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A Mathematical Model for Locating Potential Central Markets and Arranging Transportation Routes for Oil Palm Transportation in the Upper Southern Part of Thailand

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Abstract: There is no central market for oil palm in Thailand. Knowing that the central market can help reduce logistic costs and provide a suitable price for oil palm transaction, this research studies a problem of selecting locations of oil palm central markets and constructing vehicle routes for oil palm collection under vehicle speed and capacity limitation with the objective of minimizing the total cost that consists of the vehicle routing cost, the fixed operating cost and the depreciation of the central markets and the vehicles. A mathematic model of the problem is formulated and then validated using comparison and cutting methods. The problem instances are generated from real data of 439 townships of 6 provinces in the upper Southern area of Thailand. Forty-two problems are tested and solved by using a computer software. The computational results show that based on all problem instances, the total cost can be reduced by at least 5.76% when compared to the one of the existing process. In addition with a reduction of the total travel distance, the amount of carbon dioxide emission goes down by at least 13.35%.

Key words: Mathematic model, location routing problem, oil palm, carbon dioxide emission, transaction, computational results

INTRODUCTION

In Thailand, energy is considered to be the drive of the national economy since it is used in all sectors such as industrial sector, transportation, import and export businesses, and daily living. It has been known that major energy sources are lignite, coal, natural gas, electricity, and oil. After dividing energy consumption by sectors, namely, agriculture, industry, housing, business, and transportation, the result is shown in Table 1.

Table 1 shows energy consumption classified by the economic sectors from January to May in 2015-2017. It reveals that the transportation sector used the greatest amount of energy and it tended to rise in the future. When considering the increased rate from 2015-2016 and 2016-2017, they were 2.2 and 9.2%, respectively. (Anonymous, 2017). After an in-depth study of released Carbon dioxide (CO_2) from transportation in Thailand based on data from 2012-2018, the outcome is shown in Table 2 (Anonymous, 2019a).

Table 2 shows the amount of CO_2 emitted by the types of energy in the transportation system. It is that the fuel in the transportation system generates the highest amount of CO_2 emissions and is likely to increase. So, if fuel consumption in transportation is lessened, CO_2 emissions will be decreased. This is in accordance with a research by El Idrissi Adiba, *et al*. (2016) which focuses on CO_2 emissions reduction by managing transportation routing in order to achieve green transportation. Sendow *et al*. (2019) study the traffic in Manado City,

Table 1: Energy consumption for each economic branch in January to May 2015-2017 of Thailand

Branch	Quantity (thousand tons of crude oil equivalent) 2015	2016	2017	Rate of change (%) 2016	2017
Agriculture	1,735	1,542	949	-11.1	-38.5
Industry	11,859	12,270	11,664	3.5	-4.9
Housing	5,023	4,784	4,630	-4.8	-3.2
Business	2,401	2,580	2,624	7.5	1.7
Transportation	12,220	12,493	13,647	2.2	9.2
Total	33,238	33,579	33,514	1.0	-0.2

Table 2: CO_2 Emission in transport by energy type in 2012-2018 of Thailand

Years	CO_2 Emission in transport (1000 t) Oil	Coal/lignite	Natural gas
2012	55,179.14	0.00	5,919.08
2013	51,776.27	0.00	6,524.49
2014	48,782.15	0.00	6,728.93
2015	54,826.33	0.00	6,455.33
2016	60,306.26	0.00	5,924.08
2017	62,096.96	0.00	5,157.21
2018	63,262.87	0.00	4,665.52

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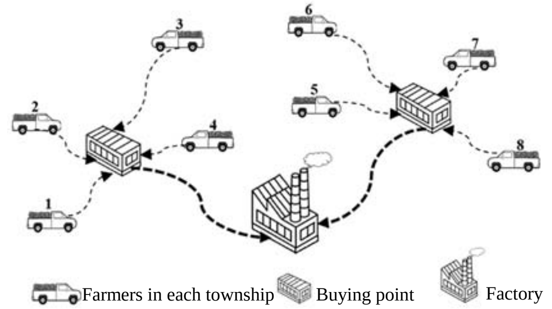

Fig. 1: Original process

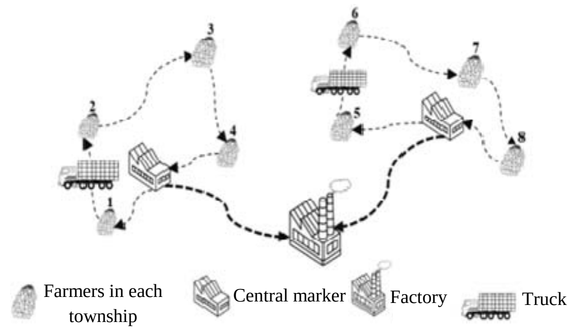

Fig. 2: Improved process

Indonesia and use a regression model to determine the relationship between the level of CO concentration, the traffic volume, the traffic speed and the wind speed. Thus research will demonstrate the reduction of the amount of CO_2 emitted by the vehicles which is resulted from the reduction of travel distance of the vehicle.

One of the economic crops of Thailand is oil palm. As it is easy to grow and requires relatively low investment, it is populated in many areas of Thailand, especially in the upper Southern part of Thailand. Oil palm can be processed and used for consumption and as a fuel. When studying the phenomenon of oil palm trading at present time as illustrated in Fig. 1, it is understand that each farmer would sell oil palm to either a nearby collecting point or a nearby factory. The farmers would compare buying prices from several collecting points before selling their products. Those collecting points would take a role of middlemen, so, the farmers could only sell palm at a low price. Then the middlemen would sell the collected palm fruit to a factory. Sometimes the factory received raw palm fruit from collecting points which could not be extracted. The current palm trading system is not effective, creating uncertainty in both buyers and sellers. When considering a trading system of other economic plants such as rubber trees which have similar trading procedures, rubber tree industry has its own central market while the oil palm industry does not. The central market works as a connection between the farmers and the factories, so, the middlemen are not needed in the trading system. In addition when oil palm goes through an auction process, its price will be higher.

The central market is responsible for trading and delivering according to the rules of the regulated market that all parties must trade at the central market price. These help them reduce transportation costs and help farmers to sell oil palm at a relatively higher price while buyers get palm fruit with better quality. To trade in the central market, quality of the oil palm fruit needs to be checked before being transported to factories, so that, the factories will be able to extract oil palm from the high-quality palm fruit. This is in accordance with a study which found that the central market increased palm transportation efficiency and farmers would earn more money. Therefore, this research proposes creating a mathematical model to help choose a location to build a central market and provide suitable routes for oil palm transportation. The central market will be responsible for gathering oil palm from farmers and transporting them back to the central market presented in Fig. 2. The operation can decrease transportation costs and reduce fuel consumption which will create less air pollution.

This research will study the process of palm transportation and create a mathematical model of the location routing problem. Then a computer program is coded and checked for its accuracy. Then the program will be tested with actual problems and the amount of CO_2 emissions obtained from improved process will be compared with that from the original. The overview of problem solving is shown in Fig. 3.

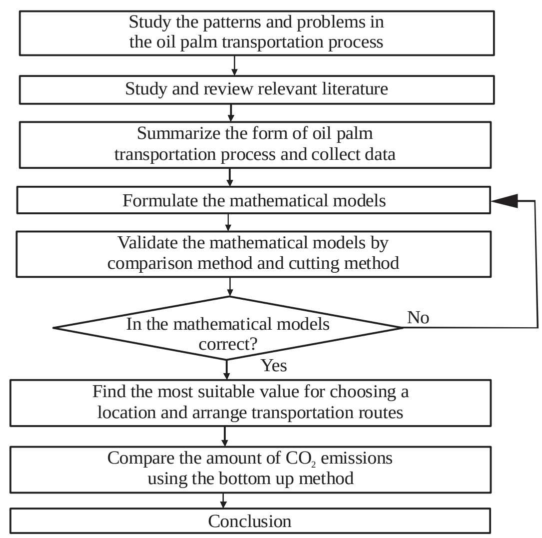

Fig. 3: Problem solving overview

MATERIALS AND METHODS

Hypothesis and characteristics of the problem: To create a mathematical model, an important step is to identify the characteristics of the problem and create hypotheses which cover all the problems. The details are as follows:

In the process of simulating a mathematical model to find a proper location and transportation routes of an oil palm central market, possible locations are being searched and the palm transportation routes were rearranged. The central market would be collecting all palm fruit from farmers in each township and transporting them back to the central market.

The amount of palm fruit collected from each farmer is divide by township areas which are referred as nodes. There were 439 nodes (439 townships, in 6 provinces). All palm fruits from every node will be transported back only to the central market. Only 61 existing oil palm cooperatives are considered as possible locations of central market as Fig. 4. Each central market has a different capacity.

To calculate distance between any places, a distance calculation program is used together with Google Maps. In township areas, the sub-district administrative office or the municipality office is used as a referent place. For the position of the cooperative, the cooperative location is used as a reference.

Vehicles that are used in transportation from the central market to farmers in each township have 3 sizes, namely 6-wheel trucks, 10-wheel trucks, and 18-wheel trucks which can carry a 10, 13 and 30.5 ton load, respectively.

There is no time window considered in the problem. The amount of oil palm harvest is constant during the year, from January to December 2017. The amount of oil palm transported to the central market in each day was certainly known. There is no mandatory practice on oil palm inventory because the transportation of oil palm must be completed within 24 h or the quality of oil palm would be affected otherwise.

Fig. 4: locations of oil palm cooperatives

Total costs consist of vehicle routing costs, the depreciation rate of the central market, the fixed cost in the operation of the central market (employee salary, office supplies, water, electricity) and depreciation of vehicles. Loading and unloading time is neglected. The amount of oil palm that is transported on each trip must not exceed the load capacity of each type of the vehicle.

The transport vehicles from each central market must return to that central market. The vehicle starts transportation by leaving the central market to collect oil palm from farmers in each township until the truck load is full or almost full. Then the truck is driven back to the central market directly. Each truck must be transported at the speed required by law, not exceeding 60 km/h in order to comply with transportation laws. The result is from the simulation of the program not from an actual situation.

The mathematic model: To solve research problems, the problems and patterns of oil palm transportation are studied first. The next step is to study and review relevant literatures, namely Facility Location Problem (FLP), Vehicle Routing Problem (VRP) and Location Routing Problem (LRP). The FLP problem is tochoose a location, regarding number, size and location of a place in order to minimize costs, distance and time. There are several options in choosing a location such as deterministic and stochastic. The former uses known and constant input as seen in a research by Boonmee *et al*. (2017), Ahmadi-Javid *et al*. (2017) and Krivulin (2017). The latter uses varied inputs to predict probability which is more likely to the actual situation as seen in a research by Amiri-Aref *et al*. (2018) and Escudero *et al*. (2018). VRP is an analysis of problem in routing under various constraints such as time, vehicle's load capacity, product distribution pattern and vehicle size. An example of routing management under vehicle's load capacity constraint is a research by Yi and Bortfeldt (2016) and Pecin *et al*. (2017), many researchers are interested in studying VRP problems including Ebadati *et al*. (2014), Elhassania and Ahmed (2016), Shafaei (2016), Mohammed *et al*. (2017) and Zuniga *et al*. (2019) which combine the FLP problem and the VRP problem to form the Location Routing Problem (LRP) problem. Because of its interesting characteristics and complexity, many researchers are interested in studying and solving LRP problems including Duhamel *et al*. (2010), Yu *et al*. (2010), Belenguer *et al*. (2011), Derbal *et al*. (2012), Escobar *et al*. (2013), Phongpipattanapan and Dasananda (2013), Prodhon and Prins (2014), Gao *et al*. (2016), Asgari *et al*. (2017), Nadizadeh *et al*. (2017) and Faraji and Nadjafi (2018). In this research, mathematical models created from developed process of the oil palm transportation concerned limitation of truck speed, the capacity of central markets and an amount of time used in transportation. The objective function of the mathematical model is to reduce the total cost including transportation costs which result in less fuel consumption and a reduction of CO_2 emissions in the air. The mathematical model is shown below:

Indices:

i : Central market nodes and farmer nodes
j : Central market nodes and farmer nodes
k : Vehicles that use palm transport

Sets:

I : A set of locations that can be set as a central market where I = {1, 2, ..., M}
J : A set of farmers where J = {1, 2, ..., N}
K : A set of vehicles where K= {1, 2, ..., R}

Parameters:

C_k : Fuel costs of vehicles k (Baht per kilometer)
F_i : Depreciation of the central market at i (Baht per day)
G_k : Depreciation of the vehicle k (Baht per day)
MC_i : Fixed expenses in the operation of the central market i (Baht per day)
MF_i : Capacity of the palm quantity of the Central market i (kilogram per day)
q_j : The total amount of palm available per day of the farmer j (kilogram)
D_k : Maximum total distance per day by vehicles k (kilometer per day)
d_{ij} : Distance between nodes i to nodes j (kilometer)
Q_k : The loading capacity of the vehicle's palm k (kilogram)
L : The total number of nodes in the system

Support decision variables: U_{ik}, U_{jk} variables prevent the occurrence of sub tour

Decision variables:

X_{ijk} : 1, (If the vehicle k is traveling from node i to node j)
X_{ijk} : 0, Otherwise
Y_i : 1, If the central market is opened at the location i
Y_i : 0, Otherwise
Z_{ik} : 1, If the vehicle k is traveling out of the node i),
Z_{ik} : 0, Otherwise
P_{jk} : The amount of palm that the vehicle k receives is still farmers in each township j (kilogram)

The objective function:

$$\text{Min}Z=\left(\sum_{i\in I\cup J}\sum_{j\in I\cup J}\sum_{k\in K} d_{ij}X_{ijk}C_k\right)+\sum_{i\in I}\left(F_i+MC_i\right)Y_i+G_k\left(\sum_{k\in K}\sum_{i\in I}\sum_{j\in J}X_{ijk}\right) \quad (1)$$

Subject to:

$$\sum_{i\in I\cup J}\sum_{j\in J}P_{jk}X_{ijk}\le Q_k \qquad \forall k\in K \quad (2)$$

$$\sum_{i\in I\cup J}\sum_{k\in K}P_{jk}X_{ijk}=q_j \qquad \forall j\in J \quad (3)$$

$$\sum_{k\in K}\sum_{i\in i\cup J}X_{ijk}\ge 1 \qquad \forall j\in J \quad (4)$$

$$\sum_{i\in I}\sum_{j\in i\cup J}X_{ijk}\le 1 \qquad \forall k\in K \quad (5)$$

$$\sum_{j\in I\cup J}X_{jik}-\sum_{j\in I\cup J}X_{ijk}=0 \qquad \forall i\in I\cup J,\forall k\in K \quad (6)$$

$$\sum_{i\in I\cup J}\sum_{j\in I\cup J}d_{ij}X_{ijk}\le D_k \qquad \forall k\in K \quad (7)$$

$$U_{ik}-U_{jk}+LX_{ijk}\le L-1 \qquad \forall i\in I,\forall j\in J,i\ne j,\forall k\in K \quad (8)$$

$$\sum_{j\in J}\sum_{k\in K}X_{ijk}\ge Y_i \qquad \forall i\in I \quad (9)$$

$$\sum_{j\in J}X_{ijk}\le Y_i \qquad \forall i\in I,\forall k\in K \quad (10)$$

$$P_{jk}\ge 0 \qquad \forall j\in J,\forall k\in K \quad (11)$$

$$\sum_{j\in J}X_{ijk}\le Z_{ik} \qquad \forall i\in I,\forall k\in K \quad (12)$$

$$\sum_{j\in J}\sum_{k\in K}P_{jk}Z_{ik}\le MF_i \qquad \forall i\in I \quad (13)$$

$$U_{ik}\ge 0 \qquad \forall i\in I,\forall k\in K \quad (14)$$

$$U_{jk}\ge 0 \qquad \forall j\in J,\forall k\in K \quad (15)$$

$$X_{ijk}\in\{0,1\} \qquad \forall i\in I\cup J,\forall j\in J\cup I,\forall k\in K \quad (16)$$

$$Y_i\in\{0,1\} \qquad \forall i\in I \quad (17)$$

The objective function is to find the lowest cost. The total cost of the system includes transportation costs, depreciation, fixed costs in the operation of the central market, and depreciation of vehicles. Constraint 2 is for controlling truck load within vehicle's suggested maximum load capacity. Constraint 3 is used to match the amount of palm fruit each truck collects and the amount of palm fruits at their departure places. Constraint 4 defines that each farmer and each collecting point are eligible for daily multiple sale. Constraint 5 defines that all the vehicles must transport product to a specific central market and there must be only one central market in every route. Constraint 6 defines that a vehicle must depart and arrive at the same location. Constraint 7 defines the maximum distance a vehicle can travel in a day. Constraint 8 is used to prevent sub tour. Constraint 9 defines that every open central market must have at least one vehicle. Constraint 10 defines that each vehicle departing from a central market can travel only on one route and the central market must be open. Constraint 11 defines that the amounts of palm that the vehicle receives from the palm provider must be greater than or equal to zero. Constraints 12 and 13 define that the amount of palm that is shipped from the palm provider must not exceed the capacity of each central market. Constraints 14 and 15 are decision support variables that must be positive. Constraint 16 and 17 are for defining binary decision variables.

Validation of the mathematical models: It is necessary to check the accuracy of the mathematical model that has been coded in the program before using it, since, it prevents from receiving false answers. This research employed 2 methods (comparison and cutting methods) to check the accuracy of the mathematical model. The first method compared transportation costs received from the program with ones from the calculation. The other method cut out one constraint from the model and considered the result whether each constraint can prevent various situations or not. An example of this method is shown in Fig. 5. The figure shows an elimination of constraint 6 which defines that a vehicle must depart and arrive at the same location. After testing with the cutting method, the result shows that the truck did not return to the central market or farmers. This implies that constraint 6 can prevent an unwanted situation and after examining the

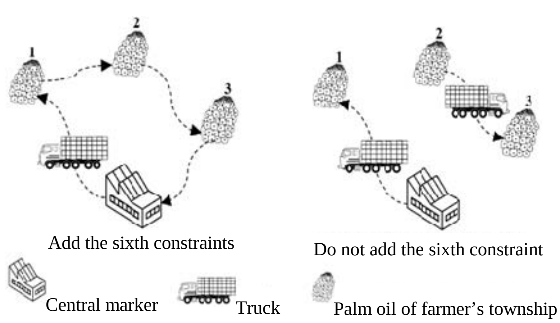

Fig. 5: The cutting method

accuracy of the mathematical model and it is found that there is no error, so, the mathematical model can be used to test further case studies.

The problem instances: Testing problems of oil palm transportation from farmers in each township are tested forty-two problems, regarding the number of farmers in each township in the upper South of Thailand. The number of central markets and vehicles depend on a total value of oil palm randomly entered in each case by using simple random sampling. In the test, the defined and to be run problem code is a number of townships/a number of central markets/a number of vehicles/and sampling times. For example, the code 15/5/5/2 means the test runs a program that has farmers from 15 townships and there are 5 prospective central markets which have 5 available vehicles and this is a second time test.

CO_2 emissions analysis in the transport sector: From the guidelines for greenhouse gas inventories recommended by the Intergovernmental Panel on Climate Change (IPCC), there are 2 methods for estimating released CO_2. The first one is top-down method which measures CO_2 directly from the amount of fuel sold in the area. The other is bottom-up method is a method which estimates CO_2 directly from the travel distance of each vehicle type. This research employed the bottom-up as it provides a more detailed result and more popular. The equation of this is shown below (Anonymous, 2016) by analyzing CO_2 emissions in the transport sector:

$$G = A \times S_i \times I_{ij} \times F_{ij} \quad (18)$$

$$VKT_i = \text{Total trips} \times S_i \times AvgDIST_i \quad (19)$$

Where:

G	:	CO_2 emissions from transportation (kg·CO_2)
A	:	Travel distance (truck·km)
S	:	Travel proportion according to fuel type or vehicle (%)
I	:	Energy consumption rate (MJ/truck·km)
F	:	The amount of carbon of each type of fuel (kg·CO_2/MJ)
i	:	Vehicle type
j	:	Fuel type
VKT_i	:	Travel distance of the vehicle (truck·km)
TotalTrips	:	Total number of trips in the area (round)
$AvgDIST_i$	:	Travel distance of the vehicle (truck·km/round)

Equation 18 is used to estimate the amount of CO_2 emissions from transportation and Eq. 19 is used to find the total transport distance based on the Activity Structure Intensity Fuel (ASIF) when the net calorific value of diesel oil is 36.42 MJ/Unit and CO_2 emission factor is 74,100 kg CO_2/TJ. This study used those equations to find out the amount of CO_2 emissions from transportation by comparing the amount of CO_2 emissions in actual situation with the amount of CO_2 emissions in various cases obtained from mathematical models.

RESULTS AND DISCUSSION

The results of the test on mathematical model regarding oil palm transportation with the IBM ILOG Optimization program by using the Intel @ Core^{TM} i7-8700CPU @ 3.2GHz 3.19GHz RAM 16.00 GB 64-bit computer is shown in Table 3.

Table 3 shows the results of the test using the program to calculate transportation costs, travel distance, total amount of palm being transported and running time for finding answers. The result from running the example 10/4/4/1 is shown in Fig. 6 (Anonymous, 2019b). The result revealed that the program can find answers for 5-15 townships of problems, however, it can not find answer for a large problem which has farmers from more than 20 townships and the program runs longer than 60 h. To solve this problem, Priti and Bala (2018) recommends using Meta-Heuristic. Therefore, in the future, the Meta-Heuristic method can be developed to solve this problem.

Table 3: The result of running a mathematical model

The problem instance	Cost (Baht)	Time (h)	Distance (km)	Quantity of palm (kg)
5/1/1/1	8,625.0750	00:00:01:31	199.30	29,655
5/1/1/2	8,695.0050	00:00:01:12	206.86	23,739
5/1/1/3	8,683.2580	00:00:01:26	205.59	30,181
5/2/2/1	15,886.455	00:00:01:09	304.30	35,478
5/2/2/2	11,426.690	00:00:01:06	381.60	50,168
5/2/2/3	13,199.915	00:00:00:95	573.30	54,580
5/3/3/1	16,589.950	00:00:01:50	318.60	63,379
5/3/3/2	19,422.765	00:00:01:18	512.90	67,828
5/3/3/3	15,366.055	00:00:01:23	686.90	78,474
10/2/2/1	12,382.215	00:00:05:84	484.90	43,027
10/2/2/2	16,427.825	00:00:19:24	309.70	37,070
10/2/2/3	17,741.325	00:00:38:56	451.70	43,419
10/3/3/1	18,018.015	00:00:34:08	402.30	60,029
10/3/3/2	16,526.005	00:00:16:32	812.30	70,244
10/3/3/3	20,463.730	00:00:26:65	1,238.00	68,046
10/4/4/1	17,759.745	00:57:25:61	825.10	92,261
10/4/4/2	19,361.210	00:02:20:36	464.20	86,767
10/4/4/3	14,779.605	00:00:24:77	623.50	85,778
15/3/3/1	19,408.890	>60	-	-
15/3/3/2	16,203.180	00:06:18:44	777.40	62,395
15/3/3/3	15,866.480	>60	-	-
15/4/4/1	20,027.505	>60	-	-
15/4/4/2	25,082.345	>60	-	-
15/4/4/3	22,314.105	>60	-	-
15/5/5/1	20,046.135	>60	-	-
15/5/5/2	23,439.175	>60	-	-
15/5/5/3	19,733.695	>60	-	-
20/5/5/1	26,502.600	>60	-	-
20/5/5/2	25,636.224	>60	-	-
20/5/5/3	26,278.747	>60	-	-
20/6/6/1	29,231.520	>60	-	-
20/6/6/2	24,578.505	>60	-	-
20/6/6/3	28,690.650	>60	-	-
20/7/7/1	26,146.170	>60	-	-
20/7/7/2	19,804.250	>60	-	-
20/7/7/3	26,805.110	>60	-	-
25/6/6/1	No solution	>60	-	-
25/7/7/1	No solution	>60	-	-
25/8/8/1	No solution	>60	-	-
30/7/7/1	No solution	>60	-	-
30/8/8/1	No solution	>60	-	-
30/9/9/1	No solution	>60	-	-

One of the objectives of a mathematical model is to reduce transportation costs. When comparing the outcome from a test with the actual costs from various problematic cases, it is found out that expenses of creating the model to open the central market and arrange the suitable route in the first phase for both situations are not considerably different. Nevertheless, when the number of farmers in each township increased with the increasing number of transportation routes, the costs is higher. Moreover, reducing transportation costs from the designed mathematical model can cut the costs at least 5.76% which show the results as shown in Fig. 7. After receiving results from the testing of 5-15 townships problems then comparison of fuel use in transportation and CO_2 emissions from calculations which show the results as shown in Fig. 8 and 9.

After obtaining the research results from small-sized and medium-sized problems, fuel consumption and CO_2 emissions from various situations are compared as shown in Fig. 8 and 9. This comparison is based on the problem of current transportation system. So, building central markets and organizing suitable transportation routes can reduce fuel consumption and CO_2 emissions at least 13.35% in each problem. It is shown that less fuel consumption meant less CO_2 emissions. This means that

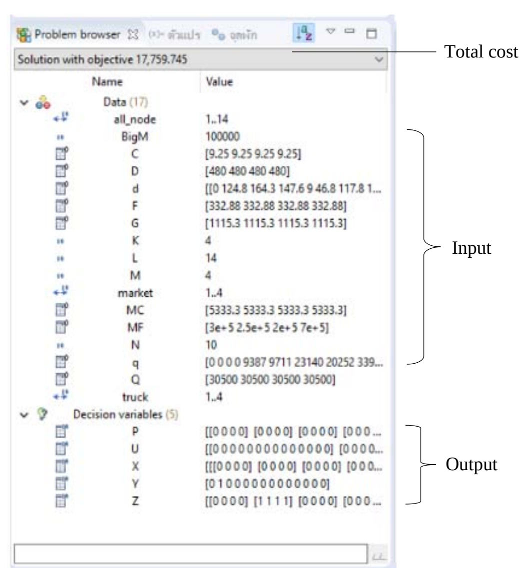

Fig. 6: The results of running the sample 10/4/4/1

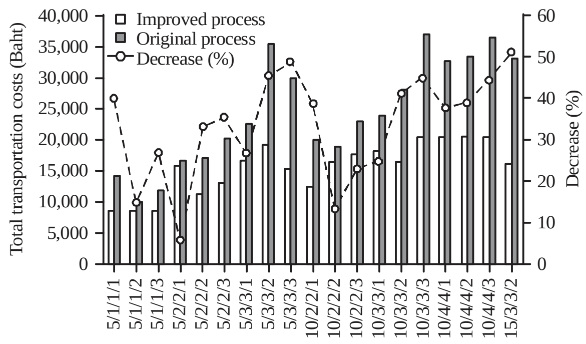

Fig. 7: The results of total transportation costs

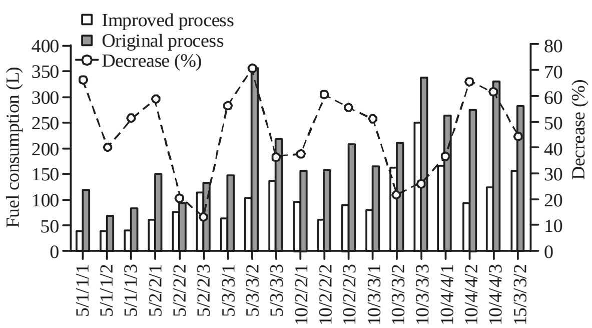

Fig. 8: The results of fuel consumption

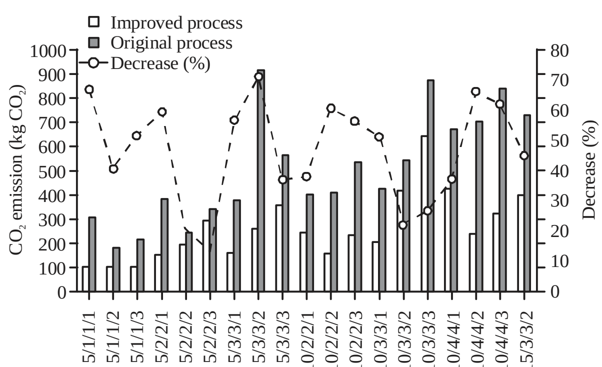

Fig. 9: The results of CO_2 emissions analysis

the mathematical model can decrease fuel consumption and CO_2 emissions which can be an interesting research problem and can be developed in the future.

CONCLUSION

This research studies the patterns and the process of palm transportation and proposes a solution by locating central markets and organizing palm transportation routes tominimize the total cost which helps decrease fuel consumptions and CO_2 emissions. The mathematical model is created under the constraints on speed limitation of vehicles, the capacity of central markets and an amount of time used in oil palm transportation. The mathematical model is coded with IBM ILOG optimization and is used to find a solution. After running the coded program, it is shown that the mathematical model could help 5-15 townships cases reduce costs by at least 5.76% and reduce fuel consumption and the emission of CO_2 at least 13.35%. The problem with farmers from more than 20 townshipsis considered to be an NP-Hard problem that could not find the most suitable value. Therefore, in the future, the researcher will develop a solution using Meta-Heuristic procedure to solve big-sized problems.

SUGGESTION

In the future, there should be a development of Meta-heuristic methods by creating Hybrid Meta-heuristic to increase effectiveness and reduce transportation time in big-sized problems.

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