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Congestion Cost Analysis and Potential Loss of Private Vehicle on Jalan Jenderal Sudirman, Jakarta

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ABSTRACTS

In recent years, many big cities have experienced congestion in the world, including DKI Jakarta. Rapid economic growth has led to high demand for travel in the City, and rapid urbanization is one of the causes of traffic congestion. Traffic congestion is a characteristic of urban areas caused by increased economic activity, increased productivity of population movement, and inadequate facilities. Traffic congestion causes lost travel time, losses due to vehicle emissions, and increases traffic accidents. This study discusses the amount of costs incurred by vehicle users who pass Jenderal Sudirman street when experiencing congestion. This study aims to provide an overview for private vehicle users of the amount of costs incurred when using a private vehicle when passing Jenderal Sudirman street. The method used in determining Vehicle Operational Costs (VOC) is a method developed by the Institute for Affiliation and Research and Industry (LAPI) ITB 1997, while getting lost costs due to congestion is reviewed based on VOC and time value with the Income Approach method. The results show a high difference in operational costs and the loss of time value which is the total cost loss due to congestion on the road.

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INTRODUCTION

Jakarta City is Indonesia's capital city with a population of 10,609,681 people with a population density of 15,978 people every 1 km² in 2021 [1]. Jakarta is the center of development in various sectors, including government, trade, industry, tourism, and education. This makes Jakarta filled with migrants who want to settle and work in Jakarta. Therefore, Jakarta's population continues to increase yearly, with a growth rate of 0.57%/year [1]. As the population continues to grow, the trip will also continue to increase due to the need for transportation [2] [3] [4].

The trip that happened in a specific area at the same time will cause several problems. One of the problems that occur is congestion. The congestion is caused by high urbanization rates, economic growth, vehicle ownership, and road networks that do not function efficiently [5]. Congestion often occurs in the city centers due to the purpose and time of movement that coincides, especially at certain times. In addition, the use of public transportation (buses and trains) decreased by 28.4% [6].

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Congestion is one of the main sources of air pollution originating from exhaust emissions; this can affect urban air quality, the environment, and society. According to [7], the transport sector contributes 25–30 percent of global CO_2 emissions, and nearly two-thirds of total transport-related emissions come from road transport [8] [9]. While studies show that heavy traffic can also increase the risk of traffic accidents and result in death [10] [11].

This congestion problem has occurred in urban centers such as on Jalan Jenderal Sudirman, one of the roads in Central Jakarta. Jalan Jenderal Sudirman stretches for 4 km, starting from Dukuh Atas to Senayan. Jalan Jenderal Sudirman is one of the main roads in Jakarta because this street has an essential role as an economic center which can be seen on the street; there is one of the largest shopping centers, namely Grand Indonesia Mall. There are a central office area and other high-rise buildings adjacent to settlements. The problem of congestion that often occurs during peak hours on this road has disadvantages for road users, such as: causing additional costs or waste on fuel and also a waste of time and energy.

Given the importance and urgency of this topic, our paper discusses the potential cost loss due to congestion in urban transport. This paper examines the calculation of the cost of traffic congestion in Jakarta, Indonesia, with the first objective of how much potential private vehicle operating costs are. This is to find out how much potential loss of travel costs is based on vehicle operating costs. Second, the loss of travel time due to traffic jams. The resulting analysis will be used as input in developing a model for implementing congestion costs in Indonesia in the future.

METHODS

Congestion

Congestion is a condition when traffic flow passing on a specific section of the road has exceeded the planned road capacity with a road-free speed close to 0 km/hour [12]. The negative impact of this congestion is very detrimental from an economic point of view due to the increased use of fuel and the productivity of lost time, which can cause workers to be late for work, so that workers will also reduce their income.

Level of Service

The performance of road sections is a measurement taken to obtain the road's ability to create a safe and comfortable route for all road users [13]. The road level of service to show the condition can be seen from the volume, speed, delay, and queue on a section, which will be expressed by the value of the service level of a road [14].

Free Flow Speed

The free flow speed is defined as speed that is not affected by other vehicles or vehicles at zero flow level [12]. Based on PKJI 2014, the rate of free flow is obtained by the following equation:

$$V_B = (V_{BD} + V_{BL}) \times FV_{BHS} \times FV_{UK} \quad (1)$$

Information:
V_B = speed of free flow (km/h)
V_{BD}= base free flow speed (km/h)
V_{BL} = speed adjustment value due to effective lane width (km/h)
FV_{BHS} = free speed adjustment factor due to side obstacles on roads that have sidewalks
FV_{UK} = free speed adjustment factor for city size

Traffic Volume

Traffic volume is the number of vehicles that pass a certain road section at a certain time. Traffic volume is obtained by conducting a traffic counting survey. In traffic flow analysis, the classification of vehicles used to facilitate data processing consists of the following:

1. Light Vehicles (LV), such as passenger cars, microbuses, and public transportation.
2. Heavy Vehicles (HV), such as buses, 2-axle trucks, and 3-axle trucks.
3. A motorcycle (MC) is a vehicle with two or three wheels.

Data processing for this traffic volume needs to be multiplied by the vehicle equivalence value to become a light vehicle unit (LVU) in **Table 1**.

Table 1. The equivalence value of passenger cars.

Road Type	Traffic Flow/Lane (Vehicle/Hour)	ekr	
		HV	MC
2/1 and 4/2T	< 1050	1.3	0.40
	≥ 1050	1.2	0.25
3/1 and 6/2D	< 1100	1.3	0.40
	≥ 1100	1.2	0.25

Road capacity

Capacity is the maximum value of traffic flow in units of pcu/hour that can be maintained along a certain road segment [12]. Road capacity is strongly influenced by several factors, such as: base capacity factors, road width adjustment factors, and roadside and shoulder adjustment factors. Road capacity can be obtained using the following equation:

$$C = C_0 \times FC_w \times FC_{SP} \times FC_{SF} \times FC_{CS} \quad (2)$$

C = Capacity (pcu/h)
C_0 = Base capacity (pcu/h)
F_w = Carriageway width adjustment factor
F_{SP} = Directional split adjustment factor
F_{SF} = Side friction and kerb/shoulder adjustment factor
F_{CS} = City size adjustment factor

Degree of Saturation

The degree of saturation is the ratio of flow to designated capacity in analyzing the performance of a road and peak hours. The degree of saturation value close to zero is a sleeved condition that does not affect other vehicles. Meanwhile, the value of the degree of saturation close to 1 indicates that the current situation on the road is at medium capacity and density [12].

The value of the degree of saturation is obtained using the following equation:

$$D_S = \frac{QV}{C} \quad (3)$$

Keterangan:
D_S = Degree of Saturation
V = Traffic Volume (pcu/h)
C = Road Capacity (pcu/h)

Road Service Level

Service level is a qualitative measure of the influence of restrictions due to an increase in traffic volume [15].

Table 2. Level of Service.

Level of Service	Traffic characteristics	NVK (Q/C)
A	Conditions of free traffic flow, High speed, and low traffic volume	0.00 – 0.20
B	Stable flow and Operational speed are limited by traffic conditions	0.20 – 0.44
C	Stable flow and Vehicle moving speed controlled	0.45 – 0.74
D	Flow is close to stable, Speed is controllable, and V/C is tolerable	0.75 – 0.84
E	Unstable flow, Speed sometimes stops, and Demand is approaching capacity	0.85 – 1.00
F	Forced flow, Low speed, Volume above capacity, and Long queue (stuck)	≥1.00

Vehicle Operating Cost (VOC)

Vehicle Operating Cost (VOC) is the total cost required for road users to operate modes under certain traffic conditions from the origin area to the destination area [16].

VOC was calculated using a method developed by the Affiliated and Research and Industrial Institute (LAPI) ITB 1997. The components of the VOC consisted of fuel consumption costs, lubricating oil consumption costs, tire discharging costs, spare parts costs, mechanic fees, depreciation costs, capital interest, and insurance costs.

1. Fuel Consumption
   $FC = \text{Basic FC} \times (1 \pm (k_k + k_1 + k_r)) \quad (4)$
   Information:
   Base FC = $0.0284\ V^2 - 3.0644\ V + 141.68$ (/1000 km)
   K_k = correction factor due to slump
   k_1 = correction factor due to traffic flow conditions
   k_r = correction factor due to road roughness
   V = vehicle speed (km/h)
2. Consumption of Lubricating Oil
   $KBBMi = KBBMi\ basic \times F_K \quad (5)$
   Information:
   KBBMi base = consumption of lubricating oil
   F_K = roughness correction factor
3. Tire Usage (Bbi)
   $(BB_i) = (BB_i)\ basic \times tire\ price \quad (6)$
   Information:
   (BB_i) base =0.0008848 V - 0.0045333 (/1000 km)
   V = vehicle speed (km/h)
4. Spare Parts
   $(BP_i) = (BP_i)\ basic \times vehicle\ price \quad (7)$
   Information:
   (BP_i) base = 0.0000064 V + 0.0005567 (/1000 km)
   V = vehicle speed (km/h)
5. Mechanic
   $BU_i = BU_i\ basic \times hourly\ mechanic\ work\ wages \quad (8)$
   Information:
   BU_i base =0.00362 V + 0.36267 (/1000 km)
   V = vehicle speed (km/h)
6. Depreciation Charges
   $Depreciation\ fee = Basic\ Depreciation \times 1/2\ vehicle\ price \quad (9)$
   Information:
   Basic depreciation charges =1/(2.5 V+125) (/1000 km)
   V = vehicle speed (km/h)
7. Capital Interest
   Road User Cost Model 1991 in Tamin 2000 [17], [18].
   $Capital\ interest = 0.22\% \times vehicle\ price \quad (10)$

8. Insurance Cost
   Insurance cost = basic insurance cost × vehicle price (11)
   Information:
   Basic insurance cost = $= \frac{38}{500\,V}$ (/1000 km)
   V = vehicle speed (km/h)

Congestion Charges

Congestion losses are reviewed based on Vehicle Operating Costs (VOC) and time values for each vehicle type. So, cost loss due to congestion was calculated using the following equation:

$$Lost\ Cost = (VOC_A - VOC_B) + (V'_A - V'_B) \quad (12)$$

Information:
VOC_A = vehicle operating costs at a travel speed
VOC_B = vehicle operating costs at the free flow speed
V'A = time value of the difference between the speed of the free flow and the speed of travel
V'A = time value at the free flow speed

Time Value

The time value is calculated from the comparison between the difference in travel costs to the time savings between trips from origin to destination using different modes [19]. The income method is usually applied as a practical measure in developing countries to determine not only resource value but also behavioral value. In several studies, travel time based on respondent preferences is about 1.5 times greater than actual travel time [20] [21] and shows that travel time is generally considered to be longer than reality.

$$\boldsymbol{V' = \frac{\frac{GRDP}{People}}{annual\ working\frac{time}{time}}} \quad (13)$$

Study Locations

This research was conducted on the Jalan Jenderal Sudirman section, Jakarta, which began with a survey method. The observation in this study was in 2 locations, namely Dukuh Atas and FX Sudirman, Jakarta.

Data Collection

The data collected consists of primary data and secondary data. Direct surveys obtain preliminary data in the field that primary data will use to analyze road sections' performance. The primary data required are road geometry, traffic volume, and vehicle speed. The secondary data needed to obtain the value of the operational costs of this vehicle consists of vehicle prices, tires, oil, fuel, and maintenance costs to data on the amount of Gross Regional Domestic Product (GRDP).

Data Analysis

The data that has been obtained were then processed as follows:

a. Data processing related to daily traffic volume.

Data on traffic flow was obtained from a survey conducted from 06.00 to 20.00. The observed traffic flows are classified as private cars, heavy vehicles, buses, and motorbikes.

b. Determination of peak hours and traffic characteristics at peak hours.

The traffic volume data that was collected every 15 minutes was then recapitulated to find out the maximum traffic volume that occurred at what time span; this indicates the peak of the maximum flow that passes through that road section.

c. Traffic Performance Analysis

Hourly data was processed by calibrating each type of vehicle flow data vehicle/hour to passenger car units (pcu) based on the PKJI 2014 private vehicles/LV (1), motorcycles/MC (0.25), and heavy vehicles/HV (1.2). Road traffic performance was calculated with the formula:

$$\boldsymbol{C = C_0 \times FC_w \times FC_{SP} \times FC_{SF} \times FC_{CS}} \quad (14)$$

Where C is the capacity of the road section (pcu/hour), Co is the basic capacity (pcu/hour), FCw is the adjustment factor for the width of the traffic lanes, FCSP is the adjustment factor for the separation of directions, FCSF is the adjustment factor due to side friction, and FCCS is the city size adjustment factor.

d. Calculation of vehicle operating costs

The increase in vehicle operating costs caused by increased travel time resulted in losses for private vehicle users. From the results of a survey conducted on congestion problems on the road, the most visible indicator is a decrease in speed. The speed of vehicles passing through a road section depends on the length of the track and the duration of the trip. The greater the congestion encountered, the longer the travel time will be, which results in lower speeds on these roads. Speed is defined as the change in distance divided by a unit of time. In this section, we also obtain the travel time of the vehicle in a traffic jam. Delay is time lost due to reduced speed from the normal limit due to obstacles that disrupt traffic flow.

RESULTS AND DISCUSSION

Road Capacity

Road capacity was obtained by the PKJI 2014 analysis method. The capacity adjustment factors for both directions are as follows:

$$C = C_0 \times FC_w \times FC_{SP} \times FC_{SF} \times FC_{CS}$$
$$= (1650 \times 3) \times 0.96 \times 1 \times 0.84 \times 1$$
$$= 3991.68 \text{ pcu/hours}$$

The road capacity for Jalan Jenderal Sudirman at both observation points and in both directions has the same road characteristics. Therefore, the road capacity for Jalan Jenderal Sudirman only has one capacity value, which is 3991.8 pcu / hour for each direction.

Degree of Saturation and Road Service Level

Table 3. Degree of Saturation on Dukuh Atas (direction to Bundaran HI).

Date	Time	Degree of Saturation	Level of Service
Wednesday, 30 March 2022	07:30 – 08:30	0.895	E
	12:00 – 13:00	0.927	E
	17:15 – 18:15	0.750	D
Thursday, 31 March 2022	07:45 – 08:45	0.865	E
	12:45 – 13:45	0.965	E
	16:30 – 17:30	0.781	D
Saturday, 2 April 2022	08:00 – 09:00	0.524	C
	12:15 – 13:15	0.861	E
	16:00 – 17:00	0.844	E

Based on the results of the analysis, it was found that the observation point at Dukuh Atas direction of the Bundaran HI had a saturation degree value of 0.965 with a service level E. The observation at Dukuh Atas Senayan direction had a saturation degree value of 1.193 with a service level F. The road service level for observation point at FX Sudirman direction of the Bundaran HI had a saturation degree value of 1.116 with a service level of F. The observation point at FX Sudirman direction of Senayan has a saturation degree value of 1.154 with a service level of F. The recapitulation of the results of the degree of saturation analysis can be seen in **Table 3**.

Table 4. Degree of Saturation on Dukuh Atas (direction Senayan).

Date	Time	Degree of Saturation	Level of Service
Wednesday, 30 March 2022	07:30 – 08:30	1.191	F
	12:00 – 13:00	1.193	F
	17:15 – 18:15	0.752	D
Thursday, 31 Mach 2022	07:45 – 08:45	1.108	F
	12:45 – 13:45	1.154	F
	16:30 – 17:30	0.742	D
Saturday, 2 April 2022	08:00 – 09:00	0.675	C
	12:15 – 13:15	0.825	D
	16:00 – 17:00	0.812	D

Table 5. Degree of Saturation on FX Sudirman (direction Bundaran HI).

Date	Time	Degree of Saturation	Level of Service
Saturday, 16 July 2022	08:00 – 09:00	0.557	C
	13:00 – 14:00	0.786	D
	16:30 – 17:30	0.811	D
Monday, 18 July 2022	07:45 – 08:45	1.116	F
	12:00 – 13:00	1.076	F
	16:45 – 17:45	0.949	E
Thursday 21 July 2022	06:30 – 07:30	0.869	E
	12:15 – 13:15	0.738	C
	16:15 – 17:15	0.876	E

Table 6. Degree of Saturation on FX Sudirman (direction to Senayan).

Date	Time	Degree of Saturation	Level of Service
Saturday, 16 July 2022	06:30 – 07:30	0.686	C
	12:45 – 13:45	0.798	D
	17:30 – 18:30	0.796	D
Monday, 18 July 2022	06:15 – 07:15	0.848	E
	12:00 – 13:00	0.894	E
	16:45 – 17:45	0.903	E
Thursday 21 July 2022	07:30 – 08:30	1.108	F
	12:30 – 13:30	1.154	F
	16:45 – 17:45	0.742	D

Free Flow Speed

The speed of free flow was obtained using the 2014 PKJI analysis.

$$V_B = (V_{BD} + V_{BL}) \times FV_{BHS} \times FV_{UK}$$
$$= (57 + (-2)) \times 0{,}81 \times 1$$
$$= 44.55\ km/hour$$

So, the free flow speed of Jalan Jenderal Sudirman is 44.55 km/h

Vehicle Operating Costs (VOC)

Price component data for the All New Avanza 1.5 G M/T vehicle type is required in determining the VOC.

Table 7. VOC component data.

Component	Price
New car prices (All New Avanza 1.5 G M/T)	Rp 255,100,000 /vehicle
Fuel oil prices (Pertalite)	Rp 7650 /Liter
Lubricant prices	Rp 120,000 /Liter
Mechanic's wages	Rp 24,246 /Hour
Passenger car tires	Rp 590,000 /tire

Table 7 shows the results of VOC recapitulation on Jalan Jenderal Sudirman, Jakarta. At the observation point I of the Bundaran HI direction, the VOC value at a speed of 19.48 km / h, which was Rp. 16,776, at a speed of 16.83 km / h, which was Rp. 17,908 and at a speed of 7.52 km/hour, which was Rp. 25,307. At the observation point I Arah Senayan, the highest VOC value was obtained at a speed of 18.85 km / h, which was Rp. 17,099, at a speed of 14.71 km/hour, which was Rp. 18,919 and at a speed of 9.29 km / h, which was Rp. 22,985.

Congestion Charges

Congestion costs were calculated using data from the analysis of Vehicle Operating Costs (VOC) at the speed of free flow and the speed of the observation results. Congestion cost analysis was carried out to determine the magnitude of losses suffered by road users. In addition to using VOC in calculating congestion costs, a value of time is also necessary. The calculation of value of time is carried out using the Income Approach method. The data required to perform the analysis is as follows:

- The Gross Regional Domestic Product (GRDP) of Jakarta City in 2021 is IDR 728,386,100,770.00 (Source: Central Bureau of Statistics).
- The total population of Jakarta in 2021 is 10,609,681 people (Source: Central Bureau of Statistics).
- Annual working hours are based on 8 hours/day, and work five days/week in one year has 52 weeks, then the annual working hours are 2080 hours.

$$\boldsymbol{V' = \frac{\frac{GRDP}{People}}{annual\ working \frac{time}{time}} = \frac{\text{Rp}\frac{728{,}386{,}100{,}770.00}{10{,}609{,}681 \text{people}}}{2080} =}$$

Rp 33,006 people/hour **= Rp 550.10** people/minute

After obtaining the value of time at the free flow speed and the speed of the observation results, the cost loss due to congestion can be obtained as follows:

$$\boldsymbol{Lost\ Cost = (VOC_A - VOC_B) + (V'_A - V'_B)}$$
$$\boldsymbol{= (Rp\ 14{,}115 - Rp\ 12{,}019) + (Rp\ 135.45 - Rp\ 408.45)}$$
$$\boldsymbol{= Rp\ 1{,}823}$$

Cost loss due to congestion on Jalan Jenderal Sudirman has obtained loss of costs due to the most considerable congestion in the Dukuh Atas area towards the Bundaran HI, which is Rp13,219.03, in the Dukuh Atas area in the Senayan direction, which is Rp10,881.04, in the FX Sudirman area the direction of the HI Roundabout is Rp11,912 and in the FX Sudirman area towards Senayan is Rp 10,149.92.

CONCLUSION

Traffic congestion appears in urban areas with high vehicle ownership and appears in areas with high density, which can increase traffic accidents. Traffic congestion is currently one of the largest sources of air

pollution in the World, and traffic congestion and vehicle emissions are closely intertwined.

Based on the results of the analysis, that the results obtained in this study, the capacity of Jalan Jenderal Sudirman is 3991.68 pcu / hour, with the worst level of road service F. Therefore, the level of road service on Jalan Jenderal Sudirman has the characteristics of a road with the unstable flow until forced, low speed and long queues.

In addition, the results of the analysis show that the difference in travel time between actual conditions and free flow conditions causes differences in vehicle operating costs. Vehicle Operating Costs (VOC) with a speed of 6.52 km / h is Rp. 25,307.00. Furthermore, the loss of costs due to congestion which was reviewed based on Vehicle Operating Costs (VOC) and the time value for each type of vehicle on Jalan Jenderal Sudirman, obtained the most significant loss of costs due to congestion was Rp13,219.03.

For future research, it is necessary to evaluate the application of congestion costs as a traffic demand management measure adopted to reduce the impact experienced by big cities in the world in terms of traffic congestion, air and noise pollution, and high traffic accidents. Congestion and accidents have a direct impact on road users, while limits on air pollution due to emissions have also been widely exceeded in recent years. The application of congestion costs should be considered as a policy instrument to manage limited resources, especially in terms of infrastructure, and encourage road users to change their behavior in terms of using modes and choosing travel routes.

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