UNIVERSITI PUTRA MALAYSIA

OPTIMAL ROUTES FOR OIL PALM BIOMASS TRANSPORTATION TO BIOMASS FACILITY BY USING LINEAR PROGRAMMING (LP) MODEL

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ABSTRACT

Malaysia is one of potential countries to explore its biomass energy. Due to the abundant supply and availability of oil palm biomasses throughout the year, oil palm biomasses included empty fruit bunches (EFB), palm kernel shell (PKS), mesocarp fiber (MF) and others can be converted into bio-products such as bio-paper, fertilizers, electricity and others valuable products. Centralized hub to convert oil palm biomass into bio-products namely as biomass facility need to be established at strategic location. Transportation of oil palm biomass may not be economically due to the travel distance and capacity. Therefore, the main objective of this research study was to develop a tool that can decide the most optimal routes to transport oil palm biomass to the biomass facility, while maximizing the profit from biomass sale and minimizing the transportation cost by using linear programming (LP) model. General Algebraic Modeling System (GAMS) was used as the optimization tool for this optimal transportation model. Potential profit estimated by the developed model was RM38,359,737.41 per year; which Tunjuk Laut and Lok Heng only sent its biomass to one of the biomass facilities (Tunjuk Laut to Tai Tak and Lok Heng to Adela). Meanwhile, Simpang Wa Ha and Telok Sengat sent its biomass to both biomass facilities. The model can help oil palm industry to find optimal routes to transport oil palm biomass.

ABSTRAK

Malaysia merupakan salah satu negara yang berpotensi untuk meneroka tenaga biojisimnya. Disebabkan lambakan bekalan dan ketersediaan biojisim kelapa sawit sepanjang tahun, biojisim kelapa sawit seperti tandan sawit kosong, tempurung kelapa sawit, serat mesokarp dan lain-lain boleh ditukarkan kepada produk-bio seperti kertas, baja, sumber elektrik dan produk-produk berharga yang lain. Hab berpusat untuk menukarkan biojisim kelapa sawit kepada produk-bio dinamakan sebagai fasiliti biojisim perlu diwujudkan di lokasi yang strategik. Pengangkutan biojisim kelapa sawit mungkin tidak secara ekonomi disebabkan oleh jarak perjalanan dan kapasiti. Oleh itu, objektif utama kajian penyelidikan ini adalah untuk membangunkan alat yang boleh menentukan laluan yang paling optimum untuk mengangkut biojisim kelapa sawit ke fasiliti biojisim, sementara memaksimumkan keuntungan daripada jualan biojisim dan meminimumkan kos pengangkutan dengan menggunakan model pengaturcaraan linear. Sistem Permodelan Algebra Umum telah digunakan sebagai alat pengoptimasi untuk model pengangkutan optimum ini. Potensi keuntungan yang dianggarkan oleh model yang dibangunkan adalah RM 38,359,737.41 setahun, di mana Tunjuk Laut dan Lok Heng hanya menghantar biojisimnya ke salah satu fasiliti biojisim (Tunjuk Laut ke Tai Tak dan Lok Heng ke Adela). Sementara itu, Simpang Wa Ha dan Telok Sengat menghantar biojisimnya ke kedua-dua fasiliti biojisim. Model ini boleh membantu industri kelapa sawit untuk menentukan laluan yang paling optimum untuk menghantar biojisim kelapa sawit.

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LIST OF ABBREVIATIONS

LP	:	Linear Programming
MPOB	:	Malaysian Palm Oil Board
CPO	:	Crude palm oil
FFB	:	Fresh fruit bunch
GAMS	:	General algebraic modeling system
EFB	:	Empty fruit bunch
MF	:	Mesocarp fibre
PS	:	Palm shell
OPF	:	Oil palm fronds
OPT	:	Oil palm trunks
PKS	:	Palm kernel shell
AHP	:	Analytic hierarchy process
DEA	:	Data envelopment analysis
LIRP	:	Location-Inventory-Routing Problem
$profit$	:	Total profit of biomass sales
efb_{sale}	:	Total EFB sales
efb_{cost}	:	Total cost of EFB transportation process
mf_{sale}	:	Total MF sales
mf_{cost}	:	Total cost of MF transportation process
pks_{sale}	:	Total PKS sales
pks_{cost}	:	Total cost of PKS transportation process

$efb_{supply}(i)$	:	Amount of EFB available supply at palm oil mills
$efb_{quantity}(i,j)$	:	Amount of EFB supplied to the biomass facility
$mf_{supply}(i)$	:	Amount of MF available supply at palm oil mills
$mf_{quantity}(i,j)$	:	Amount of MF supplied to the biomass facility
$pks_{supply}(i)$	:	Amount of PKS available supply at palm oil mills
$pks_{quantity}(i,j)$	:	Amount of PKS supplied to the biomass facility
$efb_{capacity}(j)$	:	Capacity of EFB conversion unit
$mf_{capacity}(j)$	:	Capacity of MF conversion unit
$pks_{capacity}(j)$	:	Capacity of PKS conversion unit
$distance(i,j)$	:	Distance between palm oil mills to the biomass facilities
f	:	Transportation cost
g	:	Transportation factor

CHAPTER 1

INTRODUCTION

1.1 Malaysia Palm Oil Industry Overview

Malaysia Palm Oil Board (2018) reported that oil palm industry in Malaysia showed significant increases in 2017 against 2016. Over 5.81 million hectares were planted with oil palm in 2017, an increase of 1.3% as against 5.74 million hectares of previous year. Sarawak led as the largest oil palm planted state with 1.56 million hectares (26.8%), followed by Sabah with 1.55 million hectares (26.6%) and Peninsular Malaysia with 2.70 million hectares (46.6%) (MPOB, 2018).

In 2017, crude palm oil (CPO) production increased by 15% to 19.92 million tonnes from 17.32 million tonnes in 2016, due to higher fresh fruit bunch (FFB) processed. CPO production in Peninsular Malaysia, Sabah and Sarawak increased by 19.0%, 7.6% and 15.1% to 10.58 million tonnes, 5.22 million tonnes and 4.13 million tonnes, respectively (MPOB, 2018).

Meanwhile, FFB yield improved by 12.4% in 2017 to 17.89 tonnes per hectare as against 15.91 tonnes per hectare in 2016. FFB yield for Peninsular Malaysia increased by 18.6% from 15.77 tonnes per hectare in 2016 to 18.70 tonnes per hectare in 2017. Sabah's FFB yield recorded an increase of 7.3% to 18.35 tonnes per hectare from 17.10 tonnes per hectare; while Sarawak was equally higher at 16.13 tonnes per hectare, up by 8.5% compared to 14.86 tonnes per hectare in 2016 (MPOB, 2018).

1.2 Problem Statements

Palm oil mill company generally face problems of transporting the oil palm biomass to the biomass facility since there is often change of distance travelled by the carrier of oil palm biomass due to having no specific transport instruction. With the presence of optimal route of transportation being implemented in the transportation process, it is essential that palm oil mill company can minimize the cost during the transportation, while can maximize the profit of the palm oil mills. This research study will determine the optimal transportation route of oil palm biomass delivery to the potential biomass facilities with contributing parameters are taken into account by using linear programming model in General Algebraic Modeling System (GAMS).

1.3 Aim and Objectives

The aim of this study is to develop a decision tool that can decide optimal transportation route to transport oil palm biomass to the potential biomass facility by using linear programming model. The specific objectives of this study are:

i. To develop a model that can provide user with optimal location and optimal routes, while can minimize the transportation cost.

ii. To calculate the potential economic values for each palm oil mill that can be generated by selling oil palm biomass to the biomass facility.

CHAPTER 2

LITERATURE REVIEW

2.1 Oil Palm

The oil palm, *Elaies guineesis*, originates from the tropical rainforest regions of West Africa, and later on was introduced to the Americas, and from the East (Poku, 2002). Oil palm plantations and mill developed rapidly in countries such as Indonesia, Malaysia, Thailand, Nigeria, etc. due to the crop's favorable properties as an agro-industrial commodity (Ekpa, 1995). Malaysian Palm Oil Council reported that palm oil now is become the largest global consumption of oil and fats with 30% of consumption worldwide as shown in Figure 1. Goh *et al.* (2009) stated that an oil palm tree can last more than 25 years before replanting is required due to the declining productivity. As shown in Figure 2, the growth cycle of an oil palm tree can be divided into four phases; Immature I (0-3 years), Immature II (3-7 years), Matured (7-18 years) and Aging/Senescence (18 years and above) (Tan, 2014).

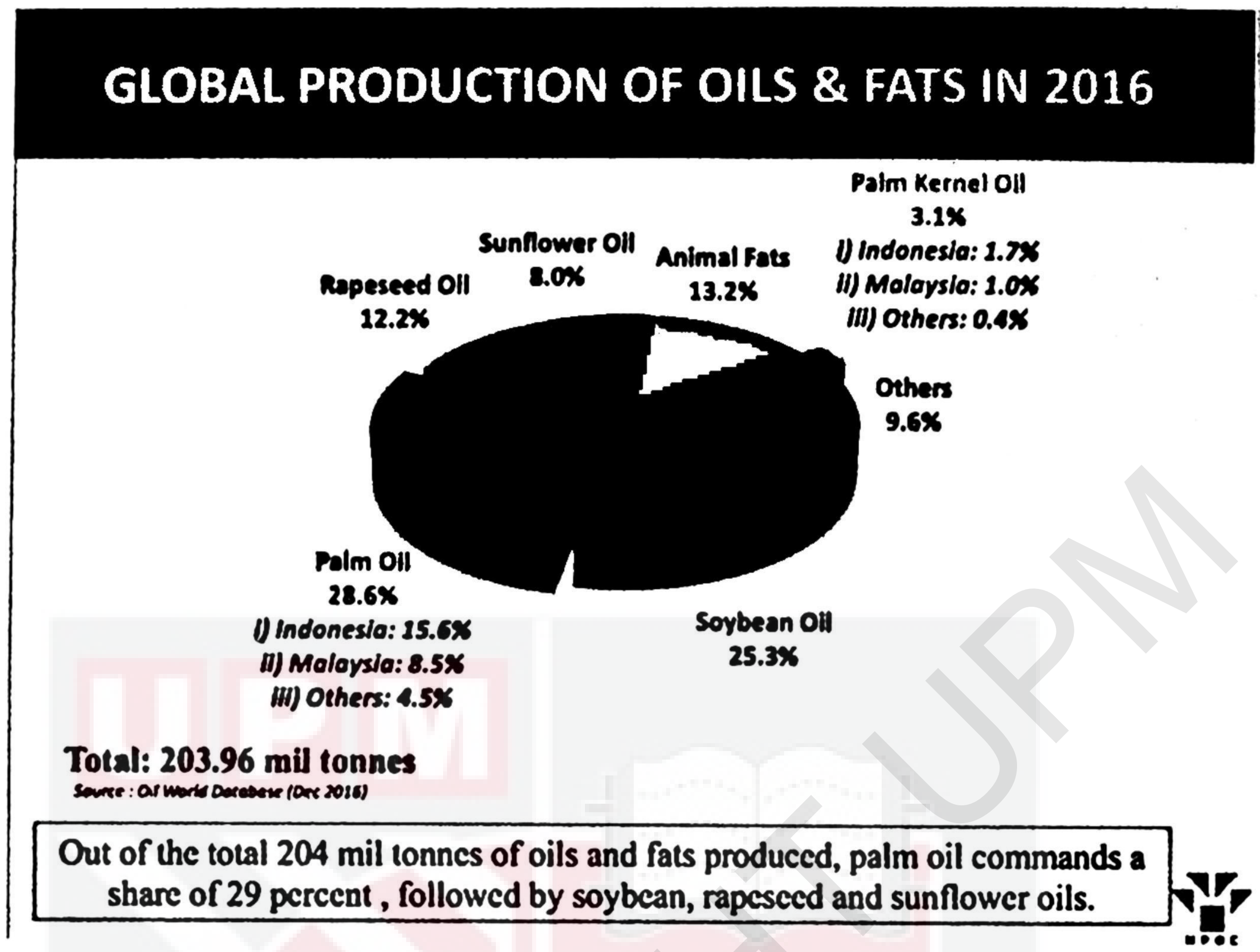

Figure 1. Global production of oils and fats in 2016 (MPOC, 2017).

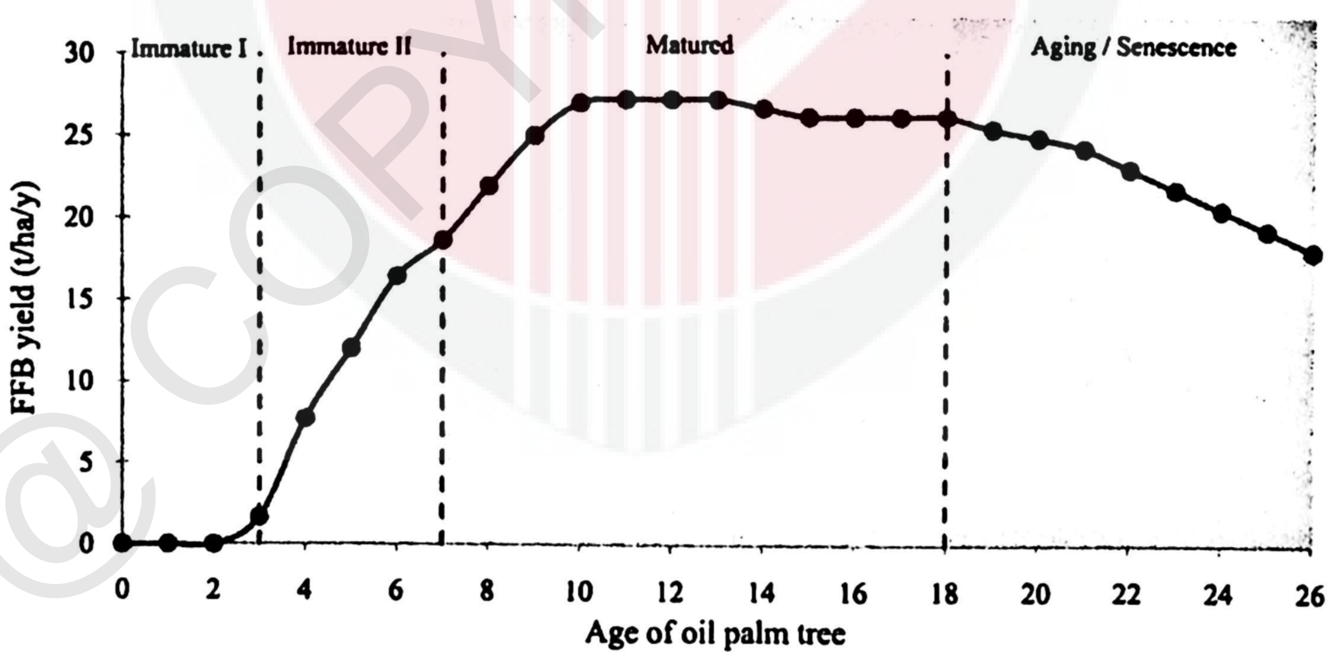

Figure 2. FFB yield by oil palm tree age (Tan, 2014).

2.2 Oil Palm Biomass

With the rising growth of oil palm production, the amount of residues generated also show a corresponding increase. One hectare of oil palm plantation can produce about 50-70 tonnes of biomass residues (Salathong, 2007). In that case, oil palm industry is the major contributing to the biomass. The oil palm industry has been known as the main sector generating abundant biomass, these include empty fruit bunch (EFB), mesocarp fibre (MF), palm shell (PS), oil palm fronds (OPF) and oil palm trunks (OPT). In 2014, the FFB processed yielded about 95.68 million tonnes and based on the standard biomass to FFB extraction rate (Table 1), the estimated oil palm biomass produce along the processes, comprises of 21.03 million tonnes of pruned OPF (50% removal from the plantation), 7.34 million tonnes of EFB, 4.46 million tonnes of PS, and 7.72 million tonnes of MF, in total 40.55 million tonnes of oil palm biomass generated (Loh, 2017). According to the Hussain *et al.* (2002), percentage amount of EFB, MF and palm kernel shell (PKS) generated on weight basis from fresh fruit bunch are 23%, 15% and 6%, as shown in Figure 3.

Table 1. Oil palm biomass availability based on standard biomass to FFB extraction rate (Loh, 2017).

Type of Oil Palm Biomass	Availability
Empty fruit bunches (EFB)	EFB (wet basis) = 22% of FFB EFB (dry weight) = 35% of EFB (wet basis)
Palm Shell (PS)	PS (wet basis) = 5.5% of FFB PS (dry weight) = 85% of PS (wet basis)
Mesocarp fibers (MF)	MF (wet basis) = 13.5% of FFB MF (dry weight) = 60% of MF (wet basis)
Palm oil mill effluent (POME)	POME (wet basis) = 67% of FFB or 0.65 m^3t^{-1} FFB
Oil palm trunks (OPT)	OPT (replanting, dry weight) = 74.48 t ha^{-1}, an average of 142 OPT is available from a ha oil palm, and only 50% can be removed from the plantation
Oil palm fronds (OPF)	OPF (pruned, dry weight) = 10.40 t ha^{-1}, 75% of oil palm trees aged 7 years are due for pruning, and only 50% can be removed from the plantation. OPF (replanting, dry weight) = 14.47 t ha^{-1}, and only 50% can be removed from the plantation

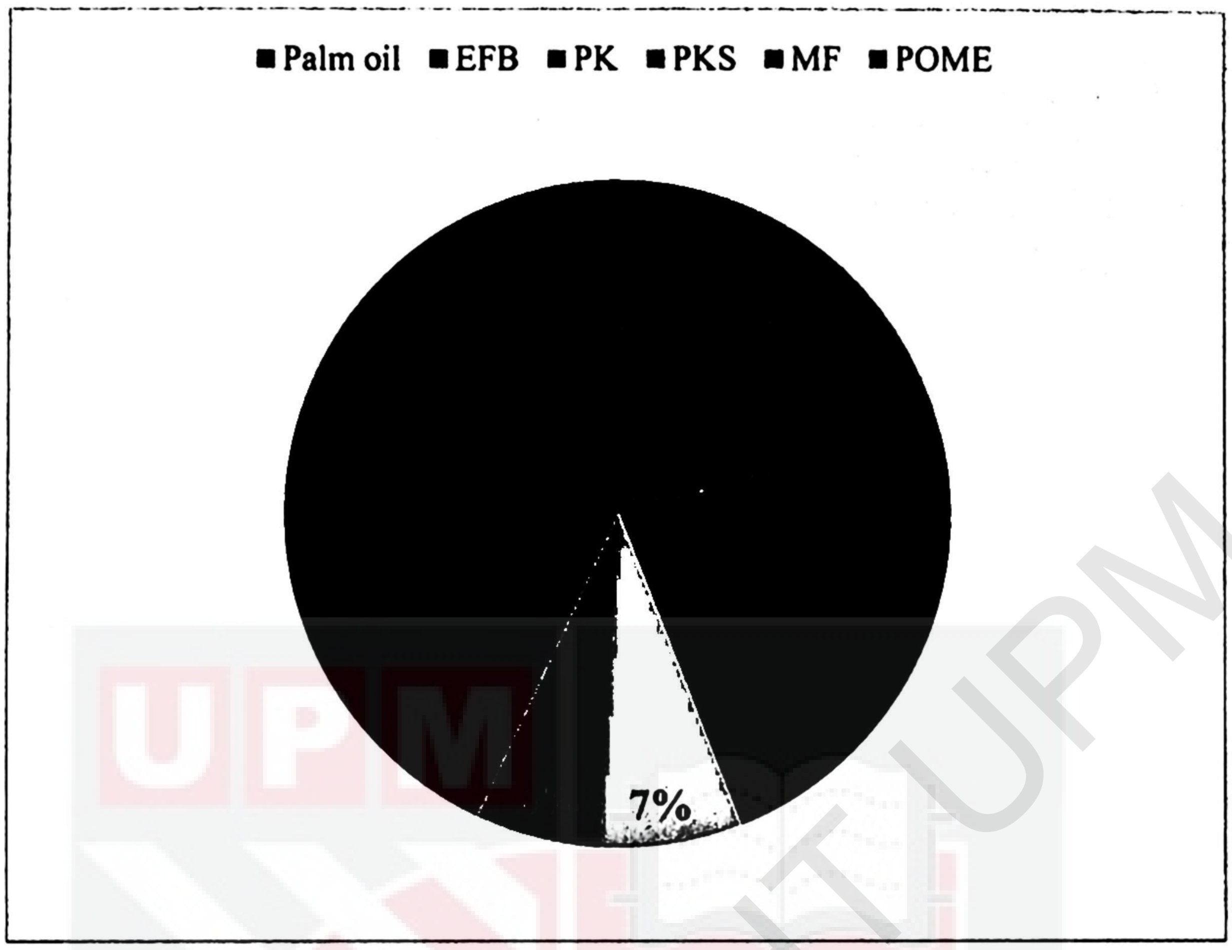

Figure 3. Components of fresh fruit bunches (FFB) (Hussain, Z *et al.*, 2002).

2.3 Transportation Optimization Model

Gupta et. al. (2018) formulated an integrated multi-objective optimization model for a sustainable transportation problem in coal mining industry using analytic hierarchy process (AHP) and data envelopment analysis (DEA) techniques for sustainable transportation leading to environmental protection, maximum speed of delivery, minimum cost of transportation and enhanced traffic safety. The AHP technique is used to estimate the weights of different types of vehicles that available for transportation, while, DEA technique is used to calculate the efficiency scores of vehicles on various routes of given transportation network.

Gupta and Kumar (2012) stated that the transportation problem is to minimize the cost of the transporting product at multiple sources and required at many destinations. On the other hand, multiple and conflicting objective functions arise in the transportation problem due to the complexity of social, environmental and economic factors. Many researchers only focused on minimizing the cost and time, in finding the optimal transportation solution for multi-objective transportation problems (Chen *et al.*, 2017; Ojha *et al.*, 2009; Pramanik *et al.*, 2016).

Eguiz *et al.* (2018) designed a model to find a recommendation for new school transport planning proposal to achieve greater operational efficiency. The model is a multi-objective optimization problem which includes the minimization of the bus costs and total travel time for all students. The model is based on the bus route planning and will follow the changes in school starting times, thus, the bus can have more than one route.

Habibi et al. (2018) designed a Location-Inventory-Routing Problem (LIRP) optimization model for designing an algae fuel production and distribution network consisting of biomass production facility, distribution facilities, and extraction sites. The proposed model minimizes the total cost of the network including the cost of locating the distribution facilities and transportation and the expected inventory costs including holding, shortage, ordering and purchase. The proposed model helps decision-maker determine the optimal location and order policy of algae fuel distribution facilities, allocation of extraction sites to these facilities, and the routing decisions.

2.4 General Algebraic Modeling System

General Algebraic Modeling System (GAMS) is one of the available optimization model tools and is used in this research study. Since the focus of this study was to solve the problems at palm oil mill by using optimization model, thus GAMS is highly recommended as GAMS has incorporated ideas drawn from relational database theory and mathematical programming and has attempted to merge these ideas to suit the needs for strategic modelers. GAMS is high-level modeling system for mathematical programming and optimization; it consists of language compiler and a stable of integrated high performance solvers (*An Introduction to GAMS*, 2011). It is specifically designed for modeling linear, nonlinear and mixed integer optimization problems which is especially useful with large and complex problems (Amosa and Thokozani Majozi, 2016).

CHAPTER 3

METHODOLOGY

3.1 Methods

Generic methodology employed in development of optimization model to transport oil palm biomass to the potential biomass facility has four main stages; Stage 1: Problem Definition, Stage 2: Superstructure Generation, Stage 3: Model Generation and Stage 4: Sensitivity Analysis. In Stage 1, the issue on transportation at palm oil mills is identified and defined. Then, issue is specified to the problem of transporting oil palm biomass to the biomass facility. In Stage 2, superstructure diagram that reflects the issue is generated. The generated superstructure is simplified in order to model of identified problem. In Stage 3, a mathematical model is formulated to solve the transportation model. The formulated mathematical model and related data regards to the oil palm biomass transportation to the biomass facility are coded in optimization tool, GAMS to solve the optimization model. In Stage 4, sensitivity analysis is performed to analyze the reliability of the developed model. Figure 4 showed generic method flowchart for optimal transportation model development.

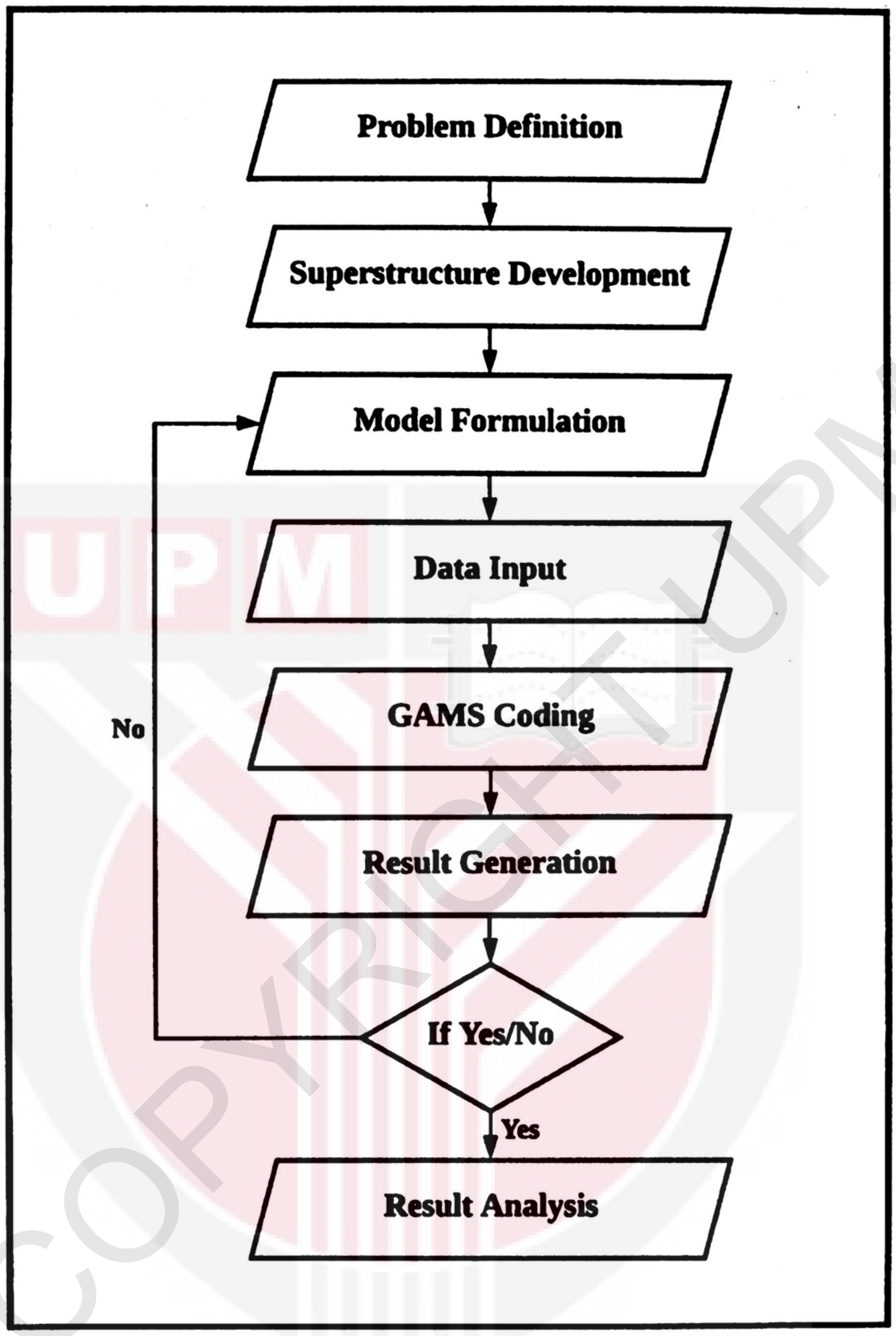

Figure 4. Generic Method Flowchart

3.2 Problem Definition

At certain location, a few numbers of palm oil mills and biomass facilities, optimal routes to transport oil palm biomass from palm oil mills to the biomass facilities need to be determined. All the oil palm biomasses generated had same mode of transportation. Thus, the oil palm biomasses that involved in this optimal transportation model are empty fruit bunch (EFB), palm kernel shell (PKS) and mesocarp fibre (MF). These biomasses were transported from palm oil mills to the biomass facilities by optimal routes that will be decided by the optimal transportation model. Several key questions need to be answered along the decision making process, (1) What are the most optimal routes for each palm oil mills to transport its oil palm biomass to the biomass facility? (2) Where is the most strategic potential biomass facility? (3) What is the profit for each palm oil mills from biomass sales?

3.2.1 Case Study and Assumptions

District of Kota Tinggi, Johor was chosen as study to demonstrate the developed model. Six palm oil mills which were considered included Simpang Wa Ha, Tunjuk Laut, Lok Heng, Telok Sengat, Adela and Tai Tak palm oil mills. Distribution of palm oil mills at Kota Tinggi, Johor as shown in Figure 5.

Following assumptions and limitation were made:

a) Capacity of conversion facility unit of each oil palm biomass at the biomass facility was shown in Table 2. Assumed capacity must be lower than the total oil palm biomass generated by palm oil mills, thus the conversion facility unit at the biomass facility run at full capacity.

b) Capacity of transportation mode is used for biomass transportation is lorry with 10 tonnes capacity.

c) Sale price for each EFB, MF and PKS are RM 250/tonnes, RM 160/tonnes and RM 170/tonnes.

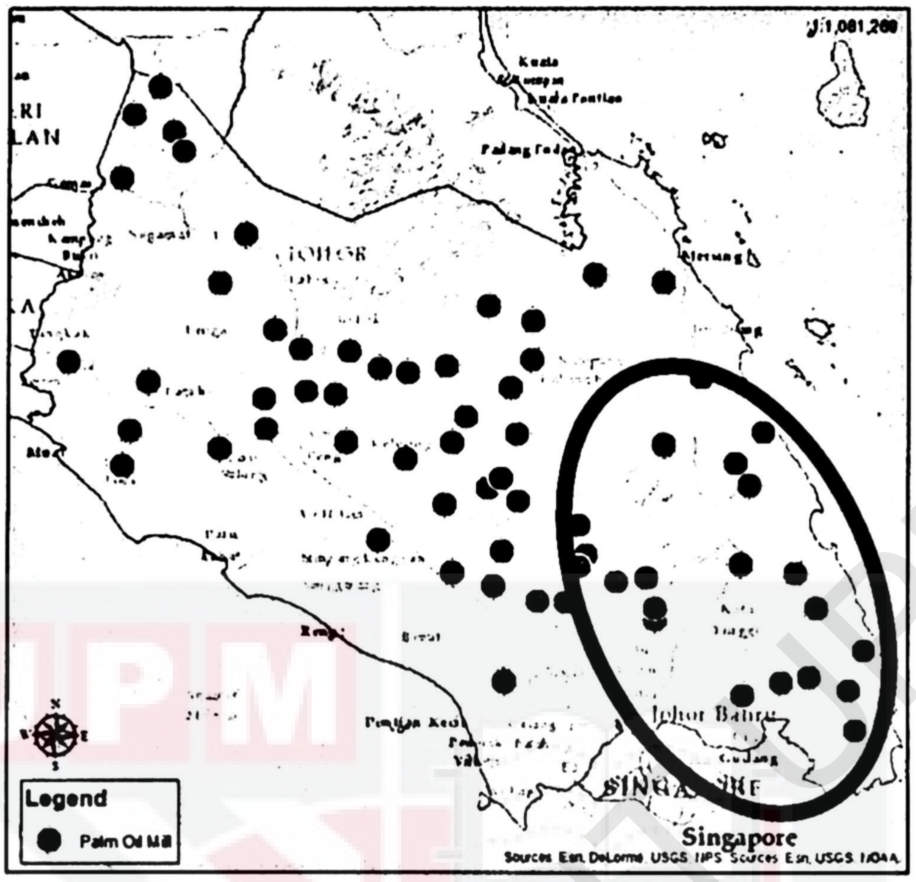

Figure 5. Distribution of palm oil mills at Kota Tinggi, Johor (Razali, 2014)

Table 2. Capacity of conversion facility unit for EFB, MF and PKS at each biomass facility.

Biomass Facility	Conversion Facility Unit of Each Oil Palm Biomass Capacity		
	EFB	MF	PKS
Adela	60,000	26,000	15,000
Tai Tak	400,00	39,000	10,000

3.3 Superstructure Development

A superstructure diagram is presented to view all possible solution for the issue as in problem definition stage; to find optimal routes to transport oil palm biomass to the biomass facility. Structure is divided into 2 sets; palm oil mills and potential biomass facility. Each palm oil mills have capacity for each oil palm biomass; EFB, MF and PKS. Meanwhile, each biomass facility has capacity for each oil palm biomass conversion unit. Possible routes are identified and established superstructure was shown in Figure 6. The simplified superstructure model contains of two sets, which are set i-type of the palm oil mills and set j-type of the biomass facilities. Meanwhile, the simplified superstructure of the optimization transportation model to transport oil palm biomass to the biomass facility was described in Figure 7.

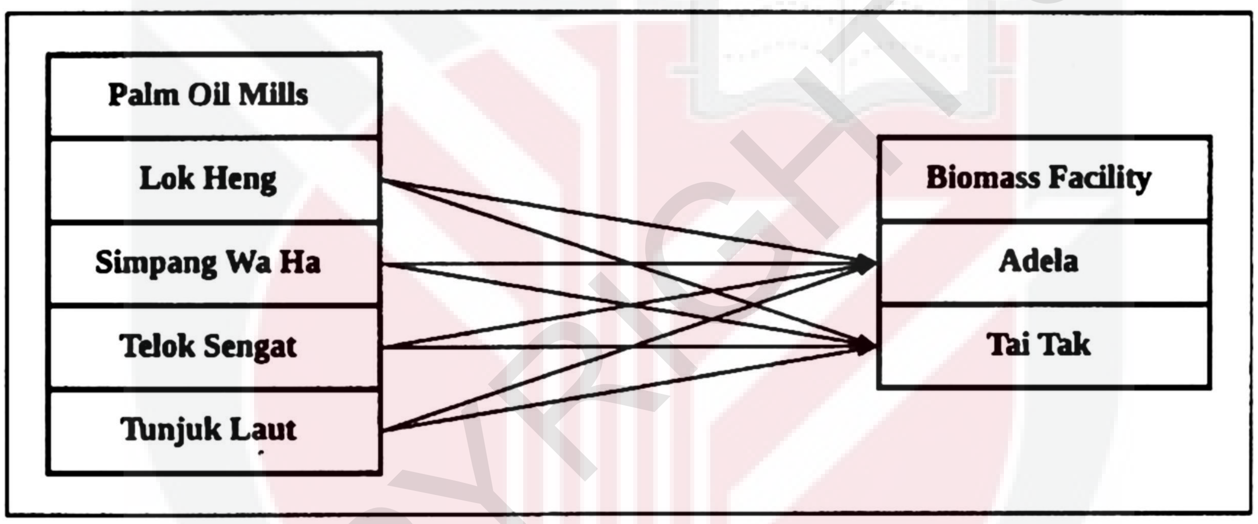

Figure 6. The superstructure of transportation optimization model.

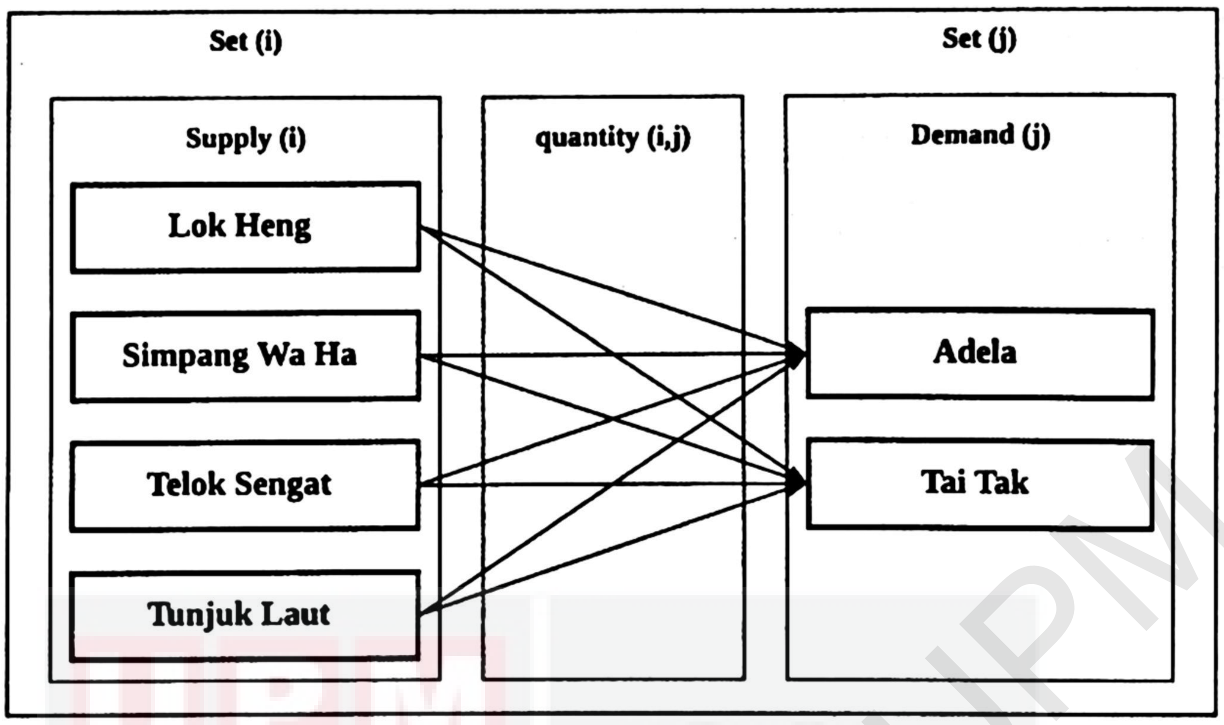

Figure 7. Simplified structure of optimal routes model.

3.4 Model Formulation

Mathematical model is formulated based on simplified superstructure diagram generated in superstructure generation. In this study, mathematical model developed aim to find the optimal routes to transport oil palm biomass, while maximizing the profit of biomass sales and minimizing the transportation cost.

3.4.1 Objective Function

The objective function of this model is to maximize the profit from biomass sales to the biomass facility, while minimize the transportation cost during the oil palm biomass delivery to the biomass facility. This function represented by the variable *profit* as shown in Equation 4.1. Objective function is calculated when the summation of the difference of sale and transportation cost of each oil palm biomass.

$$profit = \Sigma_{(i,j)} (efb_{sale} - efb_{cost}) + (mf_{sale} - mf_{cost}) + (pks_{sale} - pks_{cost}) \quad (4.1)$$

3.4.2 Equality Constraints

In the optimization transportation model, equality constraints are limitation of each set, which are the oil palm biomass supply at palm oil mills and the capacity of the conversion facility unit of each oil palm biomass at biomass facilities. Equation 4.2 – 4.4 shows the oil palm biomass supply must be greater or equal to the total quantity of oil palm biomass to be supplied from palm oil mills. This equation limit the quantity of oil palm biomass to be supplied must not surpass the ability of palm oil mills to produce oil palm biomass. Equation 4.5 – 4.7 shows the capacity of conversion facility unit at biomass facility must be greater than or equal to the total quantity of oil palm biomass to be supplied from palm oil mills.

$$efb_{supply}(i) \geq \Sigma_j \, efb_{quantity}(i,j) \quad (4.2)$$

$$mf_{supply}(i) \geq \Sigma_j \, mf_{quantity}(i,j) \quad (4.3)$$

$$pks_{supply}(i) \geq \Sigma_j \, pks_{quantity}(i,j) \quad (4.4)$$

$$efb_{capacity}(j) \geq \Sigma_i \, efb_{quantity}(i,j) \quad (4.5)$$

$$mf_{capacity}(j) \geq \Sigma_i \, mf_{quantity}(i,j) \quad (4.6)$$

$$pks_{capacity}(j) \geq \Sigma_i \, pks_{quantity}(i,j) \quad (4.7)$$

3.4.3 Sale and Cost Equation

This model is about to maximize the profit from oil palm biomass sales for each palm oil mills. Sale for each oil palm biomass at each palm oil mills are determined by the Equation 4.8 – 4.10. Meanwhile, costs for each oil palm biomass during transportation process are calculated as in Equation 4.11 – 4.13. Scalar *g* is the factor to calculate the total journey during the transportation process of oil palm biomass from palm oil mills to the biomass facility. Scalar *g* is equal to 0.2 (2 journeys per 10 tonnes). Meanwhile, scalar *j* is the unit cost for delivery in RM per km, which is RM 0.90 per km. Scalar *f* includes the fuel cost as well as labor cost.

$$efb_{sale}(i,j) = efb_{quantity}(i,j) * 250 \tag{4.8}$$

$$mf_{sale}(i,j) = b_{mf quantity}(i,j) * 160 \tag{4.9}$$

$$pks_{sale}(i,j) = pks_{quantity}(i,j) * 170 \tag{4.10}$$

$$efb_{cost}(i,j) = g * efb_{quantity}(i,j) * f * distance(i,j) \tag{4.11}$$

$$mf_{cost}(i,j) = g * mf_{quantity}(i,j) * f * distance(i,j) \tag{4.12}$$

$$pks_{cost}(i,j) = g * pks_{quantity}(i,j) * f * distance(i,j) \tag{4.13}$$

3.5 Data Input

Some of the data needed in this model were from journal, report and projected data. Data input were included in the model are the location of each selected palm oil mills, distances between palm oil mills to the biomass facilities and amount of EFB, MF and PKS generated by each palm oil mills.

3.5.1 Distance between Palm Oil Mills to the Biomass Facility

Coordinates of selected palm oil mills and amount of EFB generated by palm oil mills were shown in Table 3 (Razali, 2014). Two palm oil mills with highest amount of EFB generated per year are assumed to be the potential biomass facility.

Table 3. Detailed information on the palm oil mills location and operations at the Kota Tinggi, Johor (Razali, 2014)

Palm Oil Mills	Latitude	Longitude	Amount of EFB Generated (Tonne/year)	Role Assumed
Simpang Wa Ha	1°47'27.60"N	104° 4'26.40"E	21,600	Palm Oil Mill
Tunjuk Laut	1°58'26.40"N	103°58'44.40"E	28,800	Palm Oil Mill
Adela	1°33'10.06"N	104°11'11.94"E	38,800	Biomass Facility
Lok Heng	1°43'13.35"N	104° 7'12.25"E	28,800	Palm Oil Mills
Tai Tak	1°41'40.60"N	103°51'30.01"E	32,400	Biomass Facility
Telok Sengat	1°34'4.80"N	104° 2'38.40"E	21,600	Palm Oil Mill

Figure 8 showed the routes between the palm oil mills to the biomass facilities by using the Google Earth. Meanwhile, Table 4 showed the distance calculated between the palm oil mills to biomass facilities.

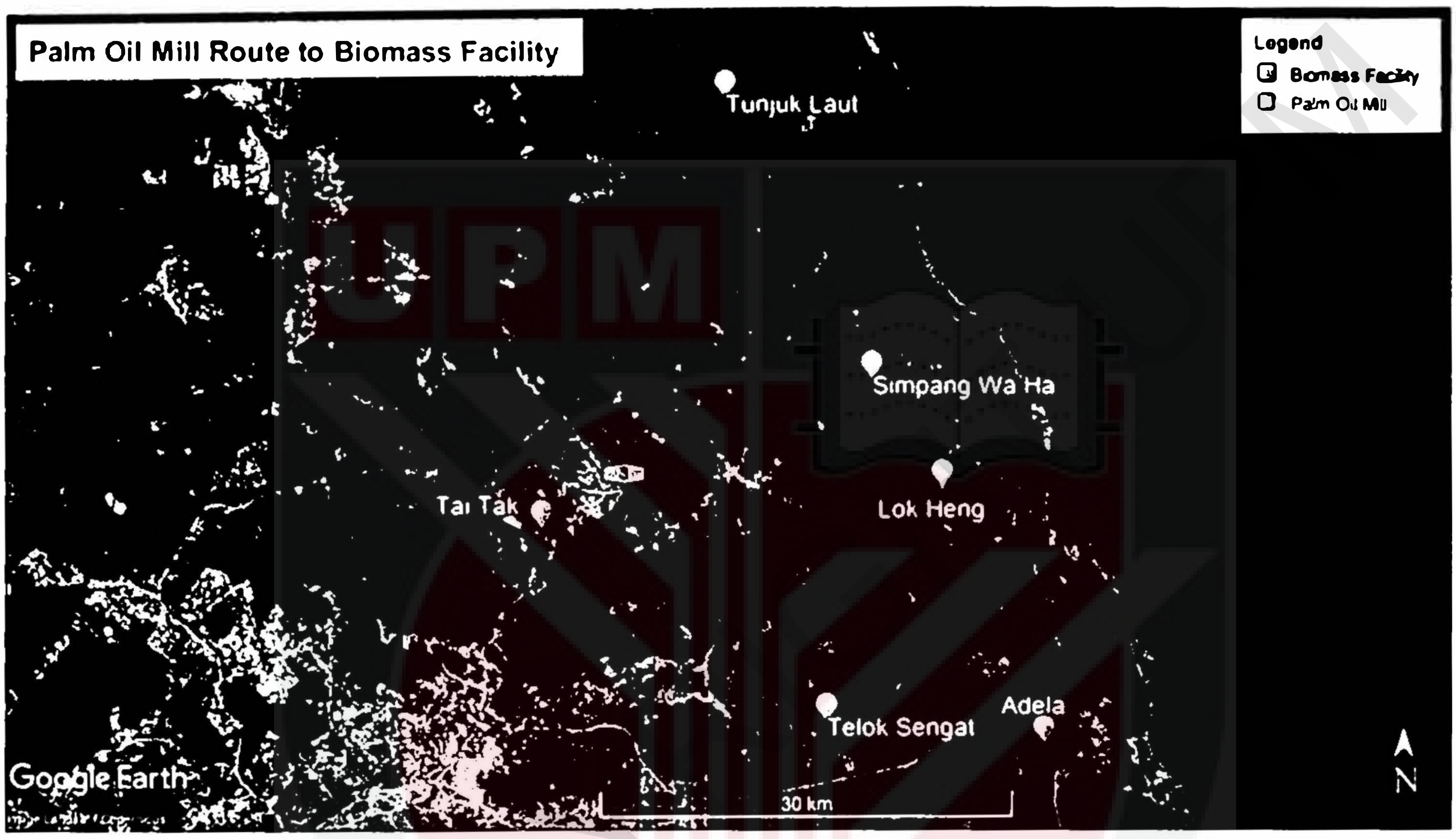

Figure 8. Location of each palm oil mills and biomass facilities and generated routes from palm oil mills to the biomass facility.

Table 4. Calculated distance between palm oil mills to the biomass facilities.

Palm Oil Mill	Distance between Palm Oil Mills to Biomass Facility, km	
	Adela	**Tai Tak**
Simpang Wa Ha	39.59	41.49
Tunjuk Laut	80.80	50.63
Lok Heng	28.98	49.54
Telok Sengat	28.19	38.12

3.5.2 Biomass Generated by Palm Oil Mills

Oil palm biomass that taken into account in this research study are EFB, MF and PKS. Amount of EFB generated (tonnes/year) by each palm oil mills was shown in Table 3 (Razali, 2014). Meanwhile, amount of MF and PKS generated (tonnes/year) were calculated as projected data.

Projected data of MF and PKS for each palm oil mills are calculated by mass balance of biomass generated to its percentage and calculation of projected data can be referred at Appendix A (Hussain *et al.*, 2002). Calculated amount of MF and PKS generated for each palm oil mills as shown in Table 5.

Table 5. Projected data of MF and PKS for each palm oil mills.

Palm Oil Mills	Biomass Generated, MT/yr	
	MF	**PKS**
Simpang Wa Ha	14,086	5,634
Tunjuk Laut	18,782	7,513
Lok Heng	18,782	7,513
Telok Sengat	14,086	5,634

3.6 Coded into GAMS

Optimization process is a decision making to identify the solution that achieves the values of performance criterion in a problem. In this stage, the developed mathematical formula is coded into GAMS optimization tool and coded mathematical model can be referred at Appendix B. GAMS win64 25.1.3 version is used in this study.

3.7 Sensitivity Analysis

Sensitivity analysis was conducted to analyze the impact of increment and reduction of the biomass supply and conversion unit capacity from each palm oil mills to the profit. The amounts of supply for each biomass at palm oil mills were adjusted to ±15%, ±30% and ±45%. Also, the capacities of conversion unit biomass at biomass facilities were adjusted to ±15%, ±30% and ±45%. Sensitivity analysis of the model can be referred at Appendix C.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Overall Model Performances

The linear programming (LP) model is coded in GAMS with the objective function of maximizes the profit of oil palm biomass sale while minimizing the transportation cost. The profits of each palm oil mills from biomass sale were shown in Table 6. Table 7, 8 and 9 showed the amount of oil palm biomass to be supplied to the biomass facility.

Table 6. Palm oil mills' profit from biomass sale.

Palm Oil Mills	Profit from Biomass Sale (RM/year)			Profit (RM/year)
	EFB	MF	PKS	
Simpang Wa Ha	5,241,970.08	2,148,600.00	916,337.89	8,306,907.97
Tunjuk Laut	6,744,820.00	2,722,940.00	1,000,523.77	10,468,283.77
Lok Heng	7,049,770.00	2,907,125.58	1,238,009.19	11,194,904.76
Telok Sengat	5,290,400.00	2,170,048.96	929,191.96	8,389,640.91
			Total Profit	38,359,737.41

Table 7. Amount of EFB supplied to the biomass facility.

Palm Oil Mills	Amount of EFB Supplied to the Biomass Facility, (MT/year)	
	Adela	Tai Tak
Simpang Waha	9,600	12,000
Tunjuk Laut	-	28,000
Lok Heng	28,800	-
Telok Sengat	21,600	-

Table 8. Amount of MF supplied to the biomass facility.

Palm Oil Mills	Amount of MF Supplied to the Biomass Facility, (MT/year)	
	Adela	Tai Tak
Simpang Waha	-	14,086
Tunjuk Laut	-	18,046
Lok Heng	18,782	-
Telok Sengat	7,218	6,868

Table 9. Amount of PKS supplied to the biomass facility.

Palm Oil Mills	Amount of PKS Supplied to the Biomass Facility, (MT/year)	
	Adela	Tai Tak
Simpang Waha	1,853	3,781
Tunjuk Laut	-	6,219
Lok Heng	7,513	-
Telok Sengat	5,634	-

4.2 Discussion

From the result of the optimal transportation model, Lok Heng sent all of its biomass to the Adela, due to the shorter distance between Lok Heng to Adela. Also, Tunjuk Laut sent most of its biomass to the Tai Tak, due to the shorter distance between Tunjuk Laut to Tai Tak. This decision led to maximization of profit, by sending biomass to nearest biomass facility. Therefore, transportation cost of biomass can be minimized. Meanwhile, Simpang Wa Ha and Telok Sengat sent its biomass to the both biomass facilities. This result is due to the location of Simpang Wa Ha and Telok Sengat are at the middle of both biomass facilities and there is no significant difference in distance; Simpang Wa Ha to Adela and Tai Tal as well as Telok Sengat to Adela and Tai Tak. Simpang Wa Ha sent its EFB and PKS to both biomass facilities and sent all of its MF to Tai Tak only. This decision due to, Tai Tak has bigger capacity of MF conversion unit (39,000 MT/year) compared to Adela (26,000 MT/year). In the meantime, Telok Sengat sent its MF to both biomass facilities (50% of MF to Adela and 49% of MF to Tai Tak), and sent all of its EFB and PKS to Adela only. This result is due to Adela has bigger capacity of conversion unit for EFB and PKS. The optimized transportation model for biomass transportation showed in Figure 9.

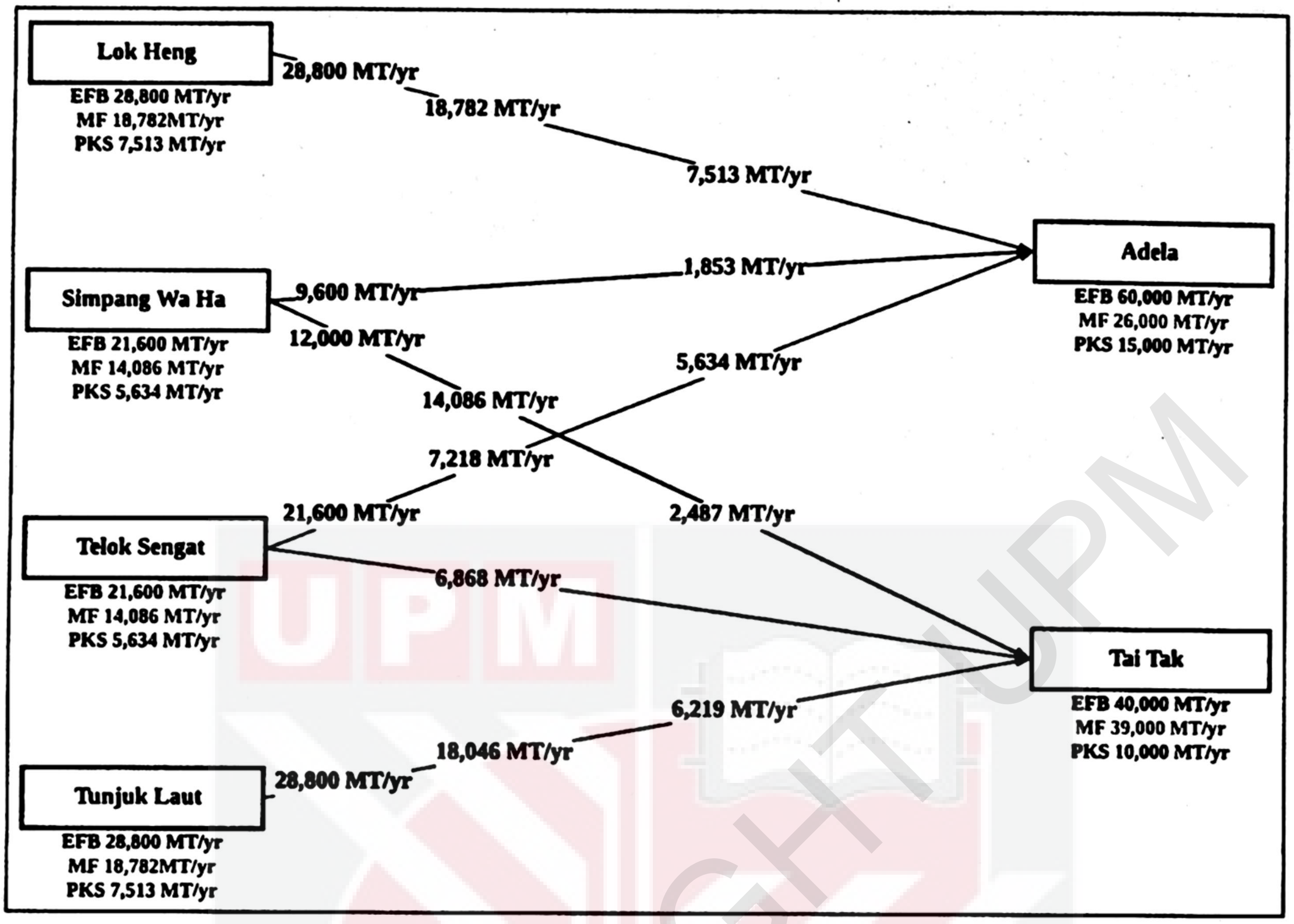

Figure 9. Optimized model for oil palm biomass transportation to the biomass facility.

4.3 Sensitivity Analysis

4.3.1 Sensitivity Analysis on Biomass Supply for Each Palm Oil Mills

From the sensitivity analysis, the increment of the biomass supply amount does not affect significantly, because the limitation of capacity of biomass facility unit. From Figure 10, reduction of supply amount of EFB plays significant role in this developed model, which it affect significant drop of profit for each mills. However, Lok Heng and Tunjuk Laut have higher drops, -7.76 and 7.64, since both mills generate larger amount of EFB supply.

Meanwhile, Figure 11 showed the reduction of supply amount of MF gives little drops to the mills profit. Lok Heng has the highest drop of -3.09% while Tunjuk Laut has -3.04%, even though, both mills generate same amount of MF supply, due to Lok Heng sends all of its MF supply to the biomass facility. Compared to Tunjuk Laut, only send its MF supply about 96%. As Figure 12, the reduction of supply amount of PKS does not significantly affect the model due to the lower generation of PKS at each mill.

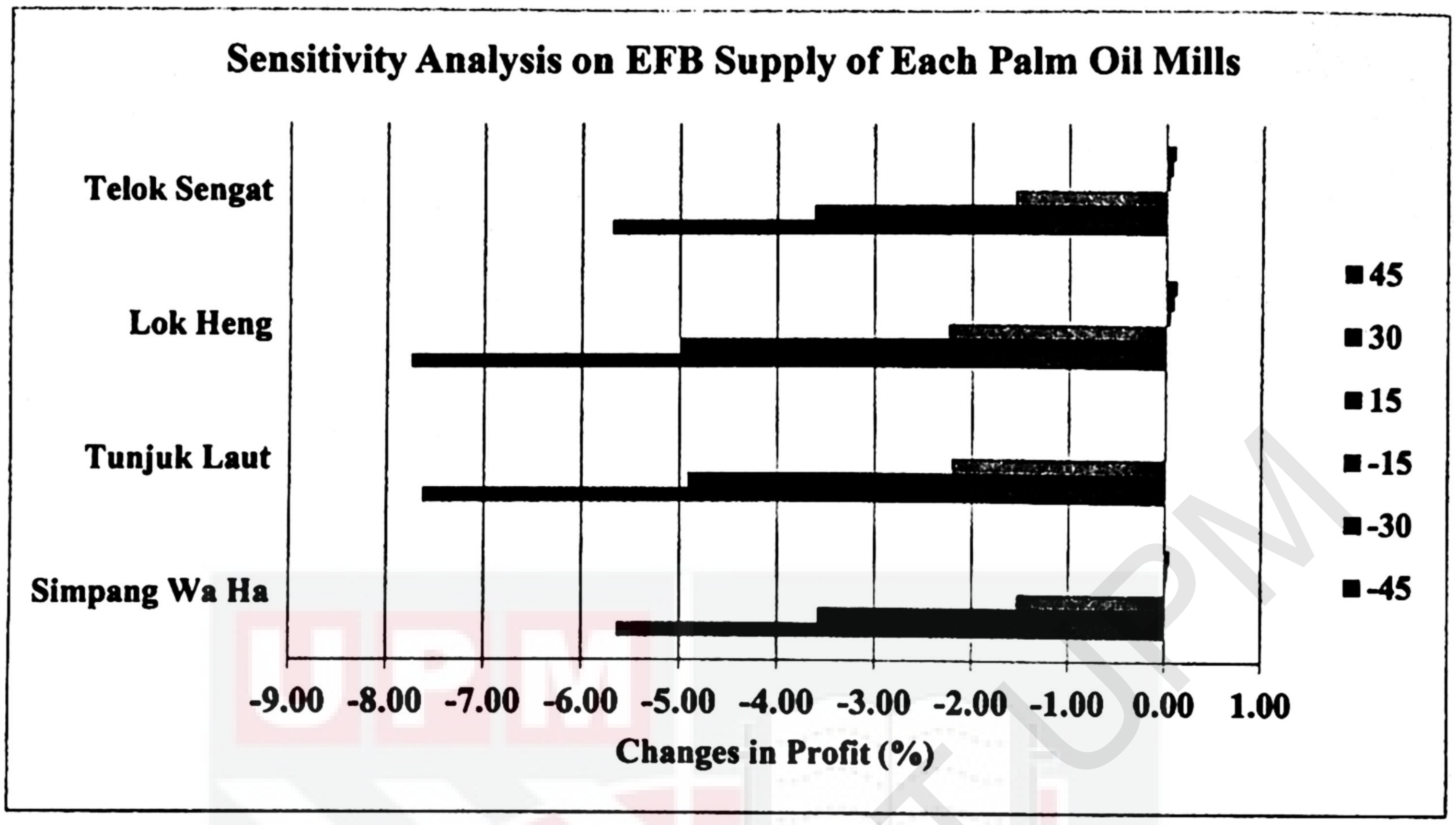

Figure 10. Sensitivity analysis on EFB supply of each palm oil mills.

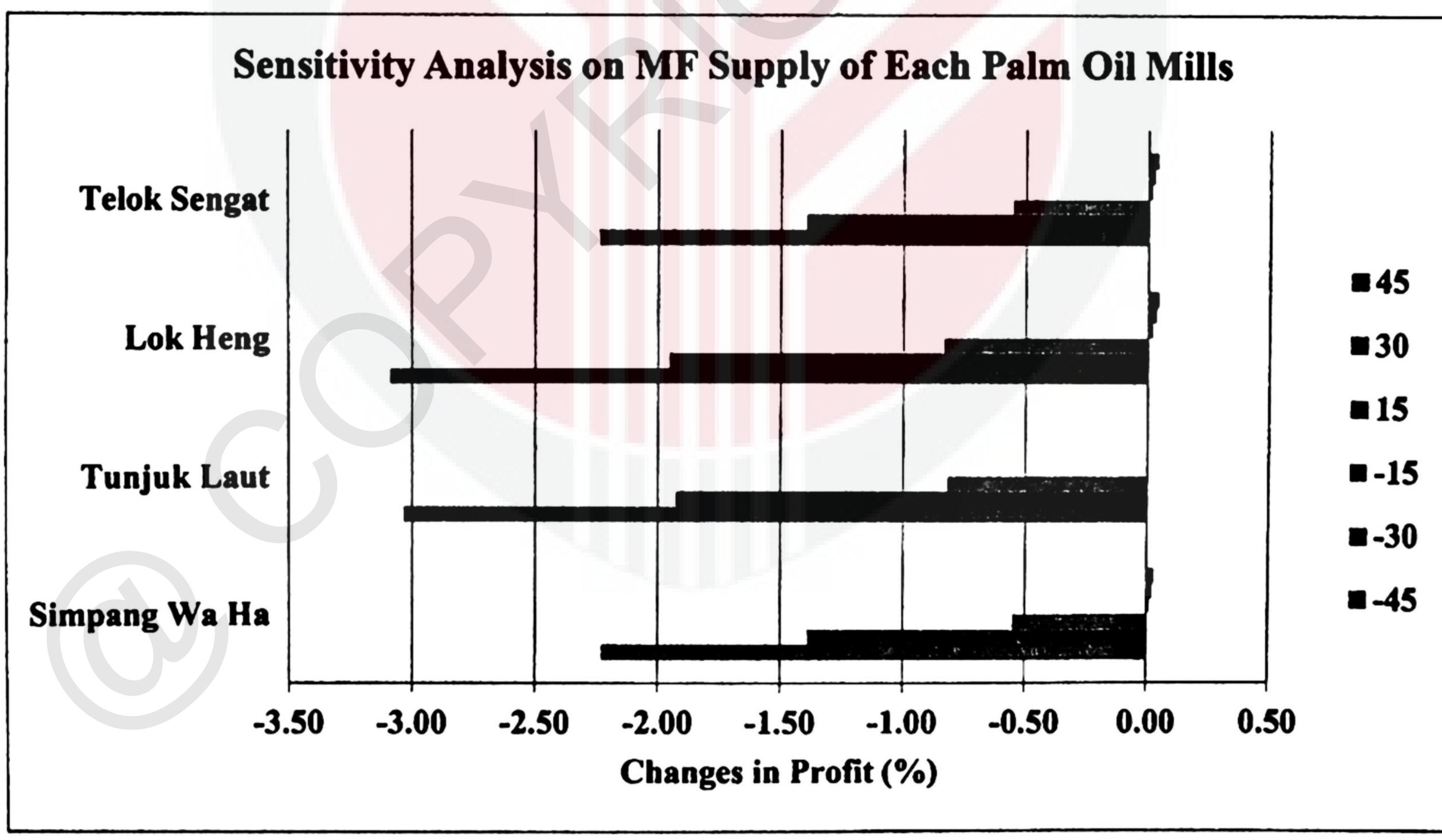

Figure 11. Sensitivity analysis on MF supply of each palm oil mills.

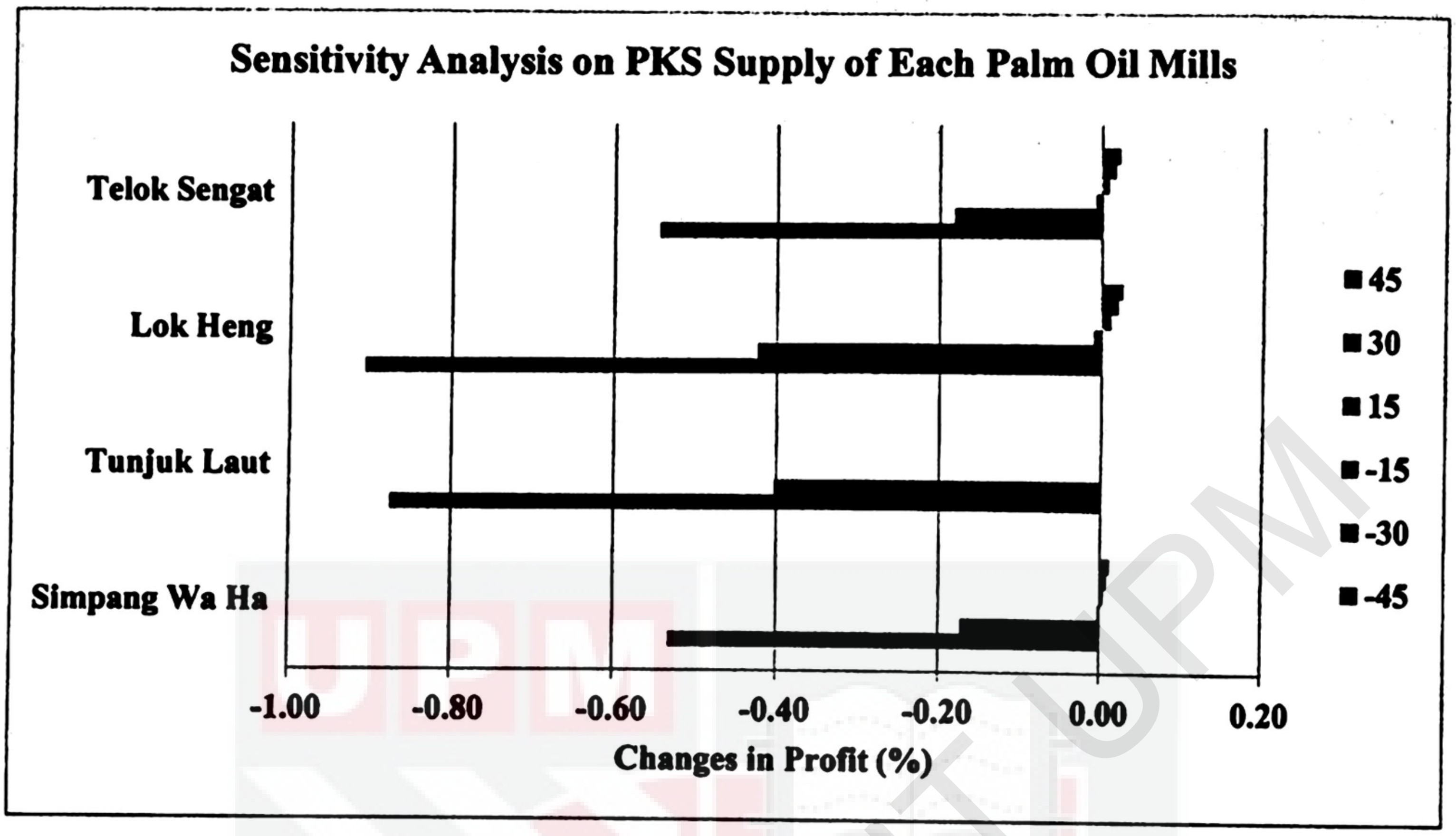

Figure 12. Sensitivity analysis on PKS supply of each palm oil mills.

4.3.2 Sensitivity Analysis on Biomass Conversion Unit Capacity

From the sensitivity analysis, increment of capacity does not affect the palm oil mills' profits because there is no increasing amount of biomass supply from palm oil mills. From Figure 13, profit changes drastically when reduction of 45% of EFB capacity at Adela, which profit drops about -17.04%. Since Adela holds 60,000 MT/year of EFB capacity compared to Tai Tak which only 40,000 MT/year, thus, reduction on EFB capacity at Adela will lead to higher losses, since huge amount of EFB supply from palm oil mills cannot be converted into bio-products.

Meanwhile, Figure 14 showed that major changes in palm oil mills profits when MF conversion unit capacity is reduced. From the analysis, it shows that reduction of 45% at Tai Tak will cause the profit drops at -6.90%. Since Tai Tak has larger MF conversion unit capacity (39,000 MT/year) compared to Adela which only 26,000 MT/year. However, reduction conversion unit capacity at Adela has slightly affects to the palm oil mills' profits (-4.68%). Reduction of PKS conversion unit capacity gives slightly decrement of palm oil mills profit as shown in Figure 15. These insignificant changes due to the fewer amounts of PKS generated at palm oil mills, also the small size of PKS conversion unit capacity at the biomass facility.

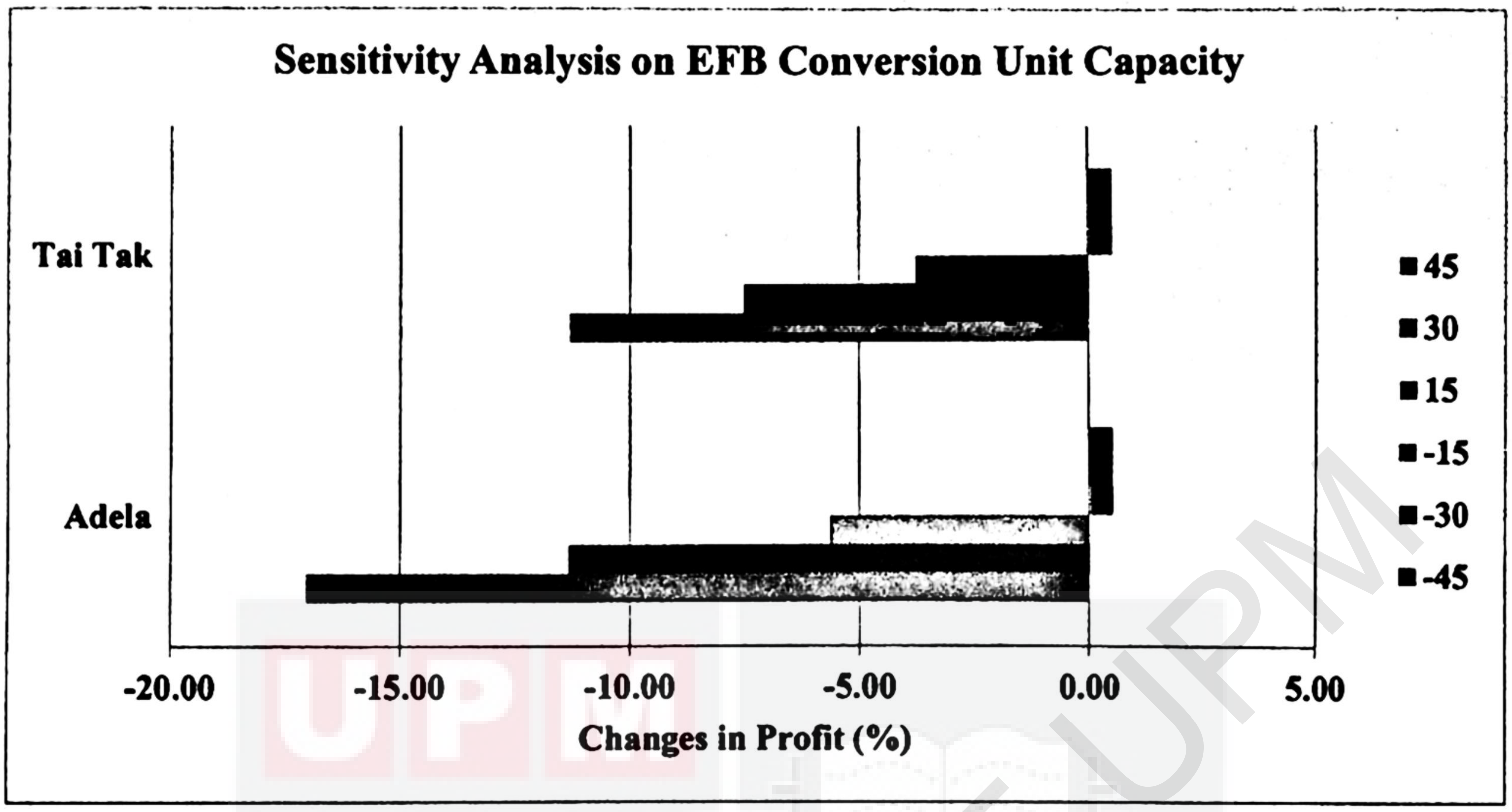

Figure 13. Sensitivity analysis on EFB conversion unit capacity.

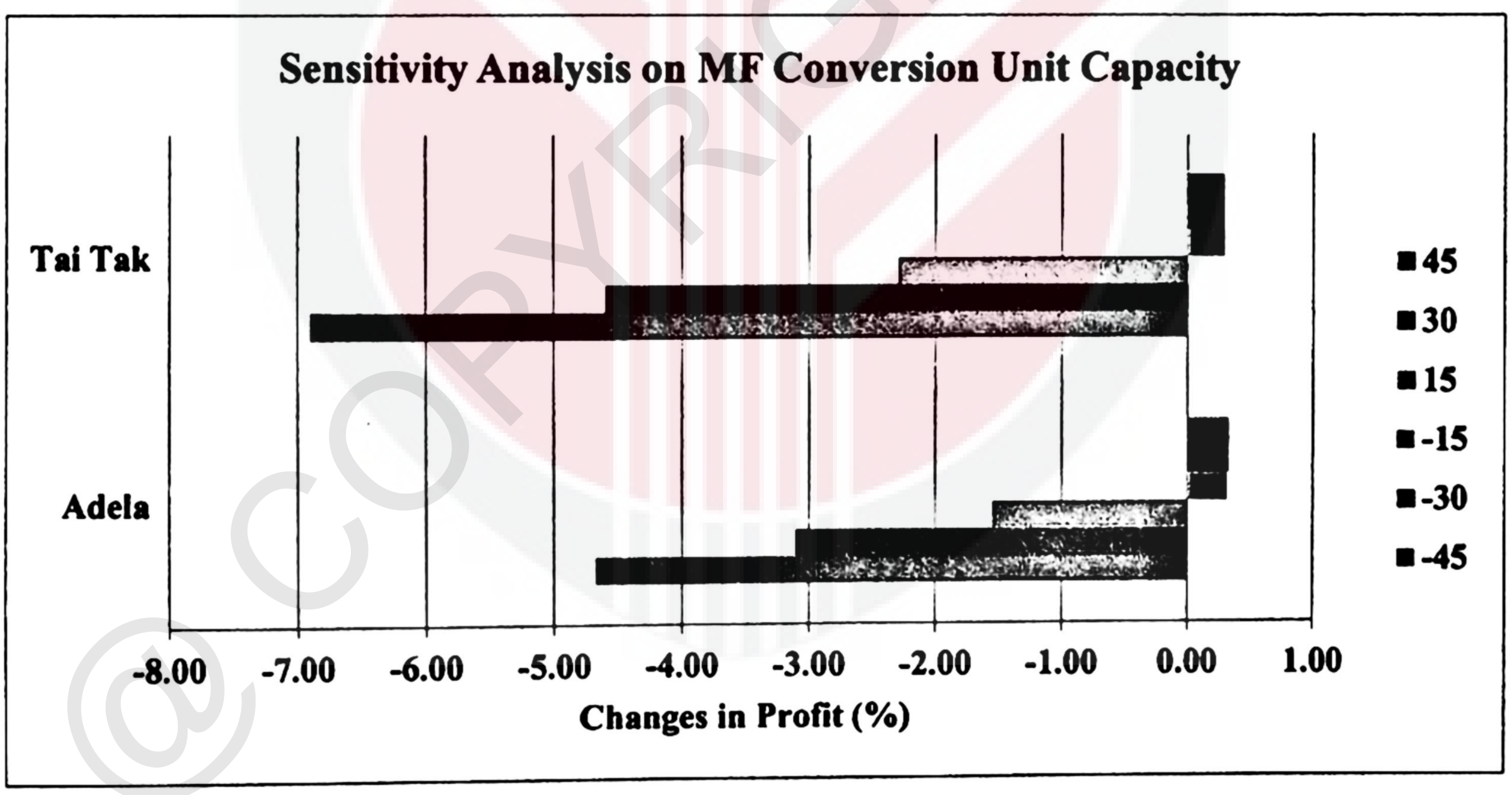

Figure 14. Sensitivity analysis on MF supply of each palm oil mills.

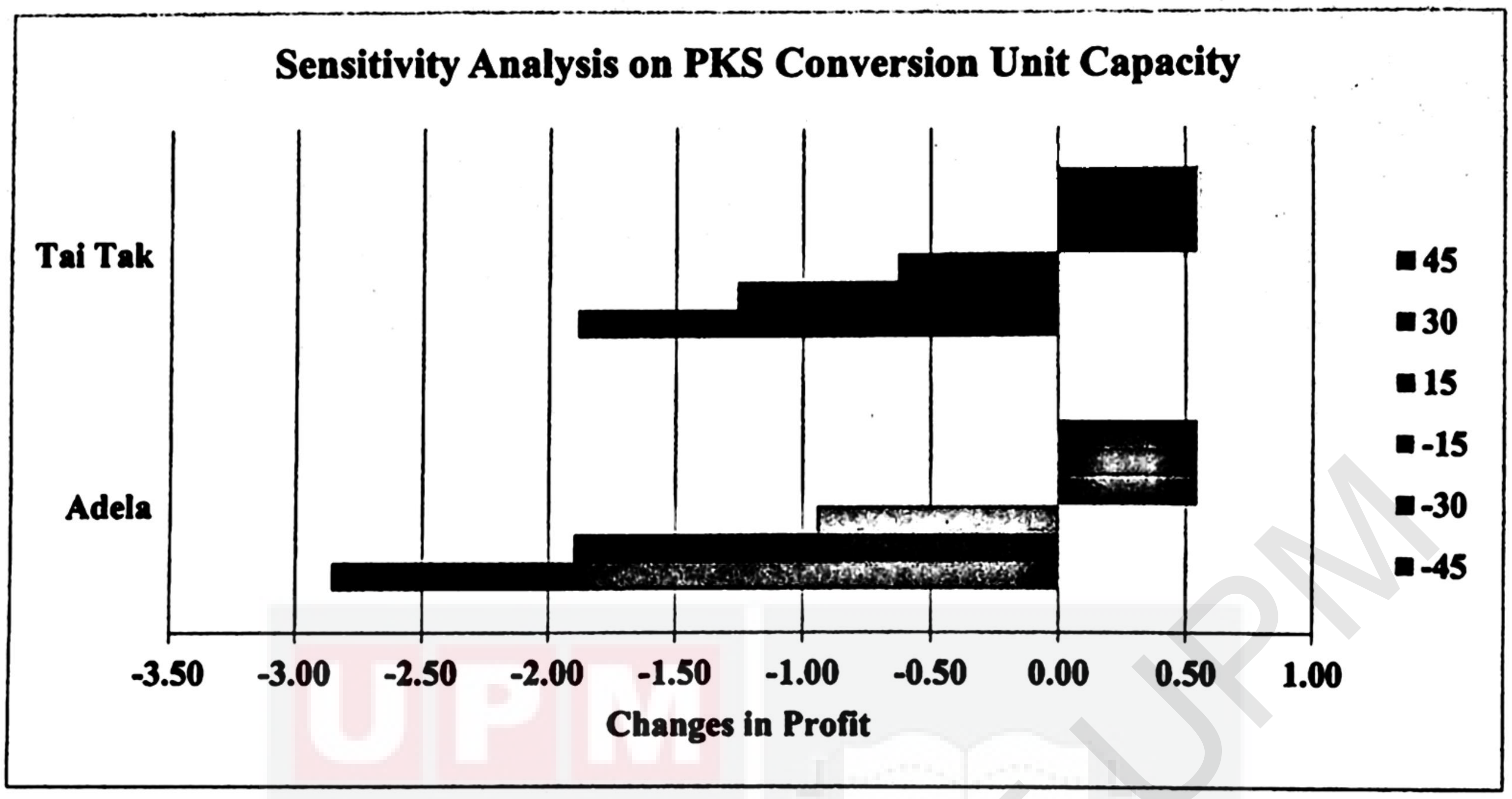

Figure 15. Sensitivity analysis on PKS supply of each palm oil mills.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, transportation cost of oil palm biomass from palm oil mills to the biomass facilities can be minimized by choosing the optimal routes of transportation. Thus, each palm oil mills can maximize its profit from the biomass sales. From this study, developed mathematical model of optimal transportation routes can decide the most optimal transportation routes to deliver oil palm biomass to the biomass facility based on linear programming by using General Algebraic Modeling System (GAMS). This model will choose the biomass facilities for palm oil mills to send its oil palm biomass along with the amount of oil palm biomass to be supplied at the biomass facilities. Besides, this model will maximize the profits from the oil palm biomass sale. Thus, this model could help decision makers in realization of oil palm biomass to bio-products activity, by selecting the optimal transportation routes. The total profit from biomass sales after considering the transportation cost is about RM 38,359,679.68. In addition, Simpang Wa Ha and Telok Sengat sent its biomass to both biomass facilities, while, Lok Heng sent its biomass to Adela and Tunjuk Laut sent its biomass to Tai Tak only. Besides, larger amount of EFB generated compared to other biomass, will affect much to the model when its amount is reduced, which drops up to -7.00% at reduction of 45%. Meanwhile, significant profits drop (up to -17.00%) when the EFB conversion unit capacity is reduced at 45%.

5.2 Recommendation

a) To include other biomasses and costs in the developed model.

b) To include more real data from industries into developed model. Some of the data used in this model were estimated based on previous studies and literature review. By using real data in the developed model can increase the accuracy of developed model.

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APPENDIX A

Projected data of MF and PKS for each palm oils mill were calculated as below.

a) Simpang Wa Ha

$$23\%\ of\ EFB generated\ at\ Simpang\ Wa\ Ha = 21{,}600\ MT/yr$$

$$15\%\ of\ MF\ generated\ \ at\ Simpang\ Wa\ Ha = 14{,}086\ MT/yr$$

$$23\%\ of\ EFB generated\ at\ Simpang\ Wa\ Ha = 21{,}600\ MT/yr$$

$$6\%\ of\ PKS\ generated\ \ at\ Simpang\ Wa\ Ha = 5{,}634\ MT/yr$$

b) Tunjuk Laut

$$23\%\ of\ EFB generated\ at\ Tunjuk\ Laut = 28{,}800\ MT/yr$$

$$15\%\ of\ MF\ generated\ \ at\ Tunjuk\ Laut = 18{,}782\ MT/yr$$

$$23\%\ of\ EFB generated\ at\ Tunjuk\ Laut = 28{,}800\ MT/yr$$

$$6\%\ of\ PKS\ generated\ \ at\ Tunjuk\ Laut = 7{,}513\ MT/yr$$

c) Lok Heng

$$23\%\ of\ EFB generated\ at\ Lok\ Heng = 28{,}800\ MT/yr$$

$$15\%\ of\ MF\ generated\ \ at\ Lok\ Heng = 18{,}782\ MT/yr$$

$$23\%\ of\ EFB generated\ at\ Lok\ Heng = 28{,}800\ MT/yr$$

$$6\%\ of\ PKS\ generated\ \ at\ Lok\ Heng = 7{,}513\ MT/yr$$

d) Telok Sengat

$$23\%\ of\ EFB generated\ at\ Telok\ Sengat = 28{,}800\ MT/yr$$

$$15\%\ of\ MF\ generated\ \ at\ Telok\ Sengat = 18{,}782\ MT/yr$$

$$23\%\ of\ EFB generated\ at\ Telok\ Sengat = 21{,}600\ MT/yr$$

$$6\%\ of\ PKS\ generated\ \ at\ Telok\ Sengat = 5{,}634\ MT/yr$$

APPENDIX B

```
Set
i 'palm oil mill' /simpangwaha, tunjuklaut, lokheng, teloksengat/
j 'biomass facility' /adela, taitak/
;


Scalar
f 'transportation cost RM/tonnes-km' /0.9/
g '2 journeys/10 tonnes' /0.2/
;


Parameter
efb_supply(i)          efb generated in each mill i
/
simpangwaha  21600
tunjuklaut   28800
lokheng      28800
teloksengat  21600
/

mf_supply(i)           mesocarp fibre generated in each mill i
/
simpangwaha  14086
tunjuklaut   18782
lokheng      18782
teloksengat  14086
/

pks_supply(i)          palm kernel shell generated in each mill i
/
simpangwaha  5634
tunjuklaut   7513
lokheng      7513
teloksengat  5634
/

efb_capacity(j)        capacity for efb j
/
adela   60000
taitak  40000
/

mf_capacity(j)         capacity for mf j
```

```
/
adela   26000
taitak  39000
/

pks_capacity(j)          capacity for pks j
/
adela   15000
taitak  10000
/
;


Table
distance(i,j)        distance in km

                 adela       taitak
simpangwaha      39.59       41.49
tunjuklaut       80.80       50.63
lokheng          28.98       49.54
teloksengat      28.19       38.12
;


Variable
profit
profitpermill(i,j)
;


Positive Variable
efb_quantity(i,j)      quantity of efb to be supplied
efb_cost               total efb cost
efb_sale               total efb sale

mf_quantity(i,j)       quantity of mf to be supplied
mf_cost                total mf cost
mf_sale                total mf sale

pks_quantity(i,j)      quantity of pks to be supplied
pks_cost               total pks cost
pks_sale               total pks sale

;
```

```
Equation
eq1     objective function

*EFB
eq2     observe efb supply limit at mill
eq3     satisfy capacity facility
eq4     calculate efb cost
eq5     calculate efb sale

*MF
eq6     observe mf supply limit at mill
eq7     satisfy capacity facility
eq8     calculate mf cost
eq9     calculate mf sale

*PKS
eq10    observe pks supply limit at mill
eq11    satisfy capacity facility
eq12    calculate pks cost
eq13    calculate pks sale

eq14    profit per mills
;

*objective function
eq1..
profit =e= sum((i,j), (efb_sale(i,j) - efb_cost(i,j)) + (mf_sale(i,j) - mf_cost(i,j))
+ (pks_sale(i,j) - pks_cost(i,j)) );

*EFB
eq2(i)..
efb_supply(i) =g= sum(j, efb_quantity(i,j));

eq3(j)..
efb_capacity(j) =g= sum (i, efb_quantity(i,j));

eq4(i,j)..
efb_cost(i,j) =e= (g * distance(i,j)) * f * efb_quantity(i,j);

eq5(i,j)..
efb_sale(i,j) =e= efb_quantity(i,j) * 250;

*MF
eq6(i)..
mf_supply(i) =g= sum(j, mf_quantity(i,j));
```

```
eq7(j)..
mf_capacity(j) =g= sum (i, mf_quantity(i,j));

eq8(i,j)..
mf_cost(i,j) =e= (g * distance(i,j)) * f * mf_quantity(i,j);

eq9(i,j)..
mf_sale(i,j) =e= mf_quantity(i,j) * 160;

*PKS
eq10(i)..
pks_supply(i) =g= sum(j, pks_quantity(i,j));

eq11(j)..
pks_capacity(j) =g= sum (i, pks_quantity(i,j));

eq12(i,j)..
pks_cost(i,j) =e= (g * distance(i,j)) * f * pks_quantity(i,j);

eq13(i,j)..
pks_sale(i,j) =e= pks_quantity(i,j) * 170;

eq14(i,j)..
profitpermill(i,j) =e= (efb_sale(i,j) - efb_cost(i,j)) + (mf_sale(i,j) - mf_cost(i,j)) +
(pks_sale(i,j) - pks_cost(i,j));

Model
power / all /
;

solve power using LP maximising profit
;
```

APPENDIX C

i. Sensitivity analysis on biomass supply of each palm oil mills.

```
Set
i 'palm oil mill' /simpangwaha, tunjuklaut, lokheng, teloksengat/
j 'biomass facility' /adela, taitak/
;


Scalar
f 'transportation cost RM/tonnes-km' /0.9/
g '2 journeys/10 tonnes' /0.2/
;


Parameter
efb_supply(i)          efb generated in each mill i
/
simpangwaha  21600
tunjuklaut   28800
lokheng      28800
teloksengat  21600
/

defb_supply(i)
/
simpangwaha  1
tunjuklaut   1
lokheng      1
teloksengat  0.55
/

mf_supply(i)           mesocarp fibre generated in each mill i
/
simpangwaha  14086
tunjuklaut   18782
lokheng      18782
teloksengat  14086
/

pks_supply(i)          palm kernel shell generated in each mill i
/
simpangwaha  5634
tunjuklaut   7513
lokheng      7513
teloksengat  5634
/
```

```
efb_capacity(j)          capacity for efb j
/
adela   60000
taitak  40000
/

mf_capacity(j)           capacity for mf j
/
adela   26000
taitak  39000
/

pks_capacity(j)          capacity for pks j
/
adela   15000
taitak  10000
/
;


Table
distance(i,j)         distance in km

              adela        taitak
simpangwaha     39.59         41.49
tunjuklaut     80.80         50.63
lokheng        28.98         49.54
teloksengat     28.19         38.12
;


Variable
profit
profitpermill(i,j)
;


Positive Variable
efb_quantity(i,j)       quantity of efb to be supplied
efb_cost              total efb cost
efb_sale              total efb sale

mf_quantity(i,j)        quantity of mf to be supplied
mf_cost               total mf cost
mf_sale               total mf sale

pks_quantity(i,j)       quantity of pks to be supplied
pks_cost              total pks cost
pks_sale              total pks sale
```

```
trip
;


Equation
eq1     objective function

*EFB
eq2     observe efb supply limit at mill
eq3     satisfy capacity facility
eq4     calculate efb cost
eq5     calculate efb sale

*MF
eq6     observe mf supply limit at mill
eq7     satisfy capacity facility
eq8     calculate mf cost
eq9     calculate mf sale

*PKS
eq10    observe pks supply limit at mill
eq11    satisfy capacity facility
eq12    calculate pks cost
eq13    calculate pks sale

eq14    profit per mills
;

*objective function
eq1..
profit =e= sum((i,j),  (efb_sale(i,j) - efb_cost(i,j)) + (mf_sale(i,j) - mf_cost(i,j))
+ (pks_sale(i,j) - pks_cost(i,j)) );
*profit =e= sum((i,j),  (efb_sale(i,j) - efb_cost(i,j))) ;

*EFB
eq2(i)..
defb_supply(i) * efb_supply(i) =g= sum(j, efb_quantity(i,j));

eq3(j)..
efb_capacity(j) =g= sum (i, efb_quantity(i,j));

eq4(i,j)..
efb_cost(i,j) =e= (g * distance(i,j)) * f * efb_quantity(i,j);

eq5(i,j)..
efb_sale(i,j) =e= efb_quantity(i,j) * 250;

*MF
eq6(i)..
mf_supply(i) =g= sum(j, mf_quantity(i,j));
```

```
eq7(j)..
mf_capacity(j) =g= sum (i, mf_quantity(i,j));

eq8(i,j)..
mf_cost(i,j) =e= (g * distance(i,j)) * f * mf_quantity(i,j);

eq9(i,j)..
mf_sale(i,j) =e= mf_quantity(i,j) * 160;

*PKS
eq10(i)..
pks_supply(i) =g= sum(j, pks_quantity(i,j));

eq11(j)..
pks_capacity(j) =g= sum (i, pks_quantity(i,j));

eq12(i,j)..
pks_cost(i,j) =e= (g * distance(i,j)) * f * pks_quantity(i,j);

eq13(i,j)..
pks_sale(i,j) =e= pks_quantity(i,j) * 170;

eq14(i,j)..
profitpermill(i,j) =e= (efb_sale(i,j) - efb_cost(i,j)) + (mf_sale(i,j) - mf_cost(i,j)) +
(pks_sale(i,j) - pks_cost(i,j));

Model
power / all /
;

solve power using LP maximising profit
;

*display efb_cost.l, efb_sale.l, mf_cost.l, mf_sale.l, pks_cost.l, pks_sale.l,capacity;
```

ii. **Sensitivity analysis on conversion unit capacity of each biomass facilities.**

```
Set
i 'palm oil mill' /simpangwaha, tunjuklaut, lokheng, teloksengat/
j 'biomass facility' /adela, taitak/
;


Scalar
f 'transportation cost RM/tonnes-km' /0.9/
g '2 journeys/10 tonnes' /0.2/
;


Parameter
efb_supply(i)        efb generated in each mill i
/
simpangwaha  21600
tunjuklaut   28800
lokheng      28800
teloksengat  21600
/


mf_supply(i)         mesocarp fibre generated in each mill i
/
simpangwaha  14086
tunjuklaut   18782
lokheng      18782
teloksengat  14086
/

pks_supply(i)        palm kernel shell generated in each mill i
/
simpangwaha  5634
tunjuklaut   7513
lokheng      7513
teloksengat  5634
/

efb_capacity(j)          capacity for efb j
/
adela   60000
taitak  40000
/

defb_capacity(j)
/
adela   1
taitak  0.55
```

```
/

mf_capacity(j)          capacity for mf j
/
adela   26000
taitak  39000
/

pks_capacity(j)          capacity for pks j
/
adela   15000
taitak  10000
/
;


Table
distance(i,j)          distance in km

              adela        taitak
simpangwaha     39.59        41.49
tunjuklaut      80.80        50.63
lokheng         28.98        49.54
teloksengat     28.19        38.12
;


Variable
profit
profitpermill(i,j)
;


Positive Variable
efb_quantity(i,j)     quantity of efb to be supplied
efb_cost              total efb cost
efb_sale              total efb sale

mf_quantity(i,j)      quantity of mf to be supplied
mf_cost               total mf cost
mf_sale               total mf sale

pks_quantity(i,j)     quantity of pks to be supplied
pks_cost              total pks cost
pks_sale              total pks sale

trip
;


Equation
```

```
eq1     objective function

*EFB
eq2     observe efb supply limit at mill
eq3     satisfy capacity facility
eq4     calculate efb cost
eq5     calculate efb sale

*MF
eq6     observe mf supply limit at mill
eq7     satisfy capacity facility
eq8     calculate mf cost
eq9     calculate mf sale

*PKS
eq10    observe pks supply limit at mill
eq11    satisfy capacity facility
eq12    calculate pks cost
eq13    calculate pks sale

eq14    profit per mills
;

*objective function
eq1..
profit =e= sum((i,j), (efb_sale(i,j) - efb_cost(i,j)) + (mf_sale(i,j) - mf_cost(i,j))
+ (pks_sale(i,j) - pks_cost(i,j)) );
*profit =e= sum((i,j), (efb_sale(i,j) - efb_cost(i,j))) ;

*EFB
eq2(i)..
efb_supply(i) =g= sum(j, efb_quantity(i,j));

eq3(j)..
defb_capacity(j) * efb_capacity(j) =g= sum (i, efb_quantity(i,j));

eq4(i,j)..
efb_cost(i,j) =e= (g * distance(i,j)) * f * efb_quantity(i,j);

eq5(i,j)..
efb_sale(i,j) =e= efb_quantity(i,j) * 250;

*MF
eq6(i)..
mf_supply(i) =g= sum(j, mf_quantity(i,j));

eq7(j)..
mf_capacity(j) =g= sum (i, mf_quantity(i,j));

eq8(i,j)..
mf_cost(i,j) =e= (g * distance(i,j)) * f * mf_quantity(i,j);
```

```
eq9(i,j)..
mf_sale(i,j) =e= mf_quantity(i,j) * 160;

*PKS
eq10(i)..
pks_supply(i) =g= sum(j, pks_quantity(i,j));

eq11(j)..
pks_capacity(j) =g= sum (i, pks_quantity(i,j));

eq12(i,j)..
pks_cost(i,j) =e= (g * distance(i,j)) * f * pks_quantity(i,j);

eq13(i,j)..
pks_sale(i,j) =e= pks_quantity(i,j) * 170;

eq14(i,j)..
profitpermill(i,j) =e= (efb_sale(i,j) - efb_cost(i,j)) + (mf_sale(i,j) - mf_cost(i,j)) +
(pks_sale(i,j) - pks_cost(i,j));

Model
power / all /
;

solve power using LP maximising profit
;

*display efb_cost.l, efb_sale.l, mf_cost.l, mf_sale.l, pks_cost.l, pks_sale.l,capacity;
```