UNIVERSITÀ DEGLI STUDI DI ROMA

LA SAPIENZA

Capacity Analysis and Improvement Proposals for Secunderabad Station

By

Sai Arvind Atluri

1722524

A Thesis submitted in conformity with the requirements for the degree of Master of Applied Science

Department of Civil and Industrial Engineering

Master's Degree in Transport Systems Engineering

Supervisor

Prof. Stefano Ricci

Academic Year 2018/2019

Acknowledgement

This thesis is imagined with the constant support and encouragement of my advisor, so many thanks to Professor Stefano Ricci of the Department of Transport Systems Engineering at Sapienza University. His guidance helped me all the time during my research and during writing my thesis.

I would like to thank all the faculty members from the Transportation Department namely Professors Guido Gentile, Mattia Giovanni Crespi, Antonio Musso, Paola Di Mascio, Gaetano Fusco, Gabriele Malavasi, Luca Persia, Massimo Guarascio, Agusto Mazzoni and Andrea Campagna who have taught and guided me in all aspects. I was one of the fortunate students who had the privilege of being taught by such esteemed professors.

I would like to thank Vasudev Reddy, Secunderabad station director, South central railway division, who helped me in providing useful data and information for the analysis of my thesis work.

I would like to thank my parents for their constant encouragement and for believing in my dreams. It would not have been possible without their support.

Capacity Analysis and Improvement Proposals for Secunderabad Station

By

Sai Arvind Atluri

1722524

Abstract

Efficient railways need to be designed, constructed and operated. Their performance must also be identifiable, and their capacity must be transparent to users. Railway capacity analysis is an important approach to determine whether the network can handle an intended traffic flow and whether there is any free capacity left for additional train services. As capacity planning is combinatorial, there are many alternatives to compare. Hence mathematical approaches are critical in finding the best solution and course of action. This thesis has considered Potthoff method and tested that presumption. The shortcomings of a prominent model for capacity analysis have been addressed. To verify their applicability and validity, they are applied and tested to a case study: the Indian railway station of Secunderabad.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

GIPR - Great Indian Peninsula Railway

INR - Indian Rupees

GPS - Global Positioning System

SCR - South-Central Railway

IGBC - Indian Green building Council

MMTS - Multi Modal Transport System

TCQSM - Transit Capacity and Quality of Service Manual

FOB - Foot over bridge

PRS – Passenger Reservation System

ATVM - Automatic Ticket Vending Machine

AC – Air Conditioning

CCTV - Closed-circuit Television

ATM - Automated Teller Machine

Chapter -1 Introduction

1.1 An overview of the Transportation and the concept of capacity used

The main concept of transportation is moving passengers and goods from one place to another. Transportation affects different aspects of human lives from daily individual level to long-term socio-economic welfare and sustainability of societies. Figure 1-1 is a schematic representation of transportation. The transportation of passengers and goods should be performed in an efficient, safe, secure and reliable manner with the lowest external and internal costs possible.

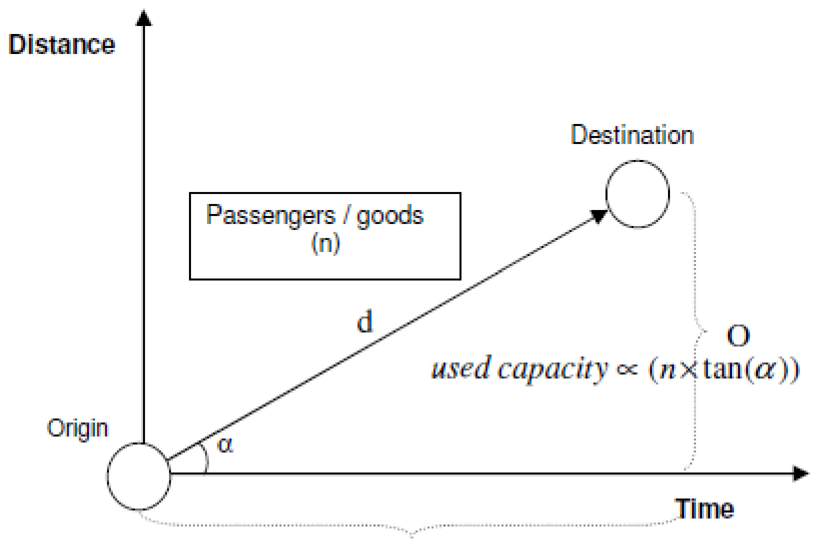


Figure 1.1 A Schematic representation of transportation and the concept of capacity

As seen in figure 1.1, tan (α) represents the speed. Therefore, used capacity is a function of passenger kilometre per hour.

Early transportation evolved from walking, domesticated animals and river boats to ox-driven carts and horse-drawn stagecoaches after the revolutionary invention of the wheel (Herbst, 2006). Steam power, diesel power, electric power and engines brought about modern transportation. Today, passengers and goods are transported via air, water, roads and rails by various modes of transportation at different socio-economic costs. However, there are some common elements in the different modes of transportation, which are vehicles, guideways (feasible paths of travel), terminals and control policy (Hall, 2003)

For each mode of transportation there are vehicles moving on guideways. The practical capacity of these guideways for accommodating vehicles might be limited or abundant. Movements of vehicles on the guideways are controlled to ensure safety. Table 1.1 provides an overview of different modes of transportation.

Table 1.1 An overview of practical capacity for different modes of transportation.

	Guideways	*Degrees of freedom on guideways*	*Practical capacity of guideways*	*Bottlenecks*	*Control policy*
Air	Air	3	Abundant	Airports	Air Traffic Control
Marine	Water	2	Abundant	Ports/Locks	Automatic Identification System
Rails	Rails	1	Limited	Station/ Junctions	Signalling
Road	Roads	2	Limited	Junctions	Traffic Lights and Signals

1.2 History of Indian Railway Transportation – 1853 to 2018

Indian Railways is the world's fourth largest railway system. Founded in 19th century, this system serves millions of tourists and locals, every day. The first passenger train of India took 400 people for 1.6 km from Mumbai to Thane. From there, the Indian Railways has evolved into a superpower industry.

1853 – 1869

Although the concept of railway system entered India in 1850, trains came to India in 1853 only. There were many political barricades to cross in acquiring land, resource, labour and others. The first train had only 14 cars. Controlled by East India Company, the system gradually grew and made additional lines like Calcutta – Delhi, Allahabad – Jabalpur and others. By the end of this era, Indian Railways covered 4000 miles in area. By 1860, eight railway companies were launched in the country including Eastern India Railway, Madras Railway, Great India Peninsula Company and others. Most of these companies were approved and commissioned by the then kings of India.

1870 – 1900

This reign liquidated many companies and external contractors were hired for controlling the railway. The length of the railway system reached 9000 miles in this region, mainly around Bombay, Calcutta and Madras. By the end of 1890, the trains started to gain many amenities like toilet, electric lights and others. The mountain trains, now called as the toy trains. were first proposed in 1854. However, the first mountain train started its maiden trip on 1881. The first mountain train of the country is the Darjeeling Himalayan Railways. Later, many other mountain train routes were linked connecting highland towns with the rest of the country. First toilets were introduced in the first-class coaches in 1891. Only since 1907, in the lower classes were provided toilets.

1901 – 1925

Since the beginning of the 20th century, Indian Railways started to make profit. Under the rule of Lord Curzon, the railway department started to flourish. East Indian Railways and GIPR (Great Indian Peninsula Railway) were nationalized by the end of this reign. During the First World War, the service of Indian railways degraded monumentally. The fund and other resources of the railway department were routed to the war needs by the British government in India.

1925-1946

This era saw the first electrical train. The size of the system grew and started serving an average of 620 million passengers per year. During the final years of the British rule in India world events continued to play a role in rail activity. The economic depression kick-started by the Wall Street Crash resulted in INR (Indian Rupees) 11million being withdrawn from the railway reserve fund. Meanwhile, World War II also stymied railway development, as wagons were extensively commandeered for military movements.

1947-1980

After independence and separation of states, numerous rail routes were built to connect different regions. The first train between India and Pakistan started in 1951. All the trains were electrified and modernized. This was the bloom period for Indian Railways. In 1982, the first enquiry counter was set up in Mumbai suburban station to indicate the upcoming trains. It was a crude manual system, in which the staffs turned the clock hands to denote the next train timing, every 2÷3 minutes.

1980-2000

Technology started to gain more momentum and metro system started in India. As a major revolution of Indian Railway, luxury train started in India. The run of luxury train started with Palace on Wheels in 1982 by Government of Rajasthan and Tourism department of India.

2000-present day

Metros and monorails are thriving within cities. Online ticketing system started in 2000s and is one of the major ways of booking train ticket, today. 4.5 billion km were additionally covered in just ten years (2001-2010). Now, the train tracks cover more than 120,000 km of area in India and special amenities like Wi-Fi, customer information system, ergogenic designs and green technologies have taken Indian Railways to the next level. Recent developments of railway system include technological amenities in unreserved class, high horsepower electric locomotive, GPS (Global Positioning System) based passenger information system, sliding doors, private catering services and many others. There is always a next step for Indian Railway. By 2019, more than 7000 stations around the world would receive free Wi-Fi service. The technology team is diving deep into finding greener source of powers.

1.2.1 An overview of the Secunderabad Railway Station

Secunderabad station was opened on 9th October 1874, when a Railway line was constructed from Secunderabad to Wadi junction by Great Indian Peninsular Railway. The H.E.H. Nizam's Guaranteed State Railway Company Ltd. guaranteed by the Hyderabad Government formed in 1885 took over the 127-mile line from Wadi to Secunderabad. The State Government acquired the Nizam's Guaranteed State Railway Company from 1st April 1930. The status did not change till 1951-52 when the Nizam's State Railway was merged with the Great Indian Peninsular Railway to form Central Railway. South Central Zone was formed in 1966 with Secunderabad as its Headquarters.

Secunderabad is one of the major junction stations of SCR (South-Central Railway) and is provided with 10 platforms. Average number of the people who are entering and leaving the station has been around 0.16 million per day. 210 passenger trains are handled per day carrying 84000 passengers. Secunderabad station is adjudged 2nd in cleanliness on Indian Railway system. Efforts are on to obtain platinum rating from IGBC (Indian Green building Council) with the coordination of all departments.

Secunderabad station has major coaching depot consisting of two yards i.e. lower yard and washing siding. There are six pit lines in both the yards with line capacity between 360 to 610 metres (capacity of 16 to 26 coaches). 22 trains with 34 rakes are primarily maintained, 3 trains with 3 rakes secondary maintenance, 26 trains (357 coaches) turnaround maintenance. On an average of 14 trains with 257 coaches per day are maintained.

Secunderabad station, an ‘A1’ category station, is one of the best model stations on Indian Railways provided with all passenger amenities. Secunderabad has now been selected for redevelopment.

Currently Secunderabad junction is planned to cater to different kinds of trains such as the following:

1. Long distance Intercity, Rajdhani;
2. Less passenger density intercity train most of which terminate or originate at Secunderabad;
3. Special trains;
4. MMTS (Multi Modal Transport System) and suburban trains;
5. Mail Express trains.

1.3 Literature Review

The goal of any railway capacity analysis is to obtain the maximum number of trains that can be operated on a given section of infrastructure, during a specific period, under certain operational conditions (Abril et al., 2008). Due to the complexity of railway system, extensive studies have been conducted by researchers to discuss definitions of railway capacity, various types of methodologies on capacity analysis and different factors affecting capacity.

1.3.1 Capacity Definition

The definition of the capacity is a classical problem in the industry. While variations exist from study to study, most research has identified railway capacity as a measure of the ability to move specific amount traffic (Krueger, 1999), or number of trains that can be scheduled into a timetable without conflicts (Lindfeldt, 2015b), over a defined rail line section with a given set of resources under a specific service plan or quality. Prior research efforts, however, have ascribed different meanings to capacity depending on the context or environment (Abril et al., 2008).

1.3.2 Theoretical Capacity

This is the number of trains that could run over a section in a strictly perfect, mathematically generated environment with trains running permanently at minimum headway. It is the upper limit of the capacity, and assumes traffic is homogeneous. Practically, however, it is not possible to achieve.

1.3.3 Practical Capacity

It is the practical limit of traffic volume that can be moved on a line section at an acceptable level of service reliability. It is a more realistic measure, take actual train mix, priorities and traffic bunching into consideration. As stated by Kraft (Kraft, 1982), practical capacity is usually around 60-75% of the theoretical capacity.

1.3.4 Used Capacity

It is the actual traffic volume that is being scheduled on the rail network, and it is usually lower than the practical capacity.

1.3.5 Available capacity

It is the difference between used capacity and practical capacity, indicating the amount of traffic that can be potentially added and handled on the network. If the available capacity allows new trains to be added, it is a useful capacity; otherwise it is considered as lost capacity.

1.3.6 Line Capacity, Node Capacity and Person Capacity

Capacity can also be categorized based on the type of each defined track section (International Union of Railways, 2013) which includes line capacity and node capacity, describing the maximum number of trains that can be operated over a section of track or over a node area in the reference time without delays at traffic signals (Kontaxi & Ricci, 2010).

Another important type of capacity related to railway transport is person capacity. Transit Capacity and Quality of Service Manual (TCQSM) (Kittelson & Associates, Inc. et al., 2013) defines person capacity as the maximum number of passengers, which can be carried over a defined track section in a given period under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty. However, the manual also states that this definition is less absolute than that of a line capacity, as person capacity is greatly determined by number of trains operated, length of the trains and loading standards. The concept of person capacity is important because it bridges train movements with human factors.

1.4 Objective of the Thesis

The main objective of the thesis is to determine how different factors affect stations capacity by means of a comprehensive analysis of the complex station. We used the Potthoff method for the evaluation of carrying capacity of complex railway nodes.

Train delays play an important role in capacity analysis. Consequently, the research presented in this thesis is focused on average delays, average delay per train and the capacity utilization coefficients at Secunderabad station.

Meanwhile, the timetable is of great importance in capacity analysis of structured railway operation, nevertheless the timetable data changes from year to year and the adopted method has a general approach not basing on a specific timetable.

1.5 Methodology

The methodology of the thesis includes four major stages: data collection, layout and geometry of the station and network representation, analysis method, performance measurements.

The first stage is to collect the necessary time table data to perform the analysis. The collected data was from the south-central railway website, which had the list of trains and the days of operation of train (frequency).

The platform number of the trains was collected from the Indian rail info. Indeed, data sorting according to the platforms was the most important for the capacity analysis.

The second stage is to find out the layout and geometry of the station and based on that to draw a network representation finalised to the operational analysis.

The third stage is to calculate the capacity analysis of the potentially critical nodes.

We consider the number of daily trains arriving and departing from the station for calculating the coefficients of utilization of the capacity.

The fourth stage is to take the results obtained from the previous stage and to find the average delay per train and the maximum number of trains the node can manage.

Chapter -2 Layout, geometry, timetable data and design of the station

2.1 Layout and geometry of the station

Station configuration addresses the geometry and functional needs of the station design. Station configuration issues involve the design of station entrances, the arrangement of the train platforms, the location and relationship of the fare control areas to the entrances and platforms, parking facilities, work and rest areas, and the integration of ancillary and support facilities with the public functions.

a. The station has 10 platforms with shelters. Three Foot-over-bridges connects all the platforms. Middle FOB (Foot over bridge) is provided with escalator facility connecting all the platforms.
b. Elevators are at both ends of Kazipet and FOB for the convenience of physically challenged and senior citizens. Elevators at both ends of Hyderabad and FOB are under construction.
c. A new building has come up on the Bhoiguda-side of the station (beside Platform 10) with new facilities like general booking counters, PRS (Passenger Reservation System) and waiting room facilities, toilets etc. The front elevation of station building on the main-side is given a face-lift without disturbing its heritage appearance.
d. The circulating area is developed on both sides of the station with improved illumination to avoid congestion of road traffic in the station
e. To ease the congestion at booking counters, additional counters are provided at four locations. At present, 21 general counters and 4 platform ticket counters are functional. There is provision of opening 6 more counters during peak periods. In addition to this ATVMs (Automatic Ticket Vending Machines), COTVMs are also provided to facilitate the passenger to take tickets with smart cards and cash.
f. Three Enquiry counters are provided to facilitate the passengers. In addition to this, touch screens are also provided. Public Address system, LED Train indication boards, LED coach indication boards are provided on all platforms.

g. 100% digital payment system is introduced for cash less transactions in all stalls, parking, prepaid waiting halls and booking offices.
h. Tel provides rail wire, a Free Wi-Fi facility in coordination with Google for passengers within station premises.
i. Waiting halls for physically challenged and senior citizens is available on Platform No: 01. Three prepaid AC waiting halls with seating capacity of 268 high standard cushioned seats are provided for passengers as value added service. Wheel Chairs and stretchers are provided at Platform No: 01 & 10 for convenience of passengers.
j. Charging Points for cell phones and laptops are provided on platforms and in all waiting halls.
k. Pay and use wash rooms are provided in the General Waiting Hall on Platform 1, 6 & 7. New deluxe wash rooms are built on Platform 10 and free of cost for the passengers travelling.
l. Automated car parking facility has been introduced at this station for the first time in South Central Railway.
m. GPS based CCTV (Closed-circuit Television) & Announcement system, to help indicate real time status of MMTS trains is available at Secunderabad, Hyderabad, and suburban MMTS stations.
n. For the convenience of the passenger’s ATMs (Automated Teller Machine) of different banks are provided on both sides of the station premises.
o. Mechanized parcel handling is in operation at the station, battery operated trucks have been introduced for movement of packages to ensure quick clearance of the parcels from the platform.
p. As a part of constant endeavour to maintain high standards of cleanliness and hygiene, mechanized cleaning has been introduced at the station. Ride-on vacuum sweepers, Ride-on scrubber-cum-drier, high pressure jet cleaners are used.
q. To conserve water a sewerage water treatment plant with a capacity of five lakh litres per day has been provided. The re-cycled water is used for gardening washing/cleaning activities at the station.
r. Sewerage treated water is being utilized for washing of coaches in Secunderabad coaching yard (pit lines 102,080 litres, plat form lines 110,880 litres = 212,960 litres).
s. Water harvesting pits are provided.

2.1.1 Station area details

Station Details	
Section	SC-KZJ
District	Hyderabad
State	Telangana
Station category	A1
Station building area	10,896 square metres
Platform area	41,832 square metres

The total number of platforms at the Secunderabad station (figures 2.1.1 and 2.1.2) are 10 (All high level). The cross-section length of each platform varies and depending upon the capacity of the train.

Platforms	Capacity	CSL of Platforms
1	26 Coaches + Engine	625 M
2	26 Coaches + Engine	686 M
3	21 Coaches + Engine	500 M
4	22 Coaches + Engine	513 M
5	22 Coaches + Engine	547 M
6	26 Coaches + Engine	656 M
7	26 Coaches + Engine	625 M
8	26 Coaches + Engine	625 M
9	24 Coaches + Engine	580 M
10	24 Coaches + Engine	580 M

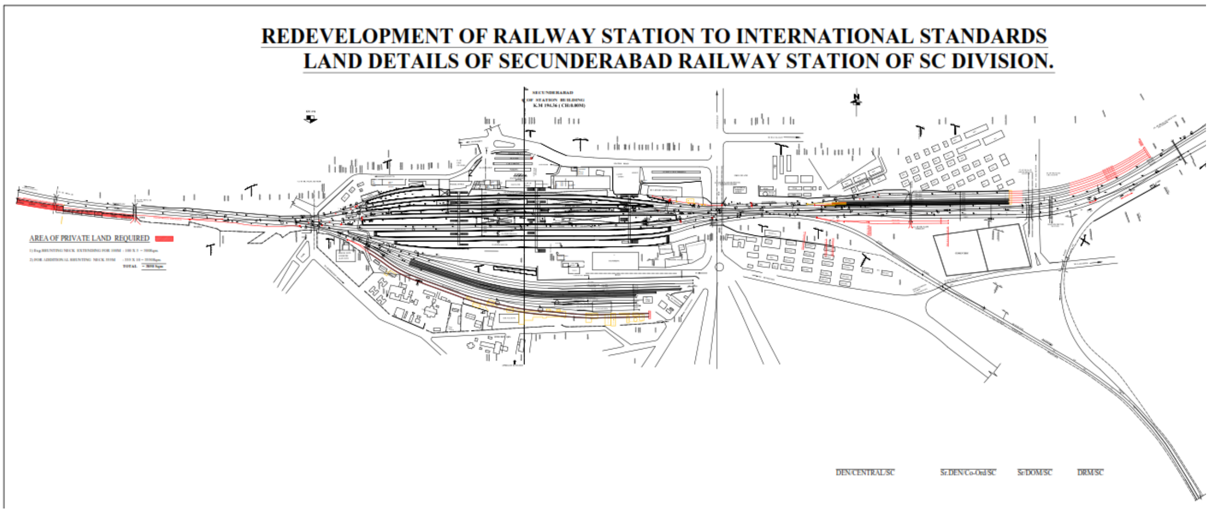


Figure 2.1.1 Yard plan and station land plan of Secunderabad railway station

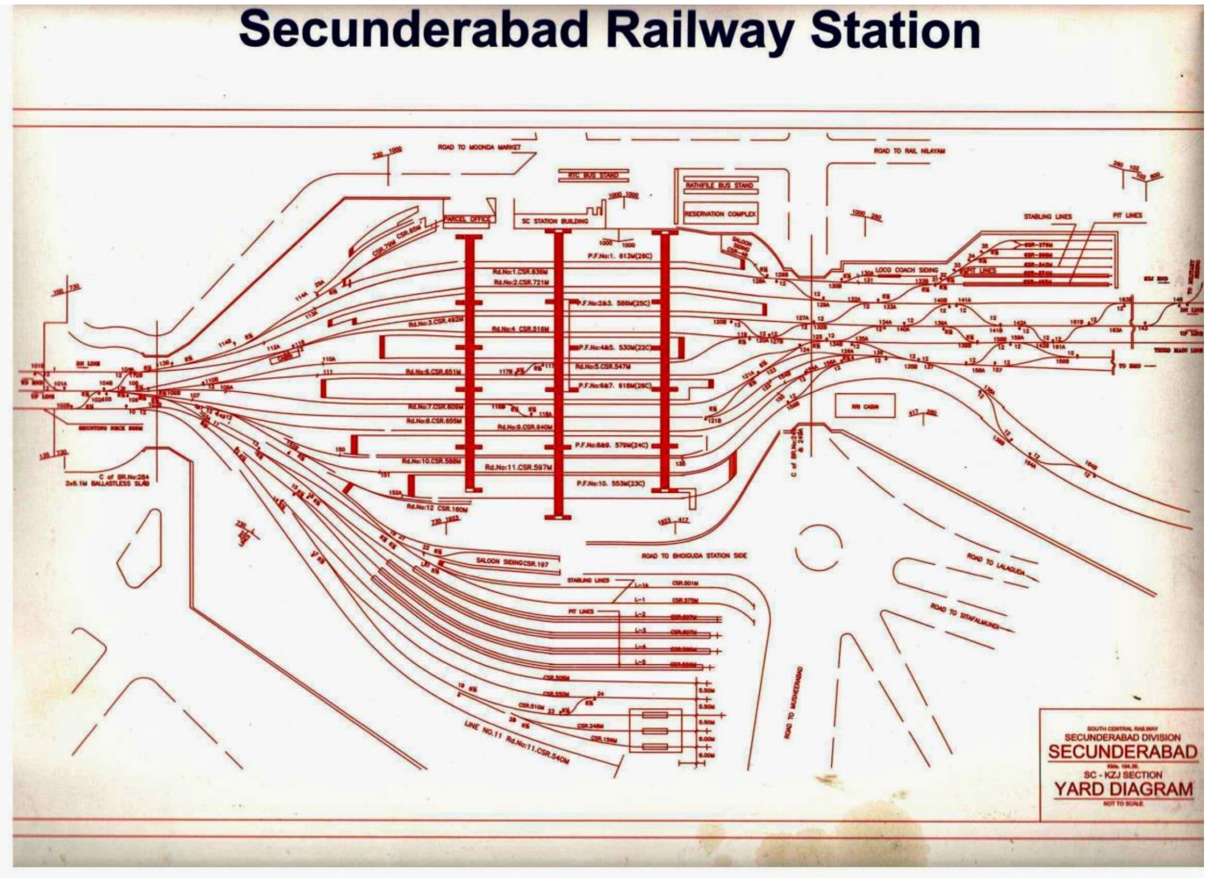


Figure 2.1.2 Layout of Secunderabad railway station

2.2 Timetable management of the station

Timetable management, such as train scheduling, rescheduling and a particular type of rescheduling, called timetable compression, are common techniques to improve the timetables with an objective to increase capacity and allow for additional trains along a given corridor. In this technique, a segment of the route is selected for compression of the existing train-paths, while considering the minimum headways and acceptable buffer times between the trains. After compressing the timetable, the unutilized capacity can be used by new train-paths, until the given time is saturated by the train-paths and buffer times.

The timetable demonstrates the schedule of all trains, which are operated in a given corridor by presenting departure/arrival times of each individual train at each station/stop point. The timetable includes information of three main parameters for scheduling the train i.e. the time of departure/arrival, platform number and the days of operation (frequency).

2.2.1 Planning the Timetable

Timetables need to balance demand for trains serving small communities and non-stop fast trains as well as the requirements of businesses that rely on freight.

We consider many factors when we plan a timetable and many of these are to keep passengers safe:

a) Speed limits vary on a length of track: e.g. at bends and over points.
b) Only one train can occupy a given section of track at any time.
c) The signalling infrastructure varies across the network; therefore, the safe distance between trains can differ along a line.
d) There is a minimum time gap required between trains using the same platform at a station.
e) Stopping, non-stopping and freight trains all travel at different speeds, therefore, a mix of these on the track affects the number of trains that can use that section of track.
f) Trains cannot run too closely together because we need flexibility if there is an incident to get trains back on time. We work hard to avoid knock-on delays.
g) Different schedules are run on during the holidays, so we work closely with the train operators to plan revised timetables.
h) Time for improvement work and routine maintenance needs to be planned in to increase capacity and keep the network running reliably.

2.2.2 Timetable explanation

a) Name & Code of the respective train.
b) Scheduled arrival time: time when train was originally scheduled to arrive at that station.
c) Scheduled departure time, when trains were originally scheduled to depart from that station.
d) Halt time: stoppage time at that station.
e) Platform number: the platform number where the train is scheduled to stop.

S.No.	Train Number	Train Name	From	To	Frequency	Days of operation	Arrival	Departure	Platform No.
1	12514	Guwahati- Secunderabad Express	Guwahati	Secunderabad	1	Saturday	04.00.	Ends Here	3
2	12719	Ajmer- Hyderabad Express	Ajmer Junction	Hyderabad	2	Friday, Sunday	00.05.	00.10.	10
3	12736	Yesvantpur- Secunderabad GaribRath Express	Yesvantpur Junction	Secunderabad	3	Tuesday, Friday, Sunday	05.00.	Ends Here	4
4	12763	Tirupati- Secunderabad Padmavati Express	Tirupati	Secunderabad	5	Except Thursday, Friday	05.50.	Ends Here	1
5	77606	Manoharabad- Secunderabad	Manoharabad	Secunderabad	6	Except Friday	10.00.	Ends Here	9
6	47178	Lingampalli- Falaknuma	Lingampalli	Falaknuma	7	Daily	10.10.	10.12.	4

Figure 2.2.2 An example of timetable Data of Secunderabad station

2.3 Categorizing the trains according to platforms

Deatils of Train Dealt on Various Platforms at Secunderabad Station										
S.NO.	PF 01	PF 02	PF 03	PF 04	PF 05	PF 06	PF 07	PF 08	PF 09	PF 10
1	17222	18112	12514	12736	12709	17406	47149	12769	12749	12719
2	12763	11304	12722	47206	12775	12737	47171	12603	12793	17255
3	12723	17015	17025	47173	12731	12592	47150	12733	12727	57660
4	17207	12703	17011	22705	11019	12783	47151	19713	12739	17022
5	67249	17319	22203	47174	57129	17205	12759	17063	18504	77605
6	18646	17201	57564	47175	12772	57131	47165	17038	17418	47213
7	17203	17221	17019	47176	20811	12747	47156	17017	77606	47153
8	17230	18520	17626	47177	17001	12591	47157	17028	19202	22691
9	12025	12792	67265	47178	12219	17206	47198	12713	17229	47152
10	12604	15016	12772	47208	12286	17208	77608	57606	18519	47154
11	12728	12774	12213	47212	22849	18645	77610	15015	12438	47211
12	12760	22850	57626	47179	17012	67267	77612	12805	17057	20809
13	67266	12806	17234	47189	17213	22882	47164	17231	12589	47197
14	22881	17320	17204	47180	12758	12724	47218	20810	12794	47155
15	17256	17016	57652	47209	77601	17405	47166	20812	12773	11020
16	12795	12734	57659	47181	77630	77618	47167	18111	17417	47214
17	12796	12732	57605	47215	19201	11303	77616	17018	18503	47158
18	12706		17202	47182	17002	47204	12720	17064	12705	47169
19	12757		17027	12748	67250	47168	47203	77617	17214	47160
20	12791		57625	47183	17010	47205	47220	19714	17232	47199
21	12437		12776	47184		47196	47170		17023	47200
22	12285		12771	47185		12590	47195		77607	47216
23	12026		17026	47217		17058	12513		22204	17020
24	12704			47186		12714	77611		12784	47161
25	12764			47187		12770	77613		12735	47201
26	12740			47210			77615		12220	47162
27	12738			47188			77619			47163
28	17037			47190						22692
29				47191						47207
30				47219						17024
31				47192						47202
32				47193						77603
33				47159						12710
34				47194						
35				12721						
36				47172						

Figure 2.3 Train dealt on various platform at Secunderabad station

2.4 Number of trains at each platform

The secunderabad station has a total of 10 platform and 11 tracks, one of them dealing with goods trains, so the respective track is not considered for the capacity analysis. As you can see from the below figures, there is no stopping of trains on the track H. We sort the number of trains at each platform basing on figure 2.3, which show the trains number at each platform and from the time table data where the frequency and days of operation are given (tables 2.4.1 to 2.4.9).

Table 2.4.1 Total number of a trains at each track on a weekly basis

Total number of a trains at each track on a weekly basis				
A	28		1	28
B	17		2	17
C	23		3	23
D	36		4	36
E	20		5	20
F	25		6	26
G	27		7	27
H	No Stopping		8	20
I	20		9	26
J	26		10	33
K	33			

Table 2.4.2 number of trains at each platform on Monday

Only Monday's				
A	7		1	7
B	1		2	1
C	3		3	3
D	-		4	-
E	7		5	7
F	5		6	5
G	9		7	9
H	No Stopping		8	5
I	5		9	5
J	5		10	2
K	2			

Table 2.4.3 number of trains at each platform on Tuesday

Only Tuesday's				
A	6		1	6
B	1		2	1
C	1		3	1
D	1		4	1
E	6		5	6
F	4		6	4
G	9		7	9
H	No Stopping		8	7
I	7		9	4
J	4		10	3
K	3			

Table 2.4.4 number of trains at each platform on Wednesday

Only Wednesday's				
A	7		1	7
B	2		2	2
C	3		3	3
D	1		4	1
E	9		5	9
F	5		6	5
G	9		7	9
H	No Stopping		8	3
I	3		9	5
J	5		10	2
K	2			

Table 2.4.5 number of trains at each platform on Thursday

Only Thursday's				
A	8		1	8
B	1		2	1
C	1		3	1
D	-		4	-
E	5		5	5
F	1		6	1
G	7		7	7
H	No Stopping		8	3
I	3		9	5
J	5		10	1

K	1			

Table 2.4.6 number of trains at each platform on Friday

Only Friday's				
A	6		1	6
B	1		2	1
C	3		3	3
D	1		4	1
E	8		5	8
F	4		6	4
G	2		7	2
H	No Stopping		8	5
I	5		9	3
J	3		10	1
K	1			

Table 2.4.7 number of trains at each platform on Saturday

Only Saturday's				
A	5		1	5
B	2		2	2
C	3		3	3
D	-		4	-
E	2		5	2
F	2		6	2
G	9		7	9
H	No Stopping		8	4
I	4		9	6
J	6		10	5
K	5			

Table 2.4.8 number of trains at each platform on Sunday

Only Sunday's				
A	5		1	5
B	-		2	-
C	1		3	1
D	1		4	1
E	8		5	8
F	2		6	2
G	10		7	10

H	No Stopping		8	4
I	4		9	3
J	3		10	3
K	3			

Table 2.4.9 Daily trains at each platform

Daily (M, T, W, Th, F, Sa, Su)				
A	15		1	15
B	10		2	10
C	16		3	16
D	35		4	35
E	6		5	6
F	14		6	14
G	17		7	17
H	No Stopping		8	9
I	9		9	10
J	10		10	26
K	26			

Chapter -3 Network representation of Secunderabad station

3.1 Network representation

3.1.1 Functions and basic schemes

1) Transit of a train:

a) Main line tracks are enough;
b) Complex layouts are not necessary.

2) Stop of a train to crossing/overtaking.

3) Stop of a train to load/unload passengers and/or goods.

4) Stop of a train manoeuvring to couple/uncouple wagons/coaches: long stay for composition/decomposition of a whole train is not included.

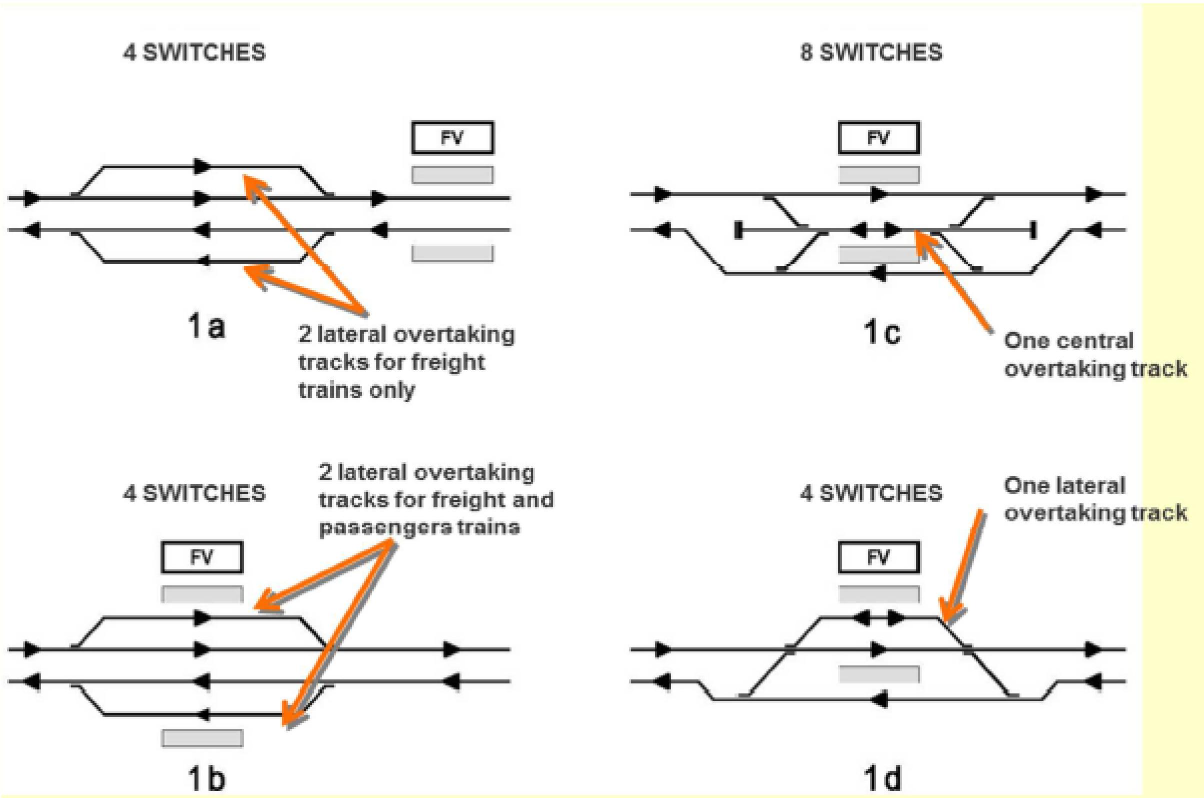


Figure 3.1.1 few examples of network representation for transit and overtaking tracks

3.1.2 Design criteria

1) Allowance of crossing/overtaking manoeuvres.

2) Minimum complexity (lower construction and maintenance cost).

3) Allowance of passengers/freight services.

4) Independence of movements (higher capacity).

5) Minimum potentially dangerous conflicts:

   a) Train Arrival (A): entrance routes;
   b) Train Departure (D): exit routes;
   c) Converging points with decreasing dangerousness: I) AA, II) AD/DA, III) DD.

The representation of the schematic layout of the Secunderabad station is in figure 3.1.2.

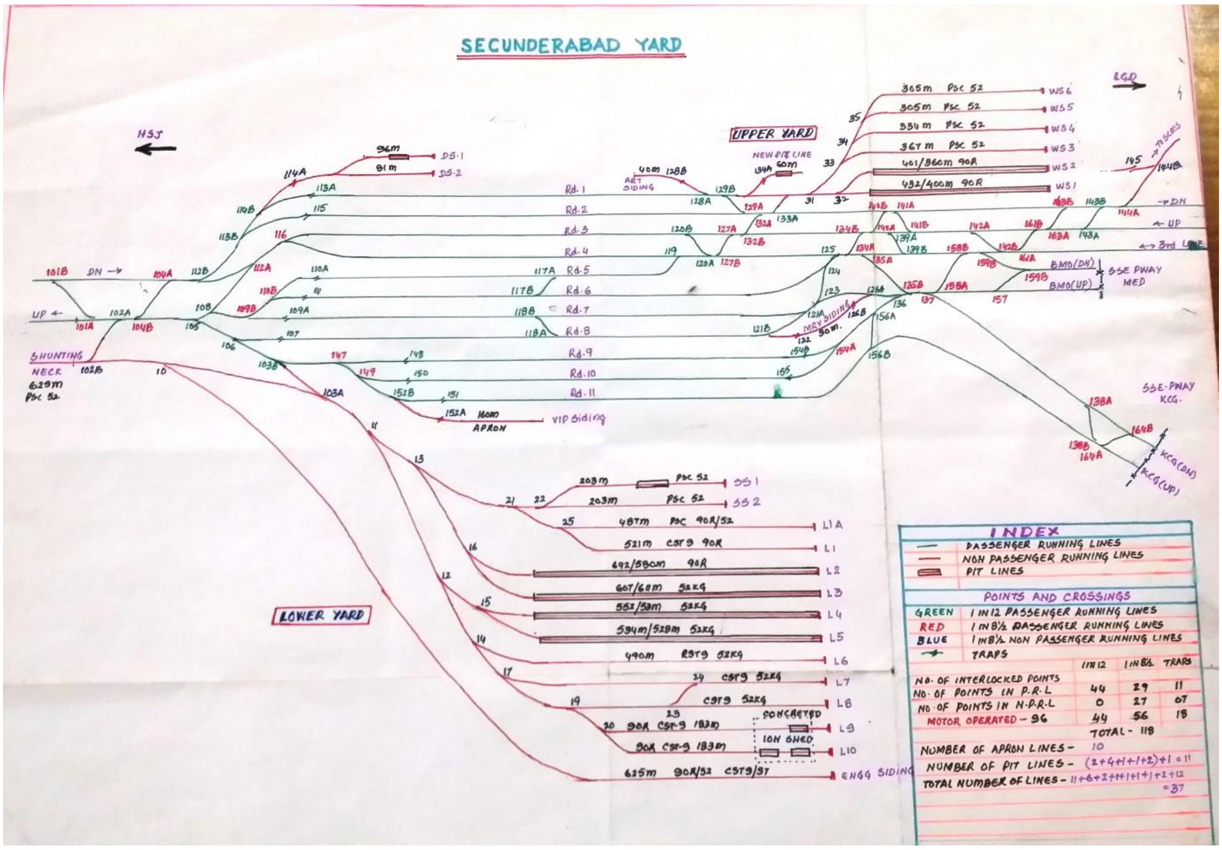


Figure 3.1.2 schematic representation of Secunderabad station

3.2 Muller figure

It is a functional representation tool (figure 3.2.1) including:

a) Expression of functions linking lines approaching to stations;
b) Design use: from functions to layout;
c) Analysis use: from layout to functions;
d) Comparative relevance of links highlighted by lines thickness (e.g. from bold to dotted lines).

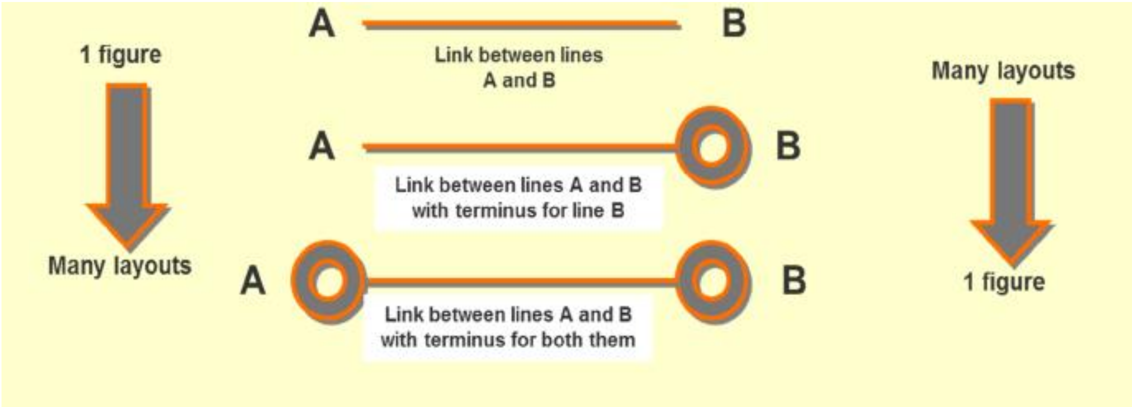


Figure 3.2.1 general concept of Muller Figure

The Muller figure representing the functions of the Secunderabad station is in figure 3.2.2.

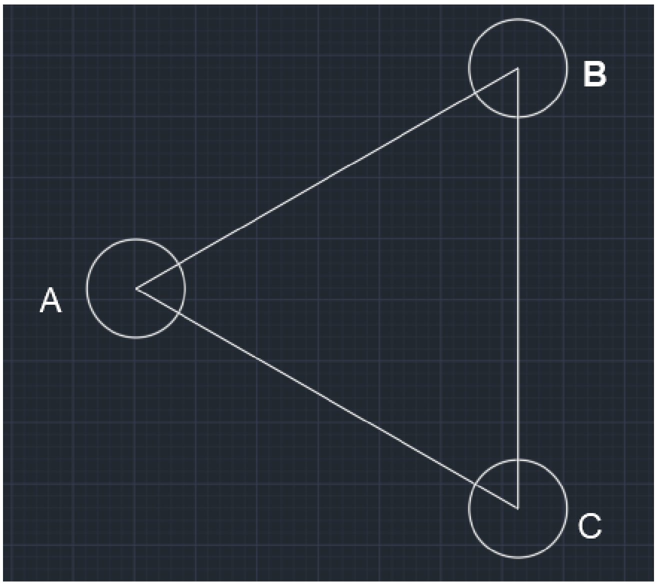


Figure 3.2.2 Muller figure of Secunderabad station

Chapter -4 Capacity analysis of the station

4.1 Analytical capacity analysis

Following a general structure of capacity management, the thesis starts by analysing the capacity using analytical methods.

Four methods were studied during the thesis work:

a) Transit Capacity and Quality of Service Manual (TCQSM) (2013);
b) Potthoff Method (1965);
c) Deutsche Bahn (DB) Method (1979);
d) UIC Compression Method (2013).

The method selected for the thesis work on the Secunderabad station is the Potthoff Method.

4.1.1 Potthoff Method

As stated by Kontaxi and Ricci, Potthoff method has become a reference method for analysing node capacity by studying the regular and the extra occupation time at the node due to conflicts of train paths (Kontaxi & Ricci, 2010). Potthoff method assume that trains could arrive at any instant of a reference period T with the same probability. As a direct result, there is no need for a timetable when applying this method. The first step of this method is to identify all possible train paths existing in the specified node area. Therefore, for this station, the potentially critical nodal areas are under consideration, where the number of running trains is high and the calculation of the utilization coefficients will help to check the operational conditions.

All the tracks in the Secunderabad station are bi-directional. Based on the schematic representation from figure 3.1.2 the entire station can be divided into 4 nodes. We check the traffic flow in these 4 nodes and calculate the coefficients of utilization. Below are the schematic representations (figures 4.1.1 to 4.1.4) of all the 4 nodes.

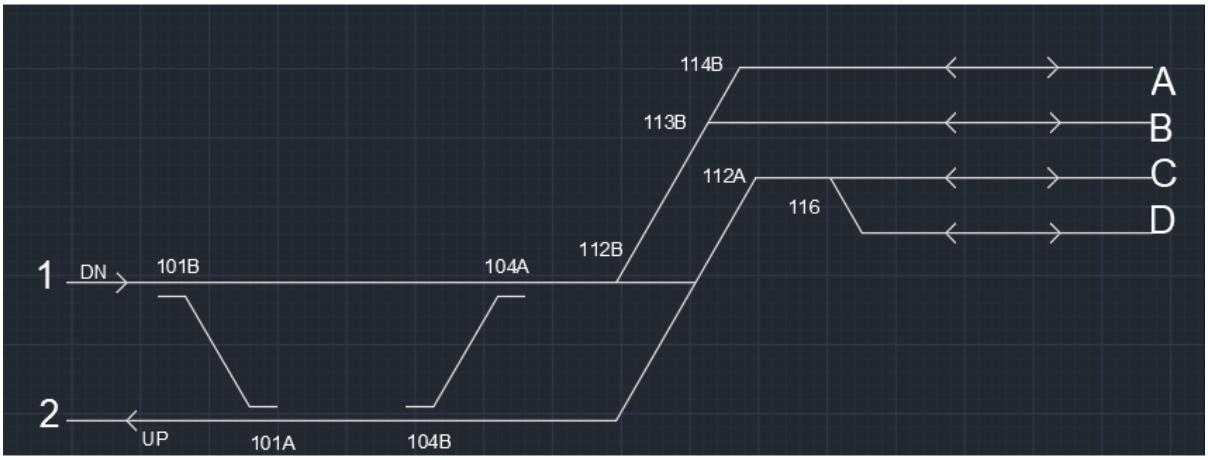


Figure 4.1.1 Node 1 of the Secunderabad Station

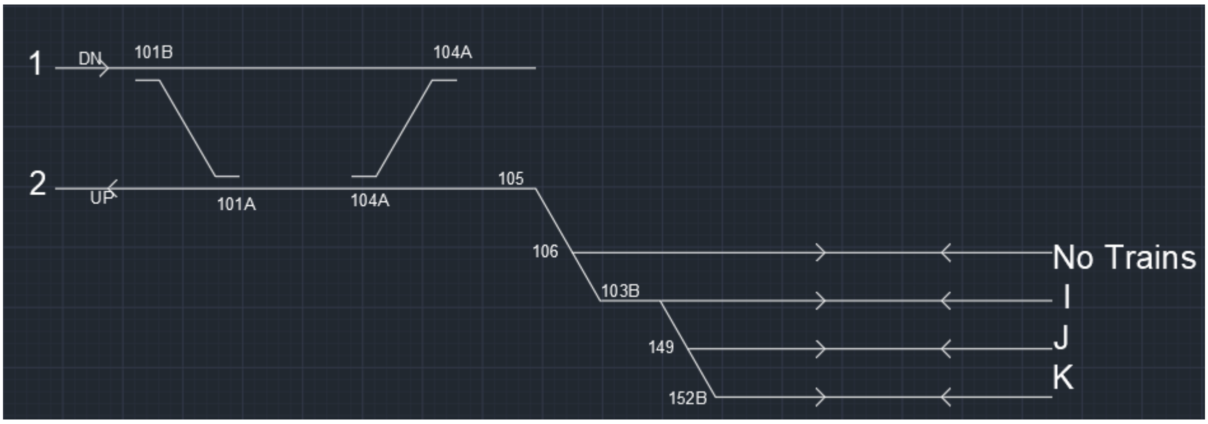


Figure 4.1.2 Node 2 of the Secunderabad Station

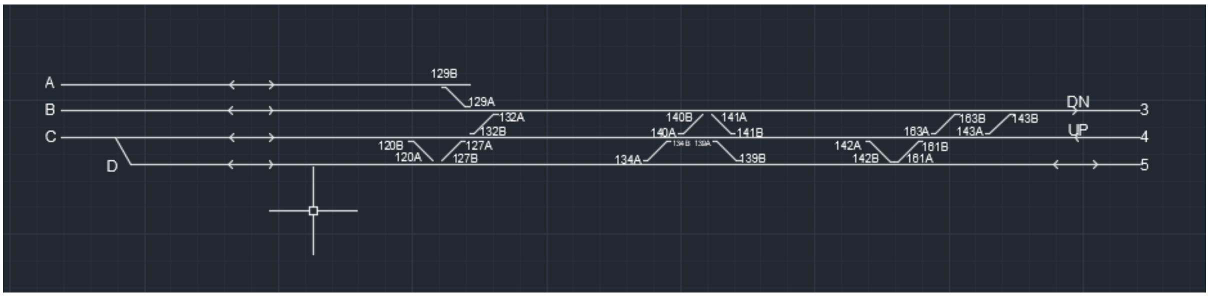


Figure 4.1.3 Node 3 of the Secunderabad Station

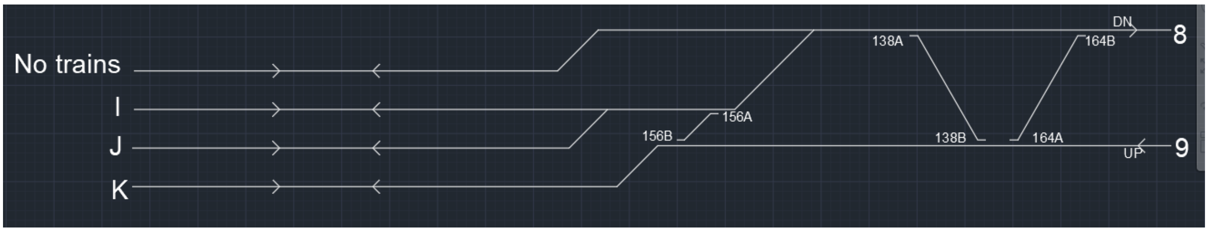


Figure 4.1.4 Node 4 of the Secunderabad Station

From Chapter 2 we consider the following daily numbers of trains arriving and departing from the station, which is the key input for calculating the coefficients of utilization.

A	15		1	15
B	10		2	10
C	16		3	16
D	35		4	35
E	6		5	6
F	14		6	14
G	17		7	17
H	No Stopping		8	9
I	9		9	10
J	10		10	26
K	26			

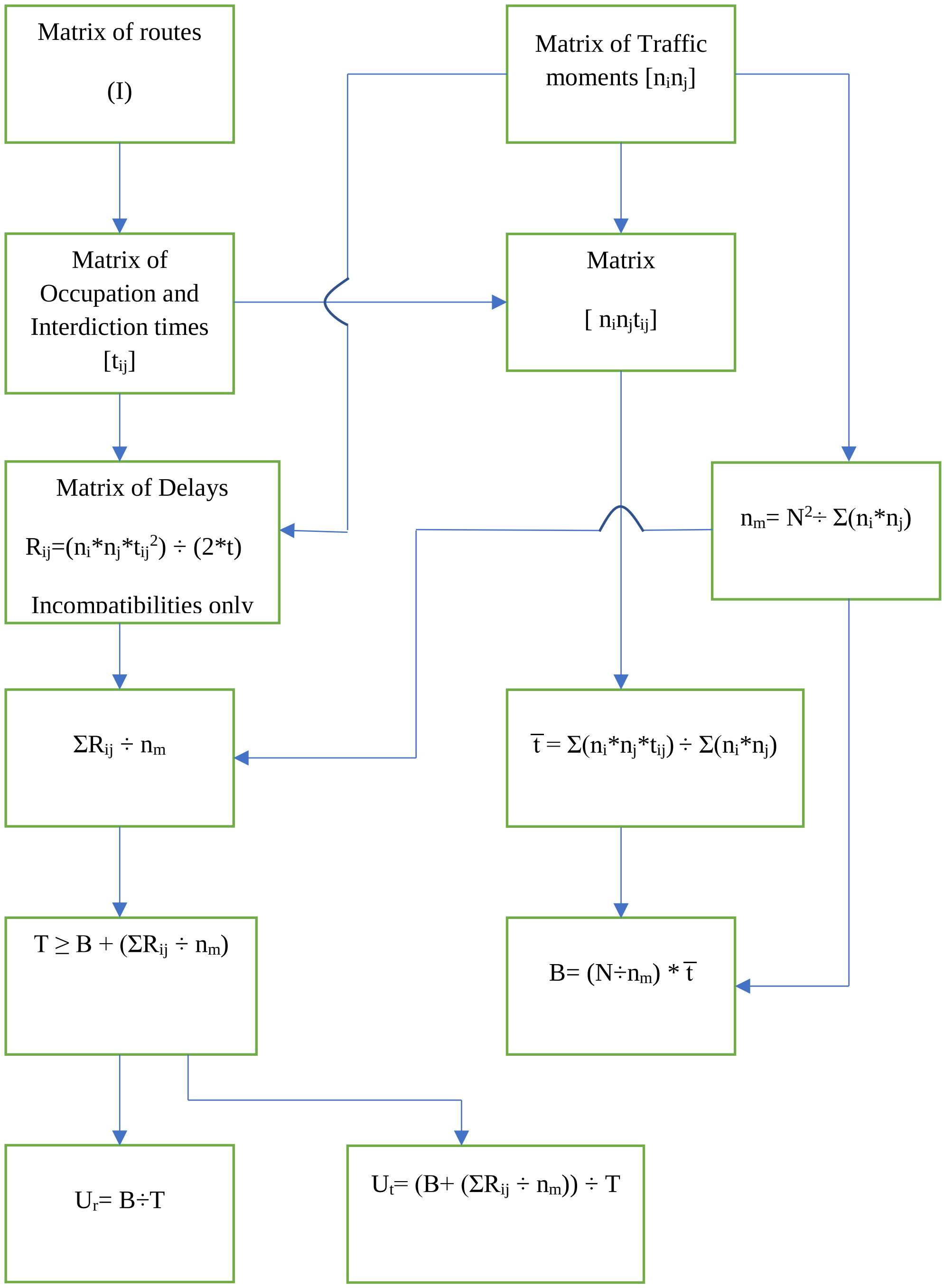
As we can see the daily number of trains arriving and departing from the station is 158. The flow of traffic is dependent on the movements of trains.

Nodes	Traffic flow
Node -1	54
Node -2	33
Node -3	32
Node -4	28

The nodes 1 and 2 are chosen as potentially critical based on the traffic flow of the trains and the analysis is done only on the nodes 1 and 2. The traffic flow in node 3 and 4 is less than node 1 and 2 so, they are not considered for the analysis.

4.1.2 Capacity check procedure

The scheme procedure for the calculation of utilization and deriving the residual capacity is below.



The steps in the figure ahead are progressively focusing to the regular and the global utilization coefficients for the analysis of any node in the station.

4.2 Analysis of the Node 1

The first potentially critical node is in figure 4.2.1 and the corresponding matrix with compatibility among the movements on the routes are in table 4.2.1.

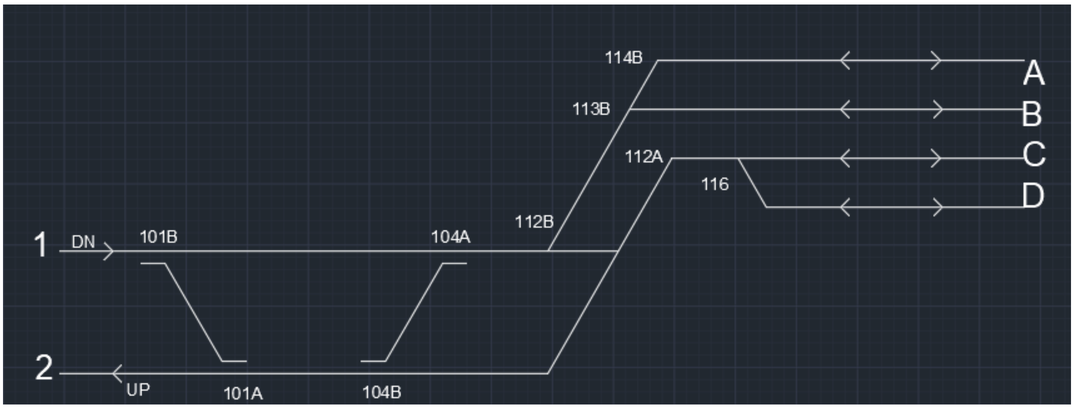


Figure 4.2.1 Node 1 of the Secunderabad station

Table 4.2.1 Compatibility Matrix of node 1

	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
1-A	A	S	S	S	Z	Z	.	.
1-B		A	S	S	Z	Z	.	.
1-C			A	S	X	X	Z	Z
1-D				A	X	X	Z	Z
A-2					A	Z	Z	Z
B-2						A	Z	Z
C-2							A	Z
D-2								A

The letter in each cell of matrix represents the type of conflict between the two intersected train routes:

a) A – between a route and itself;
b) X – intersection of routes;
c) Z – converging routes;
d) S – diverging routes;
e) D – consecutive following routes;
f) U – frontal routes.

The symbol (.) in the matrix indicates that there is no conflict between the two train routes corresponding to that cell.

After identifying the train paths, the next step is to gather information of the total number of trips that would utilize each train path *i*, denoted as n_i, the information is presented in Table 4.2.2. The total number of trips is the summation of trips of single routes: $N = \Sigma n_i = 54$.

Table 4.2.2 number of trips per route

Path i	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
N	8	4	2	32	1	1	4	2

The average number of trips that can simultaneously run within the node area is defined by $n_m = N^2 / \Sigma(n_i*n_j)$.

Where:

N = Total number of movements ($N = \Sigma N_i = \Sigma N_j$);

$n_i = n_j$ = Number of trips associated with path *i* and path *j*.

The matrix of traffic moments includes the n_i*n_j products.

The system can be represented as that n_m trains simultaneously circulate within the node area for a $\bar{t}$ time.

Table 4.2.3 matrix of traffic moments

Node-1									
N		8	4	2	32	1	1	4	2
	$\mathbf{n_i*n_j}$	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
8	1-A	64	32	16	256	8	8	32	16
4	1-B	32	16	8	128	4	4	16	8
2	1-C	16	8	4	64	2	2	8	4
32	1-D	256	128	64	1024	32	32	128	64
1	A-2	8	4	2	32	1	1	4	2
1	B-2	8	4	2	32	1	1	4	2
4	C-2	32	16	8	128	4	4	16	8
2	D-2	16	8	4	64	2	2	8	4
54	$\mathbf{\Sigma(n_i*n_j)}$	432	216	108	1728	54	54	216	108

The following step is to determine the occupation time t_{ij} of the paths based on the compatibility matrix identified in Table 4.2.1.

Cells indicating the incompatibility of two train paths would require a value of occupation or interdiction time. In other words, it is the period of time that a trip on path *j* has to wait when a trip on path *i* is performed. A similar table layout as the compatibility matrix includes cells replaced by the occupation or interdiction time (t_{ij}) as shown in below. When $i = j$, it represents the occupation time of a trip on path *i*; otherwise it indicates the interdiction time for a trip on path *j* when path *i* is occupied. The value is highly dependent on the specific infrastructure layout. To calculate the Interdiction matrix, t_{ij} the data below is required.

Time (t) [min]	1440
Length of an 8 Coach Multi modal Transport System Train [m]	180
Length of an 18 Coach passenger Train [m]	450
Length of a 24 Coach Intercity, Express, Superfast Train [m]	600
Track length from previous signal location of the conflict point to the release point (Di) [m]	1000
Uniform Speed (Vi) [m/s]	4.17
Cross over length from 101B-114B [m]	180
Cross over length from 101B-113B [m]	140
Cross over length from 101B-112B [m]	100
Cross over length from 112B-116 [m]	100
Cross over length from 114B-104A [m]	110
Cross over length from 113B-104A [m]	70
Cross over length from 112B-104A [m]	30
Distance from Track 1- Track 2 [m]	1.45
Cross over length from 101A-147 [m]	120
Cross over length from 101A-149 [m]	160
Cross over length from 101A-152B [m]	200

Platform A, B, J deal with 24 coach trains	
Platform C, I deal with 18 coach train	
Platform D, K deal with 8 coach train	
Length of Platform A [m]	625
Length of Platform B [m]	686
Length of Platform C [m]	500
Length of Platform D [m]	513
Length of Platform I [m]	625
Length of Platform J [m]	580
Length of Platform K [m]	580

We calculate the occupation/interdiction time matrix in seconds (table 4.2.4.a) and divide it by 60 to calculate the delay of each train in terms of minutes (table

4.2.4.b). The cross over lengths for the nodes are taken with the help of google maps by measuring the distance.

From table 4.2.3 the matrix of movements the $\Sigma(n_i*n_j)$ is taken

$\Sigma(n_i*n_j) = 2916$

$n_m = N^2 / \Sigma(n_i*n_j) = (54*54) / (2916) = 1$

$\overline{t} = \Sigma(n_i*n_j*t_{ij}) / \Sigma(n_i*n_j)$

Table 4.2.4.a Matrix of occupation/interdiction times [s]

t_{ij}	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
1-A	426.86	417.27	407.67	407.67	187.05	177.46	0.00	0.00
1-B	417.27	417.27	407.67	407.67	177.46	177.46	0.00	0.00
1-C	371.70	371.70	395.68	395.68	131.89	131.89	155.88	155.88
1-D	306.95	306.95	330.94	330.94	67.15	67.15	91.13	91.13
A-2	320.14	320.14	320.14	320.14	320.14	320.14	320.14	320.14
B-2	325.18	325.18	325.18	325.18	325.18	325.18	325.18	325.18
C-2	0.00	0.00	258.99	258.99	258.99	258.99	258.99	258.99
D-2	0.00	0.00	197.36	197.36	197.36	197.36	197.36	197.36

Table 4.2.4.b Matrix of occupation/interdiction [min]

$t_{ij}/60$	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
1-A	7.11	6.95	6.79	6.79	3.12	2.96	0.00	0.00
1-B	6.95	6.95	6.79	6.79	2.96	2.96	0.00	0.00
1-C	6.19	6.19	6.59	6.59	2.20	2.20	2.60	2.60
1-D	5.12	5.12	5.52	5.52	1.12	1.12	1.52	1.52
A-2	5.34	5.34	5.34	5.34	5.34	5.34	5.34	5.34
B-2	5.42	5.42	5.42	5.42	5.42	5.42	5.42	5.42
C-2	0.00	0.00	4.32	4.32	4.32	4.32	4.32	4.32
D-2	0.00	0.00	3.29	3.29	3.29	3.29	3.29	3.29

From the table 4.2.5 the value of $\Sigma\ n_i*n_j*t_{ij}$ is taken.

$\Sigma(n_i*n_j*t_{ij}) = 14404.18$

$\overline{t} = \Sigma(n_i*n_j*t_{ij}) \div \Sigma(n_i*n_j) = (14404.18) / (2916)$

$\overline{t} = 4.94$ min

Table 4.2.5 Intermediate calculation matrix [min]

$n_i*n_j*t_{ij}$	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
1-A	455.32	222.54	108.71	1739.41	24.94	23.66	0.00	0.00
1-B	222.54	111.27	54.36	869.70	11.83	11.83	0.00	0.00
1-C	99.12	49.56	26.38	422.06	4.40	4.40	20.78	10.39
1-D	1309.67	654.84	353.00	5647.96	35.81	35.81	194.40	97.20
A-2	42.68	21.34	10.67	170.74	5.33	5.33	21.34	10.67
B-2	43.36	21.68	10.84	173.43	5.42	5.42	21.68	10.84
C-2	0.00	0.00	34.53	552.52	17.27	17.27	69.06	34.53
D-2	0.00	0.00	13.16	210.52	6.58	6.58	26.31	13.16
$\Sigma (n_i*n_j*t_{ij})$	2172.69	1081.23	611.65	9786.35	111.58	110.30	353.59	176.79

This method also proposes a way to calculate total delay imposed due to incompatibility of the conflicting paths within the node:

$R_{ij} = (n_i*n_j*t_{ij}^2) / (2T)$

Table 4.2.6 Matrix of delays [min]

R_{ij}	1-A	1-B	1-C	1-D	A-2	B-2	C-2	D-2
1-A	1.12	0.54	0.26	4.10	0.03	0.02	0.00	0.00
1-B	0.54	0.27	0.13	2.05	0.01	0.01	0.00	0.00
1-C	0.21	0.11	0.06	0.97	0.00	0.00	0.02	0.01
1-D	2.33	1.16	0.68	10.81	0.01	0.01	0.10	0.05
A-2	0.08	0.04	0.02	0.32	0.01	0.01	0.04	0.02
B-2	0.08	0.04	0.02	0.33	0.01	0.01	0.04	0.02
C-2	0.00	0.00	0.05	0.83	0.02	0.02	0.10	0.05
D-2	0.00	0.00	0.01	0.24	0.01	0.01	0.03	0.01
ΣR_{ij}	4.36	2.16	1.23	19.65	0.11	0.11	0.33	0.17

Where R_{ij} is the average delay, T is taken as the reference time for the analysis.

The total delay considering simultaneous movements of n_m trains in the system is defined as the ratio $\Sigma R_{ij} / n_m$.

From the table 4.2.6 $\Sigma R_{ij} / n_m$ = 28.12 / 1 = 28.12 min.

The total occupation time is calculated by $B = (N / n_m) * \overline{t}$.

Substituting the calculated values, it is B = (54 / 1) * 4.94 = 266.74.

The coefficient of utilization of the station is defined by $U_r = B / T$.

Where U_r is the regular utilization coefficient:

U_r = 266.74 / 1440 = 0.18

And U_t is the global utilization coefficient

$U_t = (B + (\Sigma R_{ij} / n_m)) / T$

$U_t = (266.74 + (28.12)) / 1440$

$U_t = 0.20$

Finally, the total delay considering simultaneous movements of n_m trains in the system is defined as the ratio between total delay ΣR_{ij} and n_m. Thus, it must be verified that:

$T \geq B + (\Sigma R_{ij} / n_m)$

4.3 Analysis of the Node 2

The second potentially critical node is in figure 4.3.1 and the corresponding matrix with compatibility among the movements on the routes are in table 4.3.1.

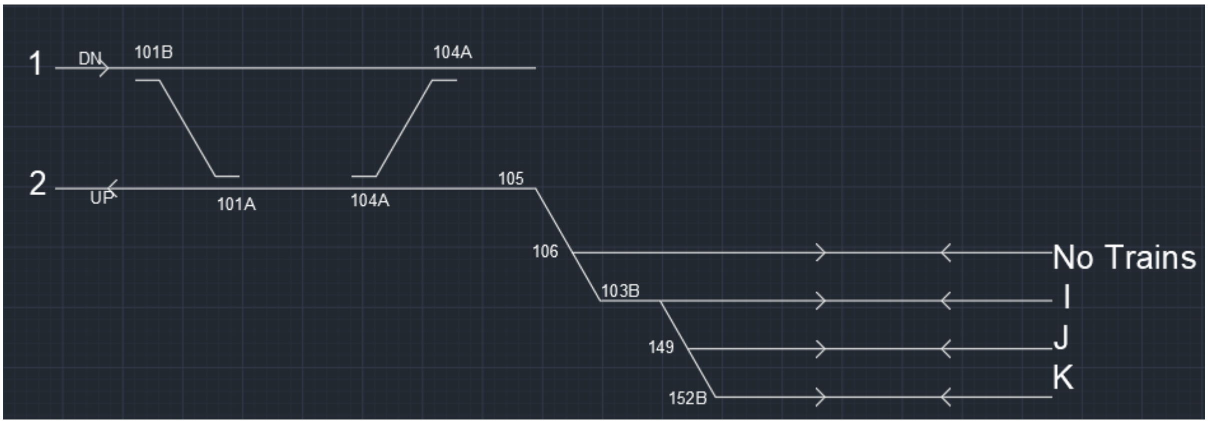


Figure 4.3.1 Node 2 of the Secunderabad station

Table 4.3.1 Compatibility Matrix of node 2

	1-I	1-J	1-K	I-2	J-2	K-2
1-I	A	S	S	Z	Z	Z
1-J		A	S	X	Z	Z
1-K			A	X	X	Z
I-2				A	Z	Z
J-2					A	Z
K-2						A

The letter in each cell of matrix represents the type of conflict between the two intersected train routes:

a) "A" – between a route and itself;
b) "X" – intersection of routes;
c) "Z" – converging routes;
d) "S" – diverging routes;
e) "D" – consecutive routes;
f) "U" – frontal routes

After identifying the train paths, the next step is to gather information of the total number of trips that would utilize each train path i, denoted as n_i, the information is presented in Table 4.3.2. The total number of trips is the summation of trips of individual paths: $N=\Sigma n_i=33$.

Table 4.3.2 number of trips per route

Path i	1-I	1-J	1-K	I-2	J-2	K-2
N	1	2	2	2	4	22

The average number of trips that can simultaneously run within the node area is defined by $n_m = N^2 / \Sigma(n_i{*}n_j)$.

Where:

N = Total number of movements ($N = \Sigma N_i = \Sigma N_j$);

$n_i = n_j$ = Number of trips associated with path i and path j.

The matrix of traffic moments includes the $n_i{*}n_j$ products.

The system can be represented as that n_m trains simultaneously circulate within the node area for a $\overline{t}$ time.

Table 4.3.3 Matrix of Traffic Moments

Node-2							
N		1	2	2	2	4	22
	n_i*n_j	1-I	1-J	1-K	I-2	J-2	K-2
1	1-I	1	2	2	2	4	22
2	1-J	2	4	4	4	8	44
2	1-K	2	4	4	4	8	44
2	I-2	2	4	4	4	8	44
4	J-2	4	8	8	8	16	88
22	K-2	22	44	44	44	88	484
33	**Σ(n_i*n_j)**	33	66	66	66	132	726

The following step is to determine the occupation time t_{ij} of the paths based on the compatibility matrix identified in Table 4.3.1. Cells indicating the incompatibility of two train paths would require a value of occupation or interdiction time. In other words, it is the period of time that a trip on path *j* has to wait when a trip on path *i* is performed. A similar table layout as the compatibility matrix includes cells replaced by the occupation or interdiction time (t_{ij}) as shown in below. When $i = j$, it represents the occupation time of a trip on path *i*; otherwise it indicates the interdiction time for a trip on path *j* when path *i* is occupied. The value is highly dependent on the specific infrastructure layout. To calculate the Interdiction matrix, t_{ij} the data below is required. To calculate Interdiction matrix the data which is used for the analysis of node 1 is used for the analysis of node 2.

We calculate the occupation/interdiction time matrix in seconds (table 4.3.4.a) and divide it by 60 to calculate the delay of each train in terms of minutes (table 4.3.4.b). The cross over lengths for the nodes are taken with the help of google maps by measuring the distance.

From table 4.2.3 the matrix of movements the $\Sigma(n_i*n_j)$ is taken

$\Sigma(n_i*n_j) = 1089$

$n_m = N^2 / \Sigma(n_i*n_j) = (33*33) / (1089) = 1$

$\bar{t} = \Sigma(n_i*n_j*t_{ij}) / \Sigma(n_i*n_j)$

Table 4.3.4.a Matrix of occupation/interdiction times [s]

t_{ij}	1-I	1-J	1-K	I-2	J-2	K-2
1-I	376.85	376.85	376.85	137.04	137.04	137.04
1-J	412.82	422.41	422.41	173.01	182.60	182.60
1-K	312.10	283.32	331.28	72.29	81.88	91.48
I-2	286.57	286.57	286.57	286.57	286.57	286.57
J-2	321.34	321.34	321.34	321.34	321.34	321.34
K-2	230.22	230.22	230.22	230.22	230.22	230.22

Table 4.3.4.b Matrix of occupation/ interdiction [min]

$t_{ij}/60$	1-I	1-J	1-K	I-2	J-2	K-2
1-I	6.28	6.28	6.28	2.28	2.28	2.28
1-J	6.88	7.04	7.04	2.88	3.04	3.04
1-K	5.20	4.72	5.52	1.20	1.37	1.53
I-2	4.78	4.78	4.78	4.78	4.78	4.78
J-2	5.34	5.34	5.34	5.34	5.34	5.34
K-2	3.84	3.84	3.84	3.84	3.84	3.84

From the table 4.3.5 the value of $\Sigma\ n_i*n_j*t_{ij}$ is taken.

$\Sigma(n_i*n_j*t_{ij}) = 4277.215$

$\bar{t} = \Sigma(n_i*n_j*t_{ij}) \div \Sigma(n_i*n_j) = (4277.215) \div (1089)$

$\bar{t} = 3.93$ min

Table 4.3.5 Intermediate calculation matrix [min]

$n_i*n_j*t_{ij}$	1-I	1-J	1-K	I-2	J-2	K-2
1-I	6.28	12.56	12.56	4.57	9.14	50.25
1-J	13.76	28.16	28.16	11.53	24.35	133.91
1-K	10.40	18.89	22.09	4.82	10.92	67.08
I-2	9.56	19.11	19.11	19.11	38.21	210.15
J-2	21.42	42.85	42.85	42.85	85.70	471.30
K-2	84.41	168.83	168.83	168.83	337.65	1857.07
$\Sigma\ (n_i*n_j*t_{ij})$	145.83	290.39	293.58	251.70	505.95	2789.77

This method also proposes a way to calculate total delay imposed due to incompatibility of the conflicting paths within the node:

$R_{ij} = (n_i*n_j*t_{ij}^2) / (2T)$

Table 4.3.6 Matrix of delays [min]

R_{ij}	1-I	1-J	1-K	I-2	J-2	K-2
1-I	0.014	0.03	0.027	0.004	0.007	0.040
1-J	0.033	0.069	0.069	0.013	0.026	0.144
1-K	0.019	0.031	0.042	0.002	0.005	0.039
I-2	0.016	0.032	0.032	0.032	0.063	0.349
J-2	0.040	0.080	0.080	0.080	0.159	0.876
K-2	0.112	0.225	0.225	0.225	0.450	2.474
ΣR_{ij}	0.234	0.464	0.475	0.354	0.711	3.916

Where R_{ij} is the average delay, T is taken as the reference time for the analysis.

The total delay considering simultaneous movements of n_m trains in the system is defined as the ratio $\Sigma R_{ij} / n_m$.

From the table 4.3.6 6 $\Sigma R_{ij} / n_m = 6.15 / 1 = 6.15$ min

The total occupation time is calculated by $B = (N / n_m) * \bar{t}$.

Substituting the calculated values, it is $B = (33 / 1) * 3.93 = 129.61$

The coefficient of utilization of the station is defined by $U_r = B / T$.

Where U_r is the regular utilization coefficient

$U_r = 129.61 / 1440 = 0.09$

And U_t is the global utilization coefficient

$U_t = (B + (\Sigma R_{ij} / n_m)) / T$

$U_t = (129.61 + (6.15)) / 1440$

$U_t = 0.09$

Finally, the total delay considering simultaneous movements of n_m trains in the system is defined as the ratio between total delay ΣR_{ij} and n_m. Thus, it must be verified that:

$T \geq B + (\Sigma R_{ij} / n_m)$

4.4 Results for the analysis of nodes 1 and 2

	Node 1	Node 2
U_r	0.18	0.09
U_t	0.20	0.09

The regular and the global utilization coefficients for nodes 1 and node 2 are calculated by using the procedure described in sections 4.2 and 4.3. The values obtained for node 1 are higher than the node 2. Therefore, we consider the values obtained for the node 1 for further analysis to check the breakage point i.e. the maximum number of trains that the node can handle.

Chapter -5 Proposals to improve and enhance station functioning

In this chapter, we take the results obtained for the node 1 in chapter 4. The total number of movements (*N*) for the node 1 is 54.

5.1 Step -1 Utilization coefficient vs. number of movements

In the step 1, an analysis of utilization coefficient vs. number of movements is taken by increasing the number of trains at regular intervals of 32 units (table 5.1.1 and figure 5.1.1).

Table 5.1.1 Movements and utilization coefficients

Total number of movements (N)	Regular utilization coefficient (U_r)	Global utilization coefficient (U_t)
54	0.18	0.20
86	0.27	0.31
118	0.35	0.43
150	0.44	0.57
182	0.53	0.71
214	0.62	0.87

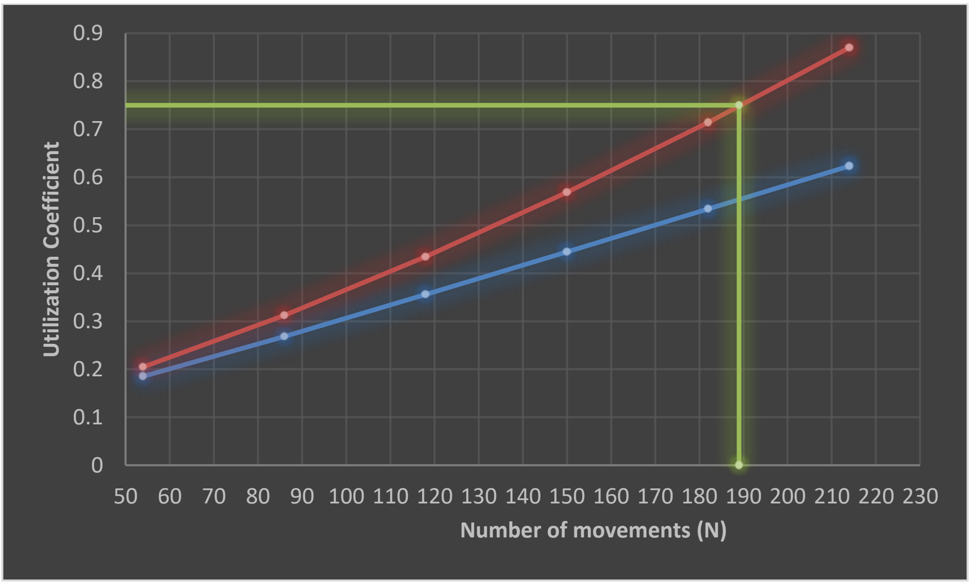


Figure 5.1.1 Utilization coefficient vs number of movements

From the graph, we can see that utilization coefficient is increasing as the number of movements of the trains is increasing.

The values of global utilization coefficient are on the orange curve and the values of regular utilization coefficient on the blue curve respectively.

In the hypothesis that the maximum total utilization rate is 75 the corresponding maximum number of movements is 189 (white line)

Therefore, we conclude that the maximum number of movements the station can manage for node 1 is 189.

5.2 Step -2 Average delay per train vs number of movements

In step 2, the average delay per train is calculated using the equation $\Sigma R_{ij} / N$ (table 5.2.2 and figure 5.2.2).

Where:

- R_{ij} is the average delay;
- N is the Number of movements.

Table 5.2.2: Movements and average delay per train

ΣR_{ij} *[min]*	*N* *[trains]*	$\Sigma R_{ij} / N$ *[min/train]*
28.12	54	0.52
63.24	86	0.73
113.50	118	0.96
178.92	150	1.19
259.47	182	1.42
355.17	214	1.66

In the graph, we can see that the average delay per train is increasing as the number of movements of the trains is increasing.

From step 1 we consider the maximum number of movements is 189 and the corresponding average delay per train is 1.48 minutes.

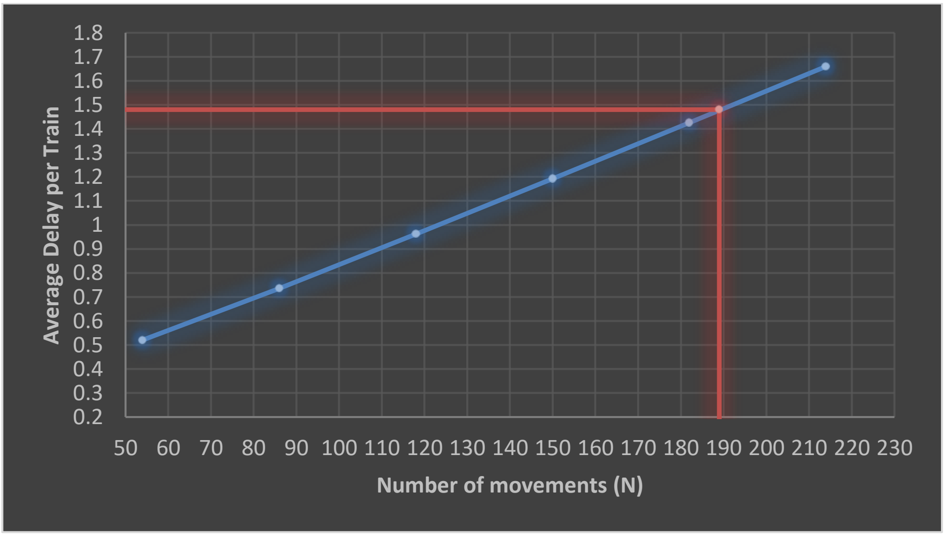


Figure 5.2.2 Average delay per train vs number of movements

Chapter –6 Conclusion

The main objective of the thesis was to determine how different factors affect stations capacity by means of a comprehensive analysis of the complex station. At first, we have analysed one method for the evaluation of the carrying capacity of complex railway nodes: Potthoff method. In particular, Potthoff method is one of the simplest and could be further developed in order to analyse a complex node. The timetable is of great importance in the capacity analysis of structured railway operation. Then we have calculated the capacity analysis for the potentially critical nodes of the station based on the network representation used for the operational analysis. Train delays play an important role in the capacity analysis. Consequently, the research presented in this thesis was mainly focused on average delays, average delay per train and the capacity utilization coefficients at Secunderabad station. In the future there could be potential margins of improvement where the average delay per train could be less

Bibliography

1. HERBST, J. 2006. The history of transportation, Minneapolis, Twenty-First Century
2. HALL, R. W. 2003. Handbook of transportation science, Boston, Kluwer Academic Publishers.
3. https://www.orientrailjourneys.com/blog/history-of-indian-railways/
4. 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.
5. Krueger, H. (1999). Parametric modelling in rail capacity planning. In Simulation Conference Proceedings, 1999 Winter (Vol. 2, pp. 1194–1200 vol.2).
6. Lindfeldt, A. (2015b). Railway capacity analysis: methods for simulation and evaluation of timetables, delays and infrastructure. TRITA-TSC-PHD, (15-002). Retrieved from https://trid.trb.org/view.aspx?id=1463106
7. Kraft, E. R. (1982). JAM CAPACITY OF SINGLE-TRACK RAIL LINES (Vol. 23). Presented at the Proceedings of the Transportation Research Forum.
8. Kontaxi, E., & Ricci, S. (2010). Railway capacity analysis: Methodological framework and harmonization perspectives. In Proceedings of the 12th World Conference on Transportation Research, Lisboa.
9. Kittelson & Associates, Inc., Brinckerhoff, P., KFH Group, Inc., Texas A&M Transportation Institute, Arup, Transit Cooperative Research Program, … National Academies of Sciences, Engineering, and Medicine. (2013). Transit Capacity and Quality of Service Manual, Third Edition. Washington, D.C.: Transportation Research Board
10. https://www.networkrail.co.uk/running-the-railway/timetabling/
11. Hansen, Ingo Arne and Jorn Pachl, RAILWAY TIMETABLE & TRAFFIC, Analysis, Modelling, Simulation. 1 ed2008, Hamburg, Germany: Eurail press.
12. Alex Landex, et al. Capacity Statement for Railways. in Annual Transport Conference. 2007. Aalborg University-Denmark.
13. UIC, UIC CODE 406R-Capacity-1st edition, June 2004, International Union of Railways (UIC): Paris, France.
14. White, Thomas, Elements of Train Dispatching. Vol. 1. 2003, Mountlake Terrace, WA: VTD Rail Publishing

15. Ministry of Railways. Government of India - Manual for standards and specifications for railway stations - New Delhi, 2009
16. Network Rail - Station Capacity Planning Guidance – 2016
17. UIC - Smart Stations in Smart Cities - Paris, 2017
18. Trafikverket - Railway Stations. Layout Manual - Borlange, 2018
19. Pachl J. – Railway Operation and Control - VTD Rail Publishing, 2002
20. https://indiarailinfo.com/
21. Kontaxi, E., Ricci, S. 2009. Techniques and methodologies for carrying capacity evaluation: comparative analysis and integration perspectives. Ingegneria Ferroviaria, ed. CIFI, dicembre, pp. 1051–1080
22. Crenca, D., Malavasi, G., Ricci, S., 2005. Dependence of railway lines carrying capacity by signalling systems and track geometry. In: Proceedings of the 1st International Seminar on Railway Operations Modelling and Analysis, Delft
23. Potthoff, G. (1960). "Verkerhrsstnomungslehre", TransVeb Verlag.
24. Potthoff, G., 1963–1972. Verkerhrsstnomungslehre 1. Transpress VEB Verlag für Verkehrswesen, Berlin
25. MALAVASI G., MOLKOVA T., RICCI S., ROTOLI F. (2014), "A synthetic approach to the evaluation of the carrying capacity of complex railway nodes", Journal of Rail Transport Planning & Management. Doi: 10.1016/j.jrtpm.2014.06.001