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Country-appropriate operating cost estimation scheme based on curve fitting for rice combine harvester

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Abstract. This research explores two operating cost estimation models as a function of repair and maintenance (R&M) outlay for domestically-made rice combine harvesters: ASAE-based and power function-fitted estimation models. The goal is to establish a guideline for operating cost estimation suited to the agricultural context of Thailand. In the study, variable cost data belonged to the country's northeastern region. Simulations were carried out using MATLAB/Simulink and results compared. The ASAE-based operating cost estimations were consistently larger than those of power function-fitted model, and the divergence became more pronounced with increase in harvest area. The finding could be attributed to country-specificity in which R&M practices varied from country to country. Essentially, the power function-fitted estimation model is more suited to the agricultural context of Thailand, in comparison with the ASAE-based model which tends to overestimate the cost figure.

1. Introduction

Operational enhancement, together with labor shortage in agriculture, contributes to rapid adoption and ubiquity of domestically-made rice combine harvesters in many rice-growing countries in Southeast Asia, including Thailand [1-4]. In spite of productivity improvement, greater investment in agricultural machinery inevitably translates into soaring recurring costs. Thus, efficient cost estimation and management is key to profitable investment in rice combine harvesters.

In machine operation, operating costs vary in direct proportion to usage. In the Thai setting, the operating costs of agricultural machinery are made up of repair and maintenance (R&M) outlay, fuel cost, operator's wage, intermediary commission, transportation charge, lubrication expenditure, and administrative expenses. Furthermore, in Thailand's agricultural context, R&M expenditure accounts for a significant proportion (20-25%) of the operating cost of rice combine harvesters, depending on years in service, usage time, size of harvest area, soil condition, and crop variety. In addition, both R&M and operating costs of agricultural machinery are characterized by high non-linearity.

Conventionally, estimation of R&M outlay of farm machinery follows the American Society of Agricultural Engineers (ASAE) standards [5]. In fact, ASAE is operationally ideal for the agricultural context of the U.S., European countries, and some Middle East countries [6-8]. In other words, ASAE



scheme is more suited to rich and/or developed countries with high labor cost and systematic R&M programs in place.

In curve fitting, the accumulative R&M costs of agricultural tractors in Iran were estimated using linear, exponential, power and polynomial regression models; and the results showed that the power model was ideal in the trackers' early life (<1970 hours) and the polynomial model in later periods of the trackers' life [9]. In [10], five mathematical models (linear, logarithmic, polynomial, power, and exponential) were used to establish the relationship between accumulative R&M cost and hour of use and age of agricultural trackers; and the result revealed that the power function could best describe the relationship.

At present there exists no research on operating-cost estimation models as a function of R&M outlay specific to domestically-made rice combine harvesters. Thus, this research explores two operating cost estimation models as a function of R&M outlay using MATLAB/Simulink, i.e., ASAE-based and power function-fitted estimation models. The goal is to establish an operating-cost estimation guideline that is suited to the agricultural context of Thailand. In the study, variable cost data belonged to Thailand's northeastern region. In addition, simulations were carried out on the ASAE-based and power function-fitted operating cost estimation models and results compared.

2. Research material and methodology

Data on variable cost were gathered from 30 current owners of Thai-manufactured rice combine harvesters (i.e., 30 farm vehicles excluding pre-owned ones) in Thailand's northeastern region. The variable-cost data included annual repair and maintenance (R&M) outlay, fuel cost, operator's wage, intermediary commission, transportation charge (i.e., location-to-location transportation), lubrication, and administrative expenses. In Thailand, an intermediary acts as a business coordinator between owners of rice combine harvesters and rice farmers. Figure 1 illustrates the graphic rendition of a Thai-manufactured rice combine harvester.

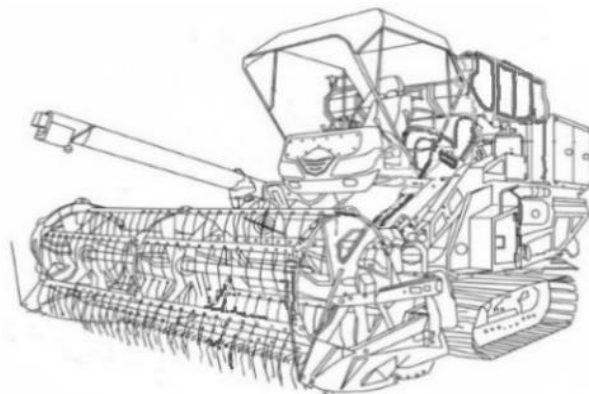


Figure 1. Graphical rendition of a typical Thai-manufactured rice combine harvester [12]

Conventionally, R&M expenses associated with agricultural machinery are estimated by ASAE standard and mathematical curve fitting models. Specifically, the accumulative R&M outlay estimation based on ASAE standard is a function of R&M cost factors (R_{F1} and R_{F2}), acquisition cost, and accumulative hours of utilization, as expressed in equation (1).

$$C_{rm} = R_{F1} P \left[\frac{h}{1000} \right]^{R_{F2}} \quad (1)$$

where C_{rm} is the accumulative R&M outlay, P is initial purchase price, R_{F1} , R_{F2} are the R&M cost factors (ASAE D497), and h is accumulative use of machine (in hour).

Meanwhile, in curve fitting, accumulative R&M expenditure is estimated based on curve fitting coefficients. In keeping with the ASAE-based estimation model, this research thus adopted power-function curve fitting in estimating R&M outlay using MATLAB/Simulink [11], as expressed in equation (2)

$$C_{RM} = ax^b \quad (2)$$

where C_{RM} is the accumulative R&M cost; a , b are curve fitting coefficients; and x is the harvest area.

Table 1 tabulates the ASAE-based R&M cost factors (R_{F1} and R_{F2}) and power function curve fitting coefficients (a , b), calculated from field data of accumulative R&M outlay relative to harvest area of 30 sampled owners of rice combine harvesters in the northeastern region.

Table 1: ASAE-based R&M cost factors and power function curve fitting coefficients

Machine	Base-models	R_{F1} or a	R_{F2} or b
Combine- harvester	ASAE	0.12	2.3
	Curve fit	4.515	1.275

3. Operating cost estimation models

3.1 ASAE-based operating cost estimation model

The operating cost estimation model based on ASAE was established and expressed in equation (3). The estimation model is a function of R&M outlay, fuel cost (F), operator's wage (W), intermediary commission (C), transport charge (T), lubricants (O), and administrative expenses (A), relative to harvest area (x).

$$C_{v(ASAE)} = C_{rm} + (F + W + C + T + O + A)x \quad (3)$$

where $C_{v(ASAE)}$ is the ASAE-based operating cost, C_{rm} is the R&M cost estimated by ASAE standard (equation (1)). Figure 2 illustrates the ASAE-based operating cost estimation model for combine harvesters.

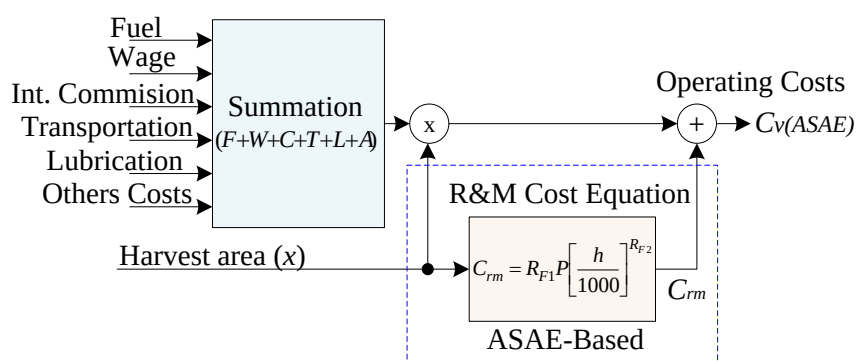


Figure 2. ASAE-based operating cost estimation model for combine harvester

Figure 3 depicts the schematic of operating cost estimation model based on ASAE standard using MATLAB/Simulink. The R&M cost factors (R_{F1} and R_{F2}) were 0.12 and 2.3, in accordance with ASAE D497 standard (Table 1), and the R&M cost estimation followed equation (1).

In simulation, the average unit cost (per *rai*) of fuel, wage, intermediary commission, lubricant, transport, and administrative expenses were THB 135; 60; 50; 7.75; 28 and 41.16, respectively, given

THB 33/USD exchange rate. A *rai* is a unit of area equal to 0.16 hectare (ha). The average acquisition cost of a new locally-made rice combine harvester was THB 2 million. In addition, the machine capacity was 3.5 *rai* per hour.

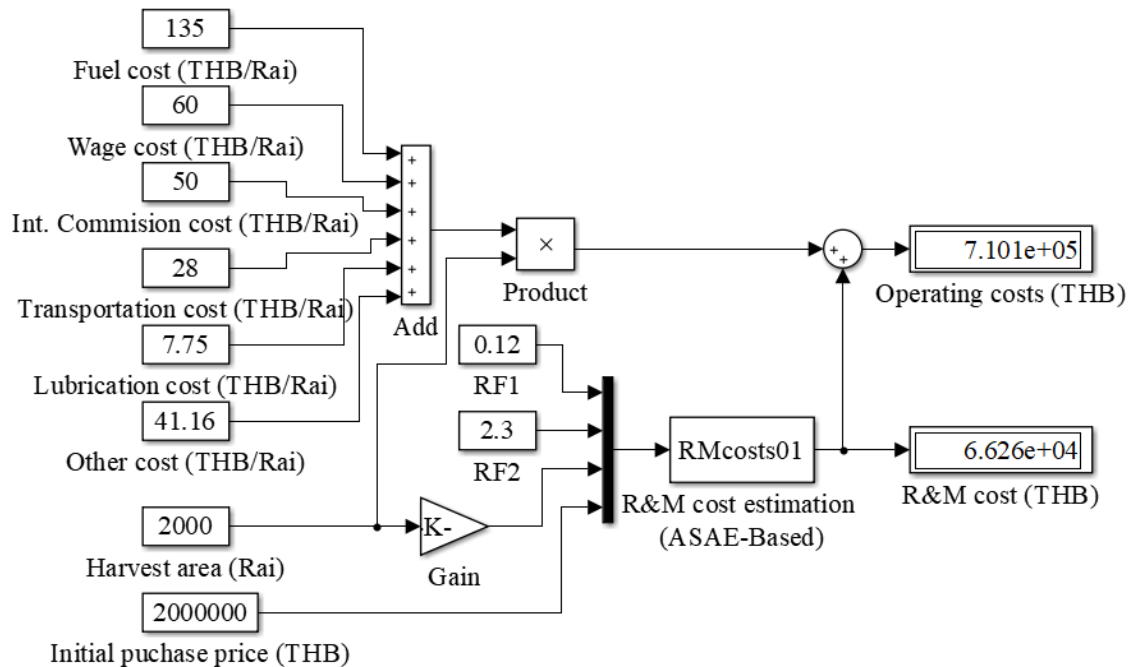


Figure 3. Schematic of the ASAE-based operating cost estimation model

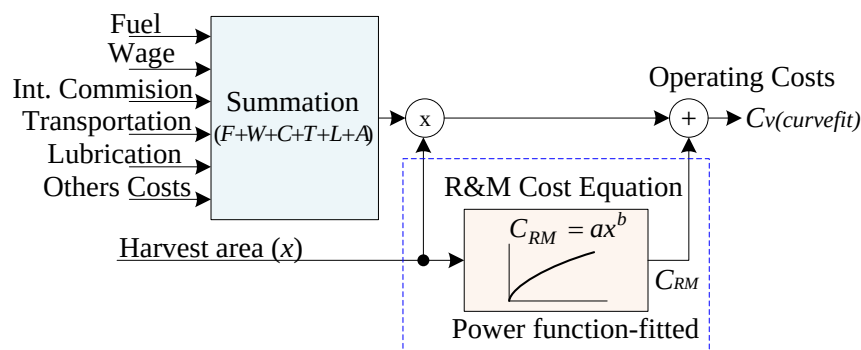


Figure 4. Power function-fitted operating cost estimation model for combine harvester

3.2 Power function-fitted operating cost estimation model

The operating cost estimation model based on power function fitting curve is mathematically expressed in equation (4). The estimation model is a function of R&M expenditure, F , W , C , T , O , and A , relative to harvest area (x).

$$C_{V(\text{curvefit})} = C_{rm} + (F + W + C + T + O + A)x \quad (4)$$

where $C_{V(\text{curvefit})}$ is the power function-fitted operating cost, C_{RM} is the R&M cost based on power function curve fitting (equation (2)). Figure 4 illustrates the power function-fitted operating cost estimation model for combine harvesters.

Figure 5 shows the schematic of power function-fitted operating cost estimation model using MATLAB/Simulink. The power function coefficients (a , b) were 4.515 and 1.275 (Table 1), and the R&M cost estimation followed equation (2).

In simulation, the average unit cost (per *rai*) of fuel, wage, intermediary commission, lubricant, transport, and administrative expenses were THB 135; 60; 50; 7.75; 28 and 41.16, respectively. Figure 6 illustrates the relationship between accumulative R&M outlay and accumulative harvest area using power function curve fitting, with R^2 of 0.9737 indicating high predictive accuracy of the power-function R&M cost estimation model (equation (2)).

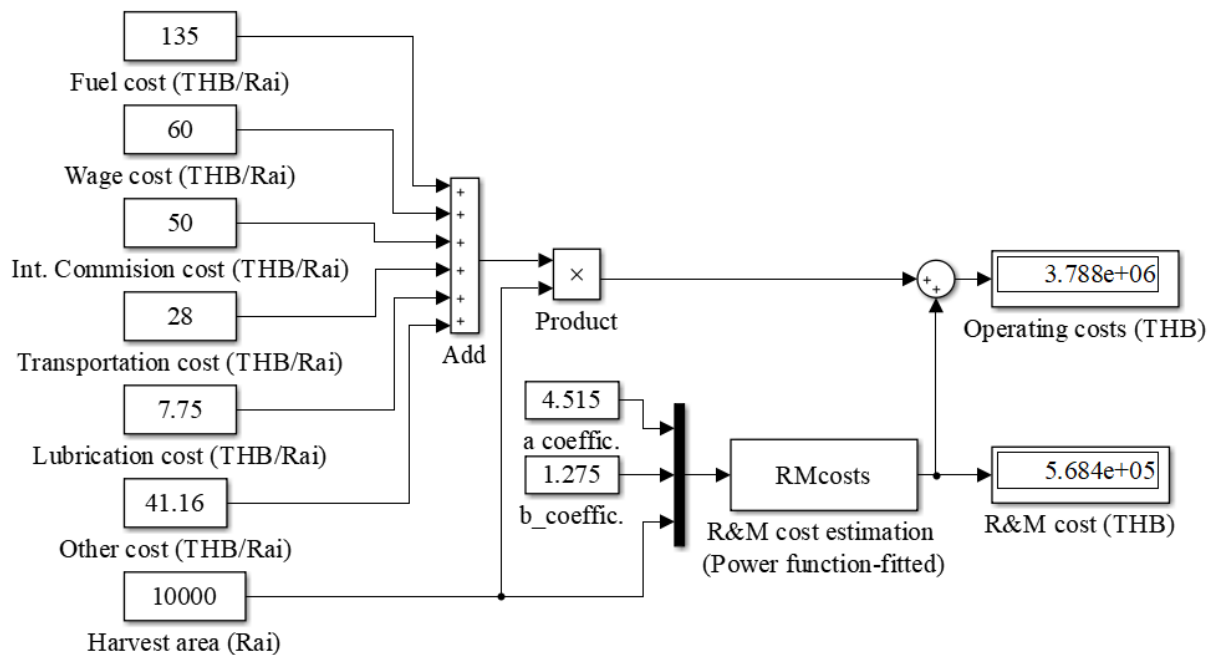


Figure 5. Schematic of the power function-fitted operating cost estimation model

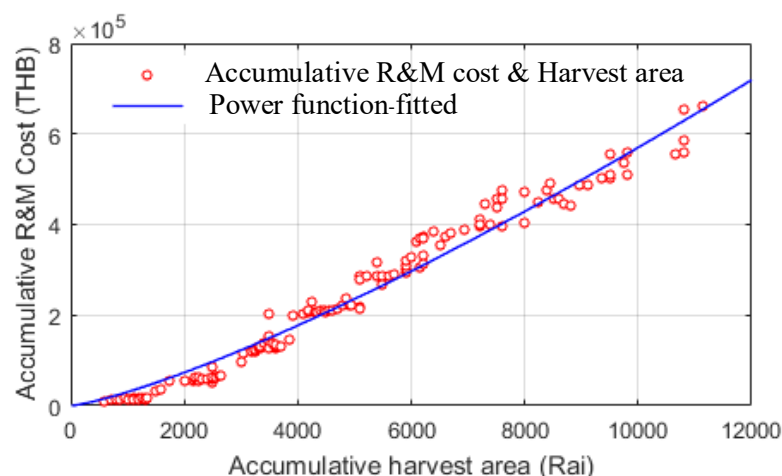


Figure 6. Power function-fitted accumulative R&M cost relative to harvest area

4. Simulation results and discussion

In this section, the ASAE-based and power function-fitted operating cost models were simulated and results compared.

4.1. ASAE-based operating cost estimation model

In simulation, the average unit cost of fuel, wage, intermediary commission, lubricant, transport, and administrative expenses were THB135; 60; 50; 7.75; 28 and 41.16 respectively. The average initial purchase price was THB 2 million, and the machine capacity was 3.5 *rai* per hour. The harvest area (x) was varied between 1000 – 12000 *rai*, in 1000-*rai* increments.

Figure 7 shows the estimated R&M and operating costs of rice combine harvesters relative to harvest area based on ASAE estimation model. The ASAE-based R&M outlay accounted for roughly 40 – 50% of overall operating cost, consistent with ASAE standards [6]. The large proportion of R&M cost was attributable to high repair and spare-parts costs in the U.S. setting (i.e., wealthy and advanced economy) as well as regular maintenance frequency, as reflected in the R&M cost factors (R_{F1} and R_{F2}). Table 2 presents the R&M and operating costs of rice combine harvesters relative to harvest area using ASAE-based estimation model.

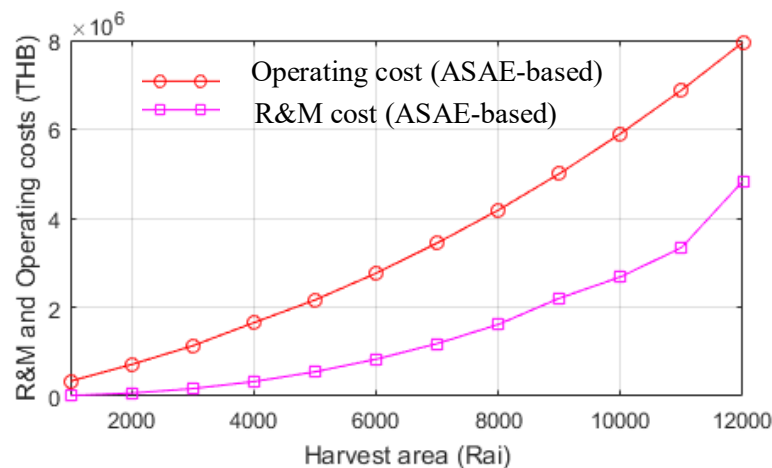


Figure 7. Estimated R&M and operating costs in relation to harvest area based on ASAE standard

4.2. Power function-fitted operating cost estimation model

In simulation, the average unit cost of fuel, wage, intermediary commission, lubricant, transport, and administrative expenses were identical to in the ASAE-based model. The harvest area (x) was varied between 1000 – 12000 *rai*, in 1000-*rai* increments.

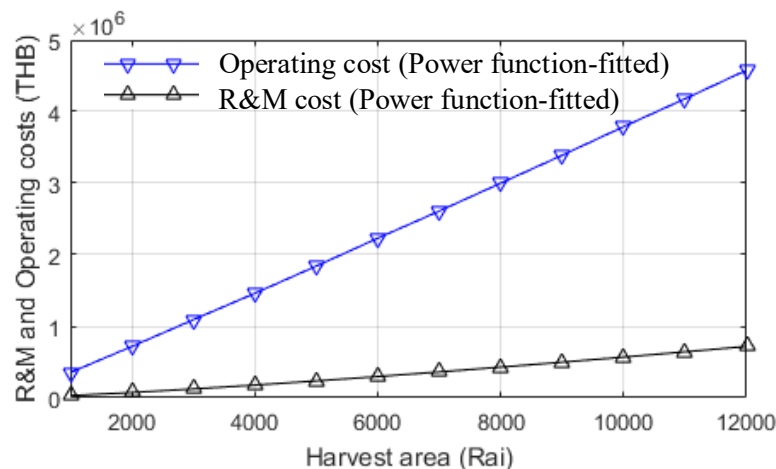


Figure 8. Estimated R&M and operating costs relative to harvest area based on power function curve fitting

Figure 8 illustrates the estimated R&M and operating costs relative to harvest area based on power function-fitted estimation model. By comparison, the R&M cost based on power function curve fitting accounted for substantially smaller proportions of overall operating cost, vis-à-vis that of ASAE standard. The comparably smaller proportion of R&M expenditure could be attributed to country-specificity (i.e., Thailand's context) where homemade spare parts are ubiquitous, repair costs are inexpensive (rock-bottom), and maintenance schedule is rarely followed. Table 2 presents the R&M and operating costs of rice combine harvesters relative to harvest area based on power function curve fitting.

4.3. Comparison between ASAE-based and power function-fitted estimation models

Figure 9 illustrates the simulated operating costs of rice combine harvesters associated with the ASAE-based and power function-fitted estimation models, in comparison with actual data. The simulation results revealed that the ASAE-based operating cost estimations were larger than those of the power function-fitted model across all harvest area sizes. Besides, the cost divergence became more pronounced as the harvest area increased. Meanwhile, the operating costs of the proposed model and actual data were compatible.

Given the country-specificity, the power function-fitted model is more suited to the Thai context for estimating the operating cost of rice combine harvesters, in comparison with the ASAE-based estimation model which tends to overestimate the operating cost.

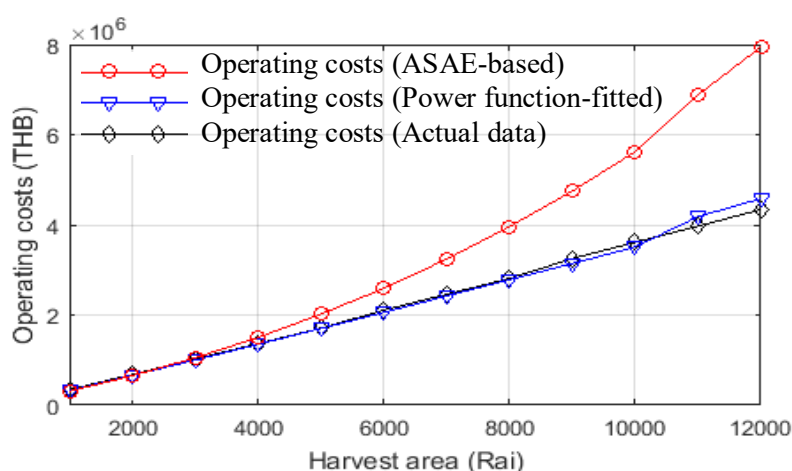


Figure 9. Comparison between estimated operating costs of ASAE-based and power function-fitted estimation models relative to actual data

Table 2. Comparison between ASAE-based and power function-fitted cost estimation models

Harvest area (Rai)	ASAE-based Model		Power function-fitted Model	
	R&M cost (THB)	Operating cost (THB)	R&M cost (THB)	Operating cost (THB)
2000	66,260	710,100	73,200	716,800
4000	326,300	1,646,000	176,700	1,464,000
6000	829,100	2,761,000	296,300	2,228,000
8000	1,607,000	4,182,000	427,700	3,003,000
10000	2,684,000	5,904,000	568,400	3,788,000
12000	4,830,000	7,946,000	717,200	4,580,000

5. Conclusions

This research investigated two conventional approaches to estimating operating cost of domestically-made rice combine harvesters as a function of R&M outlay: the ASAE-based and power function-fitted operating cost estimation models. The aim is to establish a guideline for estimating operating cost that is suited to the agricultural context of Thailand. In the study, variable-cost data were collected from Thailand's northeastern region, including R&M outlay, fuel cost, operator's wage, intermediary commission, transportation expenditure, lubrication cost, and administrative expenses. The power function curve fitting coefficients (a , b) of R&M cost were then determined. The ASAE-based and power function-fitted operating cost estimation models were simulated using MATLAB/Simulink and results compared. The ASAE-based estimations were consistently larger than those of the power function-fitted estimation model due to country-specificity, with divergence more evident as the harvest area increased. In essence, the power function-fitted estimation model is more suited to the Thai setting, vis-à-vis the ASAE-based model which tends to overestimate the operating cost figure.

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