Railway capacity analysis using Indonesian method and UIC code 405 method

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Abstract. The government has been constructing double track at Surabaya – Madiun segment to improve railway operations performance. Accordingly, after the double track has been constructed in this segment, it is necessary to analyze existing railway capacity to determine the effect of development as a cost-effective solution. Nowadays, Indonesia is using the Indonesian method as a capacity analysis method and only provides railway capacity analysis using fixed block. On the other hand, another method such as the UIC method has different variables. Therefore in this study, the railway capacity analysis uses two analytic methods that are Indonesian and UIC code 405. 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 differentiated based on its operational conditions by peak and non-peak hours or normal conditions that may also affect the capacity. It also happens in MRT Jakarta operating systems in which the headway is divided into peak and non-peak hours. Accordingly, this study could be a preliminary study for policymakers to analyze capacity in the next near future condition.

1. Introduction
Railways Strategic Plan of Transportation Ministry concerning Railway Sector of 2015-2019 [1] mentions delay data of passenger and freight trains have tended to fluctuate, and in 2014, both increased. Freight train is the most frequently delayed, the arrival delay time of which reached out 140 minutes in 2014. While, the longest arrival delay time of the passenger train happened in 2010 which was 50 minutes. Delay data of passenger and freight trains have tended to fluctuate, and in 2014 both increased. According to Sogin [2], it was caused by the different characteristics of passenger and freight trains, e.g. power, weight, braking performance, speed, priority, and on-time arrival. Therefore, delay indicates the existing railway capacity problem. In this case, capacity is represented by indicators related to infrastructure with traffic data, while the timetable is the main input in determining capacity consumption and delay indication [3].
Railway capacity analysis is one of the cost-effective solutions because of the ability to manage railway capacity more effectively. This analysis is aimed to determine the maximum number of trains that can be operated on certain infrastructure and time intervals by observing existing operational conditions [4]. Way to offset the flow of passenger and cargo mobility is by increasing connectivity on the rail network [5]. Connectivity enhancement can be done by constructing new infrastructure, using existing infrastructure, and also reactivating old infrastructure [6]. A new infrastructure project such as improving the track from single to double track is also one of solutions to increase the capacity. In 2019, Surabaya – Madiun segment was double-track constructed, where Jombang – Madiun segment has begun operating [7]. Concerning this condition, it is necessary to analyze how the capacity will be affected when the double track is in operation.

Nowadays, Indonesia uses the Indonesian method, it only provides railway capacity analysis for fixed blocks [8], it uses 3 variables as input in the capacity calculation which is the total time per day (1440 minutes), headway, and multiplier factor. Another method in railway capacity analysis namely UIC Code 405 method provides a formula which has different variables. There are 5 variables as input in the capacity calculation of the UIC method, which are reference time, average minimum headway, additional time due to the number of intermediate blocks, and additional time due to maintenance which is differenced by its utilization. Considering these conditions, it is necessary to analyze using both methods. And also, it could be a preliminary study on the railway capacity method in the next near future condition.

2. Methodology

2.1. Experimental objective

Surabaya – Madiun railway segment is currently under construction from single track become double track. The length of this segment is 152,828 km and consists of 23 stations, starting from Surabaya Gubeng Station to Madiun Station [9]. In this case, DAOP (Daerah Operasional) 8 region scope authority is Surabaya Gubeng Station to Mojokerto Station. While, DAOP (Daerah Operasional) 7 region scope authority is Curah Malang Station to Madiun Station. For detailed locations are shown in figure 1 below:

![Figure 1. Location of double track project.](image)

2.2. Data sources

The data used in this study are only secondary data. Secondary data are obtained from related institutions, including from PT.KAI DAOP 8 Surabaya and DAOP 7 Madiun. Data used in this study are GAPEKA (Grafik Perjalanan Kereta Api), track system, signaling and block system, signal service time, rolling stock data, and train speed. The detail of data function can be seen in table 1.
Table 1. Types of data and function.

| Data Types                          | Function                                                                                                                                 |
|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Grafik Perjalanan Kereta Api        | To count the number of operating trains, train departure and arrival time at a station. Furthermore, to find out the railway segment, signaling and block system, track system, etc. |
| (GAPEKA)                            |                                                                                                                                          |
| Signaling and block system          | Signaling and block system needed in railway capacity data processing and its location will determine the block section length in the UIC method. |
| Track system                        | Track system either the single track or double track becomes an important variable in railway capacity analysis                            |
| Signal service time                 | Signal service time used for headway analysis, for both single and double track.                                                            |
| Rolling stock data                  | The data referred to types of trains and train succession. Furthermore, the train type will determine its power, resistance, and also acceleration and deceleration. These data are used in the UIC method |
| Travel time                         | Travel time is used to determine operation speed.                                                                                           |
| Train speed                         | The speed used is the maximum speed and operation speed. The maximum speed is obtained from the applicable GAPEKA. Whereas, the operation speed is average speed of trains when passing a certain segment. |

2.2.3. Methods of railway capacity analysis

Supriadi [8] mentioned that railway capacity is a railway ability to accommodate train operations in the period of 1440 minutes [8]. While, UIC (1996) stated railway capacity can be acknowledged by three main parameters: infrastructure, operating systems, and service quality. Railway capacity is not static, but dynamic and bound by components forming a railway system that makes capacity depend on the specific train mix and operating conditions [3, 10]. Therefore, railway capacity will be varied along with changes in infrastructure and operating conditions. Infrastructure parameters, traffic parameters, and operating parameters are several factors that affect railway capacity [3, 11, 12]. Railway capacity is categorized into 4 types i.e. theoretical capacity, practical capacity, used capacity, and available capacity [4]. Theoretical capacity is the number of operating trains during a certain time interval; practical capacity is the actual traffic volume condition which is calculated using realistic assumptions; used capacity is the actual traffic volume occurring on the existing rail network; and available capacity is the difference between practical capacity and used capacity [4]. Furthermore, the explanation of the Indonesian method and the UIC code 405 method is as follows:

1. Indonesian Method

Supriadi [8] stated the formula used by Indonesian railways is differenced by track systems (single track and double track). This method is an analytical method in the form of mathematical equations [8], [13].

\[
K = \frac{1440}{H} \times \eta
\]  
\[
K = \frac{1440}{1} \times \eta 
\]  
\[
K = \frac{1440}{2} \times \eta 
\]  
\[
H = t_{A-B} + t_p + C
\]

Where:

\( K \) : capacity on the calculated track section

\( 1440 \): total time for 24 hours (24x60 minutes)

\( H \) : average headway
\( \eta \): The multiplier factor after deducting time factor for maintenance and time due to the operating pattern of train travel, 60% for single track and 70% for double track.

\( t_p \): travel time on a track section.

\( t_{A-B} \): travel time from the sight point of the outer signal to the station.

\( C \): signal and block service time.

Equation (1) is a formulation that applies to a single-track system. Equation (2) is a formulation used for the double-track system. Meanwhile, equation (3) is the headway calculation.

Headway calculation is a step before analyzing railway capacity. Equation (3) is the main formula to calculate the headway of the Indonesian method. However, the headway calculation of the Indonesian method is more simplified. It is divided based on the track system and block system with the value of several variables having been determined. The Indonesian method only provides formulas for fixed block system. As in the Surabaya - Madiun railway segment, the signaling system used is an electrical signal system with closed automatic block system. The Indonesian electrical signaling scheme can be seen in figure 2.

![Electric signaling headway scheme](image)

**Figure 2.** Electric signaling headway scheme [8].

2. **UIC code 405 Method**

International Union of Railways (UIC) in a leaflet code 405 proposed an analytical method for calculating railway capacity between stations sequentially. This method calculates the proportion of operating trains to calculate the headway [14–16]:

\[
P = \frac{T}{t_{fm} + t_r + t_{zu}}
\]

Where:

\( P \): capacity (per day, per hour, etc according to the \( T \) used).

\( T \): reference time (usually 24 hours for daily capacity or 1440 minutes).

\( t_{fm} \): average minimum headway.

\( t_r \): additional time due to maintenance.

\( t_r = 0.67 \times t_{fm} \) if utilization 0.6 (applicable for normal operation of the system).

\( t_r = 0.33 \times t_{fm} \) if utilization 0.75 (applicable during peak hours).

\( t_{zu} \): additional time based on the number of intermediate blocks in the track and calculated using the formula \( t_{zu} = 0.25 \times a \).

\( a \): number of intermediate block sections.
Average minimum headway for each track is calculated using the average minimum headway between two consecutive trains of the same category [17]:

$$t_{fm} = \alpha_L t_{fm_L} + \alpha_R t_{fm_R} + \alpha_M t_{fm_M}$$

This procedure considers three different types of trains:

- L = intercity train
- R = local/regional train
- M = freight train

Where $\alpha_L$, $\alpha_R$, $\alpha_M$ factors in the formula above represent the percentage of each category of total trains.

Similar to the Indonesian Method, this method also requires headway to analyze railway capacity. F. Rotoli [17] pointed out that headway at a single-track system will be affected by travel time, acceleration and deceleration time, and signal service time. On the other hand, at a double-track system, the headway will be affected by the block length, train length, speed and signal service time.

a. Headway for single track

Determine travel times with constant operating speed and acceleration and deceleration time using Equation 6 – Equation 8 [17]:

$$t_{V_{L,R,M}} = \frac{l_b}{V_{L,R,M}}$$

$$t_{a_{L,R,M}} = \frac{V_{L,R,M}}{a}$$

$$t_{d_{L,R,M}} = \frac{V_{L,R,M}}{d}$$

Where:

- $t_{V_{L,R,M}}$ = travel time with a constant operating speed
- $V_{L,R,M}$ = operating speed of each train category
- $l_b$ = length of railway segment
- $a$ = acceleration
- $d$ = deceleration

The travel time is the result of the average train operating speed of each category divided by the length of the railway segment. Therefore, the minimum average headway can be calculated using Equation 9 [17]:

$$t_{fm_{L,R,M}} = t_{V_{L,R,M}} + t_a + t_d + t_p$$

Where:

- $t_a$ and $t_d$ = time of acceleration and deceleration (the value of acceleration and deceleration is indicated by $a$ and $d$)
- $t_p$ = signal service time
- $t_{fm_{L,R,M}}$ = average minimum headway

In this case, it is assumed in single track that the railway segment between two stations can only be occupied by one train per time based on the direction of the track. Furthermore, signal service time value ($t_p$) is assumed as representing additional time from the preparation of the electro-mechanical block routing.
b. Headway for double track

The average minimum headway for double track is calculated using Equation 10 [17]:

$$t_{h_{L,R,M}} = \frac{l_{b1} + l_{b2} + L}{V_{L,R,M}} + t_s$$

(10)

Where:

- $l_b$ = length of block section
- $L$ = length of train succession
- $V_{L,R,M}$ = operating speed considered for each category
- $t_s$ = signal service time

In this case, to calculate the double-track headway, it is assumed that the railway is equipped with a three-aspect automatic block signaling system. Where the minimum distance between two trains consecutively is based on the first block that functions to guarantee the train braking distance, added with the second block that functions to guarantee sighting distance (the operating train has to find the approaching signal location clearly) and additional distance to see signals and switch, and additional train length from the block system [17]. The blocking time calculation scheme for double track can be seen in figure 3.

![Figure 3. Blocking time calculation scheme for double track [17].](image)

3. Result and discussion

In this study, the railway capacity analysis application of Indonesian method and UIC code 405 method in the Surabaya – Madiun railway segment was carried out. The analysis was performed on the existing conditions with 2 assumptions: full single-track condition which reflects GAPEKA 2017 and 50% double-track condition which reflects GAPEKA 2019. The Surabaya – Madiun segment has different number of operating trains. It is caused by several local trains that only operate in several lines in Surabaya – Madiun segment. The Surabaya – Madiun segment is divided into 22 segments for GAPEKA 2017 and 21 segments for GAPEKA 2019, which is caused by Wilangan Station which turns into an intermediate block. The railway capacities analyzed in this study are the theoretical capacity and practical capacity. Railway capacity analysis result of the Indonesian method and UIC Code 405 method can be seen in figure 4 – figure 7.
Based on figure 4 and figure 5, the largest theoretical capacity of Indonesian method and UIC method is located in the Surabaya Gubeng Station – Wonokromo Station segment. The average theoretical capacity based on GAPEKA 2017 is 136 trains/day for the Indonesian method and 95 trains/day for the UIC code 405 method. The largest practical capacity of Indonesian method and UIC method is also located in the Surabaya Gubeng Station – Wonokromo Station segment. The average practical capacity based on GAPEKA 2017 is 89 trains/day for the Indonesian method and 73 trains/day for the UIC code 405 method.
Based on figure 6 and figure 7, the largest theoretical capacity of Indonesian method and UIC method is located in the Sukomoro Station – Nganjuk Station segment. The average theoretical capacity based on GAPEKA 2019 is 247 trains/day for the Indonesian method and 137 trains/day for the UIC code 405 method. The largest practical capacity of Indonesian method and UIC method is also located in the Sukomoro Station – Nganjuk Station segment. The average practical capacity based on GAPEKA 2019 is 159 trains/day for the Indonesian method and 96 trains/day for the UIC code 405 method. The railway capacity increment is due to the double-track operation and the replacement of the signaling and block system. Moreover, it is affected by the Wilangan station that turns into an intermediate block.

4. Conclusion
The results of railway capacity analysis using these two methods indicate an improvement in railway capacity because of double-track construction in Surabaya - Madiun segment, although the railway capacity value of Indonesian Method and UIC method is different. This is caused by the different variables in each method. Besides, these two different methods will have different methodologies and complexity levels in carrying out railway capacity analysis [15], even though the headway value of both
methods is quite similar. One of the different variables is additional time due to maintenance which is differentiated based on its utilization. Utilization in the UIC method is differenced based on its operational conditions by peak and non-peak hours that may also affect the capacity. It also happens in MRT Jakarta operating systems in which the headway is divided into peak and non-peak hours or normal conditions. In addition, MRT Jakarta and LRT Jabodebek have already used a moving block system [18]. This study implies that UIC Method can be a relevant comparison method to the existing conditions, and to generalize the results of these two methods, more case studies are needed. However, it can be used as a preliminary study recommendation for policymakers to analyze capacity in the next near future condition. Furthermore, regardless the method that will be applied in the next near future, safety must be considered more, especially at railway level crossings which are still many in Indonesia, taking into account that the crossings may create several serious potential conflicts for collisions between road vehicles and trains [19]. In addition, these conflicts will also affect the railway operating system performance.

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