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Farm Machinery Operating Costs in Oil Palm Plantations: An Evaluation of Repairs and Fuel Costs

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ABSTRACT

Currently, there are only a few research literatures reported on the farm machinery costs in oil palm plantations. Therefore, this study was conducted to investigate the repairs and fuel costs of farm machinery with respect to the characteristics of oil palm plantation in Malaysia. The data for this study was collected through face to face interviews and surveys at several oil palm estates in Malaysia. The findings of this study have successfully elaborated the relationships between working hour with farm machinery repair costs, and types of main in-field operations with farm machinery fuel costs. Mathematical models for estimating cumulative repair and maintenance (CRM) costs and fuel costs for four (4) in-field operations have been successfully developed. In addition, sensitivity analysis on each mathematical models of fuel costs has also been carried out to determine the sensitivity of the fuel costs on variable changes.

KEYWORDS

Farm machinery, Mechanization, Oil palm plantation

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INTRODUCTION

Nowadays farm machinery increasingly becoming an essential input in oil palm plantation operations and its position in crop production was similar to other agricultural inputs such as land, seeds, pesticides, and fertilisers. As stated by Abdullah et al, (2010), the presence of farm machinery has given significant impact to the oil palm plantation industry thorough increasing productivity and reducing costs. In details, farm machinery has successfully reduced time for ploughing, harvesting and evacuating oil palm fresh fruit bunch (FFB), collecting loose fruits, fertiliser application, mainline transport and pest and disease control in the field. Specifically, in harvesting operation, for example, the use of farm machinery reduced labor requirement by 50% with an additional saving approximately at 30% in cost. Therefore, labour usage in oil palm plantation operations needs to be dismissed in order to run the operations to be more productive and efficient. To accomplish this objective, mechanisation was the only way forwards to take over more role of human labour in the field operations. Review an example in wheat production as mentioned by Safa et al., (2010), mechanisation almost single-handedly does all the works in the operations. The human labour was only used to handle the machines/tractors.

In relation to the profitable mechanised operations, the oil palm plantations managers should pay attention to farm machinery management since it was an important aspect that would affect the overall performances of their mechanisation program. Although farm machinery was one of the largest investment in the farm business; however, farm machinery management was still not yet in the highest priority in the process of crop production when compared to the other activities such as agronomic practices and crop protection. Whereas, according to Siemens et al*.,* (2008), knowing machinery management can help the managers in making the best decision for selecting the best machines for a given situation. In fact, Siemens et al., (2008) added, it was not unusual to find that differences in profit from one farm to the next were due solely to differences in the way machinery were selected and managed.

Being a part of machinery management tasks, estimating the operating costs which were comprised of repairs cost and fuel costs should be well-planned. This was because these costs can affect profit in farming operations. Hence, oil palm plantation managers have to be familiarised with how to accurately estimate farm machinery costs in order to be much easier come up with those profit-making decisions. According to Siemens et al*.,* (2008), repairs and fuel costs included lubricant costs take 10% and 34%, respectively of total machinery costs. Theoretically, these costs were hard to estimate because they were depending directly on the amount of machine use. In fact, the repair and fuel costs for a specific machine also vary from one geographical section of the country to another because the differences in soils, crops, climate, topography and operators. Currently fuel cost was estimated by using the formulas developed Siemens et al*.,* (2008) and ASABE (2011). In their formula, Siemens et al (2008) estimated the average fuel consumption of particular operation managing machinery by multiplying a specific constant e.g. 0.345, 0.243, and 0.406 for gasoline, diesel, and LP-gas, respectively with the tractor maximum rated PTO power in kilowatt unit. Similar to Siemens et al*.,* (2008), ASABE (2011a) also used a specific fuel constant e.g. 0.305, 0.223 and 0.366 for gasoline, diesel, and LP-gas, respectively for fuel costs estimation. In calculating repairs cost, Siemens and Bowers (2008) multiplied a percent of the purchase price with four levels machine life span e.g. 1/4 life span, 1/2 life span, 3/4 life span and full life span. In the meantime, ASABE (2011) calculated this cost based on Repair Maintenance Factor (RMF) that have been established for every single operation. Several previous researchers have also developed some models to estimate both repair and fuel costs (Calcante et al., 2013b; Bowers and Hunt, 1970; Ward et al., 1985; Al-Suhaibani and Wahby, 1999; ASABE, 2011; Lips, 2013, Calcante et al., 2013a). Nonetheless, the outcomes of the aforesaid studies were more appropriate to be used in their respective countries of origin.

Malaysian oil palm plantations have their particular conditions and were very much different with the farming operations in the countries stated in the previous studies. This was due to the differences in farm machinery operation, land topography, crop and weather conditions, repair policy and operator's skills. These factors have induced the need for further investigation of repair and fuel costs in order to the previous studies would be adaptable and applicable with oil palm plantation conditions. Thus, there was a need to evaluate repair and fuel costs data of farm machinery in oil palm plantations. This study was an effort to assess the current repair and fuel costs of farm machinery in Malaysian oil palm plantations. In this study, the RF1 (Repair Factor 1) and RF2 (Repair Factor 2) from the Repair and Maintenance formula by ASABE (2011a; 2011b) were adapted for specific farm machinery operation in oil palm plantation.

Besides, multiple linear regressions were utilised to estimate the fuel costs for specific farm machinery operation in oil palm plantation.

MATERIALS AND METHODS

Data Collection

To develop the new predictive repairs and fuel costs models, there were several data that were collected to be analysed. The required data were taken from oil palm estates in both Negeri Sembilan and Melaka states. The names and exact locations of the estates participated in this survey will not be disclose as the respective estates asked for discretion. The data for fuel cost comprised of four (4) main in-field operations of the oil palm plantation. These data were taken from both the estate management and contractors. Some crucial data were not being disclosed to protect the respective company's trade. Details of data collected as shown in table 1. Clear understandings for the full operation system were needed. Field observations and interview were conducted to understand more on the operation system of the estate.

Table 1: Data collected in detail

Type of data	**Measurement unit**
Age of machine	Year, yr
Yearly running hours	Hour, hr
Machine power	Horsepower, HP or kiloWatt
Fresh fruit bunch (FFB)	Tonnes
Fertiliser	Tonnes
Herbicide mix	Tonnes
Distance to mill	Kilometer, km
Number of trips made to mill	Trips
Distance between bins	Kilometer, km
Number of workers working for a specific day	Man-day, day
Area covered per-day for spraying and manuring	Hectare, ha

Data Analysis

Repairs cost

A total of 15 machinery represents 90% of total farm machinery of the estate were sampled in this study. Of note, 47% of the total farm machinery age was ranging from 0 to10 years. These ages were considered as common ownership period and within good range of economic machine lifespan. Meanwhile, the rest were aged more than 10 years (11 years above) and considered very risky machine lifespan due to danger of obsolescence, high repair bills and loss of reliability (Siemens et al., 2008). Hours of annual utilisation of farm machinery during the ownership period in the estates were recorded. Non-linear regression analysis was utilised to determine the *RF1* and *RF2* value for cumulative repair and maintenance costs model (expressed as percentage of the list price). Repair factors (*RF1)* and (*RF2)* for repairs cost of farm machinery in oil palm plantation were developed with reference to the models established by Calcante et al., (2013a), Calcante et al., (2013b), ASABE (2011a), ASABE (2011b) and Khoub bakht et al. (2008) as in equation 1.

$$CRM = RF_1 \left(\frac{h}{1000}\right)^{RF_2} \quad (1)$$

Where:

CRM = repair costs, RM/hour
RF_1 = repair factor 1, dimensionless
RF_2 = repair factor 2, dimensionless
h = total running hour, hour

Fuel cost

Fuel cost data collection were made on a total planted area of 1929.12 ha with an average stand per hectare of 136 palm/ha. From the interviews conducted, it was confirmed that 80% of the estate were flat, 10% of the estate were undulating while the remaining 5% were hilly area. The range of average yield for the estate was 24 to 28 tonnes/ha. Clear understandings of the full operation system were needed. Thus, field observations were made to record the process involved in the field operations. Face-to-face interviews were also conducted to understand the operation system of the estate. Pearson Correlation analysis was carried out to determine significant factors to the respective operation's fuel cost. Multiple linear regressions were carried out to determine and develop the fuel costs model for each operation. The developed predictive fuel cost model was then analysed using sensitivity analysis (equation 2) in order to determine the sensitivity of the fuel cost on changes of the variables for the four main operations. The sensitivity analysis value was used to indicate the change in fuel cost with a unit change in the variables.

$$S = \frac{Mean\ FC}{Mean\ F} \times \alpha \qquad (2)$$

Where:

S = Sensitivity analysis coefficient
Mean FC= Mean fuel costs
Mean F = Mean variable
α = Regression coefficient of the variable

In-field FFB evacuation

The in-field FFB evacuation operations begins once the harvesting of the FFB starts. After the FFB is harvested, the FFB is left on the ground along with the loose fruits. The loose fruits were collected together with the FFB to make it easy for the loader to load the FFB together with the loose fruits. Platforms were only used in hilly areas of which there were not many. Thus, the operation of the mini tractor and loaders were to cover the entire task to ensure all the FFB was collected.

Firstly, the mini tractor travels inside the task area going from tree-to-tree checking for harvested FFB, loading it manually using the strength of the loaders who use a spike as his tool. Then, the mini tractor moves on to the next tree. At the end of the task, the loader takes a count of the number of FFB collected and this was compared to the harvester's record to make sure both tally with each other. After that, the mini tractor moves on to the next task repeating the same procedure. After the mini tractor was filled to capacity with FFB, the mini tractor transfers its' load to the nearest bin. At the bin, the mini tractor uses its hydraulic jack to lift the load onto the bin. Based on personal communication with the supervisor, it was ascertained that if the mini tractor's hydraulic jack developed problems, manual loading from the mini tractor into the bin was carried out. This process was slower, but it was more fuel saving as the mini tractor was shut down during the process which can take more than five minutes to be completed. After loading, the mini tractor continues to where it previously left off.

Bins were transported by mini tractors and placed in the field in the area to be harvested on that particular day of operation. Bins were usually placed at the main road, or subsidiary/collection road, to make it accessible to the lorry that will take the bins to the mill later in the operation. Bins were placed at around 150m to 200m from the harvested task. Each task involves 50-60 trees. Meaning that, the bins placement intervals were one to every four tasks. Each bin can fill up to 10 tonnes of FFB and loose fruits. There were five bins available for loading. The dimensions of the bins were 3 × 1.5 × 1.5 metres.

Mainline transport

Mainline transport operations mostly deal with transporting the FFB to the mill. Firstly, the lorry loads the full bin on to the back of its trailer using the hydraulic system located at the back of the lorry. The lorry driver covers the bin with canvas as this helps to keep the FFB fresh by protecting the FFB from direct sunlight and rain as both these accelerates the free fatty acid (FFA) production in the FFB. Then the lorry travels as much as 7 kilometers to the nearest mill. After arriving at the mill, the lorry first weighs-in to record the lorry, plus FFB weight, on the mill's weigh bridge. After that, the lorry continues to move to the ramp for unloading. The hydraulic system was also used to unload the bin at the ramp ground. Upon unloading, a checker grades the FFB according to the ripeness standard of the mill. Different mills will have different ripeness standards, but most mills follow the Malaysian Palm Oil Board (MPOB) published ripeness standard. Then, the lorry driver receives a chit of the ripeness standard on the ramp and the lorry returns to the weigh bridge to take a second/empty weigh-in to determine the FFB's total weight delivered to the mill. Finally, the lorry travels back to the estate to either sum up the day's work or to go for a second trip. If a second trip was made, then the same procedure was repeated.

Manuring

Manuring operations started off with the fertiliser loading into the lorry. This was performed by all the manuring workers and the lorry driver. When loading was completed, the fertilizer bags were transported into the field according to the manuring schedule given by the executives. The fertilizer bags were unloaded along the main roads and sub-main roads at the rate of 2 ~ 3 bags per task i.e. 50-60 trees. The unloading process continues until all the fertilizer bags were placed. At this point, all the workers get off the lorry and start the manuring process. The lorry driver then drives the lorry to a checkpoint where the workers gather to rest or where the work ends later on in the day. The fertiliser applications were done manually by the workers. They fill as much fertiliser as they can carry in their bags and apply it using a custom bucket. The custom buckets were made to take an average of 0.5kg of fertiliser in one scoop.

Another alternate approach for the procedure of unloading the fertiliser bags was to cart around the fertilizer bags during the process of manuring. This incurs extra work for the lorry and estate management believed this increase fuel costs, but as there was no proper recording done on the process. The process was considered to have the same fuel cost as the first method. Manuring work were usually very dependent on the weather. During the rainy season, most of the manuring activities were halted to avoid wastage of fertiliser as it can leach from the soil into waterways. This delay was the reason why, at the end of any month, there was an extra manuring activity carried out to achieve the manuring target for the month. Upon completion of the work, the lorry takes the workers back to the fertilizer store. According to the field observations and interviews conducted, the range of fertiliser bags transported into the field daily were between 90 to 130 bags, which were 4.5 to 6.5 tonnes per day.

Spraying

Spraying operations starts off at the chemical store by mixing and filling chemicals into the spraying equipment. The herbicide/pesticide mixture were loaded onto the lorry trailer by the workers and drivers. Next, the lorry travels into the field bringing all the workers and herbicide mixture. Upon arrival, the workers start spraying the area in groups while being shadowed by the lorry as the lorry carries the herbicide mixture. The lorry also serves as the platform to refill herbicide mixture in the worker's knapsack sprayers. The spraying process was done manually using knapsack sprayers handled by humans. The spraying schedules were prepared by the executives, but schedules were usually very dependent on the weather. During the rainy season, most of the spraying activities were halted to avoid any wastage of herbicide as the herbicide can be drained or flushed off the weed leaves if the rain was heavy. Thus, this delay will be the reason why, at the end for any month, there will be an extra spraying carried out so as to achieve the spraying target for the month. Spraying for the day will end after all the herbicide mixture finished.

RESULTS AND DISCUSSIONS

Repair cost for farm machinery

For the repair cost, it was found out that age of machinery has a non-linear relationship with the accumulated repair cost. Thus, a specific mathematical model to predict the cumulative repairs cost for farm machinery in oil palm plantation operations has been developed and confirmed the previous study by Calcante et al. (2013a), Calcante et al. (2013b), ASABE (2011a), ASABE (2011b) and Khoub bakht et al. (2008). In the cumulative repair cost model for farm machinery in oil palm plantation, RF1 was equal to 1.4061, while RF2 was 1.6588. The model (equation 3) R^2 value of 0.8299 shows the goodness-of-fit for the model to the data was high. Thus, it was confirmed the model accuracy for predicting the repairs cost for farm machinery in oil palm plantation. The complete repairs cost mathematical model for the current study as shown in equation 3.

$$CRM = 1.4061\left(\frac{h}{1000}\right)^{1.6588} \qquad R^2 = 0.8299 \qquad (3)$$

Where:

CRM = repair costs, RM/hour
h = total running hour

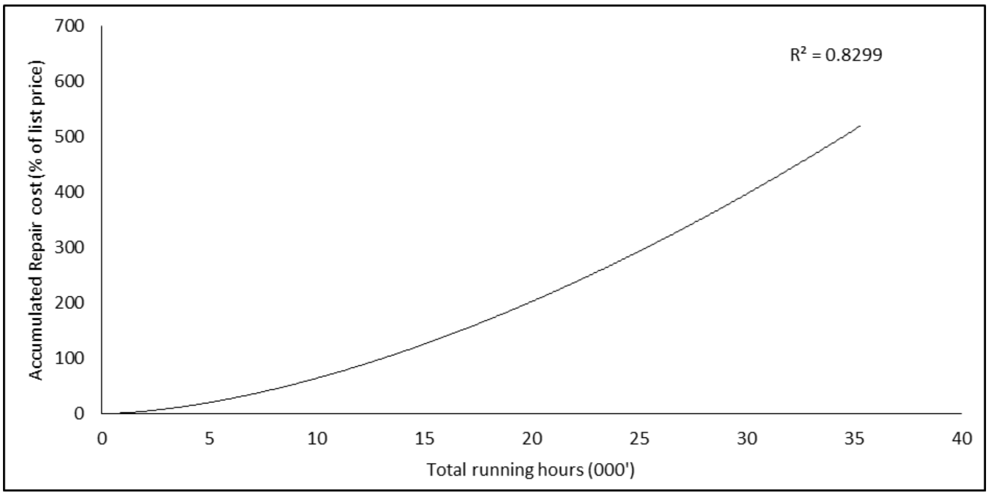

Figure 1: Oil palm farm machinery repair costs model by utilising non-linear regression of power function

As illustrated in figure 1, normally farm machinery in farmland were only utilised until 12000 hours within the ownership period. However, it was observed that farm machinery in oil palm plantations were utilised up to more than 30000 hours in the period. The longer utilisation of farm machinery in oil palm plantation was common as most of the farm machinery were used only to carry the loads e.g. FFB, fertiliser, water tank, transporting workers. Because carrying out such tasks, the machines were still reliable to be used in operations, even though they have exceeded the recommended estimated economic lifespan of farm machinery as suggested by Siemens et al. (2008) in table 2.

Table 2: Estimated economic lifespan of farm machinery adapted from Siemens et al. (2008)

Machine	Lifespan, Hours
All wheel-type tractors	12000
Crawlers	16000
Self-propelled combines	3000
Self-propelled windrowers	3000
Tillage equipment, mowers	2000
Planters, drills, large round balers	1500
Small and large square balers, rakes	2500

Figure 1 demonstrates the relationship of farm machinery accumulated running hours to the accumulated repair cost (percentage of list price) was non-linear, which was categorised into a power function with the highest R^2 value as compared to other non-linear functions. With R-square value was 0.8299, the *CRM* model shows a strong relationship between the variables.

Fuel costs for farm machinery

Fuel cost for farm machinery divided into four main oil palm plantation operations which were in-field FFB evacuation, mainline transport, manuring and spraying. It was found out that each of these operations have different factors effecting the total fuel costs for the farm machinery.

In-field FFB evacuation fuel costs

Fuel cost was correlated and significant at 0.01 level with all the available factors (Table 3) which were tractor horsepower, FFB tonnage, distance between bins, and number of workers. These factors correlated and were significant due to the nature of harvesting and in-field FFB evacuation jobs.

Table 3: In-field FFB evacuation correlation matrix

	Fuel cost	Tractor horsepower	FFB tonnage	Distance between bins	Number of workers
Fuel cost	1	0.882**	0.899**	0.468**	0.927**
Tractor horsepower	0.882**	1	0.875**	0.377*	0.763**
FFB tonnage	0.899**	0.875**	1	0.332**	0.820**
Distance between bins	0.468**	0.377**	0.332**	1	0.410**
Number of workers working	0.927**	0.763**	0.820**	0.410**	1

**Significant at 0.01 level (2-tailed)

Thus, the developed fuel cost model for FFB evacuation with the R^2 value of 0.945 as shown in equation 4.

$$FC = 1.673 + 0.630HP + 0.111MT + 0.370D + 0.520M \qquad R^2 = 0.945 \qquad (4)$$

Where:

FC = Fuel costs, RM/hour
HP = Farm machinery power, hp
MT = FFB tonnage, tonnes
D = Distance to bin, m
M = Man-day, man/day

A high R-square value indicates that the model prediction was accurate. For the FFB evacuation fuel cost model, the four variables (mini tractor horsepower, FFB tonnage, distance between bins and number of workers) would be enough to predict accurately the fuel cost for the daily operations. The results showed that the R^2 value was near to the value 1 and most likely there were no other variables needed to be considered to put into the model to make it more accurate.

Table 4: In-field FFB evacuation sensitivity analysis

No	Variables	Sensitivity analysis value
1	FFB tonnage	0.216
2	Number of workers	0.504

Sensitivity analysis in Table 4 shows that all the correlated and significant variables positively affected the fuel cost. Thus, any positive change in any of the independent variables will increase the fuel cost. Number of workers has the highest sensitivity value at 0.504. This means that an increase in the number of workers by one will increase the fuel cost by as much as RM0.504/day. This was the same with FFB tonnage. An increase in 1 tonne of FFB tonnage will increase the fuel cost as much as RM0.216/day.

In-field FFB evacuation has five factors that have been identified having direct effects on the fuel costs according to the field observation and interviews conducted with the estate staff and executives. Among the five factors, only four variables (tractor horsepower, FFB tonnage, distance between bins, and number of workers) were found to be correlated and significant to fuel cost. These factors correlated and were significant due to the nature of harvesting job. With more workers/harvesters working, there was more area/ground for the mini tractor to cover in order to collect all the harvested FFB. Although the FFB weight may be less, it was the distance that needs to be covered to load the FFB that makes the variable i.e. the number of workers working to have the highest correlation value and significance. Tractor horsepower also played a significant role in fuel cost as the relationship of tractor horsepower was directly proportional to the fuel consumption and fuel consumption was directly proportional to the fuel cost (Goering et al., 2003). But, for the estate, the mini tractors were not high horsepower tractors (Mileusnic et al., 2010). They did not use much fuel compared to typical private estates tractors. The distance between bins from the field travelled by the mini tractor after it was full of loads, was also correlated and significant, as during the travel it has to carry full load. This will eventually affect the fuel usage by the mini tractor. A 200 metres journey back to the bin with fully loaded at almost 1.5 tonnes, the mini tractor uses more fuel than it was at partial load or no load at all.

Mainline transport fuel costs

The main line transport correlation matrix was given in Table 5. Only the independent variable number of trips and FFB tonnage sent to mill were correlated and significant at 0.01 level to the dependent variable fuel cost. The distance to mill was constant and there were only two similar lorry models with the same horsepower used to take the FFB to the mill. The number of trips has the highest correlation value which once again shows that the distance the vehicle travels was the one that really affects fuel consumption in vehicles and directly affects the fuel cost. The regression test results give the coefficients on each of the inserted variables and constant for the model.

Table 5: Mainline transport correlation matrix

	Fuel cost	Number of trips	FFB tonnage sent to mill
Fuel Cost	1	0.964**	0.936**
Number of trips	0.964**	1	0.861**
FFB tonnage sent to mill	0.936**	0.861**	1

**Significant at 0.01 level (2-tailed)

Thus, the developed fuel cost model for mainline transport with R^2 value of 0.973 as shown in equation 5.

$$FC = 3.288 + 1.038MT + 13.167T \qquad R^2 = 0.973 \qquad (5)$$

Where:

FC = Fuel costs, RM/hour
MT = FFB tonnage sent to mill, tonnes
T = Number of trips, dimensionless

Mainline transport fuel cost model also has high R^2 value which almost reached the value 1. Mainline transport fuel cost model has only two variables (FFB tonnage sent to mill and number of trips) that were correlated and significant. This means that mainline transport fuel cost was only depended on the weight of the FFB delivered to the mill for each delivery and the number of trips the lorry made to the mill.

Table 6: Mainline transport sensitivity analysis

No	Variables	Sensitivity analysis value
1	FFB tonnage sent to mill	0.410
2	Number of trips	0.611

Sensitivity analysis (Table 6) shows that all the correlated and significant variables positively affected the fuel cost. Thus, any positive change in any of the independent variables will increase the fuel cost. Number of trips has the highest sensitivity value at 0.611. This means that an increase in number of trips by 1 will increase the fuel cost by as much as RM0.611/day. This was also the same with FFB tonnage sent to mill. An increase in 1 tonne of FFB tonnage sent to mill increase the fuel cost as much as RM0.410/day.

For the mainline transport, there were only two variables (number of trips and FFB tonnage) that were able to be analysed from the overall of six known variables (lorry horsepower, FFB tonnage, distance to mill, number of trips, driver's experience, and working hours). These two correlated and significant variables recorded high correlation values which showed that these two variables were related to fuel cost. The number of trips made per day was vital as it confirmed to the lowest or average amount of fuel usage. Thus, unnecessary additional trips to the mill caused higher fuel cost to the mainline transport operation. One main reason the correlation value for number of trips was higher was because of the nature of the data. The data only consisted of three values which were 0, 1 and 2 trips per day. This made the correlation value very high when compared to trips that have up to 7 or more values. FFB tonnage sent to mill was obviously a very significant variable to the fuel cost. This was because higher FFB tonnage will cause the lorry to carry more loads and to move heavier loads requires more fuel energy to be burned and this will cause high fuel usage in the engine to move the lorry at the same acceleration/velocity and this increases the fuel cost.

Manuring fuel costs

According to the manuring correlation matrix (Table 7), the dependent variable, fuel cost was correlated and was significant at 0.01 level to fertilizer tonnage, distance travelled for fertiliser distribution, area covered and number of workers working to apply fertiliser. The number of workers applying fertilisers has the highest correlation value while fertiliser tonnage has the lowest significant correlation value. This was true due to the nature of the manuring operation which relies heavily on the lorry for transportation during the manuring activities

Table 7: Manuring correlation matrix

	Fuel cost	Fertiliser tonnage	Distance travelled for fertiliser	Area covered	Number of fertiliser workers working
Fuel cost	1	0.848**	0.050	0.867**	0.900**
Fertiliser tonnage	0.848**	1	0.115	0.790**	0.686**
Distance travelled for fertiliser	0.050	0.115	1	0.059	0.147
Area covered	0.867**	0.790**	0.059	1	0.707**
Number of workers for fertiliser	0.900**	0.686**	0.147	0.707**	1

**Significant at 0.01 level (2-tailed)

Thus, the developed fuel cost model for manuring with the R^2 value of 0.870 as shown in equation 6.

$$FC = 0.565 + 1.433A + 0.303M + 0.897MT \qquad R^2 = 0.870 \qquad (6)$$

Where:

FC = Fuel costs, RM/hour
A = Area covered, ha
M = Number of fertiliser workers working, man/day
MT = Fertiliser tonnage, tonnes

For manuring predictive fuel cost model, the R^2 value was also higher than the value 0.5 and almost near to value 1. But, it was not as close as the R^2 value of both in-field FFB evacuation and mainline transport predictive fuel cost model. There were more factors that can be included into the predictive model. Factors such as contour of the field, precise distance to each block, fertiliser application rate etc. could be correlated and significant to the predictive fuel cost model (Safa et al., 2010, Mousavi et al., 2001) but due to the non-availability of the data from the estate, these factors could not be extracted and analysed.

Table 8: Manuring sensitivity analysis

No	Variables	Sensitivity analysis value
1	Area covered	0.382
2	Number of workers	0.323
3	Fertilizer tonnage	0.326

For manuring operations, the sensitivity analysis (Table 8) shows that all the correlated and significant variables positively affected the fuel cost. Thus, any positive change in any of the independent variables will increase the fuel cost. Area covered has the highest sensitivity value at 0.382. This means that an increase in area covered by 1ha will increase the fuel cost by as much as RM0.382/day. This was also the same with fertiliser weight. An increase in 1 tonne of fertiliser weight will increase the fuel cost by as much as RM0.326/day. The lowest sensitivity value was the number of workers. An increase in one worker will increase the fuel cost as much as RM0.323/day. The sensitivity analysis shows that these three variables were almost the same.

For manuring operation, fertiliser tonnage, area covered, and number of workers were variables which were correlated and significant because the weight of the fertiliser at full load to be delivered around the field played an important role in the fuel usage and fuel cost. The heavier the loads (more fertiliser was transported into the field), the fuel usage will be higher, as will be the fuel cost. The total area covered in manuring operations includes the amount of both fertilizer applied to palms and distance travelled in-field by the lorry at the end of the operations. Therefore, a larger area covered means that the total distance travelled in-field was quite high and a large amount of fertiliser was applied. High total distance travelled in-field results in high fuel usage and thus was a high fuel cost to the lorry as the lorry travelled long distances carrying loads (either full load or partial load) to cover many areas for manuring. Number of workers were also correlated to costs and significant due to the nature of the manuring operations and the area covered was also correlated and significant to the number of workers. The workers also used the lorry as their main transport into the field from the store together with the fertiliser. Any "journey" made by the fertilisers was accompanied by the workers. Thus, a high number of workers will be an extra load to the lorry while the Management sees this as an opportunity to increase the work capacity of the workers by further increasing the area for fertiliser to be applied. The distance travelled to different blocks was not correlated and not significant due to the uniformity of the data because the distance the fertilizer had to travel to each block was almost the same as the store and office was in the centre of the estate.

Spraying fuel costs

According to the spraying correlation matrix (Table 9), the dependent variable, fuel cost was correlated and significant at 0.01 level for the independent variables, number of spraying workers that working, and area covered. Number of spraying workers working was a much higher value of correlation than area covered. This was true due to the operation procedure in the estate in which the mini tractor was used mainly for transportation of both the labour and herbicides in-field.

Table 9: Spraying correlation matrix

	Fuel cost	Number of spraying workers working	Distance travelled	Area covered
Fuel cost	1	0.900*	0.050	0.599**
Number of workers for spraying working	0.900**	1	0.147	0.635**
Distance travelled	0.050	0.147	1	0.406**
Area covered	0.599**	0.635**	0.406**	1

**Significant at 0.01 level (2-tailed)

Thus, the developed fuel cost model for spraying with the R^2 value of 0.676 as shown in equation 7.

$$FC = 3.829 + 0.633A + 0.685M \qquad R^2 = 0.676 \qquad (7)$$

Where:

FC = Fuel costs. RM/hour
A = Area covered, ha
M = Number of workers for spraying working, man/day

For spraying fuel cost model, the R^2 value was still good because its value was more than 0.5 but not close to the value 1. This makes the fuel cost prediction to be less accurate (Fathollahzadeh et al., 2011). There were more factors which should be put into the predictive model. Factors such as weight of the herbicide, weight of the trailer, water tank capacity could be correlated and significant to the predictive fuel cost model but due to the non-availability of the data from the estate, these data could not be extracted and analysed.

Table 9: Spraying sensitivity analysis

No	Variables	Sensitivity analysis value
1	Area covered	0.137
2	Number of workers	0.729

For spraying, the sensitivity analysis (Table 10) showed that all the correlated and significant variables positively affected the fuel cost. Thus, any positive change in any of the independent variables will increase the fuel cost. Number of workers has the highest sensitivity value at 0.729. This means that an increase in number of workers by 1 will increase the fuel cost by as much as RM0.729/day. This was also the same with area covered. An increase in 1 ha of area covered will increase the fuel cost by as much as RM0.137/day.

For the spraying operation, number of workers, distance travelled, and area covered, were the variables that correlated with and was significant to the fuel cost. This was because the operation method of spraying relies on mini tractors as transportation means for the workers inside the field during the spraying. Adding to the weight of the workers, mini tractors carry a higher minimum weight on its trailer and thus, will increase the fuel usage and fuel cost for workers in-field transportation. The distance travelled from the store to the field was not found to be correlated to the parameters nor was the relationship significant. This may be due to the position of the store and office which were at the centre of the estate and the distance to each block was almost the same (Howard et al., 2013, Kim et al., 2013). Area covered for spraying activity was also correlated and significant to the cost due to the mini tractor was also used to transport the workers in-field and escort the workers whilst carrying the herbicide in its trailer. Thus, carrying these loads around the field increases fuel usage and fuel cost of the mini tractor.

CONCLUSIONS

Repairs and fuel costs of farm machinery in oil palm plantation operations in Malaysia has been successfully evaluated. The study has confirmed the theory saying the repairs costs vary depending on specific geographical conditions of farmland. This was proved by the RF factors of farm machinery in oil palm plantation were different with the RF developed by ASABE (2011; 2013). In this study, repairs and fuel costs specific mathematical models have been successfully developed to better reflect the conditions of farm machinery operations in oil palm plantation. There was also slight difference between the developed models compared to the standard established by previous research in different crops cultivation. This study also demonstrates the importance of machinery age, working hours, and size of farm machinery to the repair and maintenance cost for the farm machinery. In fuel costs, the findings also confirmed different type of crops cultivations influence in their respective fuel costs. In oil palm plantations, the farm machinery was utilised in a different way as compared to other crops cultivations. Farm machinery was mostly used to carry a load in the field. Farm machinery were rarely utilised to carry out the operations itself unless that particular operation has been mechanised in oil palm plantation such as fully mechanised manuring and weeding. Predictive fuel costs model for each of the four main operations (in-field FFB evacuation, mainline transport, herbicide spraying and manuring) has been successfully developed for the estates. The models can be used to predict fuel cost for these operations. All of the factors have positive value towards the fuel costs, which means the increasing of any significant correlated factors will increase the fuel costs. Conclusively, the findings of this study could contribute in assisting the development of well-managed farm machinery for getting satisfactory field operations and minimising repair and fuel costs in oil palm plantation.

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