

Impact of traffic composition on accessibility as indicator of transport sustainability

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Abstract. Sustainable transport is closely related to quality of life in the community at present and in the future. Some indicators of transport sustainability are accessibility measurement of origin/destination, the operating costs of transport (vehicle operating cost or VOC) and external transportation costs (emission cost). The indicators could be combined into accessibility measurement model. In other case, almost traffic congestion occurred on the condition of mixed traffic. This paper aimed to analyse the indicator of transport sustainability through simulation under condition of various traffic composition. Various composition of truck to total traffic flow are 0%, 10% and 20%. Speed and V/C are calculated from traffic flow to estimate the VOC and emission cost. 5 VOC components and 3 types of emission cost (CO₂, CH₄ and N₂O) are counted to be a travel cost. Accessibility measurement was calculated using travel cost and gravity model approaches. Result of the research shows that the total traffic flow has indirect impact on accessibility measurement if using travel cost approach. Meanwhile, the composition of traffic flow has an affect on accessibility measurement if using gravity model approach.

1. Introduction

Sustainable transport is closely related to quality of life in the community at present and in the future. There are 3 key elements in sustainable transport i.e. economic, social and environment. SUMMA (2004) have classified the output indicator for economic element of sustainable transport. Three of them are accessibility measurement of origin/destination, the operating costs of transport (vehicle operating cost) and external transportation costs (emission cost). The indicators are combined into accessibility measurement model. In other case, traffic congestion occurred on the condition of mixed traffic. This paper is aimed to analyse the indicators under condition of various traffic composition.

2. Literature review

Accessibility is defined as many aspects depend on the objective of the assessment. In the beginning, it is defined as "potential opportunity to interact" [1]. The definition developed until today, such as "the ease of reached or to be reached" in terms of "who", "where" and "how". It has also been reviewed by [2] and [3]. Until now, the objective and approach of the accessibility model have been improved widely. [4] explained briefly the approaches of accessibility i.e. travel cost, potential opportunity (gravity model), constrain based (time-space diagram), utility surplus and combined of two approaches. First, travel cost approach was used by [5]. The advantage of approach is easy to understand. The construction model and its parameters are simple. Second, accessibility model that frequently to use is gravity model or potential opportunity approach. The model created by [1] in the beginning and developed by several researcher i.e. [4], [6], [7], [8] etc. [9], [10] and [11] improve in another way of



accessibility model. They develop time-space constrain to calculate accessibility. Later, [12] and [13] analyse the accessibility with place rank approach.

Travel cost is a parameter that frequently used in calculating accessibility. [14] classify travel cost into function of travel time and travel distance, while [15] itemise travel cost into user cost, infrastructure cost, cost generated by destruction of environment, noise cost, accidents and safety cost and time value cost. [16] describes that travel cost of freight vehicle consist of vehicle asset, fuel, lubricant and operation and maintenance cost. In this paper, the calculation of travel cost included vehicle operating cost (VOC) and emission cost.

3. Methodology

3.1. Accessibility measurement model

As described above, there are several models to calculate the accessibility developed currently. The travel cost and gravity model approach are commonly used to analyse the accessibility. The equation of the approach is displayed below.

$$A_i = \sum [1/f(C_{id})] \quad (1)$$

A_i represents the accessibility measured for location i , $f(C_{id})$ denotes the impedance function and C_{id} is for variable of travel cost or travel time or distance. [4] describes that the model is simple and easy to calculate, however the model ignores the quality of location and travel behaviour aspect.

According to [4], gravity approaches is the most useful techniques among the accessibility model. Introduced by [1], he state that accessibility is "potential opportunity to interact" or generalized of "connection between population through distance". It has been widely discussed by [17], [18], [19], [20], and [21]. The equation below shows the form of accessibility.

$$A_i = \sum [W_j / f(C_{id}, \beta)] \quad (2)$$

where W_j is mass opportunity, $f(C_{id}, \beta)$ is impedance function, C_{id} represent travel cost variable and β denotes as travel cost coefficient. Similar to travel cost approach, this model is simple and easy to calculate, however, it has considered the quality of location.

3.2. Vehicle operating cost (VOC)

In Indonesia, there is a guideline to calculate VOC. The guideline is [22], published by Department of Public Work. According to the standard, VOC calculation divided into 2 parts; Variable cost and Fixed Cost. First part divided into 5 components i.e. fuel, lubricant, spare part, labour of maintenance and tire consumption cost. Main parameters of the components are speed, V/C, terrain and curve of road, and roughness index.

3.3. Formatting author affiliations

The components of emission cost are fuel consumption and emission factor (released by [23]). The default value of emission factor for moving resource displayed in Table 1 [23] and the value of fuel calorific in Indonesia exposed in Table 2 [24].

Refer to Guidelines for National Greenhouse Gas Inventories, general formula to calculate the emission cost is:

$$\text{Emission}_a = \sum_a (\text{Fuel}_a * \text{EF}_a) \quad (3)$$

$$\text{Fuel}_{bcd} = \sum_{bcd} (\text{Vehicle}_b * \text{Distance}_c * \text{Fuel consumption}_d) \quad (4)$$

where fuel is total amount of fuel consumption of all vehicles and distances while EF is emission factor. Fuel consumption derived from a component of VOC and converted into TJ/km before multiplied by emission factor. To estimate the emission cost, total amount of emission multiplied by unit cost of emission included CO₂, CH₄ and N₂O. According to [25], prediction of emission cost at year 2015 are \$37 (CO₂), \$970 (CH₄) and \$15,000 (N₂O) per tons. The costs equal to 481,000 IDR of CO₂, 12,600,000 IDR of CH₄ and 195,000,000 IDR of N₂O.

Table 1. Default Value of Emission Factor by IPCC 2006 (Kg/TJ) for Moving Resource

Fuel Type	Emission Factor (Kg/TJ)		
	CO_2	CH_4	N_2O
Gasoline	69300	33	3.2
diesel Fuel	74100	(1)3.9	3.9

Table 2. Fuel Calorific Value in Indonesia

Fuel Type	Calorific Value (TJ/liter)	User
Gasoline	33.E-06	Vehicle
diesel Fuel	36.E-06	Vehicle

3.4. Data collection

To calculate the accessibility measurement, the data are required. Type and assumption data can be seen at Table 3.

Table 3. Data Requirement and Default Value of Road Condition

No	Parameter	Unit	Default Value
1	Speed	km/h	Calculated
2	Grade	m/km	2.5, -2.5
3	Curve of road	°km	15
4	V/C		Calculated
5	Pavement Condition	m/km	3
5	Cumulative trip length	km	100,000
6	Traffic flow	Veh/h	500-4.500

Speed and V/C calculated from actual traffic flow using Indonesian Highway Capacity Manual 1997. Moreover, actual price of VOC component e.g. fuel, lubricant, tire, new car and labour cost of maintenance are needed.

4. Result and discussion

4.1. Traffic condition

Traffic composition divided into passenger car (PC) and trucks, while the truck also split into small truck (truck 2 axle), medium truck (truck 3 axle) and large truck (truck more than 4 axle). Several assumptions were selected to estimate the speed and V/C. First, the truck compositions from total traffic flow are 0%, 10% and 20%, while the compositions of each truck type from the total truck are 50% of small truck, 25% of medium truck and 25% of large truck. Second, road capacity is 5100 pcu/h (three lanes each direction) and free flow speed is 90 km/h. This conditions are typical of urban toll road in Indonesia. The result of V/C and speed calculation for various vehicle compositions can be seen in Table 4.

The changing of vehicle composition has an impact on traffic flow in pcu.as showed in Table 4. So that, the speed and V/C have a different value for different composition of traffic flow. At the composition of truck of 10%, the traffic flow in pcu/h increase approximately of 4%. Meanwhile, the composition of truck of 20%, the traffic flow in pcu/h increase 8%.

4.2. VOC

As described above, VOC has 5 components. Estimation of VOC for each vehicle type has unique characteristic. Figure 1(a) shows the correlation between cost of VOC component and speed for PC, Figure 1(b) shows the comparison value of VOC by type of vehicle.

Table 4. Result of V/C and Speed Calculation Based on Various Traffic Flow and Composition

Traffic Flow (veh/h)	100% PC			90% PC			80% PC		
	Traffic Flow (pcu/h)	V/C	Speed (km/h)	Traffic Flow (pcu/h)	V/C	Speed (km/h)	Traffic Flow (pcu/h)	V/C	Speed (km/h)
500	500	0.10	88.6	520	0.10	88.5	540	0.11	88.4
1000	1000	0.20	86.6	1040	0.20	86.5	1080	0.21	86.3
1500	1500	0.29	84.3	1560	0.31	84.0	1620	0.32	83.7
2000	2000	0.39	81.5	2080	0.41	81.0	2160	0.42	80.5
2500	2500	0.49	78.2	2600	0.51	77.5	2700	0.53	76.8
3000	3000	0.59	74.5	3120	0.61	73.5	3240	0.64	72.5
3500	3500	0.69	70.3	3640	0.71	69.0	3780	0.74	67.7
4000	4000	0.78	65.6	4160	0.82	64.1	4320	0.85	62.4
4500	4500	0.88	60.5	4680	0.92	58.6	4860	0.95	56.6

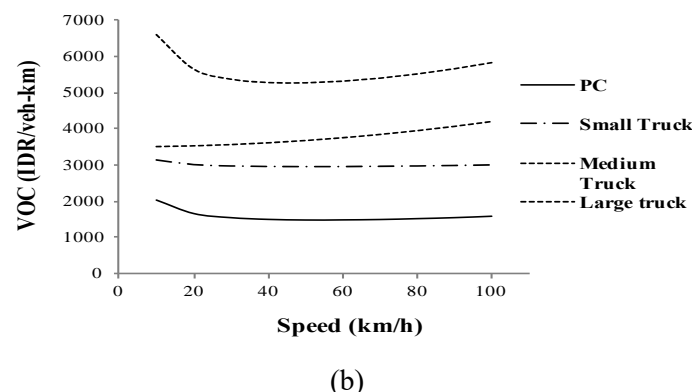
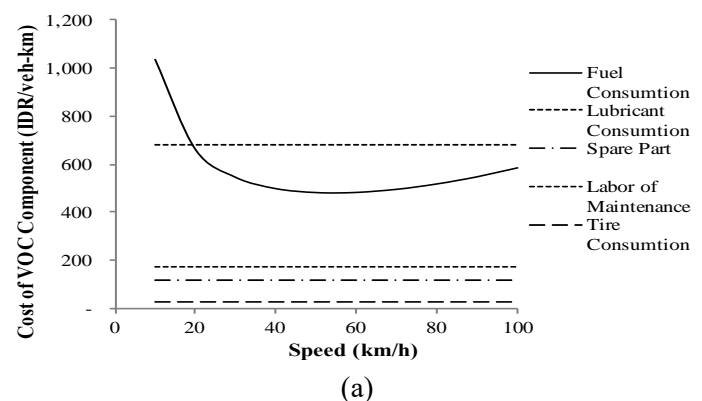


Figure 1. (a) Typical Relationship between Cost of VOC Component (IDR/veh-km) at Various Speed of PC; VOC of PC (b) VOC at Various Speed by type of vehicle

From Figure 1, it can be seen that fuel consumption and labour of maintenance costs give the highest contribution of VOC. Fuel consumption cost more sensitive than other component, although each type

of vehicle has different a pattern. It can be seen that the shape of the curve is not flat. Comparison between type of vehicle, large truck is the costliest than the others.

4.3. Emission cost

In general, emission produced by transportation are CO₂, CH₄ and N₂O. The emission cost of various speed for each type of vehicle displayed in Figure 2.

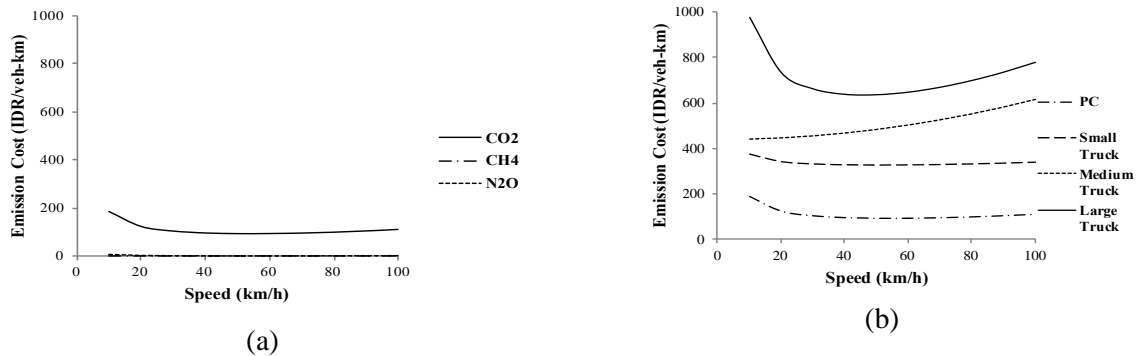


Figure 2. (a) Comparison of Emission Cost by type of emission for PC, (b) Comparison of Emission Cost by type of Vehicle

Figure 2 chart (a) illustrate the emission cost of PC. A large part of emission composed of CO₂ after that CH₄ and N₂O. Despite, unit emission cost of N₂O higher than CO₂ and CH₄, the total emission cost of CO₂ much higher than 2 others. The curve of emission cost of CO₂ is similar to fuel consumption cost. The minimum cost occurred between 20-40 km/h. Chart (b) shows the comparison of emission cost by type of vehicles. Large truck produces the highest cost than others.

4.4. Travel cost

A lot of travel cost definition developed lately. This paper defined the travel cost as the sum of VOC and emission cost. Figure 4 shows the relationship between travel cost (IDR/km) and traffic flow (veh/h). Figure 3 (a) describe the VOC and emission cost per km of road for composition of 100% PC, meanwhile Figure 3 (b) express the difference of travel cost as truck composition changed.

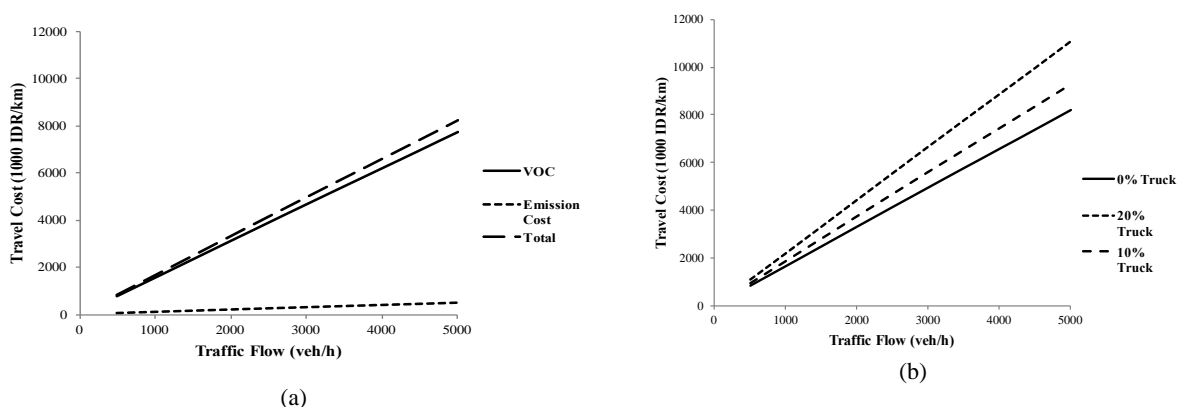


Figure 3. Comparison of travel cost at various traffic flow (a) travel cost component and (b) various composition of truck

Emission costs only about 5.9% of the travel cost and increased according to the increment of the number of truck.

4.5. Accessibility measurement

Accessibility measurement was conducted by two approaches, i.e. travel cost and gravity model approach. The result of measurement can be seen at Figure 4. Figure 4(a) shows the relationship between accessibility and traffic flow using travel cost approach, while figure 4(b) displays the calculation of accessibility using gravity model approach. Graph (a) explains that the higher traffic flow and truck composition, the accessibility decrease sharply. Graph (b) describes that the additional traffic flow had no significant impact on accessibility, on the other hand, the additional number of trucks can reduce road accessibility.

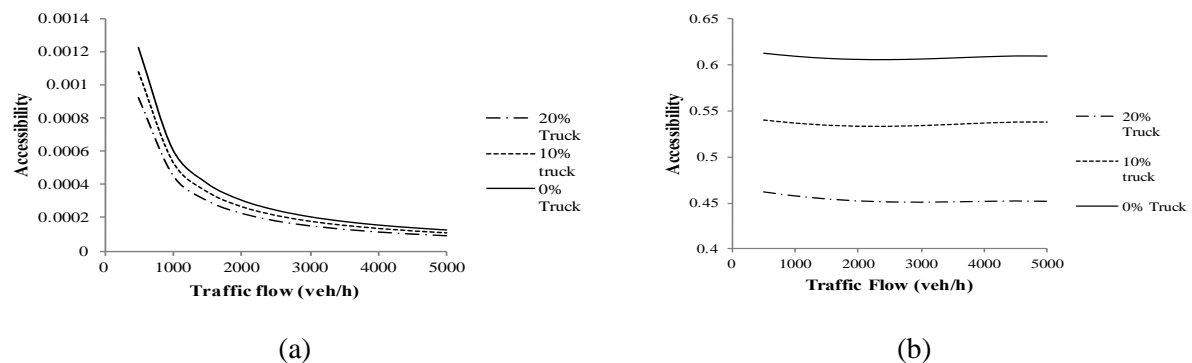


Figure 4. Accessibility measurement of (a) Travel Cost Approach and (b) Gravity Model Approach.

As described in the equation (1), accessibility measurement has only a parameter of travel cost for travel cost approach, on the other hand, result of Figure 4(a) leads to the accessibility that influenced by traffic flow indirectly. Meanwhile, Figure 4(b) conducts that composition of traffic flow more influenced to the accessibility measurement than total traffic itself.

5. Conclusion

This paper describes the relationship between accessibility measurement and the composition of truck in the point of view of VOC and emission cost that their caused.

In the city that have highly mixed traffic, the changing of vehicle composition has an impact on traffic flow in pcu. In this case, almost 4% every increase 10% of truck composition So that, the speed and V/C have a different value for different composition of traffic flow.

From the research, there are three characteristic of transport sustainability indicators. First, that fuel consumption and labour of maintenance costs give the highest contribution of VOC for all value of speed. Fuel consumption cost more sensitive than other component, although each type of vehicle has different pattern. Comparison between type of vehicle, large truck is the costliest than the others.

Second, a large part of emission composed of CO₂. Despite, unit emission cost of N₂O higher than CO₂ and CH₄, the total emission cost of CO₂ much higher than 2 others. The curve of emission cost of CO₂ is similar to fuel consumption cost. The minimum cost occurred between 20-40 km/h. Emission costs only about 5.9% of the travel cost and increased according to the increment the number of truck.

Finally, using travel cost approach, the higher traffic flow and truck composition, the accessibility decrease sharply. In other hand, using gravity model, the additional traffic flow had no significant impact on accessibility. Meanwhile the additional number of trucks can reduce road accessibility.

In a future, the characteristic of indicators can be used as initial assumption of other subject of research, such as impact of freight vehicle restriction on urban road.

6. References

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