A MECHANISTIC PROBABILISTIC MODEL TO ESTIMATE TRUCK OPERATION COST

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Abstract- Truck operations cost is the major cost element in the total supply chain for a better service. In relation to such situations, estimation of the truck operation cost has become a main factor in making important decisions. Considering the truck fleet and its operations of a company, a method of estimating the truck operation cost has been developed. The Mechanistic Probabilistic Vehicle Operation Cost Model (PVOC) has been used to estimate the truck operation cost of 6-wheel trucks and 10-wheel trucks using fuel cost, tire cost, maintenance and repair cost, oil cost, capital depreciation cost, Insurance cost, operator wages and labor cost. The PVOC calculates the probabilistic estimate of truck operating costs, including expected value and the associated uncertainty of the estimate for a selected sample. Methods have been developed for measuring the identified variables. Service life of the vehicle has been found to be the leading variable that makes greater variation in the truck operation cost as per to the deterministic sensitivity analysis. As resulted by the model, the truck operation cost of 10-wheeler is 60.505-99.126 Rs per km while the 6-wheeler cost is 26.876-59.598 Rs per km.

Keywords- Truck operation cost, POVC, 10-Wheelrs, 6 Wheelers

I. INTRODUCTION

The demand for transporting goods via trucks is increasing rapidly and limited resources on the sector calls for a keen planning and optimal way of utilizing the resources which are available in the transport sector. However, in utilizing the available resources in an optimal way, identifying the road user cost is vital. As suggested by (Velumurugan, et al., 2009) road user cost is the combination of vehicle operation cost (55-75%), time cost (20-40%) and accident and safety cost (5-10%).

Berthelot et al. (1996) suggests that vehicle operating costs are the costs associated with owning, operating and maintaining a vehicle including: fuel consumption, tire wear, maintenance and repair, oil consumption, capital depreciation, license and insurance, and operator labor and wages.

The estimation of the truck operation cost helps to identify the actual cost of operation, as it is the main factor in deciding the transport cost. This provides benefits for the operator as well as the shipper by sharing economic gains in a fare manner. In the determination of the cost effectiveness in alternative road maintenance strategies, the use of the vehicle operation cost (VOC) model is significant. In such circumstances, vehicle operation costs are a part of the road user cost in cost benefit calculation, which is being conducted to determine whether the project should be funded or not.

II. LITERATURE REVIEW

Barnes and Langworthy (2003) have presented two models of calculating both car operation cost and the truck operation cost. As this study is concerned about both trucks and other vehicles some of the data have been analyzed together. Therefore, mistakes could be expected from their methodology.

Shukri et al. (2013) modelled to determine vehicle operation cost based on the Malaysian military trucks to address their issues. Researcher insists that the driver wages, allowances insurance rates and licensing costs should be highly considered in developing the model even though they have been excluded from the study. As well as above factors, weather condition, road roughness and frequency of usage are some other factors which may affect the operation cost of a vehicle.

Akçelik and Besley (2003) have given a clear model to estimate the vehicle operation cost. But some of the important variables brought forward by previous researchers such as maintenance cost, depreciation and labor cost have not been considered in this model.

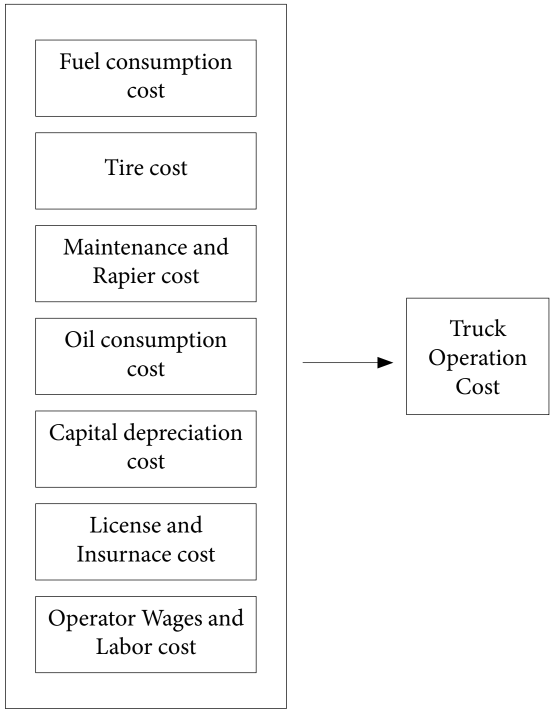
Harrison and Chesher (n.d.) have introduced a method to estimate the vehicle operation cost using a survey in Brazil. This is a result of a very large survey. Therefore, the data collection has been more complex and accurate data can be expected. Clear techniques have been used to conduct the research. Data analyzation of the study is unclear in this study. Computer software has not been used for data analysis as this research is an older one.

It has been suggested that the (Berthelot, et al., 1996) Vehicle operating costs are the costs associated with owning, operating and maintaining a vehicle including: fuel consumption, tire wear, maintenance and repair, oil consumption, capital depreciation, license and insurance, and operator labor and wages. Possible variables of the study are above mentioned factors. The model is based on analyzation of these factors. The relationship between above factors against vehicle characteristics, road geometrics, road surface type, road surface condition, environmental factors as well as the vehicle speed have been considered. An advantage of this mechanistic model is the model could be developed in to a sensitivity analysis and could identify the sensitive changes within the model. The inputs of the sensitivity analysis have been collected from published literature and interviews with heavy vehicle operators. Using the PVOC model deterministic sensitivity analysis has been developed, which illustrates a schematic of the sensitivity analysis output for each individual variable. It has been suggested that the annual kilometres travelled, vehicle operations speed and vehicle capital cost have greater effect on the output of PVOC model. Therefore, the sensitivity analysis indicates the better relationship between the above factors and the variables of the study. In finding VOC, as mentioned earlier expected VOC values calculated standard deviation of the estimated VOC resulting ranges of values on 95% confidence interval has been considered.

III.METHODOLOGY

Conceptual Framework

Figure 1 shows the conceptual framework of the study. It includes how the outcome is taken by the model. The figure indicates the primary path of approach towards the study.



The fuel cost could be expressed basically in means of resistive forces which act on the vehicle, mechanical efficiency as well as energy content of the consumed fuel.

Total resistive forces acting on a vehicle is the sum of rolling resistance and aerodynamic drag (Hertz, cited in Berthelot 1996) which can be expressed mathematically;

$R_{total} = R_{roll} + R_{drag}$

where R_{total}= total vehicle resistance (N), R_{roll} = rolling resistance (N), and R_{drag} = aerodynamic drag (N).

The rolling resistant could be expressed by using gross vehicle weight, coefficient of rolling resistance between tire and road. It has been suggested by (Berthelot et al. 1996) that

$R_{roll} = C_r W_{vehicle} k_r k_s$

where R_{roll} = rolling resistance (N), C_r = coefficient of rolling resistance, $W_{vehicle}$ = Gross vehicle weight (N), k_r = coefficient of road roughness and k_s = coefficient of road stiffness.

Resistant of the aero dynamic drag is based on the shape of the vehicle, frontal area of the vehicle, air density as well as the relative velocity between air and the vehicle. As per (Hertz, cited in Berthelot 1996) it can be expressed mathematically as;

$R_{drag}=0.5rC_d AV^2$

where R_{drag} = aerodynamic drag (N), r = air density (kg/m3), C_d = wind mean averaged coefficient of drag, A = frontal area of vehicle (m^2), and V = velocity of vehicle (m/s).

Berthelot et al. (1996) suggests that the Vehicle fuel consumption is a function of how efficient the vehicle is at converting the potential energy of the fuel into useable energy for the vehicle. It could be expressed in an equation as follows;

$fuel=R_{total} / [l_{total}(Ec_f)]$

where fuel = fuel consumption rate (l/km), l_{total} = total mechanical efficiency, Ec_f = fuel energy content (kJ/l)

Total mechanical efficiency depends on the engine efficiency, transmission efficiency and differential efficiency. It has been suggested by (Hertz, cited in Berthelot 1996)

$l_{total}=k_{engine}k_{trans}k_{diff}$

where l_{total} = Total mechanical efficiency coefficient, k_{engine} = Coefficient of engine efficiency, k_{trans} = coefficient of transmission efficiency, and k_{diff} = coefficient of differential efficiency

Tire cost;

The tire cost includes the tire type, tire quality, road conditions, and tire maintenance practices. The effect of road surface on tire costs is primarily a function of road surface texture and roughness (Cenek, cited in Berthelot 1996). It could be expressed in a mathematical equation by;

$$TC= \frac{(C_t N_t)}{(L_t K_{tt} K_{tr})}$$

TC= total tire cost (Rs/km), Ct=Cost per tire (Rs/km) N_t =Number of tires, k_{tr}=Road roughness coefficient, k_{tt} =Road texture coefficient, L_t=Life of tire(km).

Maintenance and repair cost;

It has been identified that the maintenance cost has affected the VOC by many previous researchers. The road roughness is a significant factor in deciding the maintenance cost. It has also been understood that rough roads cause the cost on maintenance to be high. The proof of character on the above is as follows; (Watanatada, et al., 1987)

$MC=M_{cf}k_{mr}$

where MC = maintenance cost (Rs/km), M_{cf} = average maintenance cost (Rs/km) and k_{mr} = road roughness coefficient

Oil consumption cost;

The oil consumption of a vehicle depends on the ownership of the vehicle. The routine of changing oil is considered in deciding the oil consumption cost. Berthelot et al. (1996) suggests

OC=OCC/D0

where OC = oil cost (Rs/km), OCC = oil change cost (Rs/service) and D0 = oil change frequency (km/service)

Capital depreciation cost;

The capital depreciation cost is calculated by considering the present value of the vehicle and its service life. (Jayaweera, et al., 2001) Suggests that the depreciation is provided for below the apportionment of the cost of a new bus under the estimated lifetime kilometres of a bus. Assumptions have been made for the model suggested by Jayaweera, and the situation states that it indicates required values which could be functional for trucks in addition to other vehicles. It could be expressed mathematically as; V/K

Where V =value of a bus in today's prices, new or at importation and K= lifetime kilometres estimated for the bus over eight years in normal operation. Assuming the above formula is applicable for trucks as well.

License and Insurance cost;

The annual license renewing fee and insurance fee is included for this particular cost. Annual license and insurance fee is converted to the "per kilometer" value of license and insurance cost as the model decides the operation cost per kilometre.

Operator wages and labor cost;

Hence this study is based on a company, its work labor cost and operator wages highly affect in deciding the vehicle operation cost. The operator wages and the labor cost are being converted into the per kilometer value for further calibrations of the modal.

Data Collection

Apart from license, insurance cost, operator wages and labor cost all the other variables cannot be collected directly. Several inputs should be taken as data. Both primary and secondary data were used in this study. Secondary data was collected referring to the previous literature. Using a survey by interviewing the truck operators of the company, primary data was collected. The target population of the study is 160 trucks which operates in a company (10 wheelers and 6 wheelers).

60 is the sample size of the study based on the Central Limit Theorem, when the sample size is more than or equal to 30, the data distribution becomes a normal. As there are 2 types of trucks, stratified random sampling technique is ideal. According to the proportions of the trucks the sample size of strata would be 30.

The model

The mechanistic probabilistic vehicle operation cost model is being used for this study. Microsoft EXCELTM is the data analysing software as it is more user friendly and it is capable in enabling the model. After the data collection, findings are being entered to a spreadsheet. For each input the Minimum Value, Average value and the maximum value is estimated. Using the average values, the expected value of the model is estimated using the equations for each variable. The following equation was used for the development of PVOC model and the Sensitivity analysis.

Truck operation cost= FC+TC+MC+OC+CDC+LIC+LC Where FC= fuel cost, TC=tire cost, MC= Maintenance and repair cost, OC= Oil cost, CDC= Capital depreciation cost, LIC= Licence and insurance cost and LC= operator wages and labour cost. Deterministic sensitivity analysis is conducted to identify the variables which are being influenced and it gives closure to make sensitive changes in the model. The analysis is focused on those variables which are affected more on the VOC. In the deterministic sensitivity analysis, the changes which occur in the VOC by the changes of input are considered. For the better understanding of the reader, the results of the sensitivity analysis are being illustrated on a graph. The Mechanistic Probabilistic Vehicle operation model provides the point estimation as per the expected value. Whereas the sensitivity analysis involves in screening the data set as well as providing the effect of uncertainty in each of the model variable.

Final finding of the model was developed by the estimated expected value of the model. The expected values for each data set which had been collected in the data collection were estimated. Using the above-mentioned data set the standard deviation was estimated. The outcome is subjected to a 95% confidence interval for an accurate and robust result. Probability density function diagram determines the expected value and the uncertainty associated with each estimate of the truck operation cost. It is the variation of the truck operation cost against the relative frequency. As it is an advance analysis of data, SPSS is used for the development of the probability density function diagram.

IV. DATA ANALYSIS

One of the main advantages of mechanistic probabilistic vehicle operation cost model is the performance of sensitivity analysis to indicate which inputs are most sensitive and influential to changes within the model. By adjusting an input one at a time, sensitivity analysis has been illustrated for both 6 wheelers and 10 wheelers. Those variables which have a higher impact on the model could be identified as the dominant variables. The user should focus on developing an accurate distribution on these dominant variables as it could cause a significant variation in the outcome of the model.

Table 1 and Table 2 indicate the values which have been used for the Mechanistic probabilistic vehicle operation cost model as well as the deterministic sensitivity analysis. These tables include the survey results which have been conducted to obtain primary data and secondary data and these data shown below have been obtained from previous literature. Average values have been used to calculate the expected value of the truck operation cost while minimum values and maximum value were the inputs for the estimation of sensitivity analysis. Table 1 summarizes the input values for 10 wheels whereas Table 2 summarizes the input values for 6 wheelers.

Using the minimum and maximum values from Table 1 and 2, Deterministic sensitivity analysis has been performed. Figure 2 illustrates the sensitivity analysis for 10 wheelers while figure 3 illustrates the sensitivity analysis for 6 wheelers. All the inputs have been subjected for the sensitivity analysis except the Number of tires and labor cost since they hold constant values which do not have any variations.

Table 1. Input values for 10 wheels

Inputs	Units	Min	Avg	Max	Data Type
Gross Vehicle weight	N	240000	245000	250000	Primary
Coefficient of rolling resistance	Dimensionless	0.003	0.004	0.005	Secondary
Coefficient of aerodynamic drag	Dimensionless	0.7	0.8	0.9	Secondary
Vehicle fontal area	square meter	8	8.1	8.2	Primary
Coefficient of engine efficiency	Dimensionless	0.35	0.37	0.39	Secondary
Coefficient of transmission efficiency	Dimensionless	0.8	0.9	0.95	Secondary
Coefficient of differential efficiency	Dimensionless	0.8	0.9	0.95	Secondary
Fuel energy content	kJ/l	35000	35300	35600	Secondary
Fuel cost	Rs/l	95	106	117	Primary
Tire cost	Rs/Tire	50000	55153.85	60000	Primary
No of tires per vehicle	Tire/veh	10	10	10	Primary
Life span of a tire	km/tire	28000	34461.54	50000	Primary
Vehicle maintenance cost	Rs/km	2.7777778	5.516683	13.75	Primary
Oil change cost	Rs/oil change	8000	15423.08	20000	Primary
Oil change frequency	km/oil change	5000	9730.769	15000	Primary
Vehicle service life	years	0.25	4.15	7	Primary
Vehicle present value	Rs	4000000	4784615	6600000	Primary
Annual kilometers traveled	km/year	20000	39020.76	60000	Primary
Annual license and insurance cost	Rs/year	75000	107153.8	150000	Primary
Average vehicle operation speed	m/s	11	14	17	Primary
Coefficient of road roughness	Dimensionless	0.85	1	1.1	Secondary
Coefficient of road stiffness	Dimensionless	0.9	1	1.15	Secondary
Road roughness tire factor	Dimensionless	0.95	1	1.05	Secondary
Road texture tire factor	Dimensionless	0.95	1	1.05	Secondary
Road roughness maintenance factor	Dimensionless	0.8	1	1.2	Secondary
Air density	kg/m3	1.1	1.2	1.3	Secondary
Labor cost	Rs	2.65	2.65	2.65	Primary
Service life of the vehicle	Km	12000	141307.7	250000	Primary

Source: Developed by authors (2018)

Table 2. Input values for 06 wheels

Inputs	Units	Min	Avg	Max	Data Type
Gross Vehicle weight	N	171000	173000	175000	Primary
Coefficient of rolling resistance	Dimensionless	0.003	0.004	0.005	Secondary
Coefficient of aerodynamic drag	Dimensionless	0.7	0.8	0.9	Secondary
Vehicle fontal area	square meter	6.6	6.65	6.7	Primary
Coefficient of engine efficiency	Dimensionless	0.35	0.37	0.39	Secondary
Coefficient of transmission efficiency	Dimensionless	0.8	0.9	0.95	Secondary
Coefficient of differential efficiency	Dimensionless	0.8	0.9	0.95	Secondary
Fuel energy content	kJ/l	35000	35300	35600	Secondary
Fuel cost	Rs/l	95	106	117	Primary
Tire cost	Rs/Tire	50000	56846.15	65000	Primary
No of tires per vehicle	Tire/veh	6	6	6	Primary
Life span of a tire	km/tire	25000	43461.54	80000	Primary
Vehicle maintenance cost	Rs/km	2	4.161699	6.923077	Primary
Oil change cost	Rs/oil change	9000	15615.38	18000	Primary
Oil change frequency	km/oil change	5000	9192.308	15000	Primary
Vehicle service life	years	1	6.153846	12	Primary
Vehicle present value	Rs	1800000	2961538	3900000	Primary
Annual kilometers traveled	km/year	21666.67	44508.55	64000	Primary
Annual license and insurance cost	Rs/year	50000	64923.08	100000	Primary
Average vehicle operation speed	m/s	11	14	17	Primary
Coefficient of road roughness	Dimensionless	0.85	1	1.1	Secondary
Coefficient of road stiffness	Dimensionless	0.9	1	1.15	Secondary
Road roughness tire factor	Dimensionless	0.95	1	1.05	Secondary
Road texture tire factor	Dimensionless	0.95	1	1.05	Secondary
Road roughness maintenance factor	Dimensionless	0.8	1	1.2	Secondary
Air density	kg/m3	1.1	1.2	1.3	Secondary
Labor cost	Rs	2.65	2.65	2.65	Primary
Service life of the vehicle	Km	60000	242384.6	350000	Primary

Source: Developed by authors (2018)

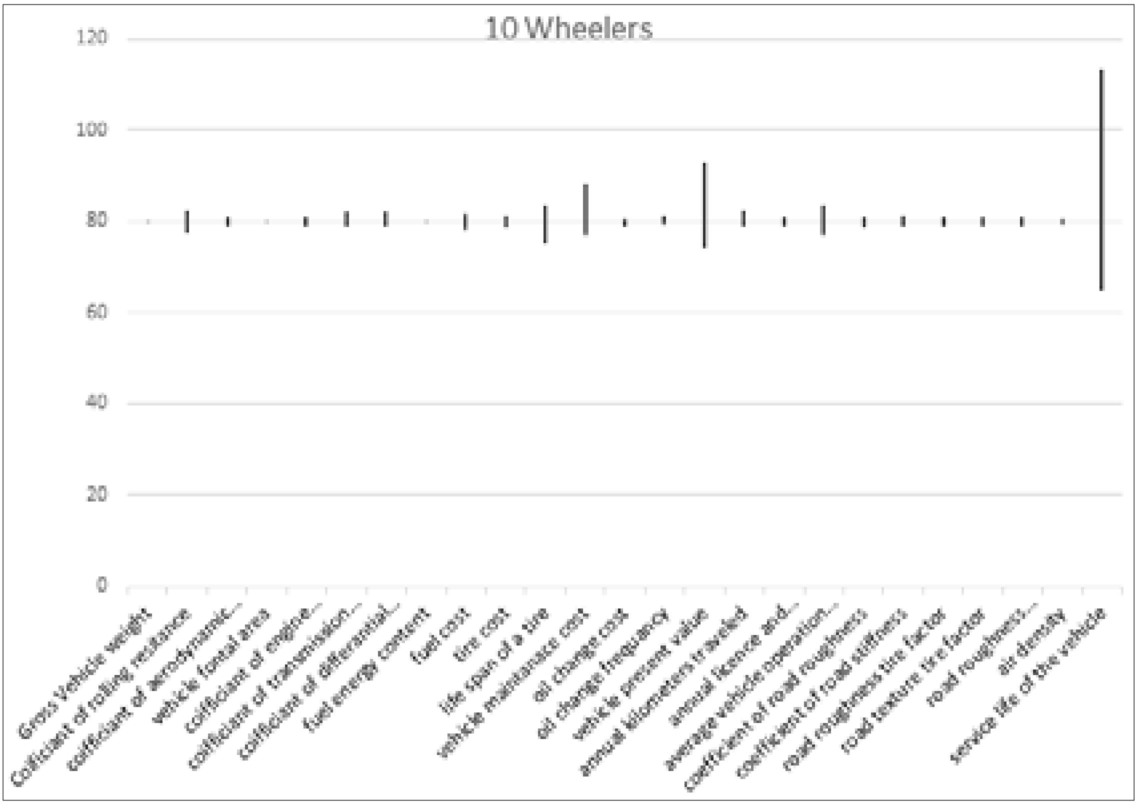


Figure 3. Deterministic Sensitivity Analysis for 6 Wheelers

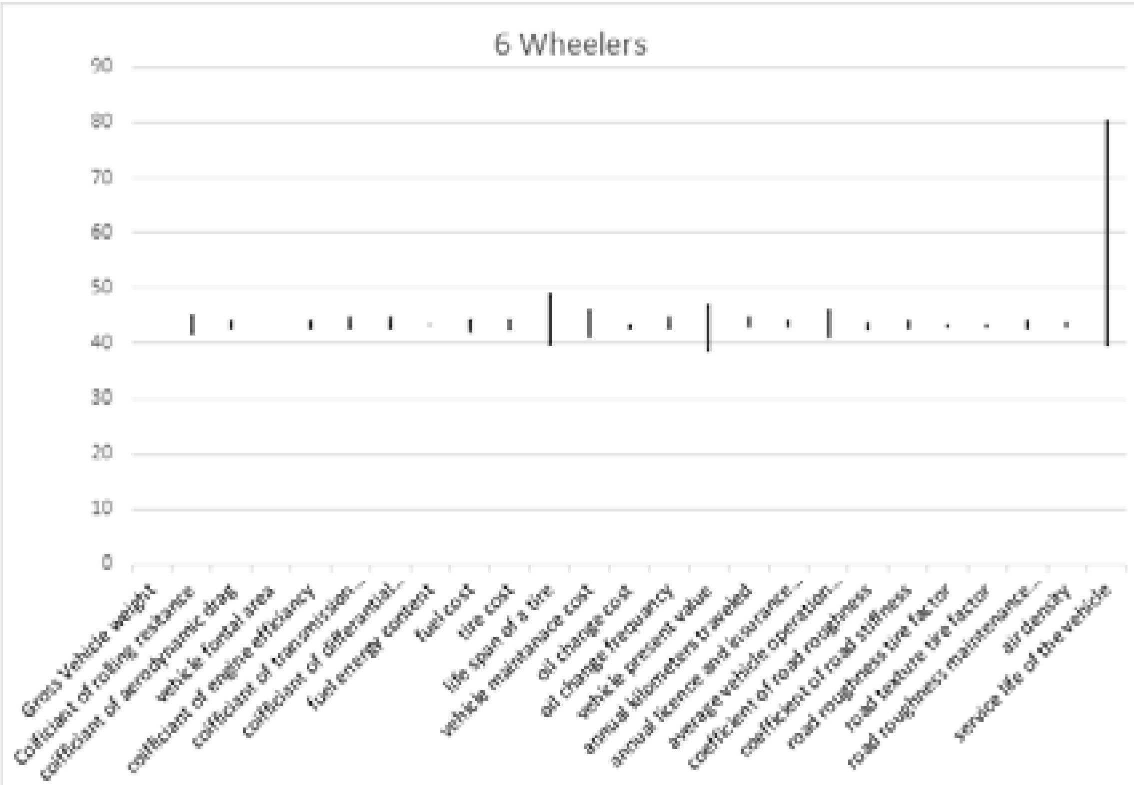


Figure 2. Deterministic Sensitivity Analysis for 10 Wheelers
Source: Developed by authors (2018)

As per the results of the sensitivity analysis service, the life of the vehicle, vehicle present value, vehicle maintenance cost and life span of a tire consume the largest effect on the output of the model for both types of vehicles. In addition to that, the sensitivity analysis figures out the variables which have the least affecting uncertainty. The inputs which show high sensitivity towards the model should receive proper attention; hence an accurate probability distribution should be maintained.

Even though the deterministic sensitivity analysis is not used to decide which variable should be dropped, it was used in focusing more on developing an accurate probabilistic set of inputs.

In obtaining the Truck operation cost, by the usage of average values in Table 1 and Table 2, expected values have been derived. Here the mechanistic probabilistic vehicle operation cost model has been driven out. Also in calculating the variables, equations which

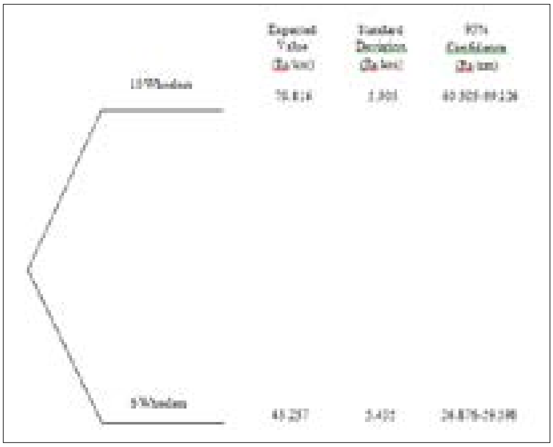


Figure 4. Truck Operation Cost,
Source: Developed by authors (2018)

were mentioned in the methodology have been used. Furthermore, standard deviation has been calculated and the values obtained by the model have been subjected to a range corresponding to a 95% confidence interval.

Figure 4 indicates the expected values, standard deviations and 95% confidence interval range of the values taken by the mechanistic probabilistic vehicle operation cost model. The values have been obtained for both 10 wheelers and 6 wheelers.

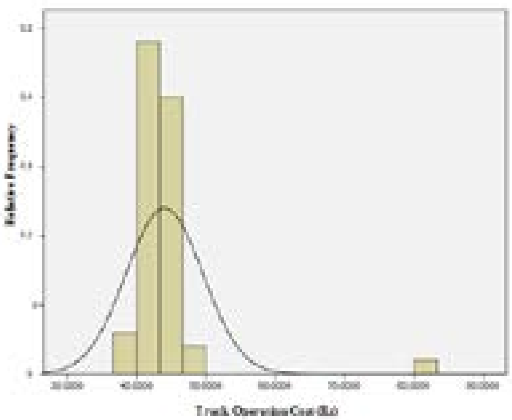


Figure 5. Probability Density Function for Ten Wheelers

Figure 5 and figure 6 illustrate the Probability Density Function of the two truck types calculated by mechanistic Probabilistic Vehicle Operation Cost Model. This is the output distribution of the study. The expected value and the uncertainty associated with each estimate of the truck operation cost could be obtained by this distribution. Identification of the uncertainty in the estimated values would lead toward a more accurate and strong analysis of the difference in cost, or the statistical significance of the estimations compared to a certain criterion. For 10 wheelers the skewness value would be 1.156 and for 6 wheelers skewness value would be 1.872. Hence both values are between -1.96 and +1.96 both the sequences are normal.

V. CONCLUSION AND RECOMMENDATIONS

Conclusion

The importance in developing a truck operation cost has been brought forward by the researcher. This subject stream consists of a less amount of literature and models of estimating the truck operation cost. In consideration to the existing vehicle operation cost, models are found to be as follows: Firstly, the considerable amount of data is required to develop the model and the absence of a specific model for truck operation cost. Lack of flexibility of the model is considered as the third factor followed by the lack of agreement with the in conditions in Sri Lanka. The final factor is the existing vehicle operating cost whereas models do not quantify the uncertainty associated with the vehicle operating costs. As an advance method of estimating the truck operation cost, the Mechanistic Probabilistic Vehicle operating cost model could be used to overcome stated problems. The Mechanistic Probabilistic Operation Cost Model offers the following advantages aimed at the user: user definable, matching with the Sri Lankan Context, Model required minimal data collection, provides a full audit trail and Quantifies the uncertainty associated with the truck operation cost. This is basically a user-friendly model in estimating the truck operation cost which is based on basic principles of engineering that could be applicable for any truck operation scenario.

The truck operation cost which is being obtained by the model has been paired with the internationally published literature. It shows that the model could be applied in obtaining an accurate value for truck operating cost.

Recommendations

The model could be used by the researchers and users in the intention of calculating the truck operation cost. Because of its user-friendly interface, it could be used as an easier method in estimating the truck operation cost.

In relation to the development of the model a few assumptions have been made. Secondary data (coefficient of rolling existence, coefficient of aerodynamic drag, coefficient of engine efficiency, coefficient of transmission efficiency, coefficient of differential efficiency, fuel energy content, coefficient of road roughness and stiffness) for the study has been extracted from the previous literature, under conditions of Canada and the USA. Assumptions have been made that the condition in Sri Lanka coincides with those of the above-mentioned countries. The same secondary data values have been used for both 10 wheelers and 6 wheelers. Also, more assumptions have been brought upon that the secondary data values would be the same for both 10 wheelers and 6 wheelers. The model has been developed along with the assumption that all operating roads involve the same conditions.

Several limitations have also been identified by the researcher in this study. The secondary data might not be the exact data which are accurately suitable for the conditions of the study. It could cause an effect to the final answer of the study. The growth of the range of the truck fleet could cause the primary data to be changed. As this study is based on a comparatively smaller truck fleet and smaller sample, during certain conditions the range would be inclined to differ. The following recommendations are being offered as possible ways to improve this study and to obtain more accurate results likewise; the secondary data which have been mentioned above could be collected as primary data to obtain more accurate results. To calibrate the above-mentioned data several formulas and different sources could be used. And secondly larger truck fleets could be used for the study to expand the sample size and to decrease the uncertainty of collected data.

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REFERENCES

Akçelik, R. & Besley, M., 2003. Operating cost, fuel consumption, and emission. Adelaide, Australia, University of South Australia.

Berthelot, C. F. et al., 1996. MECHANISTIC-PROBABILISTIC VEHICLE OPERATING COST MODEL. Journal of Transportation Engineering.

Gary, B. & Peter, L., 2003. THE PER-MILE COSTS OF OPERATING AUTOMOBILES AND TRUCKS. November 11, 2003. ed. Minneapolis: University of Minnesota.

Jayaweera, D., Karunathilake, C., Dheerasighe, K. & Banda, P., 2001. FORMULATION OF A FARES POLICY FOR BUS TRANSPORT SERVICES, Colombo: Ministry of Transport.

Papagiannakis, A. T. & Delwar, M., 1999. Methodology to Improve Pavement Investment Decisions, s.l.: National Cooperative Highway Research Program.

Velumurugan, S., Madhu, E., Ravinder, K. & Gangopadhyay, S., 2009. Updation of Road User Cost for Evaluation of Road Projects. Indian Journal of transport, pp. 205-225.

Watanatada, T., Ashok, M. D. & Lima, P. R. S. R., 1987. Vehicle Speeds and Operating Costs, Baltimore and London: The John Hopkins University.