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The Effect of Level Crossing on the Railroad Line Capacity

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Abstract Changing the railway line from single track to double track will increase the railway line capacity, which means there is an additional number of train trips. Even though it has become a double track, the train trip still passes through a level crossing. If the number of train trips increases, it will result in more frequent level crossing gates being closed, or it can also result in more extended gate closing times. When the level crossing gate is closed, there will be a road traffic conflict; the traffic will stop and form a queue. The more often the level crossing gate is closed, the more road traffic conflicts will increase. By using the Indonesian method for calculating the railway line capacity, the change from single track to double track will increase the railway line capacity by 2.35 times. However, this calculation has not considered the existence of a level crossing, so this study aims to determine the amount of the railway line capacity that can be achieved, which is influenced by the level crossing without significantly increasing road traffic conflicts. The research method was carried out by taking data on train trips and road traffic at the level crossing that exists today, which is still a single line, then simulating the conditions when it has turned into a double track. Simulations are carried out by adding the number of train trips according to the double track capacity. Simulation results showed that at the level crossing, the factor affecting the increase in the railway capacity line is the headway time between the closing of the level crossing gate. For headway time values below or equal with 2.5 minutes, the line capacity increases by 1.5 times the single-line capacity. As for the headway time value above 2.5 minutes, the line capacity increases to 2.35 times the capacity of the single line. From this research, it can be concluded that the level crossing affects increasing the capacity of the railway line. To achieve maximum railroad capacity, the headway time between closing the level crossing gate must be more significant than 2.5 minutes.

Keywords Double Track, Railway Line Capacity, Level Crossing

1. Introduction

Most of the existing railway network in Indonesia is still single-track railways. In the masterplan of Indonesia's railways [1], the Indonesian Government has planned to turn a single track into a double-track railway. In constructing a double-track railway, the concept used is only to build a new railway next to the existing railway, not including doing work related to removing the level crossing [2]. So although the double-track railway has been used for train trips, there is still a train trip that passes through a level crossing. The change from a single track to a double-track railway can increase the number of train trips, which also means increasing railway line capacity [3].

Based on existing regulations [4], when a train trips through a level crossing, the level crossing gate must be closed, and all highway traffic must temporarily stop. This condition causes traffic delays for highway users [5]. The occurrence of highway traffic delays will form vehicle queues and congestion on the highway.

The more train trips, the frequency of trains passing through the level crossing will be more frequent so that the possibility of closing the flow of highway traffic will be more frequent or will be longer. More frequent or more prolonged traffic closures will also lead to longer and longer queues that eventually occur congestion on the highway. The change of single track to double-track railways for the addition of railway line capacity is very beneficial to rail transportation but can be detrimental to highway transportation. Ideally, the increase in the number of train trips does not interfere with the performance of highway traffic.

Theoretically, based on the Indonesia method formulation for calculation of railway line capacity, the change from a single-track railway to a double-track railway will increase the capacity of the railway line by 2.35 times. However, this calculation has not considered the existence of a level crossing. This study aims to determine the amount of the railway line capacity that can be achieved, which is influenced by the level crossing without significantly increasing highway traffic conflicts.

2. Literature Review

Level crossing between the railway and the highway is the meeting location of land transportation modes with different infrastructure systems, so it often causes problems related to each mode of transportation. A phenomenon in a level crossing encourages researchers to conduct research related to the level crossing. Gruyter [5] has conducted research to identify the impacts of level crossing. The results showed 18 types of impacts consisting of 8 types of impacts related to transportation and economy, seven types of impacts related to social conditions, and three types of impacts related to environmental conditions.

Some researchers have conducted research on topics related to railway line capacity, among others. Sogin [6] investigated the addition of passenger train trips by changing the freight train travel schedule after changing from a single line to a double track to increase the capacity of the railway line. The result shows that adding passenger trains to a corridor will increase the delay of freight trains. On single track, the most significant impact on freight trains is due to the higher priority of the passenger train rather than its speed. In a double-track configuration, the delay is mostly eliminated, and a higher speed differential between train types causes more overtake conflicts.

Jakob [7] researched the impact of faster freight trains on railway capacity and operational quality. As a result of the study, the overall operational quality can be enhanced by allowing freight trains a higher maximum speed. Freight trains can occasionally use their allowed higher speed level only when needed. Luca [8] conducted a simulation-based approach for supporting a threshold analysis aiming at identifying the maximum number of trains to be operated on a line, given the related infrastructural and operational constraints.

Research related to level crossings has been carried out by several researchers, including: Irawati [9] conducted level crossing research on Pecindilan Surabaya road to see the delay and length of queues when the level crossing gate was closed. The research results showed that the length of the track closures significantly influences the magnitude of delays and the length of queues. Utami [10] researched the intersection of Gayungkebonsari Surabaya road to get a mathematical model of the relationship between the length of the closing time of the crossing with the number of train chains and train speed, and the second model is the relationship between the length of the crossing closing time and the length of the vehicle queue. While Widyastuti [11] conducted research related to the level crossing on Imam Bonjol Blitar road, there is a positive relationship between the train lengths and the duration of gate closing time. However, the train speed has a negative relationship. Moreover, the length of the train has a positive relationship with the length of the vehicle queue. Widyastuti [12] also conducted research at the crossing of Jemursari Surabaya road to get two models, which are: the first model is the relationship between the length of the train, train velocity, and the closing time of the railway level crossing, and the second model is a relationship between the closing time of the railway level crossing and the length of the vehicle queue.

To calculate double-track railway capacity in Indonesia, Widyastuti [13] researched to compare the calculation of railway capacity using the Indonesian method and the UIC method. The analysis result of both methods shows an improvement in railway capacity because of the double-track construction. These two methods have different results due to each variable. Moreover, one of the UIC variables is additional time due to maintenance differentiated based on its utilization. Utilization in the UIC method is differenced based on its operational conditions by peak and non-peak hours or normal conditions that may also affect the capacity.

3. Research Object and Methods

3.1. Research Object

The object in this research is one of the level crossings in Surabaya, namely JPL 10 on Gayungkebonsari road with coordinates -7.32370, 112.72181. Fig. 1 indicates the location of the research object. The railway located at the JPL 10 level crossing is a single-track railway that connects Wonokromo station with Sepanjang Station. The distance between Wonokromo station and Sepanjang station is 6,806 kilometers, the distance between Wonokromo station and JPL 10 is 3,706 kilometers, and the distance between Sepanjang station with JPL 10 is 3.1 kilometers.

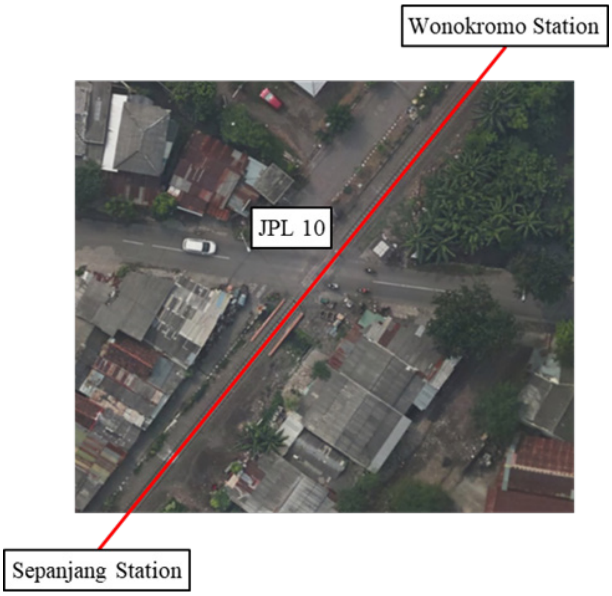

Figure 1. Location of the research object

The type of highway at the level crossing is a two-line two-direction highway undivided. The width of this highway is six meters. This type of vehicle that passes through the highway consists of passenger vehicles, mini trucks/minibusses, motorcycles, and unmotorized vehicles.

3.2. Research Method

Fig. 2 is a flowchart that shows the stages in carrying out this research, namely:

1. The first stage of this research is to get the characteristics of level crossings in the current conditions, including the volume of highway traffic that passes through level crossings for 24 hours, train trips that pass level crossings, and the closing of level crossings gate. The method for obtaining characteristic data is to conduct observation surveys at level crossings for 24 hours.
2. From the characteristic data of level crossing, the next stage is to create a mathematical equation model that shows the relationship between the queue that occurs with the volume of traffic and the length of the closing time of the level crossing gate. Another mathematical model is the relationship between queueing dispersal time and the queue that occurs.
3. The next stage is to simulate the additional scheduling of train trips because the railway line has changed into a double-track railway. In scheduling new train trips, consider the minimum headway between trains on each rail line and theoretical capacity calculations.

Minimum headway calculation using (1):

$$H = \frac{60 \, x \, S_{A-B} + 180}{V} + 1.5 \qquad (1)$$

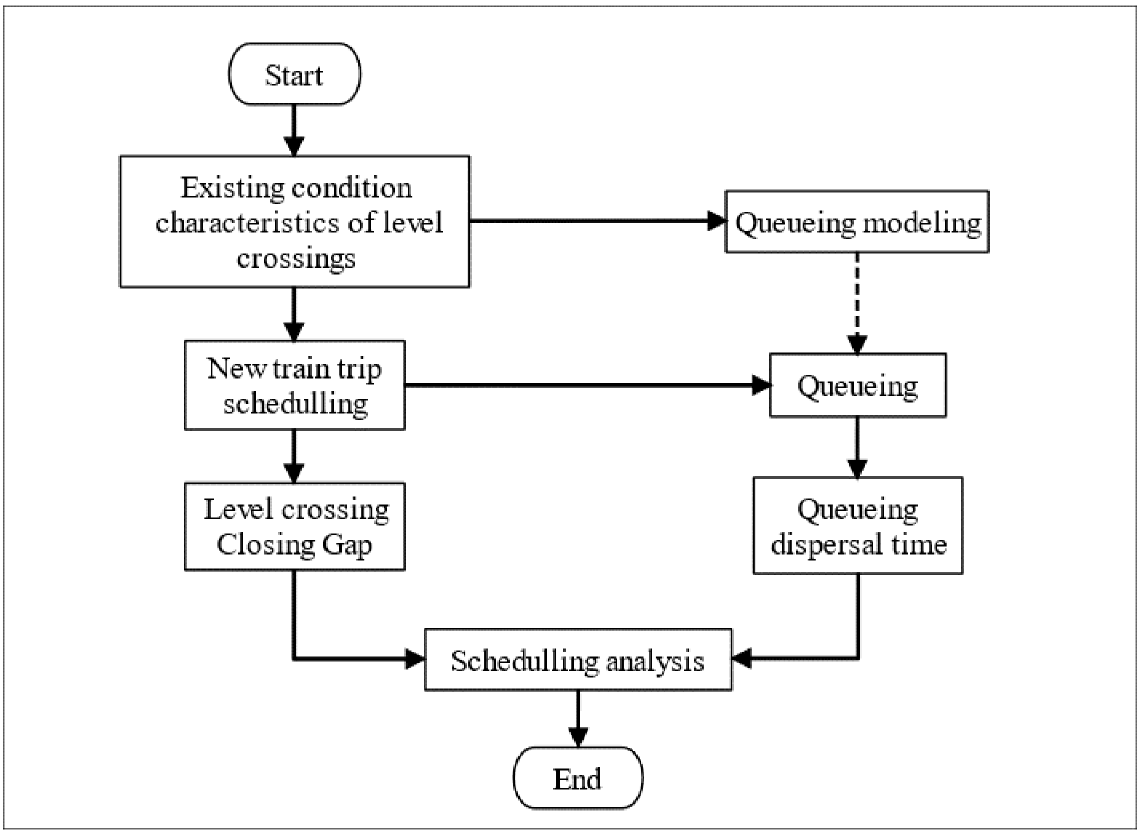

Figure 2. Research method flowchart

with:

H = headway between trains (minutes)

SA-B = distance between station A and station B (km)

V = train trip speed (km/h)

The Indonesian method formula for calculating rail capacity for a single railway line is (2):

$$K = \frac{1440}{H} X\,0{,}6 \quad (2)$$

Moreover, for the double-track railway line is (3):

$$K = \frac{1440}{H} X\,2\,\mathrm{X}\,0{,}7 \quad (3)$$

with:

K = double-track railway capacity (train/day)

H = headway between trains (minutes)

4. Using the queuing model in the previous stage will get queues and queueing dispersal times from the new scheduling of train trips results.
5. The following final stage analyzes the new train trip schedule by comparing the queueing dispersal time with the gap closing times of level crossings. Train trips cannot be applied if the queueing dispersal time is greater than the gap closing time. The total number of train trips that can be applied is considered the capacity of double-track railways lines affected by a level crossing.

4. Discussion

4.1. Highway Traffic Characteristic

One result from the observations at a JPL 10 is traffic volume, namely the number of vehicles passing through the level crossing for 24 hours. Fig. 3 shows the percentage of vehicle types passing through the JPL 10 level crossing.

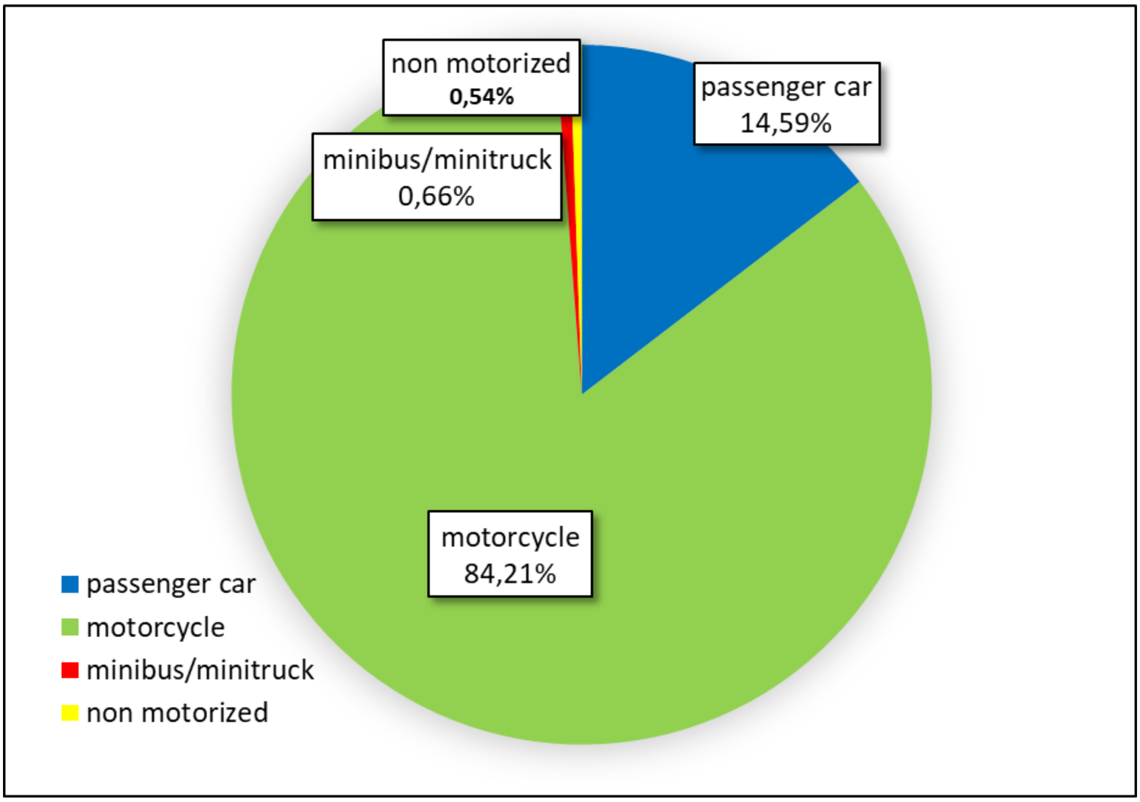

Figure 3. The percentage of vehicle types passing a level crossing

The percentage of vehicles passing through the crossing by vehicle type for 24 hours is passenger cars by 14.59%, motorcycles by 84.21%, minibusses/mini trucks by 0.66%, and non-motorized vehicles by 0.54%.

Fig. 4 shows 24-hour fluctuations in traffic volume consisting of westbound, eastbound, and total level crossing traffic volume. It is seen in Fig. 4 that from 00:00 to 05:00, the volume of traffic is relatively small, then from 05:00, the volume of traffic tends to start increasing until 07:00. From 07:00 to 19:00, the traffic volume tends to be constant, with an average traffic volume of 973 Passenger Car Equivalent (PCE)/hour. From 19:00 to 24:00, the volume of traffic tends to decrease. Overall the average daily volume is 659 PCE/hour.

4.2. Railway Characteristic

The number of trains passing through the JPL 10 level crossing for 24 hours is 29 trips, 14 trips from Wonokromo station to Sepanjang station, and 15 trips from Sepanjang station to Wonokromo station. The average headway train trip is 41.76 minutes.

Fig. 5 shows the train trip pattern (trajectory) between Wonokromo and Sepanjang stations that pass through level crossing JPL 10.

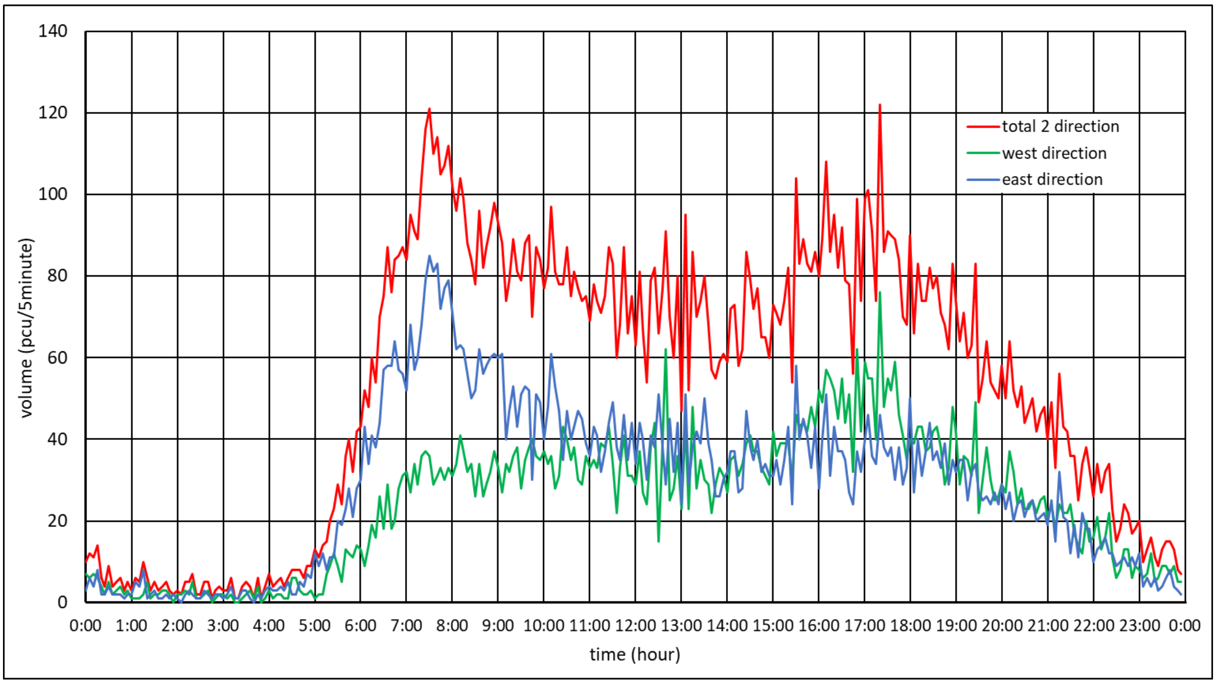

Figure 4. Traffic volume fluctuation

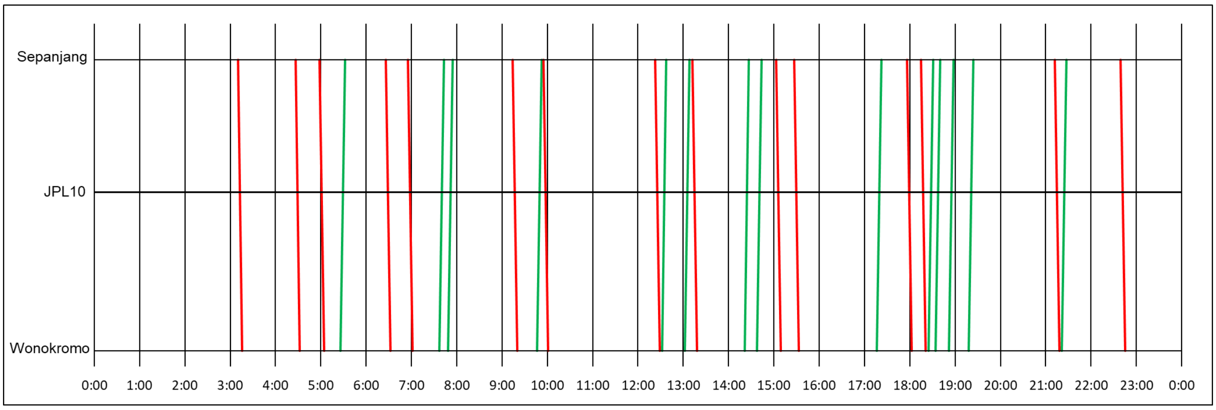

Figure 5. Train trajectory between Wonokromo station and Sepanjang station

Headway calculations for the railway line between Wonokromo station and Sepanjang station, with S_{A-B}, is the distancebetween Wonokromo station and Sepanjang station, 6,806 kilometers. V is the average speed when the train runs between Wonokromo station and Sepanjang station at 70 km/h, with (1) obtaining a headway value of 10 minutes. For a headway of 10 minutes, using the railway capacity calculation formula based on the Indonesia method obtained a railway capacity of 86 trips/day for the single-line railway. With the number of train trips per day of 29 trips and the capacity of a single-track railway line of 86 trips/day, the railway capacity used is only 33.72%

4.3 Level Crossing Characteristic

Table 1 shows the characteristics of level crossing indicating the things that happen when the level crossing gate is closed, namely the number of closures of the crossing door in a day, the length of time closing the level crossing gate, the time headway between the closure of level crossing gate, and the queue of vehicles that occur on the highway and queueing dispersal time.

Table 1. Level crossing Characteristic

Number	Description	Unit of measurement	Value
1	Total closing	times/day	29
2	Average duration gate closing	minutes	1.08
3	Longest duration gate closing	minutes	2.53
4	Fastest duration gate closing	minutes	0.38
5	Average gate closing time headway	minutes	41.75
6	Longest gate closing time headway	minutes	147.80
7	Fastest gate closing time headway	minutes	8.27
8	Average vehicle queueing	PCE	12
9	Minimal vehicle queueing	PCE	1
10	Maximal vehicle queueing	PCE`	31
11	Average queueing dispersal time	minutes	0.85

4.4. Mathematical Model

From data of the level crossing, the mathematical relationship model between queues that occur, traffic volume, and duration of level crossing gate closing is stated with the equation $Y_1 = 0.15735\ X_1 + 10{,}02035\ X_2 - 4{,}28839$ with Y_1 as the queue that occurs, X_1 is the volume of highway traffic, and X_2 is duration level crossing gate closing. Moreover, the mathematical relationship between queueing dispersal time and the queue that occurs can be expressed by the equation $Y_2 = 0.0652\ Y_1 + 0.027$ with Y_2 as queueing dispersal time and Y_1 as the queue that occurs.

4.5. New Train Trip Schedule

After becoming a double-track railway, a new train scheduling simulation is carried out to determine the characteristics of level crossings. The things done in the train trip scheduling simulation are:

1. Get the minimum headway of train travel on each rail line using (1). In this study, $S_{A\text{-}B}$ is the distance between Wonokromo station and Sepanjang station, 6,806 kilometers. V is the train trips average speed between Wonokromo station and Sepanjang station 70 km/hour. Equation (1) shows that the minimum headway between train travel between Wonokromo station and Sepanjang station for each rail line is 10 minutes.
2. The number of train trips that will pass through level crossings is assumed to equal the double track capacity. The calculation of double rail capacity uses (2). For a 10-minute headway, the double-track rail capacity between Wonokromo Station and Sepanjang Station is 202 train trips/day, or 101 train trips on each railway line. The new train trip schedule is carried out by compiling a departure schedule for 101 train trips from each station with a headway of at least 10 minutes.
3. Based on Fig. 4 traffic volume fluctuations, the average traffic volume is relatively constant from 07.00 to 19.00. In scheduling new train trips to get the maximum effect, then at 07.00 - 19.00, it is assumed that there are train trips with headway every 10 minutes on each railway line.
4. Simulations are also carried out on the train departure schedule from each station so that the headway for closing the level crossing gates can vary.

4.6. Analysis Train Trip Schedule

The change from a single line to a double-track railway impacts the pattern of train trip operations while passing through the level crossing. When closing the level crossing gate, the single-track railway only serves train trips in one particular direction so that the headway between the closing of the level crossing gate will be the same as the headway of the train trip on the train trip line. In conditions that have turned into the double-track railway, the operating pattern of train trips at the level crossing is possible to cross between trains in the opposite direction. So that one time, the closure of the level crossing gate can occur only one train trip, or there can be two train trips in the opposite direction. Because the level crossing with a double-track railway can be a cross between trains, there are two headways: the headway between the train trip and the headway between the closing of the level crossing gate.

Headway at level crossing varies depending on the departure schedule of the train trip from each departure station. Headway between train trips at the level crossing affects the headway of closing the level crossing gate and the duration of closing the level crossing gate. Simulation of train trip scheduling produces a headway value for train trips at the level crossing between 0.5 to 9.5 minutes. The simulation results also showed a value between 0.5 minutes to 10 minutes for the headway closing the level crossing gate.

If the headway value for the level crossing gate closure is 0.5 to 2.5 minutes, the queue after the gate is opened cannot be completely exhausted. However, the closure of the level crossing gate must be closed again. At the headway value of the level crossing gate closure is 0.5 minutes, the solution to prevent endless queues is to combine two adjacent level crossing gate closures into one level crossing gate closure. In this way, the headway between level crossing gates will change to 10 minutes, which also impacts the duration of the level crossing gate closures, namely the closing duration of level crossing gates from 1.1 minutes to 1.6 minutes. For the headway value between level crossing gate closures of 1.5 to 2.5 minutes, merging the closure of the level crossing gate cannot be done because, based on simulations, if merged, the closing duration changes to 2.6 to 3.6 minutes. Closing the level crossing more than 2 minutes resulted in more queues and longer queueing dispersal times. For the value of the headway of closing the level crossing gate greater than 2.5 minutes, the queue of vehicles that occurs at the time of closing the level crossing gate can be exhausted in its entirety before closing the next level crossing gate.

According to the Indonesia method, a double-track railway capacity with a headway of 10 minutes between Wonokromo station and Sepanjang station is 202 train trips/day or 101 train trips on each railway line. The simulation of train trip scheduling assumes that in the period between 07:00 and 19:00 with a 10-minute headway, there are 146 train trips in 2 directions or 73 train trips in each direction on each rail line. Against the double-track railway capacity, the percentage of train trips between 07:00 and 19:00 is 72.28%. The remaining 56 train trips in two directions (28.82%) are assumed to run outside from 07:00 to 19:00.

The simulation results show that if the headway value for closing the level crossing gate is less than or equal to

2.5 minutes, 50% of train trips at 07.00 – 19.00 will cause queues that do not run out at the closing of the next level crossing gate. By assuming that if there is a queue that does not run out at the closing of the next crossing, then train trips cannot be carried out, at 07.00 - 19.00 there are only 73 train trips in 2 directions or a total of 24 hours can only be 129 trips. Meanwhile, for the headway value for closing the level crossing gate for more than 2.5 minutes on all train trips from 07.00 to 19.00, the queue of vehicles at the closing of the level crossing gate can be utterly exhausted before the closing of the next level crossing gate. So from 07.00 to 19.00, there are 146 train trips in 2 directions or 202 trips in 24 hours.

By assuming the number of train trips in the simulation results as the capacity of the double-track railway, namely the maximum number of train trips that can pass through the double-track railway. The amount of the double-track capacity of the railway which is affected by the level crossing is:

- For the value of the headway closure of the level crossing gate less than or equal to 2.5 minutes, the capacity of the double-track railway is 129 trips/day.
- For the value of the headway closure of the level crossing gate greater than 2.5 minutes, the capacity of the double-track railway is 202 trips/day.

Based on (1), the capacity of a single railway with a headway of 10 minutes is 86 trips/day. Comparing the double-track railway's capacity with the single-track railway's capacity, the magnitude of the increase in capacity due to the change from a single track to a double-track railway can be known. The considerable value of capacity addition is as follows:

- On the double-track rail lane, if the headway value of closing the level crossing gate is less or equal to 2.5 minutes, the double-track rail lane capacity is 129 trips/day, which is an increase in capacity of 1.5 times the capacity of the single-track railway.
- On the double-track rail line, if the headway value of closing the level crossing gate is more significant than 2.5 minutes, the double-track rail line capacity is 202 trips/day, which is an increase in capacity of 2.35 times the capacity of the single line of the railway.

Fig. 6 shows the double-track railway capacity value against the level crossing gate closing headway. The circle marker shows the value of single-track line capacity with a 10-minute train trip headway based on the Indonesian method calculation formula of 86 trips/day. The square marker shows the value of double-track line capacity with a 10-minute train travel headway based on the Indonesian method calculation formula of 202 trips/day. The triangle red marker indicates double-track lane capacity with a 10-minute train trip headway affected by the level crossing. On the red line, if the headway of the level crossing gate closes by 1.5 and 2.5 minutes, the double-track capacity is 129 trips/day or only increased by 1.5 times the capacity of the single line. On the headway of the level crossing gate closes larger than 2.5 minutes, the capacity of the dual-track railway affected by the level crossing is 202 trips/day or an increase of 2.35 times the single line capacity.

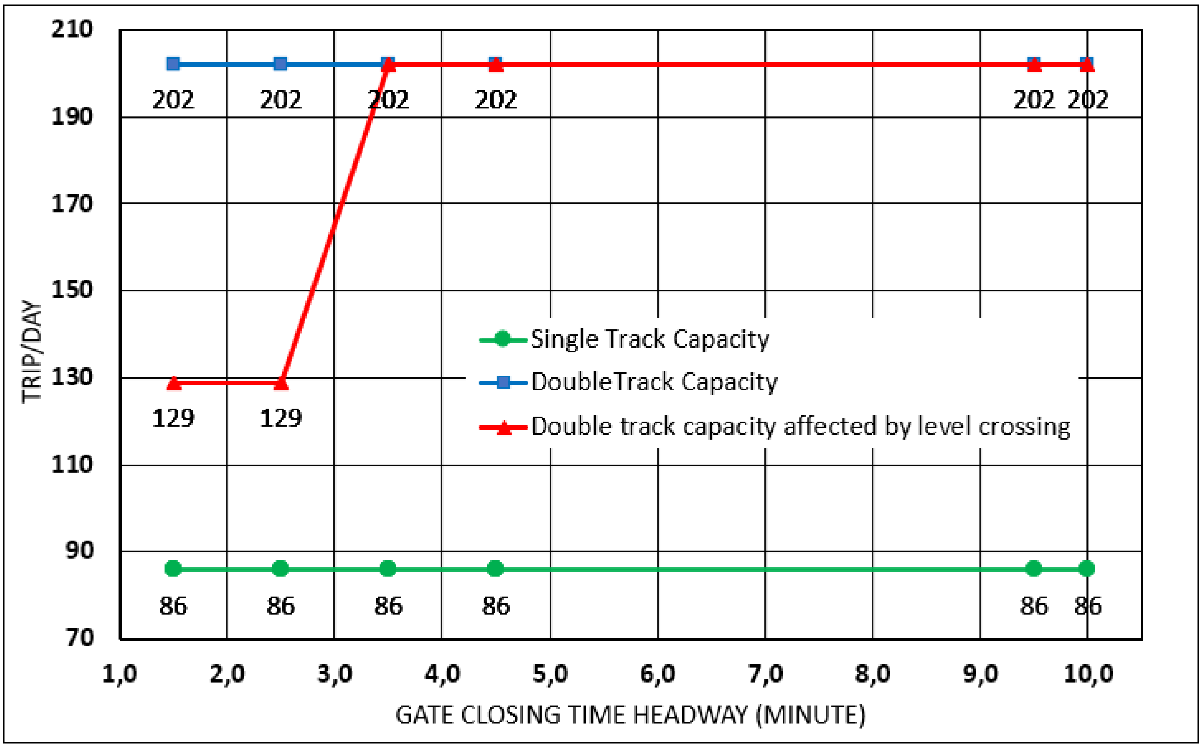

Figure 6. Railway capacity against gate closing headway

5. Conclusions

A mathematical model shows the relationship between the queue that occurs, highway traffic volume, and duration of level crossing gate closing, based on the data obtained at the current level crossing is $Y_1 = 0.15735\ X_1 + 10.02035\ X_2 - 4.28839$ with Y_1 as the queue that occurs, X_1 as traffic volume on the highway and X_2 as the duration of level crossing gate closing. Moreover, the mathematical relationship between queueing dispersal time and the queue that occurs can be expressed by the equation $Y_2 = 0.0652\ Y_1 + 0.027$ with Y_2 as queueing dispersal time and Y_1 as the queue that occurs.

It is found from the simulation results that the main factor affecting the capacity of the double track railway line with the level crossing is the headway between the closure of the level crossing gate. For the value of the headway closure of the level crossing gate less than or equal to 2.5 minutes, the capacity of the double-track railway is only 129 trips/day. For the value of the headway closure of the level crossing gate greater than 2.5 minutes, the capacity of the double-track railway can reach 202 trips/day.

Compared to the capacity of the single-track railroad, for the value of the headway closure of the level crossing gate is less than or equal to 2.5 minutes, the capacity of the double-track railway is an increase in capacity of 1.5 times the capacity of the single-track railway. For the value of the headway closure of the level crossing gate greater than 2.5 minutes, the capacity of the double-track railway is an increase in capacity of 2.35 times the capacity of the single line of the railway.

The existence of the level crossing will only impact increasing the capacity of the railway line if the headway of the level crossing gate closing is less or equal to 2.5 minutes only.

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