Analytical technique for optimizing capacity of railway link airports

M.F. El-Sayed[1], H.S. Riad[2], H.N. Zohny[3] and M.S. Zahran[4]

[1] Military Technical College, Cairo, Egypt
[2] Faculty of Engineering, Ain Shams University, Cairo, Egypt
[3] Faculty of Engineering, Ain Shams University, Cairo, Egypt
[4] Military Technical College, Cairo, Egypt

m.fathy@mtc.edu.eg

Abstract. The rail system's capacity serves as a gauge for the calibre of train operation. There are numerous techniques to improve the capacity of Railway trains serving airports. The ability to choose the strategy that will cost them the least money is crucial for decision makers and infrastructure managers to possess at their disposal. This decision-making process can be complicated at times, and how to improve capacity is a crucial choice that will have a big financial impact. In this article, we discuss the key ideas and procedures for carrying out line capacity studies. The study would include suggestions for improving line capacity. The two objectives of this study were to analyse a critical block that specifies the lowest possible time headway and the variables affecting line capacity. The study demonstrates how capacity varies in response to elements including train speed, stability, train heterogeneity, train number, and the separation between railway signals.it concluded that the speed variance between the two trains had a direct impact on the minimum headway. The headway also increased as the speed differential did. whereas impacted by block length, it has an inverse relationship. The block length increases, but the time headway decreases.

Keywords. Capacity, railway lines, airports, optimizing.

1.Introduction

Many countries are currently dealing with the issue of having too many individual cars within their territorial boundaries. This contributes to the nations' deficiencies in terms of pollution emissions, excessive energy request, and traffic overcrowding, The authorities of these nations encourage car-free days in an effort to address the existing challenges., limiting traffic zones, controlling the proliferation of private automobiles, promoting people's public transportation, stimulating and encouraging sustainable transportation systems, The UK Government sets an aim of reducing CO_2, which is mostly released by the transportation sector, by 80% by 2050 and providing substitute energy sources[1]. India has emphasized rail transportation above roads and airlines. Liu et al. developed a sustainable transport system approach in China using a high-speed railway (HSR), electric vehicle (EV), and urban rail transit (URT) system to minimize CO_2 emissions and conserve energy [2]. Current methods divide the infrastructure into smaller sections to calculate consumed capacity, making them unsuitable for real-world use[3]. A rail service is an environmentally friendly means of transportation that generates few greenhouse gases, transports people

 doi: 10.1088/ASAT.2023.344366

and products efficiently per energy unit serves a lot of people all at once, and is the harmless mode of transportation. As a result, several countries believe that rail transportation should be broadly adopted to reduce emissions. as shown in figure (1)

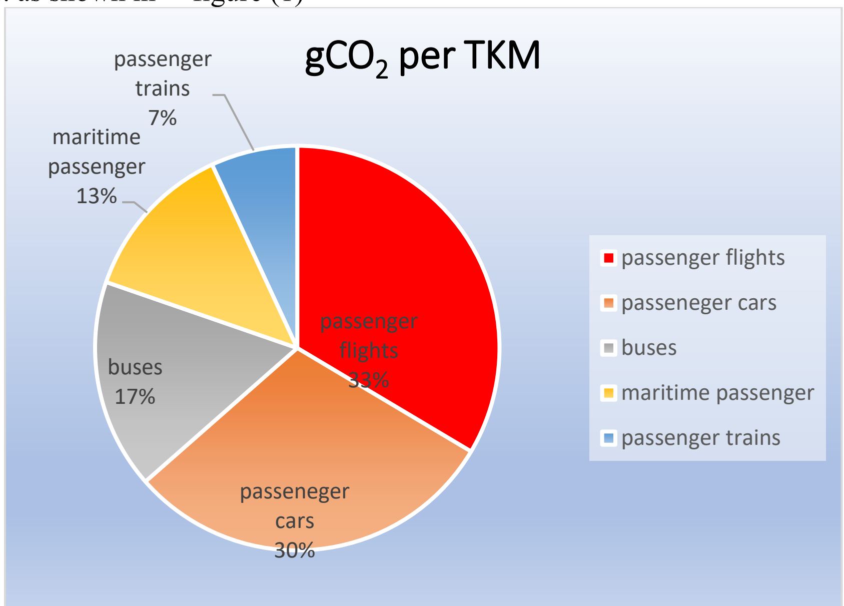


Figure 1. Pollution Emissions Comparison between different transportation means

Source: Fraunhofer ISI and CE Delft, 2020

It is also conceivable to use the railway network to connect border airports to save time and convey the greatest number of people and goods in a much shorter time than individual cars such as in Union-Pearson Express and VIA Rail, Canada's national passenger railroad carrier[4]. The TTC's (Toronto Transit Commission) bus, streetcar, and subway systems are all accessible from Union Station as shown in figure (2).

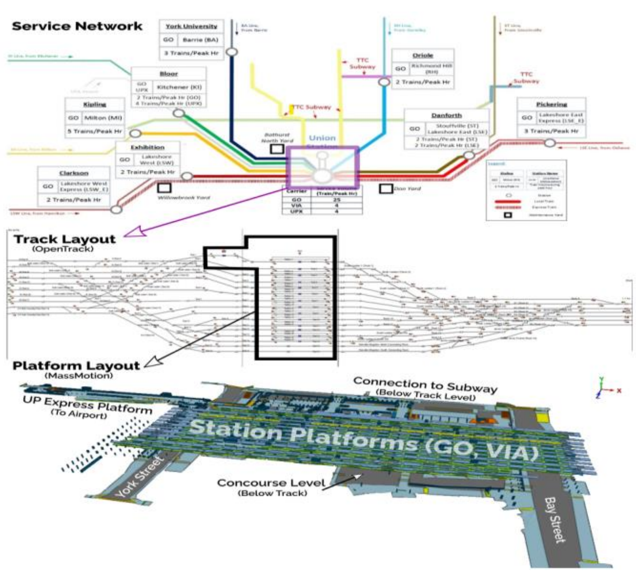


Figure 2. Service network, track layout and platform layout at Union Station[4].

2. Capacity

The capacity of roads is reasonably simple to calculate; the capacity is typically expressed in cars per hour. However, determining capacity on railways is more complex because capacity is dependent on both infrastructure and scheduling. Railway capacity was already defined in several ways over the years, for example:

1. The ability to run trains on time is what defines an infrastructure facility's capacity.
2. The ability of the infrastructure to accommodate one or more schedules is known as capacity.

2.1 types of capacity

1. Theoretical capacity: It is the extreme capacity of the line. it is the maximum limit of trains that could travel a given route in a given amount of time under the most ideal, mathematically produced conditions, with no delays and, ideally, at least headway. It frequently makes the assumptions that all locomotives are the same, all traffic is the same, and trains run continuously throughout the day at the same intervals. It ignores the impacts of actual variations in traffic and operations. The train numbers that are evaluated mathematically cannot be operated.
2. Practical capacity: It is the volume of "sample" traffic that can performed on a line and still have a respectable level of reliability. The "representative" traffic reflects the actual clustering, prioritization, and mixing of trains, and so on. Practical capacity provides a more reasonable criterion, even though theoretical capacity is the top theoretical range. As a result, practical capacity is computed using more realistic assumptions relating to projected operational quality and system consistency as exposed in figure (3) It is the amount of capacity that, under typical operating circumstances, can be offered indefinitely. Usually, it operates between 60 and 75 percent of theoretical capacity.

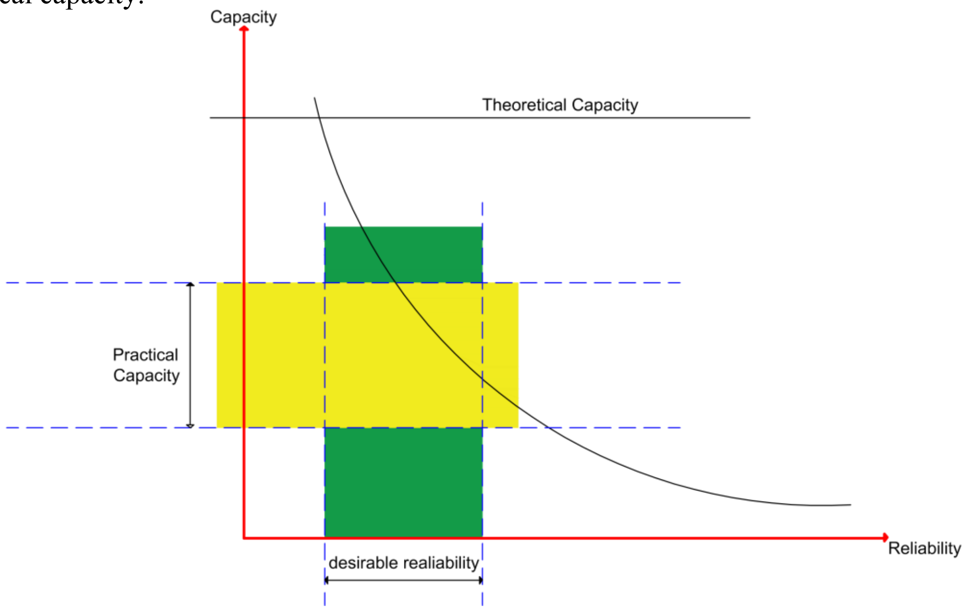


Figure 3. Relationship between practical and theoretical capacity[5]

3. Used capacity: It represents the actual network traffic volume. It depicts genuine traffic and activities on the track line. It is naturally less than practical capacity.
4. Available capacity: It is the division between Used Capacity and Practical Capacity. It represents the new traffic volume that might be managed by the route. It is effective capacity if it allows for the addition of new trains; otherwise, it is wasted capacity.

The difficulty in defining railway capacity stems from the fact that there are various parameters that can be measured.

2.2 Factors affecting on the capacity

According to the UIC Code 406, the most important characteristics impacting service level are

- the amount of rolling stocks.
- regular speed.
- service heterogeneousness.
- reliable schedule

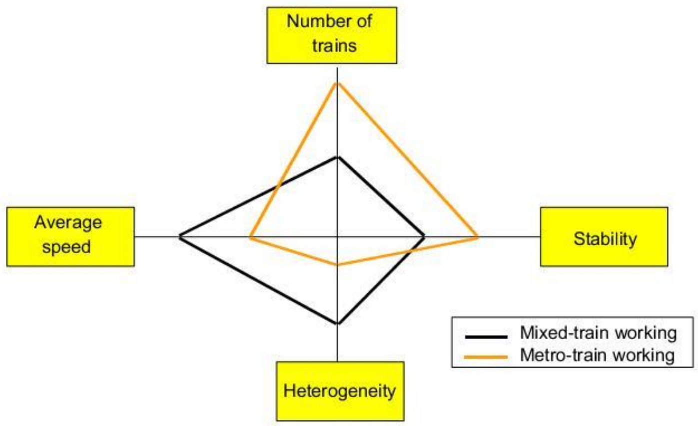


Figure 4. Balance of capacity as defined by UIC Code 406.[6]

Figure (4) illustrates that the number of trains, consistency of the schedule, high regular speed achieved, and variability of the trains all contribute to capacity. A railway network, for example, can attain a high average speed by having a high variability - a mix of Express, rapid and slower regional trains serving all stops. The disadvantage of this, however, is that it is not viable to run as many trains with high stability (punctuality) as if all trains ran at the same speeds. If more trains are to be run, they must be run with less traffic conditions and thus at a lower average speed.

Numerous studies suggested various techniques to assess railway capacity. Pachl only distinguished between analytical and simulation capacity methodologies[7]. Analytical, optimization, and simulation methods were divided into three categories by Abril et al. (2008)[8] . However, Han (2016) divided these techniques into four categories: Methods Using Analysis, Graphics, Optimization, and Simulation[9]. The mathematical relationships created by the analytical railway capacity models, which are used to assess railway capacity, enable railway planners to gauge the effectiveness of their network.

3. Methods to evaluate railway capacity

3.1 Analytical methods: These are incredibly basic models meant to find a possible first answer. These techniques can also be compared or used as a source of reference. They are created to simulate the railroad environment using algebraic or mathematical formulas. Typically, they begin with theoretical capacities and determine practical capacities as a percentage of the theoretical capacities or by increasing the theoretical capacities by regularity margins. Burdett and Kozan (2006) is among the most previous references on railway capacity. They create a number of methods for calculating theoretical capacity[10]. These methods consider a variety of railway factors, such as the mix of train lines, signal positions, or delay times.

3.2 Optimization methods: In comparison to purely analytical formulae, they are expected to present more strategic solutions to the railway capacity issue. The basis of optimization techniques for assessing railway capacity is the acquisition of optimal saturated timetables. The majority of the time, enumerative algorithms and mixed-integer linear programming formulations are used to create these optimal timetables. Saturation is one type of optimization technique. This method boosts line capacity by scheduling a maximum number of extra train services into a time schedule (starting with either a blank time schedule or an initial reference timetable). In practice, if too much quantities of the unused capacity are utilized to run more trains, this could lead to serious reliability problems because it would reduce the buffer times that allow for the absorption of minor incidents. Landex et al. provide an example of this technology by discussing the application of the compaction technique in Denmark

3.3 Simulation methods: A simulation is the repeated imitation of how a system or process would work in the real world. It is the representation of a system's dynamic behavior by switching between states in accordance with predetermined rules. To verify a given schedule, simulation methods offer a model that is as accurate as possible. Simulation has frequently been used in conjunction with other techniques for train scheduling, leading to what are known as "hybrid models." On the proposal timetable, they can identify delays and examine interferences. This paper does not attempt to analyze commercial simulation environments in its entirety. However, we provide a brief description of a few key simulation environments:

- A simulation tool called Open-Track (Open Track Railway Technology) is used to provide insights into railroad operations. It computes train movements while taking the signaling system and schedule into account. Additionally, it manages simulation in which various station and initial delays are generated randomly.
- Full train simulation functionality is available in Multi-Rail (Multimodal Applied Systems), which displays train conflicts in granular graphical and tabular formats. When defining the various aspects of the track curvatures and switches in the track administrator, the user has the ability to define the conflict rules. Additionally, Multi-Rail has a seven-day computation scheme based SuperSim that runs very quickly and generates a full trip plan for each traffic record.
- A simulation model for railroad networks is called SIMONE (InControl Enterprise Dynamics). It can assist with determining a timetable's robustness, locating and quantifying network bottlenecks, and analyzing cause-and-effect relationships when delays occur.

4. Railway capacity using analytical method

railway capacity is measured and enhanced in many studies using analytical models as:

- Line capacity according to UIC Code 406 [5]

$$\text{Capacity} = \frac{time\ period}{minimum\ headway}$$

- Transit Cooperative Research Program (TCRP) [11]

$$\text{Capacity} = \frac{3600}{(\min seperation\ time)+(\max station\ dwell\ time)}$$

- Scott's approach

  Using the longest travel time of the longest block section, it is conceivably the simplest method to calculate line capacity.

  - Scott formula for single lines:

$$\text{Capacity} = \frac{1440}{T+t} * f$$

T = travelling time

t = block section time

f = efficiency time

- Scott formula for double lines:

$$Capacity = \frac{2*1440}{Tu+Td+t} * f$$

Tu = travelling time for the upper train.

Td = travelling time for the down train.

- Mathematical model for calculation of capacity[12]
  - For sections of passenger/freight trains

$$Capacity = 22.151 + 23.187T.T + 53.34\, S.S - 1.485\text{Lb} + 0.218S_p + 0.354S_f$$

  - For sections of passenger trains.

$$Capacity = 25.362 + 25.356T.T + 35.429\, S.S - 1.252\text{Lb} + 0.33S_p$$

  - For sections of freight trains.

$$Capacity = 28.878 + 26.960T.T + 36.436\, S.S - 1.557Lb + 0.406S_f$$

Where:

T.T=track type, S.S=signal system, Lb=block length. Sp=speed of passenger train, Sf= speed of freight train

4.1 Headway Effect

Headway is the primary factor influencing the calculation of railway capacity. Time headway is an important criterion for estimating line capacity and generating timetables. It is described as the amount of time that passes between two pieces of rolling stock, or the variance in time between the front ends of two trains that pass each other while travelling in the same direction down the same lane. (t2 – t1)[13]. As shown in figure (5).

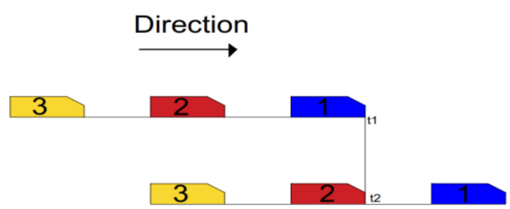


figure 5. Meaning of time Headway

The four time components listed below are added to determine the headway time by (ERTMS) [8]and figure (6) illustrates each one graphically

4.2 Definitions [13]

Travelling time (TT)	it is the length of time needed to travel between two successive virtual signals.
Operating time (OT)	Safety time depending on the signal system

Braking time (BT)	it is the time required to travel the spacing needed to bring a train to a stop in front of an electronic signal.
Releasing time (RT)	It is the duration required for a train to go its whole length across the signal. Release time is influenced by train length and speed

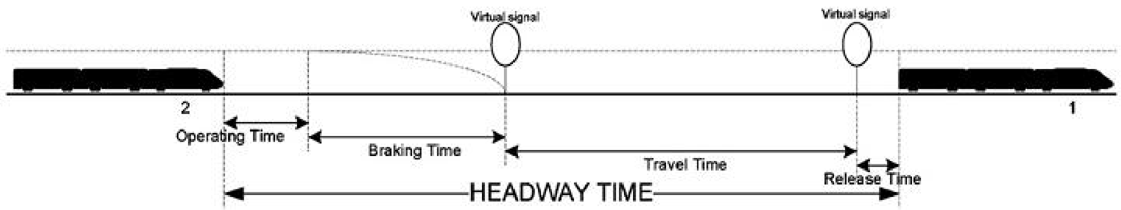


figure 6. Representation of Headway Time[14].

4.3 Time headway can be calculated by the following equation

H =TT+OT+RT+BT [15]

Where:

H = Headway time

$$H = \frac{BL}{V} + \frac{l}{V} + \frac{D_{br}}{V} + O.T$$

And:

BL= block length
l=train length
V=train speed
D_{br}=distance of braking $D_{br} = \frac{V^2}{2a_r}$
a_r=braking deceleration

5. Analysis and case study

There are multiple cases that can be used to calculate headway. Researchers has to be conscious of it. As previously mentioned, there are various train speeds on the railway network (faster-slower). In order to determine the minimum headway, various cases were examined in this paper. As shown in figure (7), there cannot be a conflict between any two block sections due to restrictions in order to properly calculate the minimum headway.[16]

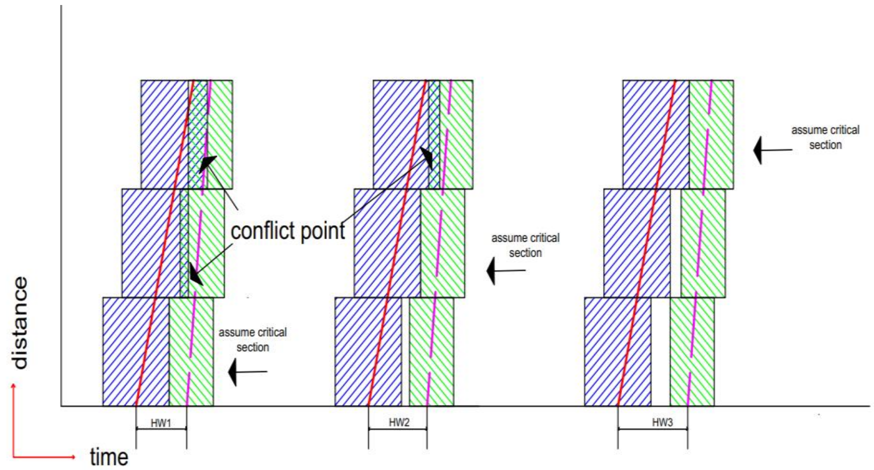


Figure 7. Determination of critical section

5.1 Case study of headway

Headway calculation can be clarified by using the following example:
IF number of wagons =20, wagon length=26.4m, locomotive length=20m, deceleration rate=300m/s2, operating time=9min.

l(m)	O.T (min)	a_r (m/sec2)
548	9	300

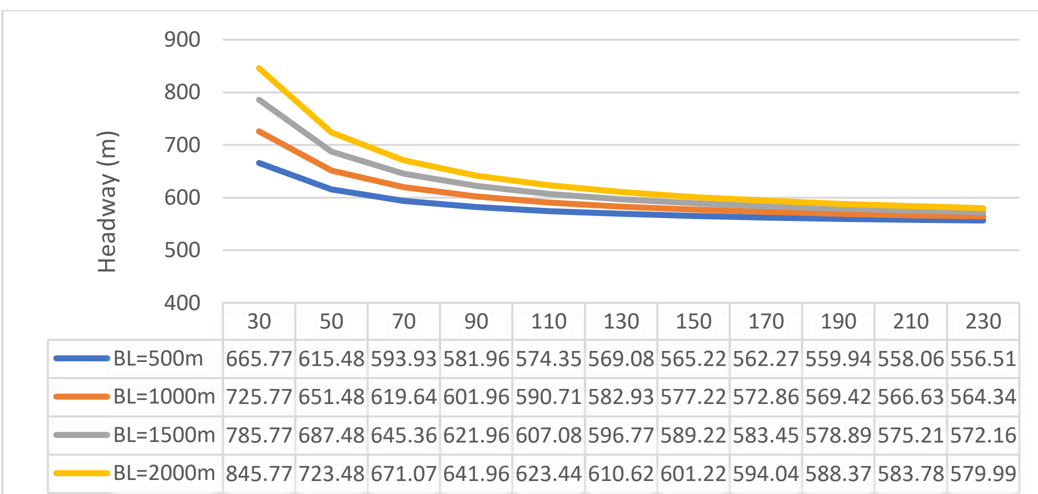


Figure 8. Headway as function of block length under various speed

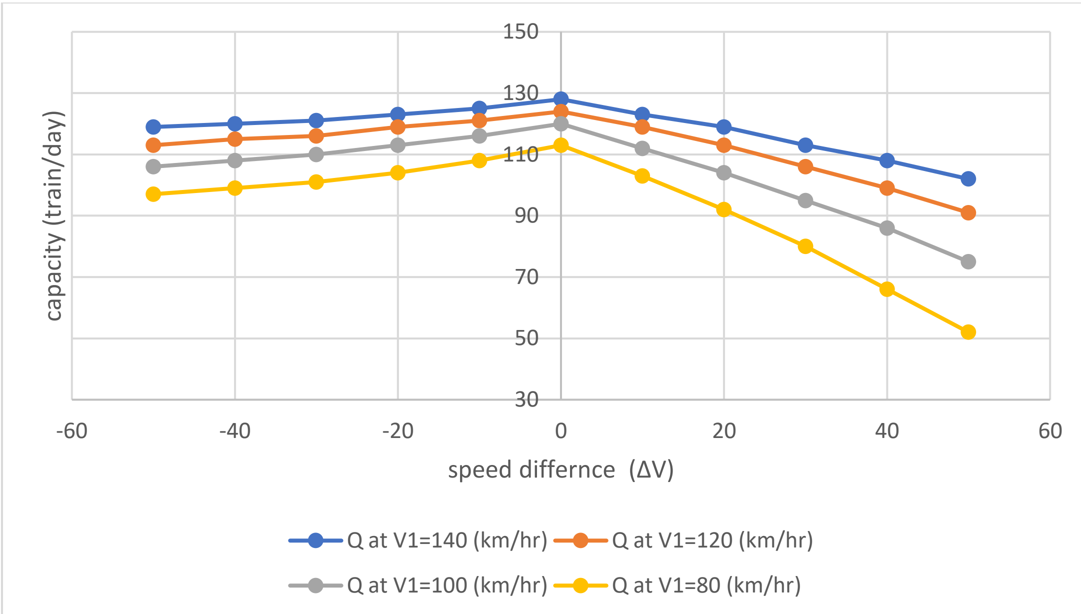
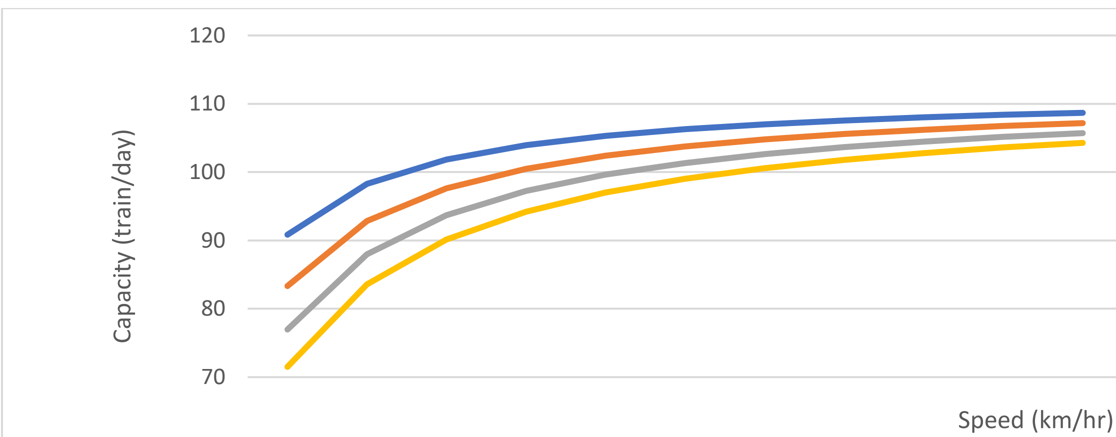


Figure 9. Relation between speed difference and capacity



	30	50	70	90	110	130	150	170	190	210	230
Q1 under Hw1	91	98	102	104	105	106	107	108	108	108	109
Q2 under Hw2	83	93	98	100	102	104	105	106	106	107	107
Q3 under Hw3	77	88	94	97	100	101	103	104	104	105	106
Q4 under Hw4	72	84	90	94	97	99	101	102	103	104	104

Figure 10. Relation between capacity and speed under various headway

6. CONCLUSIONS

This study demonstrates that the effect of speed variance of the two successive trains on the capacity, variation of Headway and block length under various speed. It is concluded that.

- The minimum headway was directly affected by the speed difference between two trains. As the speed difference increased, the headway increased.
- Additionally, the block length increased when the time headway decreased.
- determining the conceptual time headway for rail transit companies to organize local or short-distance operations at the same specific sections.
- accurate train scheduling necessitates a study of station-to-station travel times, taking into account a train's acceleration, cruising, and deceleration. Additionally, careful thought must be given to where passing will occur.
- Optimization models can be used to decide the most effective minimum headway.

REFERENCES

[1] Kelly K A, McManus M C and Hammond G P 2014 An energy and carbon life cycle assessment of industrial CHP (combined heat and power) in the context of a low carbon UK *Energy* **77** 812–21
[2] Liu W, Hu W, Lund H and Chen Z 2013 Electric vehicles and large-scale integration of wind power - The case of Inner Mongolia in China *Appl. Energy* **104** 445–56
[3] Zhong Q, Xu C, Yang R and Zhong Q 2023 Equivalences between analytical railway capacity methods *J. Rail Transp. Plan. Manag.* **25** 100367
[4] Pu Y S, Srikukenthiran S, Morrow E, Shalaby A and Klumpenhouwer W 2022 Capacity Analysis of a Passenger Rail Hub Using Integrated Railway and Pedestrian Simulation *Urban Rail Transit* **8** 1–15
[5] Jamili A 2018 Computation of practical capacity in single-track railway lines based on computing the minimum buffer times *J. Rail Transp. Plan. Manag.* **8** 91–102
[6] Navarro L M, Fernandez-Cardador A and Cucala A P 2021 Design of indicators to guide capacity improvements in urban railway lines *J. Urban Mobil.* **1** 100003
[7] Xiao J, Pachl J, Lin B and Wang J 2018 Solving the block-to-train assignment problem using the heuristic approach based on the genetic algorithm and tabu search *Transp. Res. Part B Methodol.* **108** 148–71
[8] Kurai V, Dariano A, Goverde R and Dariano A An assessment of railway capacity Related papers
[9] Han J, Yue Y and Zhou L 2016 A Microscopic Simulation Method to Calculate the Capacity of Railway Station 37–43
[10] Burdett R L and Kozan E 2006 Techniques for absolute capacity determination in railways *Transp. Res. Part B Methodol.* **40** 616–32
[11] Parkinson, T. and Fisher I 1996 *TCRP Report 13: Rail Transit Capacity*
[12] Rahoma D M S, Heikal A Z, Zohny H N and Kotb A S 2021 Proposed models to calculate and optimise line capacity under different operation conditions for egyptian railway network *J. Appl. Eng. Sci.* **19** 77–83
[13] Landex A, Kaas A H and Hansen S 2006 *Railway Operation*
[14] Abril M 2008 An assessment of railway capacity **44** 774–806
[15] Zinder Y, Lazarev A A, Musatova E G, Tarasov I A and Khusnullin N F 2016 Two-Station Single Track Scheduling Problem *IFAC-PapersOnLine* **49** 231–6
[16] Sangphong O, Siridhara S and Ratanavaraha V 2017 Determining critical rail line blocks and minimum train headways for equal and unequal block lengths and various train speed scenarios *Eng. J.* **21** 281–93
[17] Sangphong O, Siridhara S and Ratanavaraha V 2017 Determining critical rail line blocks and minimum train headways for equal and unequal block lengths and various train speed scenarios *Eng. J.* **21** 281–93