

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

Hassan Khaksar¹

Received: 2024/11/06

Accepted: 2025/06/08

Abstract

Capacity of lines and stations is one of the most influential and important factors in network planning and operation. Various methods and methodologies exist for calculating capacity. Accurately and appropriately determining this concept in railway network lines is a very complex task. This becomes even more important when considering the number of network blocks and their different characteristics and properties. In recent years, the Scott method has been used to calculate line capacity. This research aims to identify the various methods of calculating capacity in networks. Furthermore, while comparing these methods, an attempt has been made to introduce a suitable method for use in the country. To this end, by considering the characteristics of the country's railway network and calculating the capacity of 8 selected routes, an attempt has been made to identify a method suitable for the country's railway network. The International Union of Railways (UIC) has presented methods for calculating network capacity under codes 405 and 406. Based on the results of this research, the method presented in the UIC406 guideline, which is the latest and most up-to-date method of this union, has a good fit with the country's network conditions and can be used in the country's railway network. One of the outputs of this study is a software for calculating the capacity of the country's rail network based on UIC code 406. The outputs of this software include train capacity (train set of each block), tonnage capacity in two modes of dominant tonnage and maximum tonnage (nominal tonnage), network bottlenecks based on the performance-to-capacity ratio, and sensitivity analysis of various solutions to increase network capacity.

Keywords: Capacity Analysis, UIC 406, Rail network

* Corresponding author. E-mail: h.khaksar@iau.ac.ir

¹ Assistant Professor of Civil Engineering, North Tehran Branch, Islamic Azad University, Tehran, Iran

1. Introduction

With the continuous growth of the global economy and increasing global trade, the importance of transportation and communication services has gradually increased, and a significant portion of resources has been focused on this sector. Under such circumstances, transportation and communication services in our country have also acquired special conditions due to Iran's strategic position in the region. One of the parameters that can indicate the current status of service provision in this sector is the level of system efficiency. Efficiency, according to the definition of the Organization for Economic Cooperation and Development (OECD), is defined as the ratio of the quantity or value of output to the quantity or value of one of the inputs. Based on this, we can talk about capital efficiency, raw material efficiency, and labor efficiency. This concept has gradually evolved and encompasses the concepts of effectiveness and efficiency. Therefore, efficiency is a measure of how production factors are combined and used to achieve organizational goals in a way that yields the maximum results and returns with the least cost. Accordingly, efficiency is the ratio of output to input and can include various inputs. These various inputs can include quality, extent of operations, consumption of raw materials, capital equipment, skill level of labor, and so on. One of the most important parameters affecting the efficiency of the transportation network capacity is the rail system. Rail transportation systems are considered one of the safest, most cost-effective, environmentally friendly, and reliable systems for both urban and intercity transportation. The high capacity of this system in transporting goods and passengers has led to increasing attention to it, and its role in today's global market is undeniable. Obviously, the development of a rail transportation system requires attention to both hardware and

software aspects. The use of rail transportation has a history of over 200 years and is one of the oldest methods of transportation for goods and cargo. Therefore, significant and remarkable progress has been made in developing its infrastructure. The use of trains compared to road transportation is very economical and cost-effective. A train with 60 55-ton wagons can carry 3300 tons of cargo, while if this cargo were to be transported by 20-ton trucks, 165 trucks would be needed, and the fuel consumption of the train is one-sixth of the fuel consumption of trucks. Another noteworthy point is that rail transportation is one of the sustainable ways to reduce road traffic fatalities and also reduce environmental pollution. Capacity is essentially the ability of a route to accommodate a specific number of vehicles. The calculation of capacity varies across different modes of transportation. Calculating railway capacity is more complex than calculating capacity for other modes of transportation. The infrastructure characteristics of the route, fleet specifications, and factors affecting train scheduling, which in turn impact train travel time, are all elements that influence capacity. Calculating the nominal capacity of rail transport in a network can lead to the allocation of resources to address capacity bottlenecks and is a significant step in increasing the efficiency of rail systems in the country. Capacity of a route is expressed in terms of the number of units transported per unit of time. For example, capacity can be expressed in terms of people per hour, tons per hour, seats per hour, or trains per hour. This definition does not consider the speed at which the transported unit is moved, although speed can be used as an important evaluation criterion for comparing routes with equal capacity. This leads to the definition of new concepts such as transport work (transported unit multiplied by the length of the route section) and transport power (transported unit multiplied by speed). The

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

capacity of a rail system is derived from the calculation of the following components:

- Block length
- Actual speed resulting from track components
- Train acceleration and deceleration characteristics
- Train length
- Station dwell time
- Infrastructure
- Fleet capacity and operating speed
- Train scheduling
- Logistics
- Axle load restrictions

Therefore, calculating the capacity of a national railway network depends on the estimation of all these factors and is a complex and time-consuming task. However, performing this task is of great importance in managing and improving the efficiency of the country's rail system. Line capacity is not a fixed value; it varies depending on the ratio of different types of trains. Therefore, estimating capacity is crucial for making decisions about whether the existing infrastructure can handle the predicted traffic load. If there is insufficient capacity, new infrastructure will need to be built. In this regard, capacity analysis techniques can be used to identify suitable locations for the construction of new infrastructure. The primary objective of this paper is to identify a suitable method for estimating the capacity of the national railway network. In this regard, while examining various existing methods in the literature, an attempt is made to introduce the most appropriate method for calculating the capacity of the national railway network through an analytical comparison of these methods with the current status of the country's railway network. Subsequently, the network capacity will be calculated using the proposed method. Another objective of this paper is to transform the proposed method into a practical application for use in railway capacity calculation operations.

2. Literature Review

As defined in UIC 406, capacity is not a specific and measurable term but requires the definition of conditions and calculations based on the stated conditions. The capacity of a railway infrastructure depends on its mode of operation. The capacity, or the number of trains that can pass through a route, is dependent on three other indicators of the railway network: the stability of the timetable, the achievable average speed, and the homogeneity of traffic (Landex, 2008). A definition of line capacity is the maximum number of trains that can pass through a specific route at a given time. For a more precise definition of capacity, we need to categorize capacity, which is presented below: The difference between the used capacity values and the optimal capacity is equal to the available capacity; this value indicates the traffic volume that can be added to the route traffic (Parkinson and Fisher, 1996).

Trains must wait at their current station until the track connecting the two stations is clear (even if the two trains are traveling in the same direction) before they can depart for the next station. In other words, a train cannot enter a section of track until the preceding train has vacated it. The time interval between the departures of trains between two stations is one of the determining factors in capacity calculations (Pachl and White, 2004).

If intermediate stations have only one platform for train stops, the overall line capacity is a function of the station capacity; because the following train will not be allowed to enter the station until the previous train has left. The stopping time and the time for passengers to board and alight play an important role in determining the minimum headway. Metro lines are an example of a line with homogeneous traffic. The simplicity of this relationship can be misleading. At least two basic factors play a role in determining capacity, which are: 1) The distance between consecutive stations, where a faster train may

overtake a slower one; 2) The order of the routes that a train is allowed to enter, along with speed limits and the distance between stations."

Under ideal conditions, the train and station signaling system has the greatest control over train stopping time and therefore line capacity. However, in non-ideal conditions, other factors also affect capacity. These factors include (Parkinson and Fisher, 1996):

- Speed restrictions due to track geometry
- Track junctions
- Track bottleneck

Therefore, understanding the factors affecting commercial train speed plays a crucial role in determining line capacity. Commercial speed is calculated by dividing the distance between the origin and destination by the arrival time. In most railway lines, various types of passenger and freight trains operate with different movement patterns. Capacity will vary based on different combinations of train types. Consequently, the commercial speed of trains is not uniform. As shown in the figure, the train paths on the time-space diagram are not homogeneous. The difference in speed of trains passing through the network is one of the key parameters affecting the capacity of railway lines (Burdett and Kozan, 2006).

The characteristics of high-speed passenger trains and the features of slow-moving heavy freight trains affect the number of trains that can pass through a defined time period (e.g., 24 hours). Increasing the speed difference between the slowest and fastest trains reduces capacity. In this case, capacity cannot be calculated using a single formula. To calculate capacity, it is inevitable to use the train timetable. As shown in the figure above, two different train sequences result in two different capacity values for the same track segment. The second part of the train movement graph (C2) has a higher capacity than the first part (C1) of the graph (Burdett and Kozan, 2006).

The evaluation of the railway infrastructure capacity is an important task for railway companies. The goal is to find the best

infrastructure development plan for scheduling new train services. The question addressed by the present study is how the existing railway infrastructure can be upgraded to decrease the total delay of existing and new trains with minimum cost. To answer this question, a mixed-integer programming formulation is extended for the integrated train scheduling and infrastructure development problem. The train timetabling model deals with the optimum schedule of trains on a railway network and determines the best stop locations for both the technical and religious services. We developed two heuristics based in variable fixing strategies to reduce the complexity of the problem. To evaluate the effect of railway infrastructure development on scheduling of the new trains, a sequential decomposition is adopted Iranian railway network. The outcomes of the empirical analysis performed in this study allow to gain beneficial insights by identifying the bottleneck corridors. The result of the proposed methodology shows that it can significantly decrease the total delay of new trains with the most emphasis on the bottleneck sections (Shakibayifar et al, 2017).

According to the definition provided in UIC406, capacity is not a specific and measurable term and requires the determination of conditions and calculations based on the mentioned conditions. The reason for the difficulty in defining capacity is the multitude of parameters affecting capacity that need to be measured. In calculating capacity, both the method presented in UIC406 and the method introduced in UIC405 can be used. UIC406 is more up-to-date and provides a newer method compared to UIC405. It should be noted that the method presented in UIC405 has been more widely used. Based on the method presented in UIC405, accurate homogenization can be determined using the journey time and considering the speed in the critical section, which provides better results for networks with a variety of trains with different speeds. In the approach presented in UIC406, the percentage

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

of capacity utilization is specified and the number of train sets is not calculated. This method is one of the most well-known methods and is widely used in Europe (Jensen et al. 2020). Pachl and White categorize railway line capacity analysis methods into two groups: analytical and simulation-based (Pachl and White, 2004). In another study, three methods of analysis for capacity calculation were presented: analytical, graphical, and simulation (Yaghini and Lesan, 2010). Additionally, some researchers have categorized capacity calculation methods into three groups: analytical, simulation, and optimization (Abril et al. 2008). Consequently, methods for calculating railway network capacity can be classified into four categories: analytical, simulation, parametric, and optimization. Analytical methods calculate line capacity based on the minimum train headway. While analytical models offer a quick way to calculate capacity, they provide limited data for analysis (Khadem et al. 2010). Given the simplicity of the relationships used and the approximate nature of the related parameters, one cannot expect very high accuracy from this method, but it can be used as a quick and practical method in large networks (Pachl and White, 2004). Simulation models have higher accuracy but require a lot of data and computer calculations. Parametric models fall between these two methods (Libardo et al., 2011). Optimization models, with the aim of evaluating capacity, focus on optimizing the railway network and obtaining an optimal train timetable. In analytical methods, capacity is calculated based on computational relationships and using line data and train schedules. In this method, theoretical capacity is usually calculated, and then operational capacity is obtained as a percentage of theoretical capacity or through a safety margin. One of the advantages of this method is its suitability for identifying bottlenecks. However, its disadvantages include high dependency of outputs on input parameters and changes in train composition. Probabilistic

approaches or queuing theory can be used in this category (De Kort et al. 2003; Kukec and Mlinari, 2003). However, for more detailed train scheduling, other methods must be used. Examples of analytical methods include the Scott method and the UIC405 method. The UIC405 method calculates a more realistic value by calculating the average headway (considering the probability of four types of headways) and calculating the values of buffer time and additional time; because it considers more effective factors (Yaghini and Lesan, 2010). In another study, the UIC405 formula was found to be more suitable for double-track and two-way single-track lines compared to the actual capacity calculation model and the Railsis simulation software (Montazeran, 2006). Also, Dalvand in 2007, by comparing the Iranian railway formula with UIC405, showed that the UIC405 formula provides better and more realistic results compared to the railway formula for calculating the capacity of the Lorestan axis (Dalvand, 2007). Other analytical relationships can consider different groups of trains and their difference lies in how the value of the train headway is considered. Each of these formulas has been presented according to the traffic of the respective country's railway, and these weaknesses can probably be justified by considering the conditions of that country's railway. The basic capacity relationship is the UIC405 model, and its difference lies in how the headway is calculated. Capacity calculation and analysis based on the European Rail Traffic Management System (ERTMS) is used to analyze the capacity of lines with signaling and communication systems (Abril et al. 2008).

3. Methodology

Various methods have been proposed for calculating railway network capacity, including Scott, European Rail Traffic Management System (ERTMS), UIC405, and UIC406. Each of these methods has its advantages and disadvantages, and the selection of a method for calculating the capacity of a country's railway

system should be based on the country's specific characteristics and regional features. Therefore, it cannot be concluded that all of the mentioned methods are suitable and acceptable for calculating the capacity of a country's railway system. Rather, the appropriate method for calculating the capacity of a country's railway network should be selected through the study and comparison of these methods.

Calculating capacity for lines where all trains travel at the same speed and have the same stopping time at stations is quite straightforward. The train movement graph in this case is shown in the figure below. In this case, the capacity CT is obtained from the following relationship, which includes T as the time period under consideration and d as the train headway (Burdett and Kozan, 2006).

$$CT = \frac{T}{d} \quad (1)$$

3.1. Scott's Method

The most common method for calculating capacity in Iran is the Scott's method. This is one of the oldest mathematical methods proposed for calculating railway capacity. In this method, capacity for the critical path is calculated based on the running time of the slowest train on the critical path.

$$C = \frac{1440 - W}{T + t} \times K \quad (2)$$

The Scott relationship parameters are as follows:

C: Capacity in terms of mixed train pairs (freight and passenger) per day;

W: Blocking time (minutes) for maintenance and repair;

T: Running time of the slowest freight train on the critical path;

t: Safety headway between trains traveling in the same direction and opposite directions;

K: Efficiency factor; applied based on scheduled and forced stop times, rates of unforeseen delays, existence of crossings and priority, delays and out-of-schedule train movements, etc. This factor is usually considered to be 70%.

The value of T in the denominator of the Scott relationship is the circulation period of trains for the longest possible running time. This value for single-track (double-direction) lines is equal to the sum of the slowest running times of trains in both directions, and for double-track (single-direction) lines, it is equal to the average of the slowest running times of trains in both directions.

The capacity calculated by the Scott relationship is close to reality if the line is used only for freight trains. However, if passenger trains also operate on the axis, the actual capacity may be higher than the value calculated by the Scott relationship. Therefore, the value calculated by the Scott relationship can be considered as the lower limit of capacity, in such a way that the actual capacity of the axis, under normal conditions, does not fall below this value."

3.2. UIC405 Method

The UIC 405 code, introduced by the International Union of Railways in 1996, provides a method for calculating capacity based on running time, authorization time, and block release time. By extracting four types of headways and considering buffer and additional times, it proceeds to calculate capacity. This relationship has been presented with the view that all railway systems in the world can use it, and it considers parameters such as the number of trains and the relative share of different types of trains. The steps for determining capacity using the UIC 405 method are as follows: 1) Determining the study section; 2) Grouping trains based on running time; 3) Determining the number of trains in each group; 4) Calculating the average headway; 5) Calculating buffer and additional time. The capacity calculation formula in the UIC 405 method is as follows:

$$C = \frac{T - W}{t_{fm} + t_r + t_{zu}} \quad (3)$$

"C: Line capacity in terms of the number of trains during the study period;

T: Study period;

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

W: Maintenance and repair blocking time;
 t_{fm} : Average headway between all trains;
 t_{zu} : Additional time;
 t_r : Buffer time;

If we want to calculate capacity for a 24-hour period, the value of T is considered to be 1440; and if we want to calculate based on peak hour, the value of T is considered to be 60 minutes. If some hours of the line are blocked for maintenance and repair operations, the maintenance and repair operation time is subtracted from 1440 minutes. The difference between the actual headway and the minimum acceptable headway is called buffer time. Considering that capacity decreases with an increase in the number of sections, a variable called additional time is defined and calculated using the formula $t_{zu} = 0.25 * a$ (a = number of track blocks).

This relationship for calculating capacity is different for single-track and double-track lines, and for cases with and without a train timetable. It is worth noting that the main difference between the UIC 405 relationship and other proposed relationships for calculating capacity is the way the train headway is calculated.

Calculation of the average train headway (t_{fm}): Assume that the starting point of the outbound journey is station A, and the destination of the outbound trains is station B. Similarly, the starting point and destination of the inbound trains are B and A, respectively. As shown in the figure below, there can be 4 different cases for calculating the headway between two consecutive trains. These headways are: outbound-outbound, outbound-inbound, inbound-inbound, and inbound-outbound. For each of these cases, there is a specific method for calculating the headway, which is presented in Table 1.

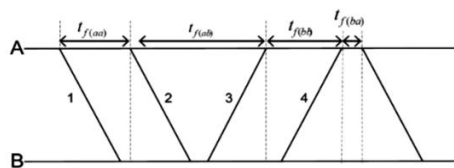


Figure 1. Various train states on space-time graph

Table 1. Calculating headway under various conditions

Condition	From Stop	En route
1	$t_{f(aa)}$ $= t_{1AB} + t_b + t_a$	$t_{f(aa)}$ $= t_{1AB} + t_b$
2	$t_{f(bb)}$ $= t_b + t_a + t_{2BA}$	$t_{f(bb)}$ $= t_b + t_{2BA}$
3	$t_{f(ab)}$ $= t_{1AB} + t_b + t_a$ $+ t_{2BA}$	$t_{f(ab)}$ $= t_{1AB} + t_b$ $+ t_{2BA}$
4	$t_{f(ba)} = t_b + t_a$	$t_{f(ba)} = t_b$

This document presents a train timetable, detailing the journey times and frequencies of various train services. Trains are categorized into groups based on their journey duration, and an average journey time is calculated for each group. As per UIC405 guidelines, each axis should have between 2 and 4 groups. Based on this data, the average headway between trains is calculated.

$$t_{fm} = \frac{\sum(n_i \times n_j \times t_{fij})}{\sum(n_i \times n_j)} \quad (4)$$

where i is the previous train and j is the following train. n_i and n_j are the number of trains in each group, and t_{fij} is the headway between groups.

3.3. UIC406 Method

Method 405 presents a capacity calculation approach that extracts four types of headways based on journey time and then calculates capacity by considering additional times. However, in Method 406, the capacity calculation methodology is based on the compression of train movement graphs, and capacity is considered as the ratio of the occupied line time to the available time in the study period. Furthermore, the block time model is commonly used to calculate train movement schedules. Block time refers to the time during which a section of the track (a block or a part of the track authorized by the system for train movement) is exclusively allocated to a specific train, and other trains cannot enter it.

Therefore, the block time starts when permission is granted for a train to enter a specific block (indicated by a green signal). The train movement authorization must be issued before the train enters the safe braking distance of the desired block. The block time ends when the train completely passes through the block and all signals return to the free state. Only then can the traffic controller authorize another train to enter the block. Therefore, the block time of a line is longer than the time the block is occupied by the train. An example of the application of the block time model in train movement scheduling and network capacity calculation is shown in Figure 2. The steps involved in calculating the capacity used in this method are presented in three stages. Based on the journey times of passing trains, train grouping and then compression of the train movement graph are performed, and finally, the capacity used in the railway is calculated. The inputs of the proposed methodology include the journey times of passing trains and the number of trains in each track and in each direction, and time parameters including the track release time and the time required to obtain permission to enter the track for a train that wants to enter the track from a standstill. Stage 1: Grouping trains based on journey time: For capacity analysis, if there is more than one type of train, it is necessary to consider several different combinations of trains. At this stage, trains are grouped based on their journey times and direction of travel, and are used in determining the headway. To simplify calculations, trains with more or less the same journey duration are grouped together. It should be noted that the train group refers to trains with similar journey times and the same direction. The effect of train type on capacity has been previously investigated. Stage 2: Compression of the train movement graph: To calculate the capacity used by the track, the track occupancy time is calculated in the compressed graph state. The track capacity used by the prepared timetables can be represented by approximating the block

time staircase as much as possible and in a virtual manner. Of course, this is done without considering the headway times and without changing the order of the trains. This method is called compression. To do this, both graphical and computational analysis methods can be used. It should be noted that the compression of the movement graph is performed for track sections with similar characteristics. According to UIC 406, railway lines should be divided into smaller lines at junctions where the number of railway lines changes. Railway lines should be broken at each junction, such as where railway lines change from a double-track to a single-track. The time obtained after compressing the graph of grouped trains is called the track occupancy time and is used in step 3 to calculate the capacity. Stage 3: Calculation of the used capacity: What is known as the capacity used in UIC 406 is the ratio of the track occupancy time to the available time in the study period. The UIC406 relationship calculates the used capacity using the sum of the infrastructure occupancy time, headway time, and additional times.

$$K = \frac{k \times 100\%}{t_u} \quad (5)$$

In this regard, K represents the percentage of capacity utilization, k is the total capacity utilization time (the sum of the time a train takes to completely traverse a block and the additional time required to maintain optimal line operation), and t_u is the available time window in minutes. The value of k is equal to the sum of four different times: t_A (line occupancy time, obtained in the previous step), t_B (headway time), t_C (additional time for single-track lines), and t_D (time for maintenance and repairs). If the capacity is calculated for a 24-hour period, the value of t_u (available time window) is considered to be 1440 minutes. If the capacity is based on peak hour traffic, the time window is considered to be 60 minutes. In case of maintenance operations, the blockage time must also be considered. The value of the parameter k (total capacity utilization time) can

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

be indirectly obtained using the average headway of trains. The average headway of trains in the UIC406 method is calculated in the same way as in the UIC405 method. By calculating the average headway of trains (t_{fm}) and based on the total number of trains passing through the track, the value of the parameter k (total consumption time) can be calculated.

$$k = N \times t_{fm} \quad (6)$$

where N represents the total number of trains passing through each track. The utilized capacity of a railway axis is equal to the maximum utilized capacity of the tracks in that axis; since the track that is occupied for a longer period of time will be the limiting and determining factor for train operation.

$$K_{corridor} = \text{Max}\{K_{Block 1}; K_{Block 2}; \dots; K_{Block n}\} \quad (7)$$

Where $K_{corridor}$ represents the utilized capacity of the corridor (with n tracks) and $K_{Block n}$ denotes the utilized capacity of the n th track. The practical capacity of each track can be calculated by considering the critical values presented in the table above. In this way, the utilized capacity is determined based on the type of traffic, the study period, and the critical values. Subsequently, based on the average headway between trains, the maximum number of passing trains (capacity) can be calculated while maintaining optimal operational conditions.

$$C = \text{Max}\{K, K_{critical}\} \times 100 \times \frac{t_U}{t_{fm}} \quad (8)$$

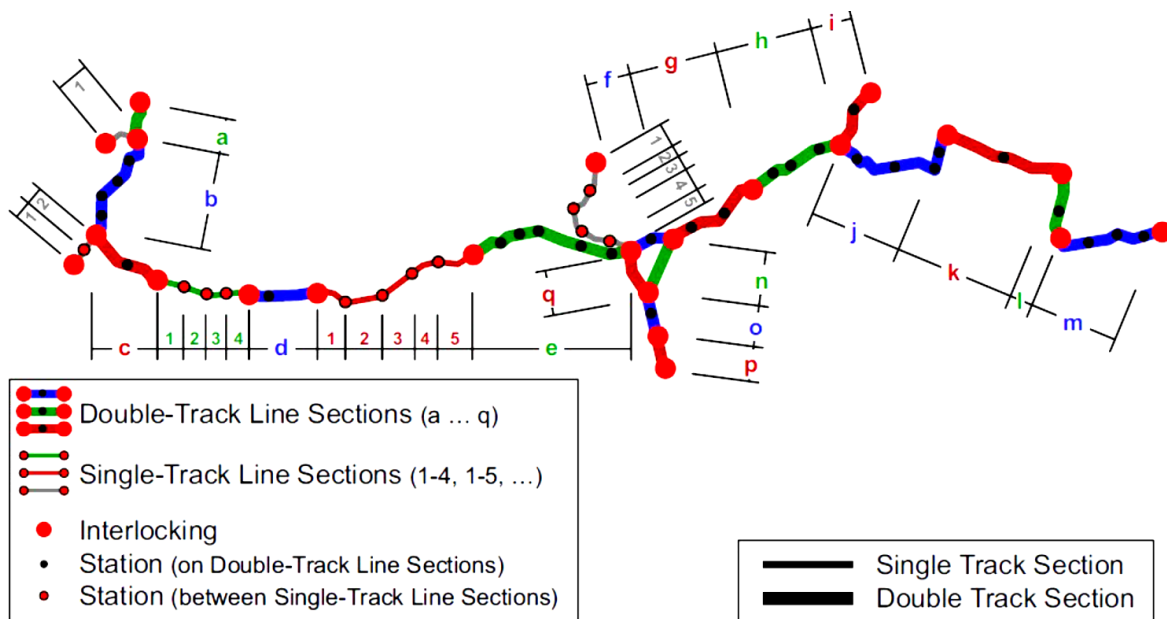


Figure 2. An example of infrastructure-based segmentation of a railway corridor

Each of the mentioned methods has its own advantages, disadvantages, and limitations. It is not possible to definitively state which method is better than the others, but considering the current situation of the Iranian network and the simultaneous use of the same network by passenger and freight trains, it seems that the UIC406 method can provide more accurate and suitable results for calculating the capacity of the Iranian railway network.

The data required for determining railway network capacity using the mentioned methods generally include, but are not limited to: Network Topology, Train Schedules (Timetables), Infrastructure Characteristics, Rolling Stock Characteristics, Operational Rules and Regulations, Traffic Mix.

4. Modelling and Research Findings

In this research, the railway network database of 1399 (2021) was used. In these studies, various routes of the country's railway network, including the most important railway bottlenecks in the country, have been investigated. This database contains more than three million rows of output in an Excel file, providing the following information for each train movement in a block at different times and directions with different origin and destination stations. A sample of this database is also shown in the table below:

- Origin and destination region, axis name
- Year, season range, and effective day
- Train number, code, order, train name, movement number
- Origin and destination station, station code, and origin and destination station of the block

Entry and exit time from the station, actual time and scheduled time to calculate headway, stopping time, occupied and available time, and headway for each block in the UIC406 capacity calculation method, the train schedule and movement database was used. Another parameter for calculating the capacity of the country's railway network using the UIC406 method is the available time window. To calculate this parameter, we need the stopping and blocking time in each block. The more stopping and blocking in a block, the less available time window and the lower the line's passing capacity. To calculate the stopping time, the operational time database of freight and passenger trains was used, and to calculate the blocking of lines in blocks, the database of line and train blocking in blocks was used. In this database, there are more than 28,000 rows of output in an Excel file, providing the following information for each stop and block of a block. This information is for the entire year 1399 (2021). A sample of this database is also shown in the next table.

- Origin and destination region

- Train number
- Type of blockage
- Origin and destination station
- Stopping time
- Stopping hour

Reasons for stopping to calculate the daily stopping time in each block in the UIC406 capacity calculation method, the average stopping time in each block throughout the year was used. To determine the capacity routes and identify the blocks in each route, the capacity route database was used. In this information, for each region, the routes and blocks in each route are determined, which are used in the stage of determining the capacity of railway routes. This information has about 560 rows, based on which the capacity routes of the railway network and block titles are extracted. To determine the tonnage capacity of each route, a train weight report is required. For this purpose, a train weight report was obtained. This database has more than 120,000 rows, and the following information is provided for each train movement:

- Train number, region, and train name
- Formation date and time
- Origin and destination station
- Net weight, train weight, train length
- Wagon specifications

Empty and full trains to identify the bottlenecks of the railway network and compare the capacity of each route with the performance and demand of that route, the performance and demand reports of the routes are needed. In this regard, the 1399 (2021) performance database and the 1401 (2023) demand database were obtained. The mentioned databases were entered into the Python software, and using the coding of the formulations presented for each method, the railway network capacity in the country was calculated. The methods for which the capacity was calculated are as follows:

- American method
- Scott method
- UIC405 method
- UIC406 method

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

Also, to enable the comparison of the calculated capacity with the existing network status, the existing network performance and the calculated and currently used capacity of the railway company are also presented in the

analyzes. In Figure 3, the train RAM capacity calculated by the aforementioned methods is presented alongside the existing network performance.

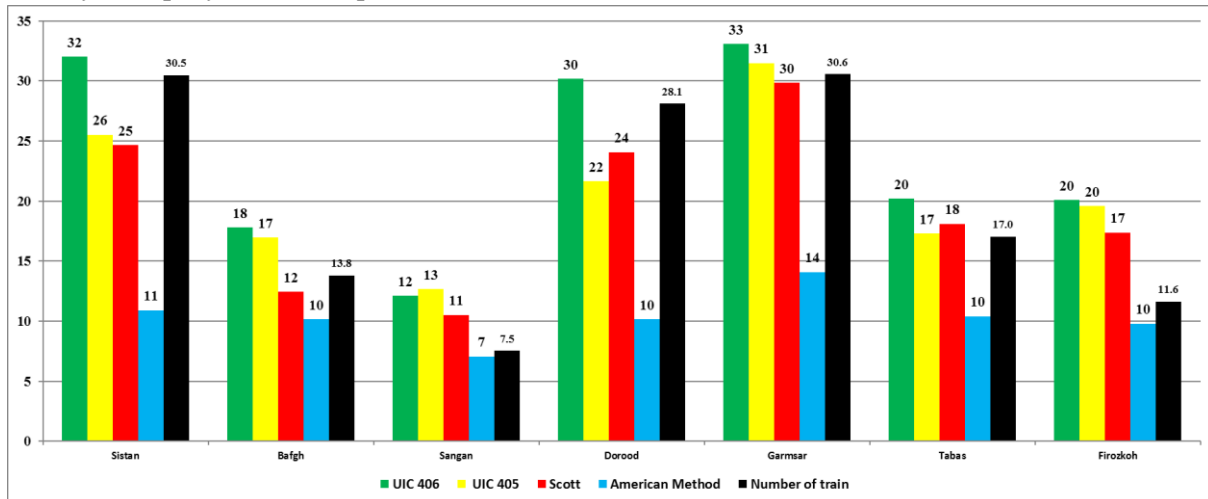


Figure 3. Capacity of selected railway lines using various methods (train RAM)

5. Conclusion

This research undertook a comprehensive investigation and analysis of various methodologies for calculating railway network capacity. Based on an initial assessment of the current operational context of the Iranian railway network, a localized adaptation of the Scott method was employed to provide an initial capacity estimation. Recognizing the advancements in the field, the study also examined the capacity calculation methods proposed by the International Union of Railways (UIC), specifically methods 405 and the more contemporary and widely adopted 406. Our analysis and calculations strongly indicate that the UIC406 method is the most suitable approach for accurately determining the capacity of the Iranian railway network, providing a stronger concluding statement on its suitability. Furthermore, this revised conclusion explicitly outlines the significant implications of adopting the UIC406 method for network planning and operation in Iran, detailing the potential benefits of its implementation. Finally, it also provides recommendations for practical implementation strategies to facilitate

the adoption and effective utilization of this method.

The implications of adopting the UIC406 method for network planning and operation in Iran are significant. Implementing this more accurate capacity assessment can lead to more efficient timetable scheduling, better identification of potential bottlenecks, and optimized infrastructure utilization. This, in turn, can support strategic decisions regarding infrastructure upgrades, investment in new lines, and the development of more reliable and efficient rail services for both passenger and freight transport across the country.

For future research, it would be beneficial to:

- Develop and implement software tools based on the UIC406 methodology tailored to the specific data structures and operational characteristics of the Iranian railway network.
- Investigate the integration of UIC406 with other operational planning tools and models to create a more holistic approach to railway network management in Iran.
- Conduct comparative studies between the results obtained from the localized Scott method and the UIC406 method on real-world

data to quantify the improvements in accuracy and identify potential areas for refining the localized approach.

Furthermore, regarding implementation strategies, policymakers and railway operators in Iran should consider investing in the necessary data collection systems and training to facilitate the widespread adoption and effective utilization of the UIC406 method for informed decision-making in railway network planning and operation."

6. References

- Abril, M., Barber, F., Ingolotti, L., Salido, M. A., Tormos, P., & Lova, A. (2008). An assessment of railway capacity. *Transportation Research Part E: Logistics and Transportation Review*, 44(5), 774-806.
- Burdett, R. L., & Kozan, E. (2006). Techniques for absolute capacity determination in railways. *Transportation Research Part B: Methodological*, 40(8), 616-632.
- De Kort, A. F., Heidegott, B., & Ayhan, H. (2003). A probabilistic (max) approach for determining railway infrastructure capacity. *European Journal of Operational Research*, 148(3), 644-661.
- Harrod, S. (2009). Capacity factors of a mixed speed railway network. *Transportation Research Part E: Logistics and Transportation Review*, 45(5), 830-841.
- Jensen, L. W., Schmidt, M., & Nielsen, O. A. (2020). Determination of infrastructure capacity in railway networks without the need for a fixed timetable. *Transportation Research Part C: Emerging Technologies*, 119, 102751.
- Khadem-Sameni, M., Preston, J., & Armstrong, J. (2010, January). Railway capacity challenge: measuring and managing in Britain. In *Joint Rail Conference* (Vol. 49071, pp. 571-578).
- Kozan, E., & Burdett, R. (2004). Capacity determination issues in railway lines. *CORE 2004: New Horizons for Rail*, 31.
- Krueger, H. (1999, December). Parametric modeling in rail capacity planning. In *WSC'99. 1999 Winter Simulation Conference Proceedings. Simulation-A Bridge to the Future* (Cat. No. 99CH37038) (Vol. 2, pp. 1194-1200). IEEE.
- Kukec, J., Mlinarić, T. J., & Čičak, M. CALCULATING RAILWAY LINE CAPACITY USING THE QUEUING THEORY.
- Lai, Y. C., & Barkan, C. P. (2009). Enhanced parametric railway capacity evaluation tool. *Transportation research record*, 2117(1), 33-40.
- Landex, A. (2008). Methods to estimate railway capacity and passenger delays. Technical University of Denmark.
- Libardo, A., Pellegrini, P., & Salerno, G. (2011, February). Capacity in railway junctions and optimal route management. In *4th International Seminar on Railway Operations Modelling and Analysis*.
- Ljubaj, I., Mikulčić, M., & Mlinarić, T. J. (2020). Possibility of Increasing the Railway Capacity of the R106 Regional Line by Using a Simulation Tool. *Transportation Research Procedia*, 44, 137-144.
- Merel, A., Gandibleux, X., Demasse, S., & Lusby, R. (2009). An improved upper bound for the railway infrastructure capacity problem on the pierrefitte-gonesse junction. *Actes du dixième congrès de la Société Française de Recherche Opérationnelle et d'Aide à la Décision*, 62-76.

A Model for Determining Railway Network Capacity (Case Study: Iran Network)

- Pacht, J., & White, T. (2004, January). Analytical capacity management with blocking times. In TRB Annual Meeting.
- Parkinson, T., & Fisher, I. (1996). Rail transit capacity (Vol. 13). Transportation Research Board.
- Rosell, F., & Codina, E. (2020). A model that assesses proposals for infrastructure improvement and capacity expansion on a mixed railway network. *Transportation Research Procedia*, 47, 441-448.
- Shakibayifar, M., Hassannayebi, E., Mirzahosseini, H., Zohrabnia, S., & Shahabi, A. (2017). An integrated train scheduling and infrastructure development model in railway networks. *Scientia Iranica*, 24(6), 3409-3422.
- UIC Leaflet 405-1, 1983. Method to be used for the Determination of the Capacity of Lines, International Union of Railways.
- UIC Leaflet 405 OR, 1996. Links between Railway Infrastructure Capacity and the Quality of Operations, International Union of Railways.
- UIC Leaflet 406, 2013. Capacity, International Union of Railways.
- Weik, N., Warg, J., Johansson, I., Bohlin, M., & Nießen, N. (2020). Extending UIC 406-based capacity analysis—New approaches for railway nodes and network effects. *Journal of Rail Transport Planning & Management*, 100199.