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Optimizing Freight Train Operations A Case Study of Junction Planning at JIIPE

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Abstract

Timeliness, fast execution, and effectiveness in freight transport are the reasons why freight trains are the preferred mode of transportation for many manufacturing companies. To Developed of the railway utilization for freight transport, the Indonesian government has implemented policies, including the integration of the railroad junction with JIIPE (Java Integrated Industrial and Ports Estate) along the main line of the North Java Railroad (PP 71 2021). However, the growing number of trains originating from the junction poses challenges to existing schedules, particularly impacting the Surabaya Pasarturi - Bojonegoro railroad segment. This study aims to calculate train schedule based on headway and capacity, proposing adjustments to the departure frequency at Duduk Station in line with the train timetable (Gapeka) 2021 for the Surabaya Pasarturi - Bojonegoro Segment 12 of 17 alternative trains per day west direction and 18 of 21 alternative trains per day east direction. It is essential to note that this proposed frequency exceeds theoretical capacity, emphasizing the need for careful planning of additional trains within the constraints of capacity theory to maintain operational efficiency.

Keywords

Train schedules, freight transport, railway capacity

INTRODUCTION

Being on time, swift execution, and effectiveness are the reasons freight trains are the preferred mode of transportation for numerous manufacturing enterprises in dispatching their commodities. Nonetheless, the advancement of rail-based freight transportation necessitates the implementation of diverse innovations and policies. Domestic manufacturing firms choose rail transport over alternative modes due to its economic viability and swift execution capabilities. Notably, the freight-carrying capacity of a single train equates to that of 30 trucks, thereby resulting in cost efficiencies for manufacturing entities [1]. Consequently, the development of railway infrastructure emerges as a crucial imperative for fostering economic growth.

The evolution of container activity presents significant challenges for terminal operators striving to maintain operational efficiency, particularly for transshipment ports engaged in extensive intermodal container transshipment operations, encompassing sea-rail and sea-truck transfers. Amidst the various advancements employed to expedite operations at seaports, the 'on-dock' railway system distinguishes itself by directly linking seaports with the inland railway network [2]. Constructing new infrastructure is a resource-intensive and time-consuming endeavor; therefore, the effective utilization of existing network facilities through the optimization of line planning, network schedules, shifts, and maintenance assumes paramount importance. Of the myriad principles influencing this optimization, schedule planning stands out as a particularly influential factor, giving rise to an extensive domain of research. From a general perspective, this domain can be categorized into three primary fields: scientific programming, simulation-based optimization strategies, and expert systems. Scientific programming aims to formulate the globally optimal timetable or reschedule the existing timetable [3].

Rail transportation constitutes a fundamental component in the integration of a seaport with the broader urban infrastructure. Rail is commonly regarded as an efficient mode of cargo movement [4]. To address the escalating demand for rail operations, railroad administrators must devise plans approaching full capacity. However, as certain elements of the railroad network reach or approach capacity, these elements can be identified as "critical resources." Intersections, serving as nodes facilitating the connection of railway lines, become critical resources when traffic on connecting lines becomes substantial [5].

The management of freight rail transportation is subdivided into various sub-problems, encompassing crew scheduling, blocking issues, yard location challenges, train route optimization, locomotive scheduling complexities, and train scheduling and delivery dilemmas. Scheduling freight trains presents unique challenges due to their lower priority compared to passenger trains, which operate at higher speeds and adhere to fixed schedules [6]. The assignment of freight trains to specific track segments and times mirrors the resolution of a track capacity allocation problem, with the overarching goal of ensuring that shipments conveyed by the trains align with preferred logistical timelines.

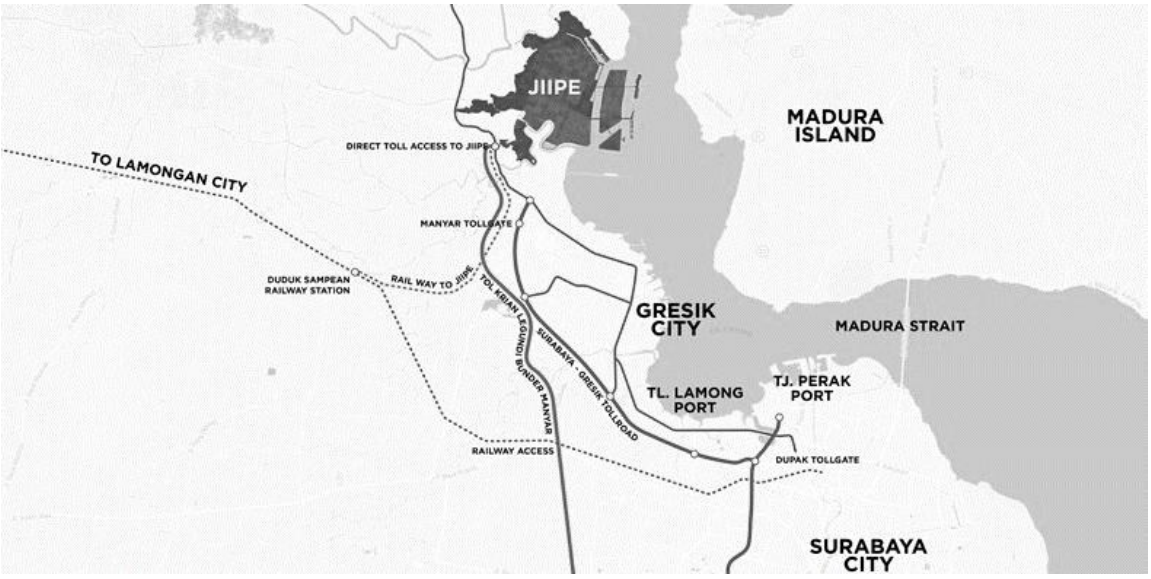

Figure 1 Industrial area and port (JIIPE) connected plan with existing the Main Railroad in North Java [20].

The schedules derived from this allocation process govern the departure and arrival times of each train at various destinations, playing a pivotal role in fulfilling customer commitments. These schedules not only dictate the timing of train movements but also significantly impact demand, which is contingent upon service frequency, thereby influencing waiting times, delays, and overall delivery timelines. To address the dynamic nature of demand, an effective freight scheduling methodology is imperative, one that strikes a balance among performance metrics, schedules, delays, user costs, and demand fluctuations [7].

The scheduling of trains poses a combinatorial optimization challenge, wherein the primary objective is to determine the arrival and departure times at each station traversed by the train [8]. Throughout the entire planning process, the headway between successive trains undergoes constant adjustments due to varying speeds and operational conditions. On each line, the headway represents the minimum time interval between two trains along the entire planning trajectory. Establishing a detailed blocking time schedule becomes essential to ascertain the minimum headway. In the context of Indonesian railway scheduling [9], dwell time emerges as a critical consideration, with the Ministry of Transportation, as the infrastructure owner, and PT Kereta Api Indonesia (Persero), as the intercity train operator, assuming responsibility [10]. To optimize schedule efficiency, execution times and minimum travel times (although not universally applicable) are calibrated to optimal values, occasionally at the expense of precision to minimize the impact on overall transportability [11].

In the context of Indonesia, railway traffic regulations consider that train operations must conform to the aspect traffic capacity. The envisioned traffic capacity is contingent upon variables such as train operating speed, block distance, operating facilities, and infrastructure maintenance time [12]. Furthermore, as underscored by Supriadi, railway capacity is defined as the track's ability to accommodate train travel operations within a 1440-minute period, equivalent to 24 hours. Various methods exist for conducting railway capacity analysis, with one such method being the Indonesian approach. This analytical method takes the form of a mathematical formula and currently provides capacity analysis exclusively for fixed blocks or fixed blocks only. Influential factors in the Indonesian Method include speed, distance of road plots or blocks, type of track system, and the signalling system and blocks [13]. According to the Indonesian railway method, converting a single-track railway line to a double track would significantly augment its capacity, leading to an increase in the number of train trips [14]-[15].

The efficiency between trade and transportation demand is a very important effect of economic development in countries. There is a need for sustainability infrastructure, especially in terms of exports and imports in port area to ensure competitiveness on a global scale [16]. Rail and road terminals, integral components of the transportation network, significantly contribute to the competitiveness of intermodal transport by ensuring the swift, secure, and efficient transfer of intermodal loading units. However, these terminals face challenges due to their complex nature and the rapid advancements in multi-yard railway intermodal terminals [17].

In an attempt to improve the efficiency of freight transport, the Indonesian government has implemented policies to develop rail infrastructure in industrial zones and ports. As an example, they aim to connect the railroad to Java Integrated Industrial and Ports Estate (JIIPE) [18]. A railroad extends north on Java Island near JIIPE, and there's a rail line connecting to the industrial area in Gresik on the south side of JIIPE, yet it operates infrequently[19]. For additional details on the proposed connection between JIIPE and the Main Railroad in North Java, refer to Figure 1 [20].

RESEARCH SIGNIFICANCE

This aim of this study is to determine additional alternative train schedules based on headway of the existing train schedules from train timetable (GAPEKA) 2021. In this study, alternative train schedules have been added from the Duduk station in both the west direction and east directions, with sections being reviewed, specifically from Surabaya Pasar Turi Station to Bojonegoro Station. Additionally, the schedule the replacement schedule is used as a reference for the number of new trains that do not exceed the railway capacity on this segment.

METHODOLOGY

A. COLLECTION OF TECHNIQUE DATA

The process of collecting data in this study uses only one type of data, namely secondary data. Obtaining secondary data comes from related agencies, namely PT. KAI, especially DAOP 8 Surabaya (Indonesian Railway Company Operation Regional 8 Surabaya). This is because the case study of this research is the Surabaya Pasarturi–Bojonegoro segment, which is the operating area of the operational region Surabaya. The data to be obtained is in the form of infrastructure conditions and the train timetable (GAPEKA) for the year 2021 [21]. The segment reviewed uses a Surabaya Pasarturi-Bojonegoro segment because there is high traffic in this segment.

B. TECHNIQUE OF DATA ANALYSIS

The first analysis is calculating the number of trains to schedule new trains based on Train Timetable 2021 (GAPEKA 2021). The addition of the new train calculates the maximum practical headway of the existing train schedule for 2021. The maximum practical headway is used in scheduling to minimize dwell time for the new train. The theoretical headway can be calculated from the limit speed of the segment, and the practical headway can be calculated from the average speed of the segment. In this study, the equation for calculating headway if the segment uses a manual signal system with block posts Eq. 1 and Eq. 2 can be used [13]:

$$\text{Theoritical headway} = \frac{60 \times S_{a\text{-}b} + 180}{V_{Limit}} + 1 \qquad (1)$$

$$\text{Practical headway} = \frac{60 \times S_{a\text{-}b} + 180}{V_{Average}} + 1 \qquad (2)$$

S : Distance between stations (Km)
V : Speed (Km/H)

C. TECHNIQUE OF THE ALTERNATIVE NEW FREIGHT TRAIN SCHEDULING ADDED

For adding new freight train scheduling, use the maximum headway of the before and after existing trains in each station for one day. Travel time of a new train; travel time of an existing freight train with lost time due to acceleration and braking. The new freight train added is calculated until the train cannot headway before and after train scheduling in the train timetable. The all-new freight train starts at Duduk Station, continues west until Bojonegoro Station, and continues east until Surabaya Pasarturi Station. The Concepts of new train adding can be explain at figure 2.

The scheduling process employs Microsoft Excel to identify vacant time slots, utilizing the maximum headway criteria during evaluations of departure and arrival times at each station. The initial step involves arranging the existing train departure and arrival times chronologically, starting from the earliest time at the first station and progressing to the latest.

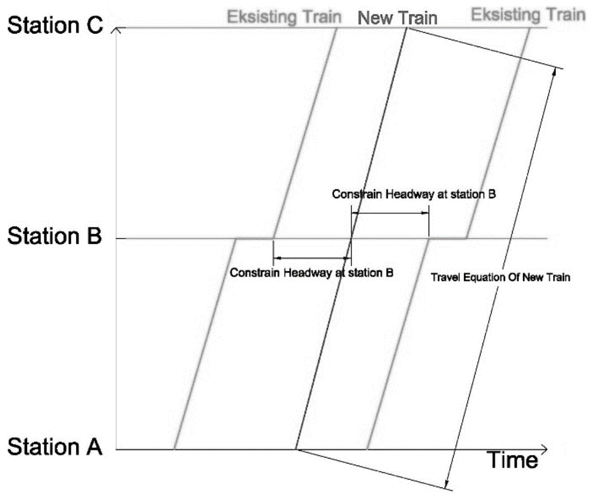

Figure 2 Concepts of additional new train.

Subsequently, the analysis focuses on identifying headway distances between existing trains that exceed the specified maximum headway. This iterative procedure is executed at each station within the reviewed segment, culminating with the final station. Ultimately, additional train travel lines are inserted into time slots corresponding to headways that satisfy the prescribed criteria. The Sorting Concepts at the Train’s Timetable at Microsoft Excel can be explained in figure 3.

	First Station		Last Station	
	Arrival	Departure	Arrival	Departure
Exsiting train 1	↓	↓	↓	↓
Exsiting train 2	↓	↓	↓	↓
Exsiting train 3	↓	↓	↓	↓
	Sort 1	**Sort 2**	**Sort 3**	**Last Sort**

Figure 3 Sorting Concepts at the Train’s Timetable.

D. TECHNIQUE OF CALCULATING THE RAILWAY CAPACITY

Use the Indonesian method's railway capacity to determine an alternative scheduling limit. Railway capacity is categorized into 4 types: theoretical capacity, practical capacity, used capacity, and available capacity. 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 [13].

Single Track

$$K = 1440/H \times \eta \qquad (3)$$

Double Track

$$K = 1440/(1/2H) \times 2 \times \eta \qquad (4)$$

K : capacity on the calculated track segment
1440 : total time for 24 hours (24x60 minutes)
H : Average headway
η : 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

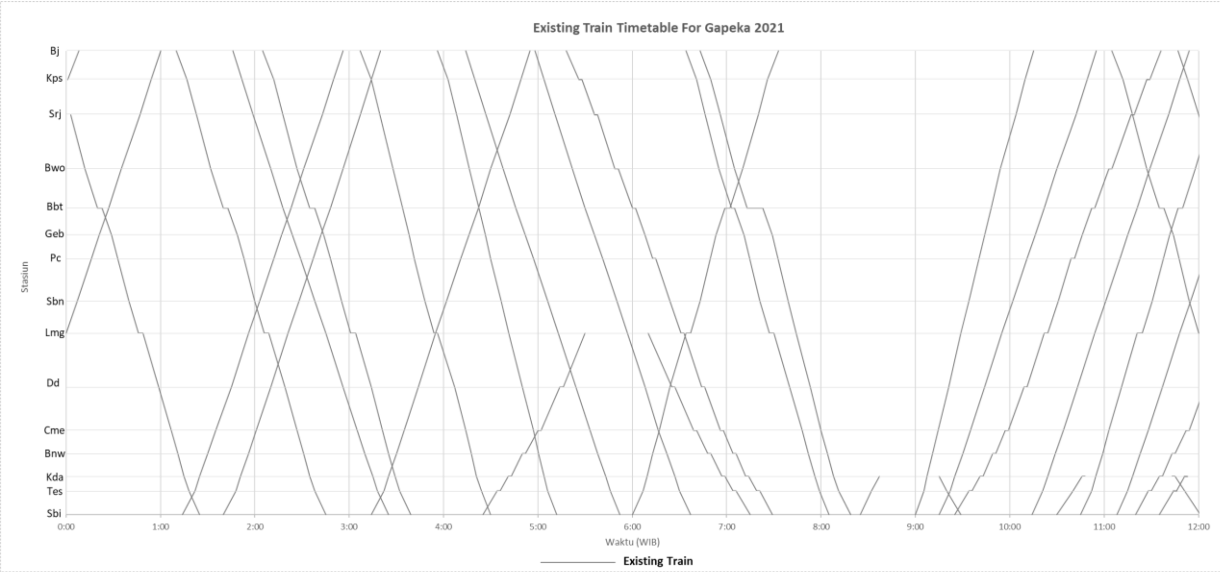

Figure 4 Exsiting Train Timetable 2021 at 00.00-12.00

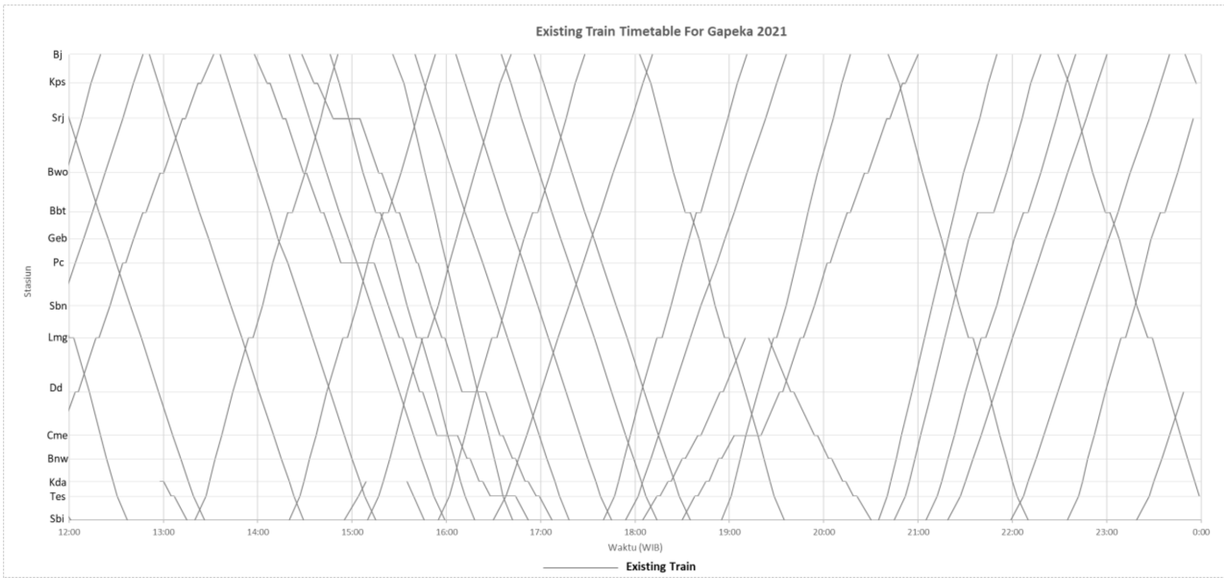

Figure 5 Exsiting Train Timetable 2021 at 12.00-00.00

RESULTS AND DISCUSSIONS

The figure 4 and figure 5 is existing train timetable 2021 of Surabaya Pasarturi- Bojonegoro segment. In this Figure x axis is time, y axis is station of Surabaya-Bojonegoro segment, and Thin continuous line is travelling line of existing train. So the train timetable can give information about number of train, schedull of train at each station, train travel time between each station, and Long time for the train to stop at the station.

From train timetable (Gapeka) 2021 on the Surabaya Pasarturi - Bojonegoro segment, there are 3 types of trains, namely intercity passenger trains, local passenger trains and Freight trains. it was found that intercity passenger and freight trains have less travel time, the characteristics of this trains is have a have a small slope line because they do not stop at many stations. For high travel time, a local train is the longer the characteristics of this trains is have a have a large slope line because it stops at many stations and have time lost of passenger boarding, acceleration and braking time.

From Figure 6 can be explain about Average Headway Between 2 Station from train timetable 2021, The result of headway calculation be seen that theoretical headway is always greater than practical headway. This is because theoretical headway uses train travel time based on maximum speed, while practical headway uses train travel time, which is influenced by time lost due to acceleration and braking. The largest practical headway in the Surabaya Pasarturi to Bojonegoro segment is 18 minutes in the Dd-Lmn and Srj-Kps segments, and the smallest practical headway is 7 minutes in the Tes-Kda segment. The headway calculation for each segment is influenced by the speed and travel time of all trains operating on one day obtained from the existing train schedule. The speed and travel time of each train are influenced by the type of train.

The calculated new freight train added base on maximum headway of segment reviewed. For west direction the reviewed segment is Duduk Station until Bojonegoro Station. Furthermore, for East direction the reviewed segment is Duduk Station until Surabaya Pasarturi Station. This reviewd segment that is used because on segment with high train traffic in railroad

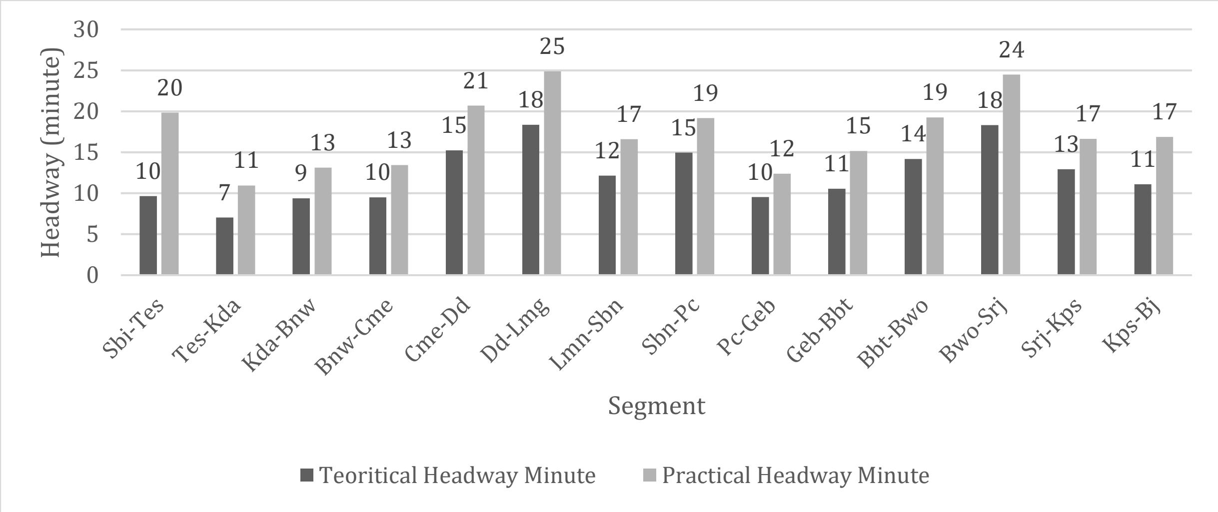

Figure 6 Headway calculate of Surabaya Pasarturi – Bojonegoro segment.

network. Maximum headway is used because the new freight train schedule that will be added is to minimize overtaking conditioned with existing trains to minimize dwell time of new freight train added. The following are the calculation Step using Microsoft Excel:

1. Enter all existing train schedules From Gapeka at each station.
2. For west direction Sorts all existing train schedules to the west from Duduk station to Bojonegoro station starting from the earliest departure to the latest departure. For East direction Sorts all existing train schedules to the west from Duduk station to Surabaya Pasarturi station starting from the earliest departure to the latest departure.
3. Determine for each headway each arrival and departure station of more than 21 minutes to the east and more than 25 minutes to the west. The headway is obtained from the largest practical headway on the segment that the additional new freight train schedule will pass at reviewed segment.
4. Insert additional train travel lines on available headway requirement at each station on segment reviewed.
5. Determine number new train can be added on each direction.

The result of the added new train of timetable 2021 as alternative new freight train can be shown in Figure 7 and figure 8. In this figure dash-dot line is alternative new freight train scheduling to west, and long dash line is alternative new freight train scheduling to East Form train timetable (Gapeka) 2021, the number of alternative new freight trains added based on headway can be departure from Duduk station to the west is 17 trains per day and to the east is 21 trains per day. The number of this new train is obtained of slot from maximum headway between existing train schedules at departure and arrival times at stations in the segment reviewed. The calculation of the alternative means that not all of them can be operated because the number of freight trains added must be considered in terms of capacity. So required capacity calculation for consider number of new train added for accommodate efiiciency of train operational in this segment.

The results of the available capacity calculation for the Surabaya Pasarturi - Bojonegoro section, then reviewed using Equation 4, can be explained in Figure 9. Equation 4 is used because the Surabaya Pasarturi - Bojonegoro

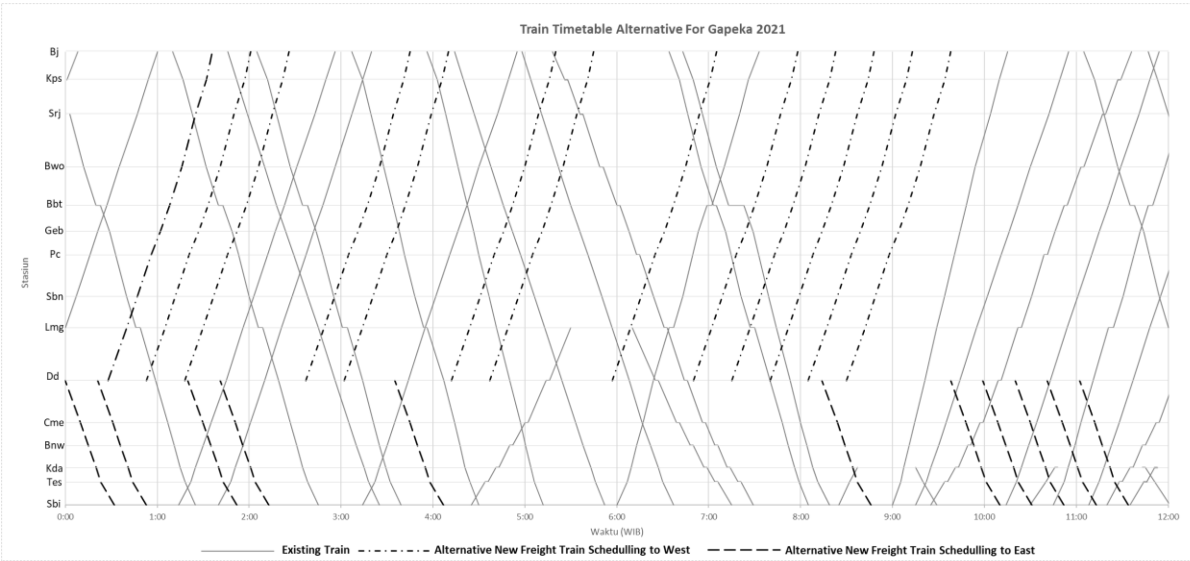

Figure 7 Train Timetable 2021 with New Train Alternatives at 00.00-12.00

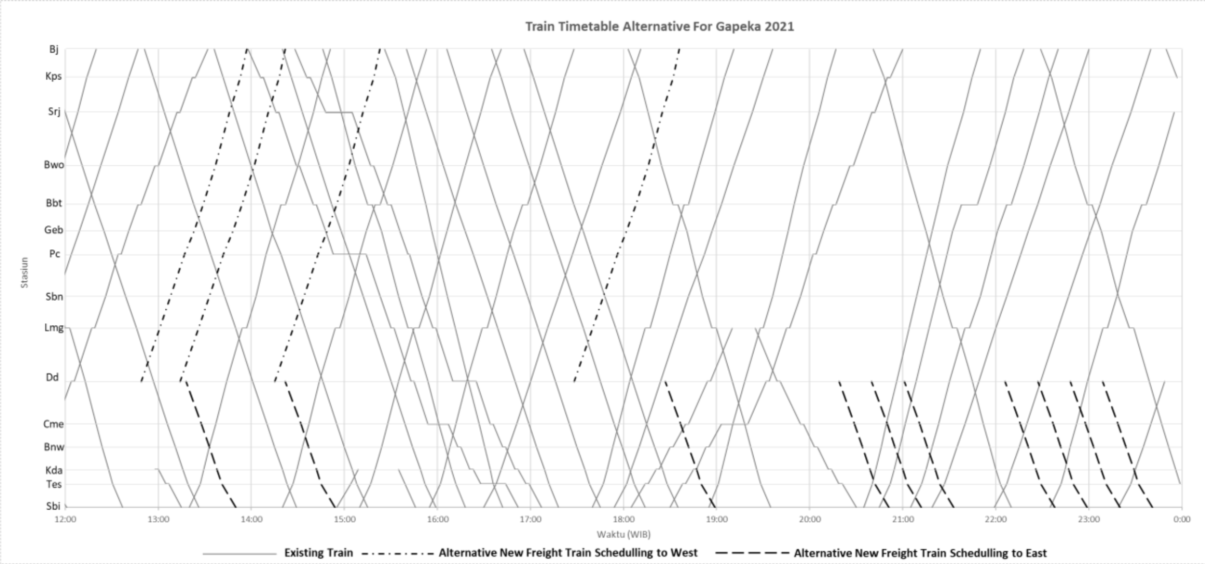

Figure 8 Train Timetable Schedule with New Train Alternatives at 12.00-00.00

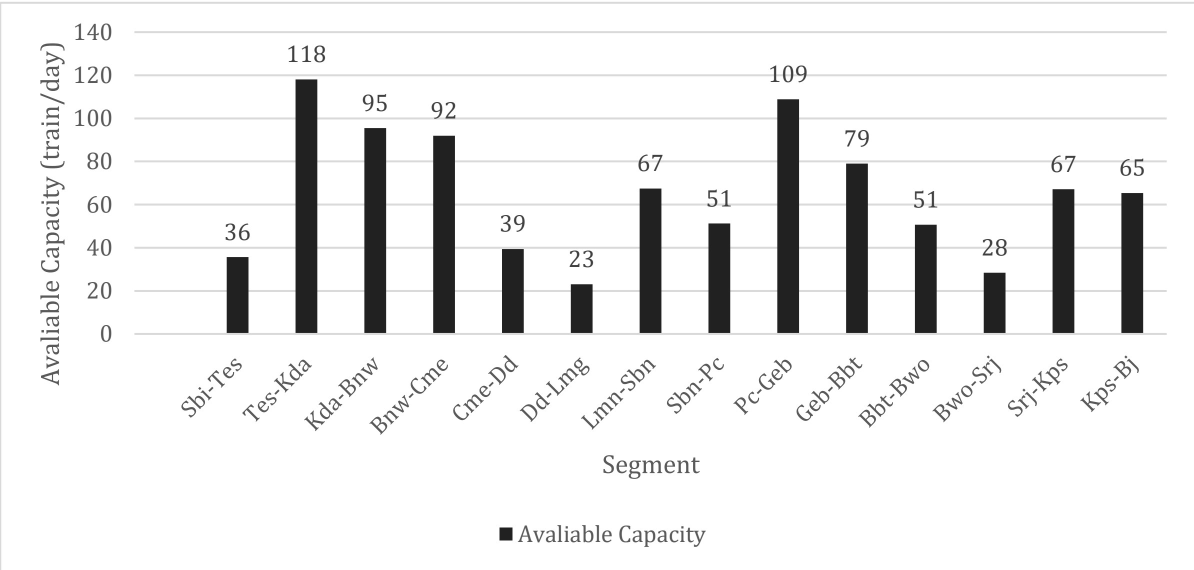

Figure 9 Avaliable capacity two direction calculate of Surabaya Pasarturi – Bojonegoro segment

section uses a double track system. These calculation results are obtained from practical capacity calculations minus the number of existing trains operating in each segment. The results of this calculation are still in available capacity in two directions, so it is necessary to calculate available capacity in each direction to find out the number of trains that can be added both to the west and to the east. The calculation of the number of trains that can be added in each direction will be explained in following table 1 and 2.

From Table 1 and 2, the capacity available calculation that can be used to add trains is explained, namely from Surabaya Pasarturi to Bojonegoro Station in each segment. The number of additional trains that will be used is based on the smallest capacity of the revised segment. So the limit of the alternatif train can be added. Duduk station to Bojonegoro station is 18 trains per day at Sbi-Tes Segment. And the limit of alternative trains that can be added from Duduk station to Bojonegoro station is 12 trains per day at Dd-Lmn Segment. The available capacity, based on the Indonesian railway equation, uses a 70% efficiency for double-track systems.

Table 1 Avaliable capacity to east

Segment	Avaliable Capacity To East
Sbi-Tes	18
Tes-Kda	59
Kda-Bnw	48
Bnw-Cme	46
Cme-Dd	20

Table 2 Avaliable capacity to west

Segment	Avaliable Capacity To West
Dd-Lmn	12
Lmn-Sbn	34
Sbn-Pc	26
Pc-Geb	54
Geb-Bbt	39
Bbt-Bwo	25
Bwo-Srj	14
Srj-Kps	34
Kps-Bj	33

CONCLUSIONS

The conclusions obtained from the research include the following:

- The number of new freight can be added for departure at Duduk Station into main line railroad with manually calculation if only base on headway from train timetable (Gapeka) 2021 at Surabaya Pasarturi-Bojonegoro Segment is a 17 train/day to west and 21 train/day to east. However if calculate with Indonesian railway capacity method with factors in maintenance and train travel patterns in this case. For double-track systems, trains can operate at 70% capacity daily so the new train can be departure from duduk station is a 12 train/day of number of alternative train to west and 18 train/day of number of alternative trains to west.
- The Indonesian railway capacity Calculation new train added that does not overload of railway capacity can be accumulated the maintenance time and reduces the risk of delays in train operational.

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