section discusses how and when was the palm oil introduce into Malaysia. Statistics of palm oil industry such as oil palm planted area, production of CPO, number of mills in Malaysia and so on are presented as well in the next sections.

2.5.1 Palm Oil Production in Malaysia

Palm oil industry in Malaysia could be classified into three phases which were experimental phase from late 1800s to 1900s, plantation development phase from early of 1900s to 1960s, and expansion phase since 1960s until present (Teoh, 2002). The expansion phase underwent in Sabah and Sarawak only after 1960s.

Although planting development phase of oil palm started in the early of 1900s, the oil palm planted area increased rapidly in the expansion phase in 1960s.

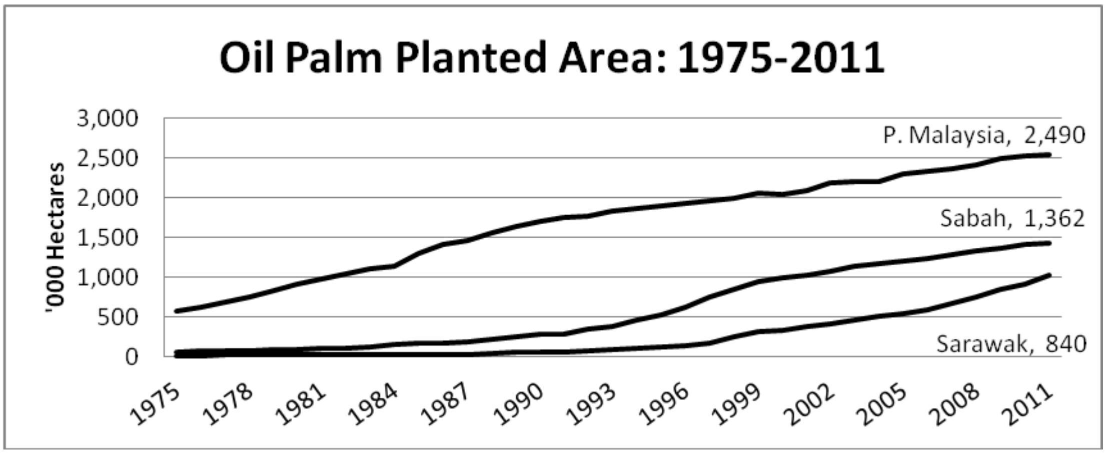

Figure 2.3: Oil palm planted area: 1975-2011 in hectares (MPOB, 2012a)

Figure 2.3 shows the increasing of oil palm plated area from year 1975 to 2011. In 1975, total oil palm planted area in Peninsular Malaysia was 568,561 hectares and increased by 347.93% to 2,546,760 hectares in 2011. Oil palm planted area in Sabah shows an increase of 1,372,623 hectares to 1,431,762 hectares while Sarawak shows an increase of 1,007,496 hectares to 1,021,587 hectares within 37 years. Due to the limitation of new lands for planting oil palm in Peninsular Malaysia, the commercial planting of oil palm has been expanded dominantly in Sabah and Sarawak. According to Figure 2.3, the planting rate in Sabah was aggressive since early of 1970s.

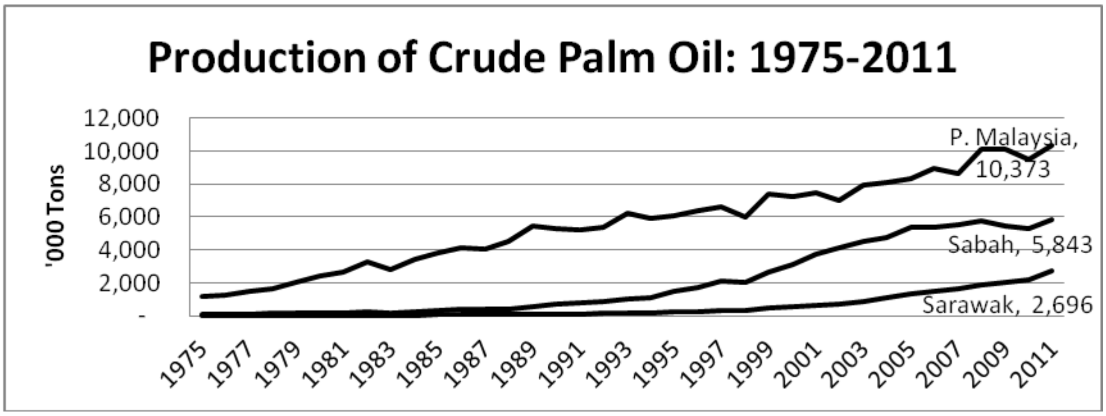

Figure 2.4: Production of CPO in Malaysia: 1975-2011 in tons (MPOB, 2012b)

The production of CPO in Malaysia increased significantly every year. Figure 2.4 records the production of CPO in tons from 1975 to 2011. In 1975, peninsular Malaysia produced a total of 1,136,796 tons CPO while Sabah produced 116,248 tons and Sarawak only produced 4,529 tons. However, the volume for production of CPO has increased 9,236,025 tons in peninsular Malaysia, 5,726,917 tons in Sabah and 2,691,005 tons in Sarawak. Total of CPO produced in 2011 was 18,911,520 tons, which was almost 15 times to the volume produced in 1975. In 2011, Sabah produced CPO of 50.26 times to the volume produced in 1975. The significant increase in Sabah reflected the rapid expansion of oil palm planting policy in the state.

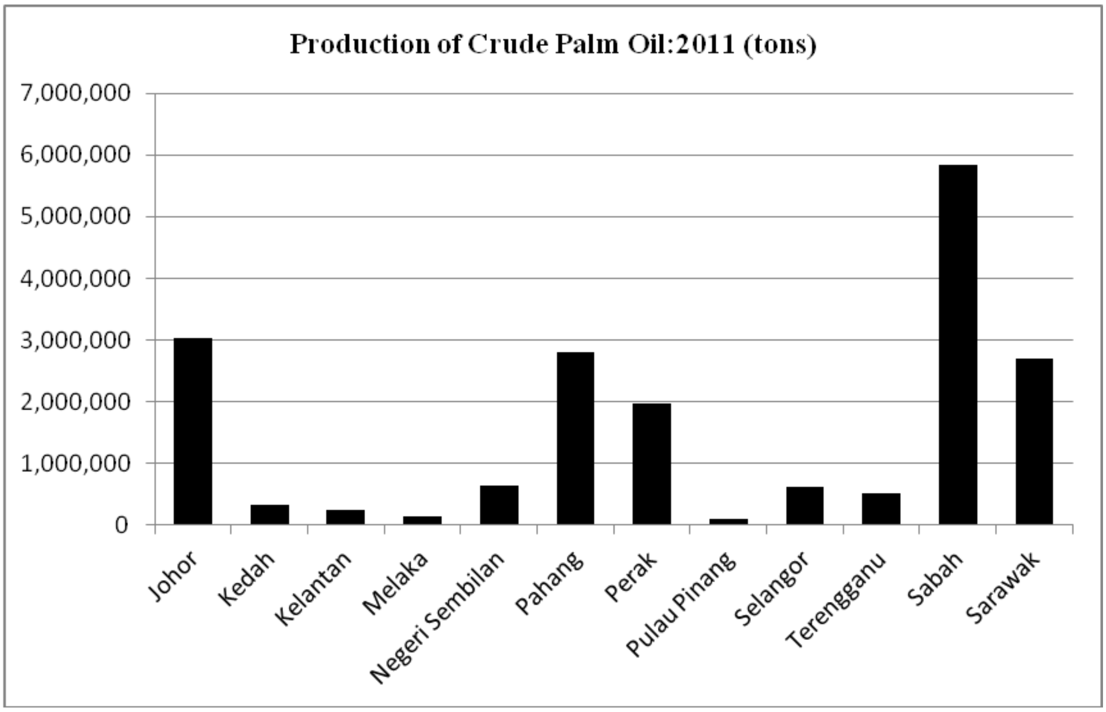

Figure 2.5: Production of CPO according to states: 2011 in tons (MPOB, 2012b)

Figure 2.5 shows the production of CPO at different states in Malaysia in the year 2011. Sabah shows the highest production of CPO with 5,843,165 tons and it stands 31.90% of the total CPO produced in Malaysia. This phenomenon was due to the rapid expansion of oil palm planted area in Sabah and became the largest CPO producer since 1999 (Teoh, 2002). Other major CPO producing states are Johor, Pahang, Perak, and Sarawak with percentage of 15.98%, 14.80%, 10.38%, and 14.25% respectively.

2.6 Palm Oil Mill

Over the past 50 years, both government and private sectors in Malaysia had put lots of effort in the palm oil industry and apparently a great improvement has been achieved by leading the palm oil industry among Asian countries. There are about five million hectares of land in oil palm cultivation and about 19 million tons of CPO production in 2011. Thus, the number of POM and capacity are necessary to