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Optimizing Railway Capacity Concerning Freight Transport Addition

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***Abstract*—To enhance railway utilization for freight transportation, it is crucial to integrate railroads with industrial zones and ports. This is particularly important for the central line railroad of North Java, which is located near numerous ports and industrial zones in East Java. A comprehensive analysis of railway capacity is necessary to ensure smooth train traffic flow. This study uses Indonesian methodology equations and a linear programming approach to assess the feasibility of adding more trains and establishing suitable headways. The case studies focus on train insertions from potential stations connected to ports in both westward and eastward directions. The train timetables of PT KAI (Indonesia's Railway Company) as a train operator for 2019 and 2021 serve as the basis for this analysis. The analysis reveals that in 2019, it is possible to introduce 11 trains per day from Duduk Station heading west and 14 trains per day from Duduk Station heading east. Looking at the 2021 timetable, the analysis suggests the potential introduction of 12 trains per day heading west and 18 trains per day heading east from Duduk Station. These findings provide valuable insights for developing effective strategies to ensure efficient and seamless freight transportation by rail in Indonesia. This analysis highlights the potential for increasing train frequency and capacity, which can contribute to the overall development and growth of the railway sector in Indonesia.**

***Keywords*—Freight transport; railway capacity; train scheduling.**

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I. INTRODUCTION

Seaports are vibrant for driving economic growth, as they facilitate national import and export activities. To effectively meet the evolving demands of trade and transportation, seaports must establish globally competitive infrastructure and provide high-quality services across short, medium, and long-term horizons [1]. In the field of freight transportation planning, assessing the impact of policies aimed at mitigating adverse effects and promoting sustainable resource utilization is crucial for fostering economic development [2]. Rail and road terminals emerge as essential components of the transportation network within this context, significantly contributing to the competitiveness of intermodal transport [3]. Their primary objective is to ensure the swift, secure, and efficient transfer of intermodal loading units.

However, these terminals often face numerous challenges due to their complexity and the rapid advancements in multi-yard railway intermodal terminals [4]. The freight transportation sector heavily relies on the railway network, requiring a comprehensive consideration of various factors influencing transportation conditions. These factors include the type of wagon utilized, cargo weight, extent of partial loading, the center of gravity height, railway line condition, track irregularities, crosswinds, and operational speed. By thoroughly assessing these factors, it becomes feasible to identify and address the most challenging situations for transportation [5]. Efficient transport systems are paramount for the seamless operation of cities or regions. Ports and railways serve as vital conduits for the movement of goods and people, thereby facilitating trade, economic growth, and social connectivity [6]. A well-developed port and railway system are essential for ensuring efficient and cost-effective goods transportation, with ports serving as gateways for international trade, enabling large-scale import and export activities [7].

In recent years, freight railways have emerged as the cornerstone of contemporary goods transportation due to their economic viability, substantial capacity, and reliable safety measures [8]. Furthermore, railway transportation is efficient and cost-effective, with low emissions per unit of transportation, which aligns with the new idea of green logistics. Therefore, the development of green ports and combined rail and sea transportation could contribute to the development of green logistics and ports to a certain extent [9].

With the development of the port and industrial area in Gresik, Indonesia, which is near the northern rail line of Java, integrating with the railway system is very important. This research aims to advance freight transportation planning and infrastructure development by analyzing the factors that influence the increase of freight train transportation from ports and industrial areas, thereby optimizing railway capacity for additional freight transportation.

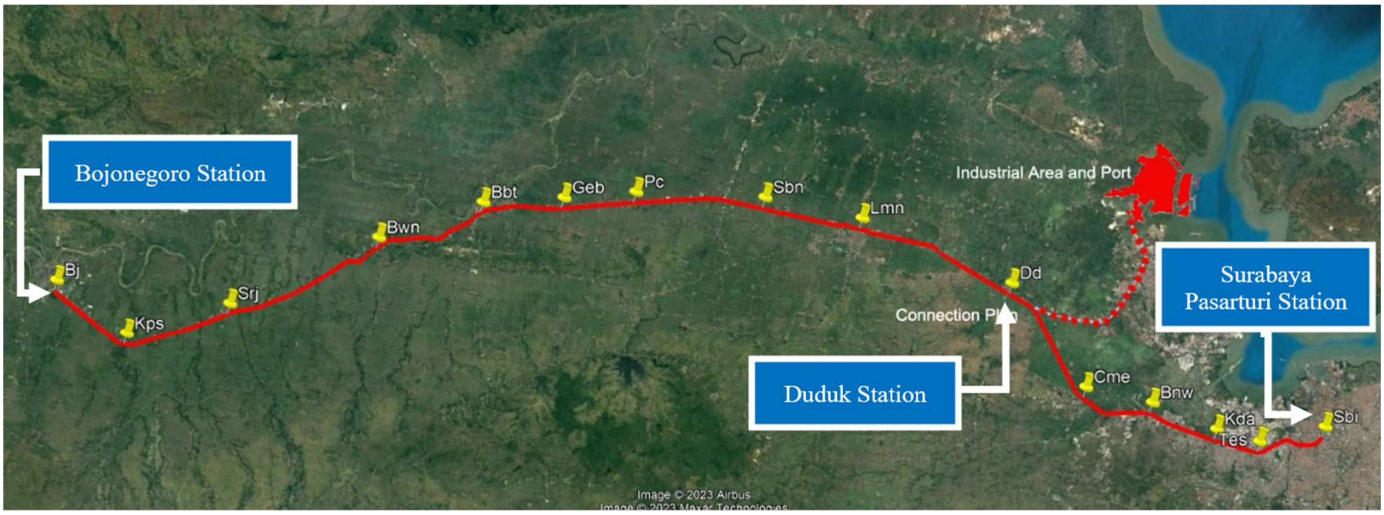

Fig. 1 The industrial area and port are connected to the existing railroad Surabaya Pasarturi Railroad.

II. Materials and Method

A. Materials

The railway capacity concept is a fundamental pillar within the realm of railway transportation. Previous studies have underscored that railway capacity is primarily influenced by factors such as train frequencies, timetables, rolling stock capacities, running times, and velocities [10]. Capacity evaluation strategies can be grouped into three main categories: analytical, optimization, and simulation. Analytical strategies rely on simple equations and require minimal data inputs, providing a broad overview of capacity utilization. This is particularly useful for strategic planning in railway operations. Optimization strategies use mathematical models to identify objectives and constraints, such as maximizing train throughput, identifying bottlenecks, maximizing revenue, or minimizing delays. The simulation requires the most detailed data and provides highly accurate results [11]. Scholars have offered definitions of railway capacity from both macro and micro perspectives, considering factors such as infrastructure, station layout and scale, and transport organization. The existing literature extensively details these calculation methods.

In Indonesia, railway traffic regulation stipulates that train operations must not exceed the railway traffic capacity, determined by variables like train operating speed, block distance, operating facilities, and infrastructure maintenance time [12]. In other definition, the railway traffic capacity is the ability of a train track to accommodate train travel operations within 1440 minutes or equivalent to 24 hours [13]. Indonesia's railway company, PT KAI, utilizes GAPEKA to provide comprehensive information on train schedules, station layouts, train types, station distances, and other relevant data [14], [15]. Railway capacity is influenced by various factors, broadly categorized into technical and operational aspects. Technical factors encompass transportation facility capabilities, such as the minimum headway determined by the signaling system and the train speed profile influenced by vehicle dynamics. Operational factors include utilization strategies of existing facilities, such as stopping patterns and mixed traffic timetables, contributing collectively to the overall capacity of the railway system [16].

Standard methods are commonly applied to calculate railway capacity based on the existing timetable, with simulation tools used to analyze potential improvements. For instance, converting a single-track railway line to a double-track can substantially increase its capacity, resulting in more train trips. Following the Indonesian approach for calculating railway line capacity, this transformation is projected to amplify the capacity by a factor of 2.35 [17].

The consequences of various aspects of train-related heterogeneity on the realization of railway operations are well known in literature and practice. Increased heterogeneity also creates a risk that the rest of the network will appear and spread delays, which can easily lead to performance degradation. Countermeasures include the proper identification of preassigned time reserves or the selection of appropriate train traffic patterns in specific rail services [18]. Passenger and freight transport integration is well known, and service quality depends on key service parameters. However, it has not yet been established what limits may be placed on them to offer a quality integrated service in the future [19].

The operation of trains is characterized by events when planning railway services. The start or end of an operation may be represented by one event. Crossing of trains over the railway network or dwell procedures at stations are typical operations [20]. Several train timetabling models often rely on fixed values for running time in open-track segments and minimum headways. However, introducing scheduled intermediate stops adds extra running time and signal occupation time during the acceleration and deceleration. Furthermore, when creating a realistic train timetable, various practical factors must be considered [21]. A dwell time delay is identified when the time spent at a station exceeds the planned duration. This discrepancy is determined by calculating the difference between the actual departure and arrival times.

Our dataset records time in hours and minutes, with seconds omitted, limiting our ability to detect deviations shorter than a minute. Importantly, prolonged stay times are classified as delays for passenger trains only if they result in a delayed departure. If a train arrives early at a station and waits to synchronize with the timetable before departing on time, it is not classified as a delay[22]. Station dwell time variations can significantly influence railway system capacity. Even minor disruptions lasting a few seconds can adversely impact network performance, progressively obstructing the timeliness of other services and resulting in cumulative reactionary delay [23]. During peak hours, the duration of stops at stations can harm the transportation system's overall capacity, mainly when many passengers rely on the service. If a train experiences an extended dwell time at a station can disrupt the subsequent train. Consequently, the following train may need to decrease its speed or even come to a complete halt [24].

Goods arrive and leave the harbor range by either rail/road transport or ships. In numerous cases, the parcel of products exchanged by rail is lower than the one utilizing the street. If the rail handle inside the rail-sea yard was quick and proficient, rail could be used more to transfer goods to and from root and goals, rather than using the road [25]. Freight trains are considered to be the primary mode of transportation due to their cost-effectiveness and high safety [26]. To promote railroads for freight transport, the Indonesian government has formulated policies to develop railroads connecting industrial areas and ports. One such policy aims to establish connections between the railroad and the Industrial area and Ports at Gresik (East Java) and the main line of the North Java railroad [27]This strategic endeavor necessitates a multi-criteria analysis considering critical criteria such as the Cost of Construction, Land Availability, Intermodal Requirements, Potential Conflict, and Operational Patterns.

Considering these main criteria, a railway connection to Duduk station is the best choice. [28]. The allocation of train capacity plays an essential role in the revenue management of railway companies. Determining the distribution of passengers and freight within the limited train capacity involves decisions related to train carriage allocation and the capacity assigned to each carriage [29]. It's worth noting that the increased number of trains stemming from the new junction could impact the existing train schedule, particularly the Surabaya Pasar Turi-Bojonegoro train section, due to the high traffic density on that segment. The objective of this research is to analyze the optimal insertion of freight trains into the reviewed segment based on the Indonesian railway capacity method, with a case study involving the plan to connect the Pasarturi-Bojonegoro Surabaya Section with an industrial area and port which can be explained in Figure 1.

B. Research Method

1) Calculate Railway Capacity

In this study, capacity calculations are performed using the Indonesian method. The capacity of the segment from Surabaya Pasarturi (Sbi) to Bojonegoro (Bj) is calculated since this segment significantly impacts the addition of new trains from the planned railway development (Duduk Station) to the industrial and port area of JIPPE in Gresik, Indonesia.

Secondary data from the Gapeka document provided by PT. KAI is used in this study. Information on the track system, signaling system, block system, speed limits for each segment, and the number and schedule of trains already in operation are included in this document. This data will be used to calculate theoretical and practical headways. Given that the segment from Surabaya Pasarturi (Sbi) to Bojonegoro (Bj) uses a fixed block system with electric manual signals, theoretical and practical headway calculations will be performed using equations 1 and 2 as follows:

$$\text{Theoretical headway}=\frac{60\ x\ S_{\text{a-b}}+180}{V_{\text{Limit}}}+1 \quad (1)$$

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

where:
$S_{\text{a-b}}$: Distance between stations (Km)
V_{Limit} : Track Speed Limit between Station (Km/H)
V_{Average} : Average Train Speed between Station (Km/H)

The headway is determined by finding the speed of all trains in each segment. Then, we identify the longest and shortest time gap between trains for each segment, starting from Surabaya Pasarturi Station to Bojonegoro Station. The theoretical headway calculation is derived from the segment's speed limit, while the practical headway calculation relies on the average train speed within the segment.

The calculation of railway capacity, employing the Indonesian method, is the foundation for optimizing the Surabaya Pasarturi-Bojonegoro segment. This optimization targets accommodating freight trains from the industrial area and port, connecting through Duduk station to the west and east.

Railway capacity is divided into four categories: theoretical capacity, practical capacity, used capacity, and available capacity.

- Theoretical capacity: Maximum number of trains operable within a specific time interval.
- Practical capacity: Traffic volume under real-world conditions, considering practical constraints.
- Used capacity: Actual traffic volume on the existing rail network.
- Available capacity: Derived as the difference between practical and used capacity.

This comprehensive approach ensures a thorough understanding of the network's capabilities and limitations, facilitating optimization. Used capacity reflects the actual traffic volume present on the existing rail network, showcasing the real-time utilization of resources. Available capacity is then derived as the numerical difference between practical and used capacity. This multifaceted approach to railway capacity assessment ensures a comprehensive understanding of the network's capabilities and limitations, facilitating the optimization process. The formulation has been used as follows:

$$\text{K}=1440/\text{H}\ x\ \eta \quad (3)$$

$$\text{K}=1440/(1/2\text{H})\ x\ \eta \quad (4)$$

where:

K : Capacity on the calculated track section
1440 : Total time for 24 hours (24x60 minutes)
H : Average practical and theoretical 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

Equation (3) represents a formulation applicable to a single-track system, while Equation (4) applies to a double-track system. In this case study, the segment from Surabaya Pasarturi (Sbi) to Bojonegoro (Bj) uses a double-track system, and Equation (4) is therefore applied. This equation calculates the capacity of each segment, with the smallest capacity identified being used as the basis for adding new trains.

2) Train Insertion Scheduling

Identify the new freight train's start, end, and intermediate Station. In the eastbound direction, the route starts at Duduk Station (Dd) and ends at Surabaya Pasarturi Station (Sbi). The intermediate stations are Cerme Station (Cme), Benowo Station (Bwn), Kandangan Station (Kda), and Tandes Station (Tes). In the westbound direction, the new train insertion calculation segment starts at Duduk Station (Dd) and ends at Bojonegoro Station (Bj). The intermediate stations are Lamongan Station (Lmn), Surabayan Station (Sbn), Pucuk Station (Pc), Gembong Station (Geb), Babat Station (Bbt), Buwerno Station (Bwo), Sumberrejo Station (Srj), and Kapas Station (Kps).

In this study, the travel time for the new trains to be added in each direction is determined based on the current Gapeka data, with additional time considered for acceleration after the initial station and braking before the final station. Extra travel time is not considered for intermediate stations. The number of new trains to be added is determined based on the segment's smallest capacity between the initial and final stations in each direction. The headway used is determined based on the largest headway of the segment between the initial and final stations in each direction to minimize dwell time and anticipate potential delays from existing trains.

In the linear programming model, the decision variables are identified as the components to be considered in this study. These decision variables are formulated into an objective function, representing the goal to be achieved, while the constraint function represents the limitations of the objective function. The constraints for this study include the train schedule and the headway used. The simulation was carried out using the open-source Python program to simplify calculation, making it easier for the model to be used in similar cases with different existing train timetables (Gapeka) and new train Plan data.

The designed stages of simulation are as follows:

- Determine input parameter:
  - Train Timetable Existing
  - Available Capacity
  - Headway used.
  - Plan new train travel directions.
- Determine Simulation Process:
  - Run objective function with each train's existing train constraint.
  - Changing to a new train becomes a new constraint.
  - Iteration until no new train can be added. The number of iterations is based on available capacity in each direction, calculated using the Indonesian railway capacity method.
- Determine output parameter:
  - New train timetable (New Train and Existing Train)
  - New train timetable Graph (New Train and existing Train)

III. Results and discussion

A. Result

1) Result Capacity Calculation:

The Indonesian Method for railway capacity analysis was applied to the Surabaya Pasarturi - Bojonegoro segment, featuring a double-track rail system equipped with fixed blocks and manual electric signals. Based on the Indonesian method, headway calculations are influenced by the number of tracks, signaling system, blocks, and speed, as shown in equations 1 and 2. The calculation of theoretical headway involved utilizing the segment's speed limits. In comparison, the practical headway was determined based on the average speeds of trains operating in both directions on each segment. The calculated theoretical headway and practical headway for the reviewed segments are presented in Table I.

TABLE I
Headway calculated result from existing train timetable (GAPEKA)

Segment	Headway Gapeka 2019		Headway Gapeka 2021	
	Theoretical (minute)	Practical (minute)	Theoretical (minute)	Practical (minute)
Sbi-Tes	10	23	10	20
Tes-Kda	7	11	7	11
Kda-Bnw	9	13	9	13
Bnw-Cme	10	13	10	13
Cme-Dd	15	20	15	21
Dd-Lmn	18	25	18	25
Lmn-Sbn	12	17	12	17
Sbn-Pc	15	19	15	19
Pc-Geb	10	12	10	12
Geb-Bbt	11	15	11	15
Bbt-Bwo	14	19	14	19
Bwo-Srj	18	24	18	24
Srj-Kps	13	16	13	17
Kps-Bj	11	16	11	17

From the headway calculations in Table I, the theoretical and practical capacities for each segment were determined. The remaining capacity for each segment was then calculated by subtracting the number of trains operating in both directions from the practical capacity. The largest remaining capacity in the 2019 Gapeka was found in the Tes-Kda segment, with 129 trains per day, and the smallest in the Dd-Lmn segment, with 23 trains per day. In the 2021 Gapeka, the largest remaining capacity was also in the Tes-Kda segment, with 118 trains per day, and the smallest remained in the Dd-Lmn segment, with 23 trains per day. The smallest remaining capacity of the reviewed segments in each direction will be used to determine the number of new trains to be inserted.

2) Result Train Insertion Modelling:

In determining the remaining capacity using the Indonesian method, it remains a computation for both directions on double-track lines. Hence, to ascertain the number of new trains to be inserted in each direction, the remaining capacity undergoes division by two. The outcomes of these calculations for each direction will be elucidated in Tables II and III as follows:

TABLE II
AVAILABLE CAPACITY FROM DUDUK STATION TO WEST

Segment Reviewed to West	Train Timetable 2019 (train/day)	Train Timetable 2021 (train/day)
Dd-Lmg	11	12
Lmn-Sbn	33	34
Sbn-Pc	25	26
Pc-Geb	54	54
Geb-Bbt	38	39
Bbt-Bwo	25	25
Bwo-Srj	15	14
Srj-Kps	34	34
Kps-Bj	35	33

TABLE III
AVAILABLE CAPACITY FROM DUDUK STATION TO EAST

Segment Reviewed to East	Train Timetable 2019 (train/day)	Train Timetable 2021 (train/day)
Dd-Cme	20	20
Cme-Bnw	49	46
Bnw-Kda	48	48
Kda-Tes	64	59
Tes- Sbi	14	18

Determining the maximum number of new freight trains that can be added relies on the capacity calculation for each direction, which is a pivotal constraint. This calculation is based on the segment with the smallest capacity under examination. For insertions from Duduk Station to Bojonegoro Station in the westward direction, the reference capacity is the minimum remaining capacity observed in segment Dd-Lmn, amounting to 11 trains per day for Gapeka 2019 and 12 trains per day for Gapeka 2021. Similarly, the reference capacity is derived from segment Tes-Sbi for insertions in the eastward direction, with 14 trains per day for Gapeka 2019 and 18 trains per day for Gapeka 2021. The development of the train insertion schedule employs the linear programming method facilitated by simulation Python tools for computational accuracy. The iterative simulation of train insertions is then bounded by the available capacity. Based on the assumptions outlined above, the following model of linear programming is constructed:

Yn = Train Position at station n (Stationing)
X_{n1} = Train arrival at station n (Time)
Xn2 = Train departure at station n (Time) segment
Mnarrival–Ndeparture=Train Gradient Velocity (Distance/Time)
H = Headway Used
Objective Function:

$$\text{Maximum } y = \sum_{\mathrm{K}=1}^{n} Y_n \tag{5}$$

$$Y_n = \{(X_{n1} - X_{n2}) \times m_{narrival} - n_{Departure}\}$$

Constrain Function:

Existing train 1:

$$X_{\mathrm{n1}}(\text{existing train}_2)\text{+H} \geq X_{\mathrm{n1}}(\text{newtrain})$$
$$X_{\mathrm{n1}}(\text{existing train}_2)\text{+H} \leq X_{\mathrm{n1}}(\text{newtrain})$$
$$X_{\mathrm{n2}}(\text{existing train}_2)\text{+H} \geq X_{\mathrm{n2}}(\text{newtrain})$$
$$X_{\mathrm{n2}}(\text{existing train}_2)\text{+H} \leq X_{\mathrm{n2}}(\text{newtrain})$$

Existing train n:

$$X_{\mathrm{n1}}(\text{existing train}_2)\text{+H} \geq X_{\mathrm{n1}}(\text{newtrain})$$
$$X_{\mathrm{n1}}(\text{existing train}_2)\text{+H} \leq X_{\mathrm{n1}}(\text{newtrain})$$
$$X_{\mathrm{n1}}(\text{existing train}_2)\text{+H} \geq X_{\mathrm{n1}}(\text{newtrain})$$
$$X_{\mathrm{n1}}(\text{existing train}_2)\text{+H} \leq X_{\mathrm{n1}}(\text{newtrain})$$

The model of linear programming method utilized to establish the schedule of additional train insertions is centered on intersections, referencing the departure stations where the additional trains commence their journeys, by train capacity and existing schedule conditions. As elucidated within the methodology, this model encompasses an objective function aimed at maximizing Y (the distance or position of the trains to be inserted) within the segments under review, as detailed in the equation where Y is a function of the speed gradient between stations (Marrival - Ndeparture), arrival time (Xn1), and departure time (Xn2) of the trains as indicated in the equation. The determination of the schedule for additional trains is constrained by the arrival and departure schedules of existing trains at each station, with the utilization of headways (H) as depicted in the equation. Once the schedule for new train insertions is derived, it is subsequently adjusted with the existing train schedule to obtain the subsequent new train schedule. This iterative process continues until the remaining capacity limit is reached.

The simulation results conducted with Python are visually represented in the train timetable graph, with the orange line depicting existing trains and the blue line indicating new freight train insertions. The scheduling of new freight trains was determined based on the minimum capacity and maximum headway of one-way reviewed segments. In the Gapeka 2019 timetable, additional freight train services were introduced between Duduk (Dd) station and Bojonegoro (Bj) station, aiming to optimize the usage of the Duduk (Dd) - Lamongan (Lmn) segment's capacity. This involved scheduling 11 daily trains with a maximum headway of 23 minutes. Based on the simulation findings, the departure times for these new freight trains from Duduk Station are as follows: 00:31, 01:25, 01:50, 03:05, 03:30, 04:30, 06:53, 10:25, 12:19, 12:44, and 13:09. Figure 2 illustrates the graphical representation of this simulation output.

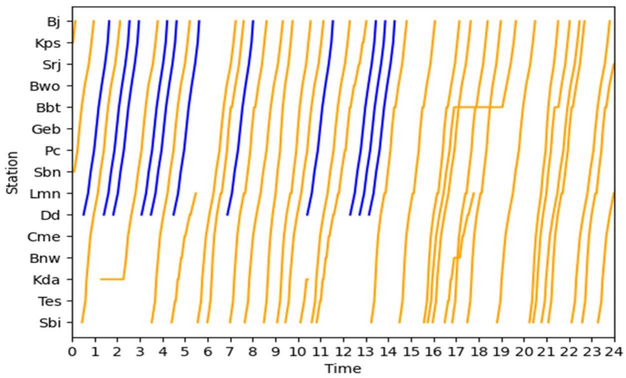

Fig. 2 New freight train insertion from Duduk station to west of Gapeka 2019

In the context of the Gapeka 2019 timetable, additional freight train services were incorporated between Duduk (Dd) station and Surabaya Pasarturi (Sbi) station, aiming to optimize the utilization of the Tandes (Tes) – Surabaya Pasarturi (Sbi) segment's capacity. This involved scheduling 14 trains daily with a maximum headway of 25 minutes.

According to the simulation results, the departure times for these new freight trains from Duduk Station are as follows: 01:34, 01:57, 02:52, 07:10, 08:17, 08:40, 09:32, 09:55, 10:18, 10:41, 17:38, 20:59, 21:22, and 21:45. Figure 3 illustrates the graphical representation of this simulation output.

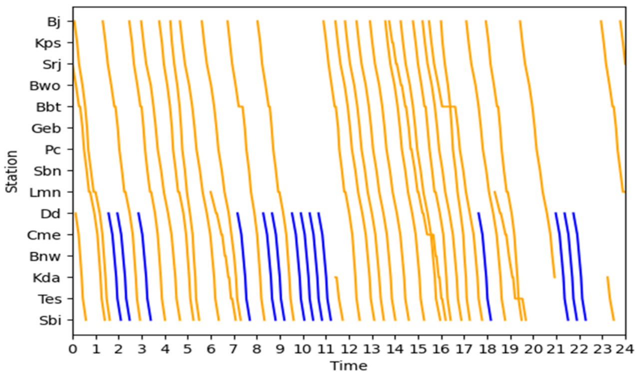

Fig. 3 New freight train insertion from Duduk station to east of Gapeka 2019

In the Gapeka 2021 timetable, the introduction of new freight train services from Duduk (Dd) station to Bojonegoro (Bj) station was designed to utilize the minimum capacity of the Duduk (Dd) - Lamongan (Lmn) segment. This segment has a capacity of 12 trains per day and a maximum headway of 25 minutes. According to the simulation results, the schedule for these new freight train departures from Duduk Station includes times such as 00:28, 00:53, 01:18, 02:37, 03:02, 04:12, 04:37, 05:57, 06:50, 07:15, 07:40, and 08:05. Figure 4 presents the graphical representation of this simulation output.

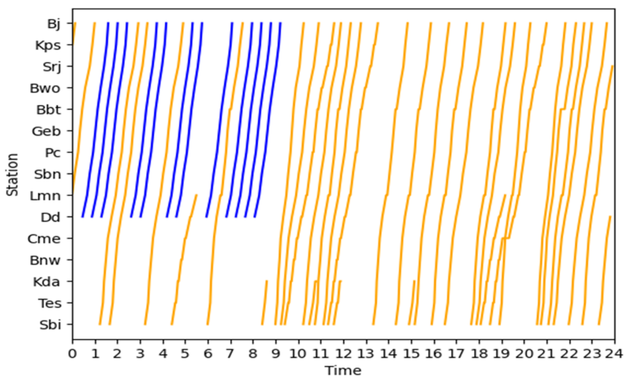

Fig. 4 New freight train insertion from Duduk station to west of Gapeka 2021

In the context of the Gapeka 2021 timetable, the introduction of new freight train services from Duduk (Dd) station to Surabaya Pasarturi (Sbi) station was planned to adhere to the minimum capacity on the Tandes (Tes) – Surabaya Pasarturi (Sbi) segment, allowing for a total of 18 trains per day. The maximum headway on the Duduk (Dd) – Cerme (Cme) segment was 21 minutes. According to the simulation results, the schedule for these new freight train departures from Duduk Station includes times such as 00:00, 00:21, 01:20, 01:41, 03:35, 08:14, 09:38, 09:59, 10:20, 10:41, 11:02, 13:18, 14:22, 18:27, 20:19, 20:40, 21:01, and 22:06. The graphical output detailing this information can be found in Figure 5.

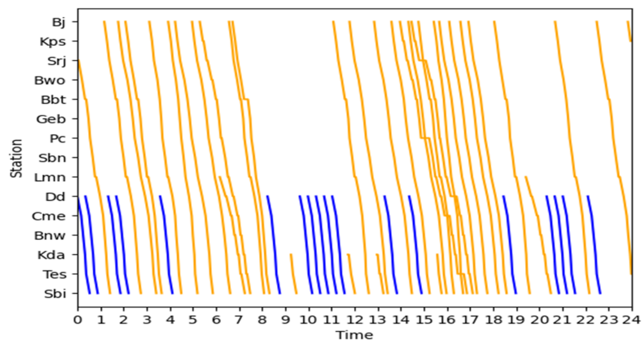

Fig. 5 New freight train insertion from Duduk station to east of Gapeka 2021

The results of the simulation model for the 2019 Gapeka, from Duduk Station (Dd) to Bojonegoro Station (Bj) in the westward direction and from Duduk Station (Dd) to Surabaya Pasarturi Station (Sbi) in the eastward direction, are obtained from Figures 2 and 3. Furthermore, the results of the simulation model for the 2021 Gapeka, from Duduk Station (Dd) to Bojonegoro Station (Bj) in the westward direction and from Duduk Station (Dd) to Surabaya Pasarturi Station (Sbi) in the eastward direction, are derived from Figures 4 and 5. These four figures show that the model can be applied in the 2019 and 2021 Gapeka case study for the Surabaya Pasarturi to Bojonegoro segment without exceeding headway and capacity constraints, employing the Indonesian method.

B. Discussion

Based on the calculations presented in the preceding subsection and referencing Gapeka 2019, it was determined that 11 trains per day could be inserted from Duduk Station heading west and 14 trains per day heading east. For Gapeka 2021, the potential increases to 12 trains per day heading west and 18 trains east from Duduk Station. Discrepancies in available train capacity between Gapeka 2019 and Gapeka 2021 result from variations in train speeds due to differences in the quantity and type of trains in operation.

Linear programming techniques utilizing Python auxiliary programs were employed to compute the feasible number of additional trains. Integrating these auxiliary programs ensures greater accuracy and practicality in results compared to manual computations. Using the Indonesian method, this model allows for determining the number and schedule of train insertions without exceeding headway and capacity constraints. It applies to other case studies that adjust train schedules and infrastructure conditions. Adjustments to infrastructure conditions can also affect speed and headway.

The Indonesian capacity calculation method includes a 70% efficiency factor. This factor accommodates operational conditions and potential disruptions in train operations. Therefore, operations remain safe if the number of trains operating does not exceed 70% of capacity. Capacity and headway calculations rely on equations derived from the Indonesian methodology. Another approach considered is the UIC 405 standard, which categorizes trains into intercity, local/regional, and freight trains based on differences in segment lengths. However, the Indonesian methodology is preferred due to the minimal differences in train lengths among these categories in Indonesia. Capacity is primarily influenced by infrastructure factors, particularly signaling and block systems. In Indonesia, a fixed block system is predominantly used for signaling. This study's infrastructure condition is a double track with manual electrical signaling, influencing the utilized headway. The enhancement of infrastructure, such as signaling systems, has the potential to diminish headway values, thereby increasing the capacity of trains operating per day for future periods.

Research conducted in the United States compared fixed block systems with moving blocks, particularly in the context of freight trains. It was found that moving block systems can potentially reduce train delays for heterogeneous freight traffic. Under a moving block system, the flow of train traffic can vary significantly compared to fixed blocks, considering factors such as speed heterogeneity, communication delays, and uncertainties in distance headway [31].

Java, the smallest among Indonesia's six primary islands, covers an area of 126,700 km2, which is equivalent to 6.8% of the nation's total land area. Despite its relatively small size, Java accommodates the most considerable portion of Indonesia's population, representing 56% of the total population of 269.6 million. Moreover, Java is pivotal in driving the national economy, as 75% of commercial activities are concentrated on the island, contributing 59% to the overall national GDP. The transportation of goods on Java amounts to 160.5 million tons, with trucks responsible for 90.3% of the total volume, leading to significant traffic congestion. The ratio of road capacity to traffic volume on major roads is 1.3 [32]. Therefore, developing railways for freight transportation could offer a sustainable solution for infrastructure development. For instance, a study in Brazil[33] and Belgium[34] assessed the anticipated economic and environmental impacts, leading to the inclusion of new railways in the transportation network.

IV. Conclusion

The findings of this research underscore the dependency of the number of freight trains insertable into the Surabaya Pasarturi – Bojonegoro segment on the available capacity, particularly from Duduk Station. For Gapeka 2019, additional capacity from Duduk Station amounts to 11 trains per day heading west and 14 trains per day heading east. Similarly, for Gapeka 2021, freight train insertions comprise 12 trains per day toward the west and 18 trains per day toward the east.

The calculations for the Pasarturi—Bojonegoro segment case study was obtained based on the simulation results of the linear programming model using Python. For the 2019 and 2021 Gapeka schedules, inserting new train schedules from Duduk Station in westbound and eastbound directions did not exceed the specified headway and capacity constraints. Therefore, this model can be a reference for future case studies, with adjustments to reflect existing conditions.

However, it is noteworthy that the train insertion scheduling, although based on the Indonesian railway capacity method and maximum headway, may not fully optimize the number of trains per day in the reviewed segment. This discrepancy arises because the Indonesian railway capacity method incorporates time accommodation factors for maintenance and train travel operating patterns. The technique allows trains to operate at 70% daily capacity in a double-track system, leading to underutilized time in the reviewed segment's train schedule.

Based on the analysis conducted in this study using the developed linear programming model (Objectives and Constrain Functions), It has been demonstrated that the model can be used without exceeding the established constraints, specifically utilizing only 70% of the capacity as a safety factor. Therefore, it can be concluded that the developed model can be applied to other locations, provided that the recommended constraints within the model are observed.

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