Impact of road rehabilitation zone on travel time to road user cost

D Kalimanto and S P Hadiwardoyo*
Civil Engineering Department, Faculty of Engineering, Universitas Indonesia,
Kampus Depok, West Java, 16242, Indonesia.

*Email: sigit@eng.ui.ac.id

Abstract. Traffic movements in the city of Jakarta are linked to the Jakarta Outer Ring Road (JORR) Toll Road. This road network has a high traffic volume because it is integrated with other toll roads that connect other cities to Jakarta. The heavy traffic volume during the road rehabilitation will cause travel obstacles such as the increasing travel time to the long delay in traffic flow at the window time. The travel delay causes losses to road users. Road management must draw attention to the impact of the road rehabilitation zone to losses time by road users, especially on toll roads. This study analyzes the impact of speed changes in the work zone with two work areas. Traffic surveys have been carried out on the Jakarta Outer Ring Road (JORR) Toll Road section S using the roadpod metrocount tool. The results of this study show the increase vehicle operation costs by 169% to 206% due to a decrease in speed due to work zone. The results of this study are expected to be the consideration of road operators in determining the time in choosing of rehabilitation by minimizing the losses of time from the road users.

1. Introduction

Road damage can trigger road users passing the road to reduce the vehicle speed. With the increasing number of vehicles, road damage affects the flow of traffic that causes traffic congestion due to all vehicles reduce their vehicle speed [1]. The road damage that occurs requires road rehabilitation depending on its severity. During the road rehabilitation, a special area called a work zone is needed to minimize the risk of workplace accidents both for road users and construction workers. The work zone means the area where road works take place and the number of lanes available are reduced [2]. The work zone for road reconstruction causes speed delays, bottlenecks and accidents [3]. In addition, it reduces the road capacity and the vehicle users must slow down their vehicle speed; as a result, it causes delays in travel [4]. Travel delay is one of the calculations in traffic studies because it calculates the direct costs of fuel consumption and indirect costs of losing time for road users [5]. The increasing consumption of vehicle fuel comes from the increased length of trips and modes of private transportation [6]. The delay in traveling with a high volume of vehicles can cause traffic congestion. Traffic congestion tends to inhibit a number of economic activities in the city [8]. The problem of traffic congestion in metropolitan cities is growing fast [9]. This congestion can bear extra costs to road users. The costs incurred due to the congestion have a negative impact on mobility, travel delays, and safety and environmental aspects [10]. The costs can be calculated...
by the traffic demand management method. It is very effective and can generate the amount of charges that can be imposed on road users as congestion costs [11].

From the aforementioned background of the previous study, road rehabilitation zone has negative effects such as speed decrease, travel delay and losses from the trip delay. Therefore, it is important to analyze the costs incurred by the road users due to road rehabilitation zone. This research was carried out in the Jakarta Outer Ring Road Toll Road Section S of Pondok Pinang/Cilandak Route. This study aims to compare the magnitude of the speed changes in the work zone which has a different obstacle and analyzes the costs incurred by road users due to travel delays.

2. Method
2.1. Experimental design
This experimental design was used to divide the locations of the obstacles into two lanes. This experiment served to compare the effects of traffic engineering carried out in each different lane along with losses from road users due to traffic engineering of road rehabilitation work zones. The following as the experimental design in this study.

| Notation | Closed Area | Length of Work Zones (m) |
|----------|-------------|--------------------------|
|          |             | Lane 1&2 | Lane 2&3 |
| Location 1 | Lane 1&2    | 278.5     | -        |
| Location 2 | Lane 2&3    | -         | 366.5    |

2.2. Study area
This research was carried out on the Jakarta Outer Ring Road (JORR) S Section of Pondok Pinang/Cilandak Route during window time with two different work areas and lanes. This research area was chosen because the Jakarta Outer Ring Road Section S Toll Road connects cities to Jakarta City. The first location had obstacles due to road rehabilitation work zone in lane one (slow lane) and lane two (middle lane), so that the remaining three lanes or fast lanes could be used. The total length of this rehabilitation work zone is 278.5 meters and had an area of 1369.7 m². The road rehabilitation works in this location included reconstruction work. The scenario of the location in this road rehabilitation work zone can be seen in figure 1 below.

![Figure 1. Scenario of the location 1 in the road rehabilitation zone](image)

For the second location, the road rehabilitation work zone was in lane two and lane three, so that the remaining one lane or slow lane can be passed. The location of this study was in STA 21 + 345/340 - 21 + 315/310 on the Jakarta Outer Ring Road Toll Road Section S of Cilandak Route. The length of this road rehabilitation work zone was 366.5 meters and had an area of 1949.5 m². The road rehabilitation
works in this study included reconstruction work. The scenario in the location of the road rehabilitation work zone can be seen in the following figure.

![Figure 2. Scenario in location 2 of road rehabilitation zone](image)

2.3. Speed decrease
Vehicle speed data were measured using roadpod metrocount tool. It served to measure the speed of the vehicle, find out the volume and type of vehicles. Measurements were made in the window time. The device was placed right before the road rehabilitation work zone. The results of these measurements obtained vehicle speed, and volume and type of vehicle. The data were then processed and used to calculate vehicle operation costs and time values.

2.4. Vehicle operation cost
Calculation of vehicle operational costs including fixed and variable costs [12]. Fixed cost was a number of costs that must be incurred at the beginning of the operation of a vehicle. It consists of depreciating vehicle prices for five years and motor vehicle tax. Meanwhile, variable costs consisted of fuel consumption costs, oil consumption costs, spare parts consumption costs, maintenance labor costs and tire consumption costs [12]. The following was a flow diagram of the calculation of vehicle operation costs.

![Figure 3. Calculation of vehicle operation costs](image)
2.5. Value of time
Value of time analysis was used to calculate the amount of time wasted, i.e. costs, due to speed decrease. Low vehicle speed produced large value of time; on the contrary, high vehicle speed produced small value of time because of the lack of time wasted. Value of time calculation used the following equations according to [13], namely:

\[
VOT = \frac{1}{S} \times \sum_{m=1}^{2} (TC_m \times OR_m) \\
TC_{m=1} = NAW \\
TC_{m=2} = 0.25 \times NAW
\]

Where; VOT is value of time (IDR/km); S is average speed (km/h); TC\textsubscript{m} is cost of travel time for travel purposes in m (IDR/Hour/passenger); NAW is Regional average wage (IDR/Hour); OR\textsubscript{m} is occupancy rate for travel purposes in m (passenger/vehicle); m equals 1 is travel during working hours and m equals 2 is travel during non-work hours.

2.6. Road user cost calculation
Road user cost was the cost incurred while the vehicle was operating. Road user cost calculation used equations according to [13], namely:

\[
RUC = BOK + VOT + Toll + AC
\]

Where; RUC is road user cost (IDR/Km); BOK is vehicle operation costs (IDR/Km); VOT is value of time (IDR/Km); AC is accident cost (IDR/Km) and Toll is Toll road fare (IDR/Km). In this study, accident cost and toll road fare were not taken into account, because the focus on calculating road user costs is the decrease in vehicle speed and the time wasted due to obstacles of road rehabilitation work zones.

3. Results and discussions
3.1. Speed decrease
Speed decrease analysis was conducted by comparing traffic flow in units of vehicle per five minutes because the data surveyed show only 4-6 hours. If it used a unit of vehicle per hour, it could not see a vehicle speed decrease that occurs because of the lack of data. The analysis was carried out at the two locations described in the experimental design. The following was a graph of the vehicle average speed in the work zone of “Lane 1 & 2” presented in figure 4.
Figure 4. Speed of traffic in the work zone of “Lane 1&2”

Figure 4 shows that in the work zone of “Lane 1 & 2”, there was a speed decrease. In this location, the road rehabilitation work zone was located at L1 (slow lane) and it blocked L2 (middle lane) with an area of 1369.7 m² and the total length of 278.5 m. Since L1 (slow lane) and L2 (middle lane) were closed, the vehicles on that lane (heavy vehicle) were forced to switch to L3 (fast lane) so that the queue occurred and the vehicle speed decreased very drastically. The following figure shows the average vehicle speed in the work zone of “Lane 2 & 3”.

Figure 5. Traffic to flow in the work zone of “Lane 2&3”

Figure 5 shows that there was decrease of vehicle speed causing vehicle queue at a certain time. In this condition, the location of the work zone was located in L2 (middle lane) and the area was closed up to L3 (fast lane) with an area of 1949.5 m² and a total length of 366.5 m. Since L2 (middle lane) and L3 (fast lane) were closed, there was vehicle queue on both lanes, and they were moved to L1 (slow lane). As a result, a vehicle queue occurs at L1 (slow lane).

From the results of data processing on speed towards vehicle flows were then compared to the designed plan according to [14] in Section S of JORR Toll. The following table shows a decrease in vehicle speed.

| Location | Actual Average Speed (Km/h) | Designed Speed (Km/h) | Speed Decrease (Km/h) |
|----------|-----------------------------|------------------------|-----------------------|
|          |                             |                        |                       |
Table 2 shows that there was speed decrease in both locations. Work zones in “Lane 1 & 2” had an actual average speed of 27 km/h and decreased by 53 km/h compared to the design speed of 80 km/h. Meanwhile, work zone in “Lane 2 & 3” had an actual average speed of 21 km/h and decreased from 59 km/h compared to the design speed of 80 km/h. The work zones in “Lane 1 & 2” had higher actual average speed than the work zones in “Lane 2 & 3” due to the lane that could be used in the work zones in “Lane 1 & 2” was the fast lane (L3), while the lane that could be used in the work zones in “Lane 2 & 3” was slow lane (L1). However, this research was only carried out within the barrier area.

### 3.2. Vehicle Queue

Analysis of vehicle queues is calculated when the vehicle speed is below 10 km/h. The vehicle queue for the obstacle area in “Lane 1 & 2” in both lanes with a length of 278.5 meters can be seen in figure 6.

![Figure 6. Vehicle queue in lane 1 & 2](image_url)

Figure 6 shows the vehicle queue for 265 minutes. The maximum vehicle queue was at 22:40 where there were 481 vehicles. If it was multiplied by the length of the passenger vehicle, i.e. 4.7 meters, the maximum queue length due to obstacles in Lane 1 & 2 would be 2261 meters or about 2.2 kilometers. The analysis of the vehicle queue for the obstacle area in “Lane 2 & 3” with a length of 366.5 meters can be seen in figure 7.
Figure 7 shows the vehicle queue for 145 minutes. The maximum vehicle queue was at 02:10 with 521 vehicles. If it was multiplied by the length of the passenger vehicle, i.e. 4.7 meters, the maximum queue length due to obstacles in Lane 2 & 3 would be 2449 meters or around 2.4 kilometers. From both analyses, the following table shows the speed decrease and vehicles queue.

| Location   | Length of obstacles (m) | Actual Average Speed (Km/h) | Vehicle Queue (m) |
|------------|-------------------------|-----------------------------|-------------------|
| Lane 1&2   | 278.5                   | 27                          | 2261              |
| Lane 2&3   | 366.5                   | 21                          | 2449              |

From Table 3, it can be concluded that the obstacles of road rehabilitation work zones can cause speed decrease and vehicle queue. In road rehabilitation work zone in lane 1 & 2, the speed decreased to 27 km/h and produced vehicle queue of 2261 m. meanwhile, in road rehabilitation works in lanes 2 & 3, the speed decreased to 21 km/h and produced vehicle queue of 2449 m. From these results, it can be concluded that the longer the obstacles, the longer the vehicle queue. It should be considered by road managers, especially JORR Toll Road Section S in planning road rehabilitation work zones.

3.3. Calculation of Vehicle Operation Costs and Value of Time
From data processing of speed, the data were used to calculate the vehicle operation costs [12]. The following table shows the total results for vehicle operation costs.

| Location   | Length (km) | Cost (IDR/km/window time) | Cost (IDR/km/day) |
|------------|-------------|---------------------------|-------------------|
| “Lane 1&2” | 0.2785      | IDR. 240,493.-            | IDR. 923,493.-    |
| “Lane 2&3” | 0.3665      | IDR. 176,410.-            | IDR. 923,747.-    |
The data processing of speed can also calculate the value of time. The value of time was calculated using equations (1), (2), and (3). The following are the total results for the value of time.

### Table 5. Calculation of Value of Time

| Location      | Length (km) | Cost (IDR/km/window time) | Cost (IDR/km/day) |
|---------------|-------------|----------------------------|-------------------|
| “Lane 1&2”    | 0.2785      | IDR. 494,164.-             | IDR. 1,897,590.-  |
| “Lane 2&3”    | 0.3665      | IDR. 320,394.-             | IDR. 1,677,700.-  |

3.4. Calculation of road user cost

The analysis of road user costs in this study was conducted by adding up the vehicle operation costs to the value of time based on the equation (4). From these results, it can be seen a graph of the road user cost comparison in the work zones in “Lane 1 & 2”.

![Graph](image)

**Figure 8.** Comparison of road user cost in the work zones in “Lane 1 & 2”

Figure 8 shows that the total road user cost generated due to the road rehabilitation work zone was IDR. 734,657.- per km during window time or IDR. 2,821,083.- per km per day. The total difference between road user costs in the work zone in “Lane 1 & 2” with normal conditions reached 206%.

For the work zones in “Lane 2 & 3”, the comparison of road user costs can be seen in the following graphic.
Figure 9. Comparison of road user cost in the work zone in “Lane 2 & 3”

Figure 9 shows that the total road user cost generated due to the road rehabilitation work zone was IDR. 496,804,- per km during window time or IDR. 2,601,446,- per km per day. The total difference between road user costs in the work zones in “Lane 2 & 3” with normal conditions reached 169%.

From the results of both analyses for normal conditions, the actual vehicle speed was changed using the designed speed with the same vehicle volume and at the same observation time. Thus, it can be seen that when the vehicle speed decreased and vehicle queue occurred, the difference in cost was normal. The component of road user costs causing the high cost was the value of time. It will be higher if the vehicle speed is lower, but if the vehicle speed is higher, the value of time will be lower.

4. Conclusion
Speed decrease can be seen if it was compared to the normal conditions (assuming using the designed speed). Work zones in “Lane 1 & 2” had an actual average speed of 27 km/h and decreased by 53 km/h compared to the designed speed of 80 km/h. Meanwhile, the work zones in “Lane 2 & 3” had actual average speed of 21 km/h and decreased by 59 km/h compared to the design speed of 80 km/h. The work zones in “Lane 1 & 2” had higher actual average speed than the work zones in “Lane 2 & 3” due to the lane that could be used in the work zones in “Lane 1 & 2” was the fast lane (L3), while the lane that could be used in the work zones in “Lane 2 & 3” was the slow lane (L1).

From the results of vehicle queue analysis, it can be concluded that due to the obstacles of road rehabilitation work zones can cause speed decrease and vehicle queue. In the road rehabilitation work zone in Lanes 1 & 2, the vehicle queue was 2261 m. Where the road rehabilitation work zones in Lane 2 & 3 produced vehicle queue of 2449 m. From these results, it can be concluded that the increasing length of obstacles can cause a longer vehicle queue. This should be considered by road managers, especially JORR Toll Road Section S in planning the road rehabilitation work zones.

The road user cost with different lane parameters for the work zone in “Lane 1 & 2” was IDR. 2,821,083,- per km per day, while the work zone in “Lane 2 & 3” produced road user cost of IDR. 2,601,446,- per km per day. This road user cost was only valid for 5091 vehicles for the work zone in “Lane 1 & 2” and 3486 vehicles for the work zones in “Lane 2 & 3”. If it was compared to normal conditions (assuming using designed speed), the total difference between road user costs in the work zones in “Lane 1 & 2” reached 206%. Meanwhile, the total difference between road user costs in the work zones in “Lane 2 & 3” reached 169%.

Acknowledgements
This research was funded by the DRPM Universitas Indonesia through the PIT 9 Grant 2019, funded with contract No. NKB-0076/UN2.R3.1/HKP.05.00/2019. The authors thank PT Hutama Karya for assisting to obtain the data.

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