0CHAPTER 3
TRAIN OPERATION AND ROLLING STOCK

3.0 Operation Philosophy

The underlying operation philosophy is to make the Bangalore Metro System more attractive and economical, the main features being:

- High frequency of train service (3-minutes head way) not only during peak periods, but also during off-peak periods (15 minutes headway),
- Short train consist (3 coaches) with high frequency service to be increased to 6 coaches as the transport demand picks up,
- Multi-tasking of train operation and maintenance staff.

3.1. Stations

Bangalore Metro consists of two lines, the East –West line from **Mysore Road Terminal** Station to **Baiyappanhalli Terminal** for a length of 18.10 kms, with 18 stations of which 4 stations will be underground and the North – South line from **Yeshwantapur** Station to **R V Road Terminal** station for a length of 14.90 km with 14 stations of which 3 stations will be underground. The two lines will cross at a common station at Majestic.

TABLE 3.1
List of Stations

(i) East – West Line

S. No	NAME	CHAINAGE	INT.-DIST	REMARK
1	MYSORE ROAD TERMINAL	0		ELE.(side platform)
2	DEPANJALI NAGAR	1117	1117	ELE.(side platform)
3	VIJAYA NAGAR	2345	1228	ELE.(side platform)
4	HOSHALLI	3446	1101	ELE.(side platform)
5	TOLLGATE	4448	1002	ELE.(side platform)
6	MAGADI ROAD	5600	1152	ELE.(side platform)
7	CITY RAILWAY STATION	6755	1155	U.G.(island)
8	MAJESTIC	7503	748	U.G.(island)
9	CENTRAL COLLEGE	8697	1194	U.G.(island)
10	VIDHAN SAUDHA	9318	621	U.G.(island)
11	CRICKET STADIUM	10643	1325	ELE.(side platform)
12	M G ROAD	11380	737	ELE.(side platform)
13	TRINITY CIRCLE	12522	1142	ELE.(side platform)
14	ULSOOR	13725	1203	ELE.(side platform)
15	C M H ROAD	14610	885	ELE.(side platform)
16	INDIRA NAGAR	15537	927	ELE.(side platform)
17	OLD MADRAS ROAD	16419	882	ELE.(side platform)
18	BAIYAPPANHALLI TERMINAL	17374	955	SURFACE(side platform)

(ii) North – South Line

LIST OF STATIONS (N-S)				
S. No	**NAME**	**CHAINAGE**	**INT.-DIST**	**REMARK**
1	YESHWANTAPUR	0		ELE.(side platform)
2	MAHALAXMI	2102	2102	ELE.(side platform)
3	RAJAJI NAGAR	3069	967	ELE.(side platform)
4	KUVEMPU	3975	906	ELE.(side platform)
5	MALLESWARAM	4728	753	ELE.(side platform)
6	SWASTIK	5864	1136	SURFACE(side platform)
7	MAJESTIC	7540	1676	U.G.(island)
8	CHICKPETE	8559	1019	U.G.(island)
9	CITY MARKET	9235	676	U.G.(island)
10	K R ROAD	10427	1192	ELE.(side platform)
11	LALBAGH	11431	1004	ELE.(side platform)
12	SOUTH END CIRCLE	12386	955	ELE.(side platform)
13	JAYANAGAR	13288	902	ELE.(side platform)
14	R V ROAD TERMINAL	14180	892	ELE.(side platform)

3.2 TRAIN OPERATION PLAN

Salient features of the proposed train operation plan are:

- Running of services for 19 hours of a day (5 AM to Midnight) with a station dwell time of 30 seconds,
- Make up time of 5-10% with 8-12% coasting.
- Scheduled speeds of 32 to 35 kmph.

3.2.1 Traffic

Peak hour peak direction trips demand (phpdt) for different years for the purpose of planning are indicated in the **Table 3.2**.

TABLE 3.2
Peak hour peak direction trips (phpdt)

LINE	YEAR		
	2007	2011	2021
Line 1 (E-W)	22442	27358	39838
Line 2 (N-S)	19585	22705	31694

3.2.2 Train Operation

Train operation plan has been formulated to meet the demand of number of passengers expected during peak hour in peak direction in different sub-sections of the East – West & the North – South Corridor.
Car composition adopted for the year 2007, 2011 & 2021 is given in **Fig 3:1**

Composition

DMC : Driving Motor Car
TC : Trailer Car
3-Car Train Composition DMC + TC + DMC
6-Car Train Composition DMC + TC + MC + MC + TC + DMC

Capacity

DMC : 322 passengers
TC : 356 passengers
3 Car Train : 1000 passengers
6 Car Train : 2068 passengers

3.2.3 Train Operation Plan

Based on the above consideration, the train operation plan (headway and train composition) planned for the years 2007, 2011 and 2021 is as under:

- **Year 2007**

(Refer Attachment 1&2)
Train operation on the East – West Corridor and the North – South Corridor is planned with 3-car trains at 4 minutes headway during the first year of operation, i.e. 2007. The 3-car train capacity with 4 minutes headway is 15000. The capacity planned is less than the peak demand. This optimum capacity may cause slight over crowding on some inter-station sections, but will avoid excessive under-loading on the balance sections.

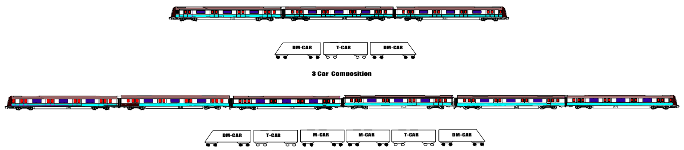
- **Year 2011**

(Refer Attachment 3 & 4)
Train operation on the East – West Corridor is planned with 6-car trains at 4 minutes headway in 2011. The 6-car train capacity with 4 minutes headway is 31020. The capacity planned is more than the peak demand, and it may cause slight under loading. The train operation on the North -South Corridor is planned with 3-car trains at 4 minutes headway in 2011. The 3-car train capacity with 4 minutes headway is 15000, This optimum capacity decided may cause slight over-crowding on some inter-station sections, but will avoid excessive under-loading on the balance sections.

- **Year 2021**

(Refer Attachment 5 & 6)
Train operation on the East – West Corridor is planned with 6-car trains at 3 minutes headway in 2021. The 6-car train capacity with 3 min headway is 41360. The capacity planned is more than the peak demand; it may cause slight under-loading. Train operation on the North-South Corridor is planned with 6-car trains at 4 minutes headway in 2021. The 6-car train capacity with 4 minutes headway is 31020, This optimum capacity decided may cause slight over-crowding on some inter station sections but will avoid excessive under-loading on the balance sections.

In case of any mismatch in the capacity provided and the actual traffic, the capacity can be moderated by suitably varying the rake composition.



6 Car Composition

Fig 3:1

TABLE 3.3
CAPACITY PROVIDED

(I) EAST – WEST CORRIDOR

Item	2007	2011	2021
Cars/train	**3**	**6**	**6**
Headway (Minutes)	**4**	**4**	**3**
PHPDT	**15000**	**31020**	**41360**

(II) NORTH - SOUTH CORRIDOR

Item	2007	2011	2021
Cars/train	**3**	**3**	**6**
Headway (Minutes)	**4**	**4**	**4**
PHPDT	**15000**	**15000**	**31020**

3.2.4. Train frequency

a) The train operation plan provides for a maximum headway of 15 minutes (4 trains/hour) during lean hours to keep the services attractive and 4-minute headway during peak time initially.

b) Peak time train frequency is proposed to be kept at 3 minutes interval as traffic increases.

c) Train frequency is proposed to be maintained at 3 minutes during the year 2021 but with 6-car trains on the East – West Corridor.

d) Train frequency is proposed to be maintained at 4 minutes during the year 2021 but with 6-car trains on the North - South Corridor.

e) No services are proposed between 00.00 hrs. to 5.00 hrs., which are reserved for maintenance of infrastructure and rolling stock.

3.2.5. Hourly Distribution

Hourly distribution of daily transport capacity and the directional split thereof is presented in **Table 3.4**. Number of trains proposed to be operated daily during peak hours in the peak direction for the year 2007 (first year of operation) for each section of the network is presented in **Table 3.5**.
Number of trains proposed to be operated daily for the year 2011 and 2021 is presented in **Table 3.6**. and **Table 3.7**

TABLE 3.4
Hourly Distribution of Transport Capacity and Directional Split
4 Minutes Headway

Time of Day	% of Daily Traffic Capacity	Directional Split
5 to 6	2.41	50:50
6 to 7	3.01	50:50
7 to 8	**6.02**	**50:50**
8 to 9	**7.23**	**50:50**
9 to 10	**9.04**	**50:50**
10 to 11	**7.23**	**50:50**
11 to12	**6.02**	**50:50**
12 to 13	3.61	50:50
13 to 14	3.61	50:50
14 to 15	3.61	50:50
15 to 16	3.61	50:50
16 to 17	**6.02**	**50:50**
17 to 18	**7.23**	**50:50**
18 to 19	**9.04**	**50:50**
19 to 20	**7.23**	**50:50**
20 to 21	**6.02**	**50:50**
21 to 22	3.61	50:50
22 to 23	3.01	50:50
23 to 24	2.41	50:50

TABLE 3.5
Hourly Train operation plan
(YEAR – 2007)
4 Minutes Headway

(I) East - West Corridor

Time of Day	Headway in Minutes	No. of Trains per day	
		UP	DN
5 to 6	15	4	4
6 to 7	12	5	5
7 to 8	**6**	**10**	**10**
8 to 9	**5**	**12**	**12**
9 to 10	**4**	**15**	**15**
10 to 11	**5**	**12**	**12**
11 to12	**6**	**10**	**10**
12 to 13	10	6	6
13 to 14	10	6	6
14 to 15	10	6	6
15 to 16	10	6	6
16 to 17	**6**	**10**	**10**
17 to 18	**5**	**12**	**12**
18 to 19	**4**	**15**	**15**
19 to 20	**5**	**12**	**12**
20 to 21	**6**	**10**	**10**
21 to 22	10	6	6
22 to 23	12	5	5
23 to 24	15	4	4
Total No. of trains per direction per day		**166**	**166**

Rake formation : 3 cars

TABLE 3.5
Hourly Train operation plan
(YEAR – 2007)
4 Minutes Headway

(II) North - South Corridor

Time of Day	**Headway in Minutes**	**No. of Trains per day**	
		UP	**DN**
5 to 6	15	4	4
6 to 7	12	5	5
7 to 8	**6**	**10**	**10**
8 to 9	**5**	**12**	**12**
9 to 10	**4**	**15**	**15**
10 to 11	**5**	**12**	**12**
11 to12	**6**	**10**	**10**
12 to 13	10	6	6
13 to 14	10	6	6
14 to 15	10	6	6
15 to 16	10	6	6
16 to 17	**6**	**10**	10
17 to 18	**5**	**12**	12
18 to 19	**4**	**15**	15
19 to 20	**5**	**12**	12
20 to 21	**6**	**10**	**10**
21 to 22	10	6	6
22 to 23	12	5	5
23 to 24	15	4	4
Total No. of trains per direction per day		**166**	**166**

Rake formation : 3 cars

TABLE 3.6
Hourly Train operation plan
(YEAR - 2011)
4 Minutes Headway

(I) East - West Corridor

Time of Day	**Headway in Minutes**	**No. of Trains per day**	
		UP	**DN**
5 to 6	12	5	5
6 to 7	10	6	6
7 to 8	**5**	**12**	**12**
8 to 9	**5**	**12**	**12**
9 to 10	**4**	**15**	**15**
10 to 11	**5**	**12**	**12**
11 to12	**5**	**12**	**12**
12 to 13	6	10	10
13 to 14	10	6	6
14 to 15	10	6	6
15 to 16	6	10	10
16 to 17	**5**	**12**	**12**
17 to 18	**5**	**12**	**12**
18 to 19	**4**	**15**	**15**
19 to 20	**5**	**12**	**12**
20 to 21	**5**	**12**	**12**
21 to 22	6	10	10
22 to 23	10	6	6
23 to 24	12	5	5
Total No. of trains per direction per day		**190**	**190**

Rake formation : 6 cars

TABLE 3.6
Hourly Train operation plan
(YEAR – 2011)
4 Minutes Headway

(II) North - South Corridor

Time of Day	Headway in Minutes	No. of Trains per day	
		UP	DN
5 to 6	12	5	5
6 to 7	10	6	6
7 to 8	**5**	**12**	**12**
8 to 9	**5**	**12**	**12**
9 to 10	**4**	**15**	**15**
10 to 11	**5**	**12**	**12**
11 to12	**5**	**12**	**12**
12 to 13	6	10	10
13 to 14	10	6	6
14 to 15	10	6	6
15 to 16	6	10	10
16 to 17	**5**	**12**	**12**
17 to 18	**5**	**12**	**12**
18 to 19	**4**	**15**	**15**
19 to 20	**5**	**12**	**12**
20 to 21	**5**	**12**	**12**
21 to 22	6	10	10
22 to 23	10	6	6
23 to 24	12	5	5
Total No. of trains per direction per day		**190**	**190**

Rake formation : 3 cars

TABLE 3.7
Hourly Train operation plan

(YEAR – 2021)
3 Minutes Headway

(I) East - West Corridor

Time of Day	Headway in Minutes	No. of Trains per day	
		UP	**DN**
5 to 6	10	6	6
6 to 7	6	10	10
7 to 8	**5**	**12**	**12**
8 to 9	**4**	**15**	**15**
9 to 10	**3**	**20**	**20**
10 to 11	**4**	**15**	**15**
11 to12	**5**	**12**	**12**
12 to 13	6	10	10
13 to 14	6	10	10
14 to 15	6	10	10
15 to 16	6	10	10
16 to 17	**5**	**12**	**12**
17 to 18	**4**	**15**	**15**
18 to 19	**3**	**20**	**20**
19 to 20	**4**	**15**	**15**
20 to 21	**5**	**12**	**12**
21 to 22	6	10	10
22 to 23	10	6	6
23 to 24	10	6	6
Total No. of trains per direction per day		**226**	**226**

Rake formation : 6 cars in 2021

TABLE 3.7
Hourly Train operation plan
(YEAR – 2021)

4 Minutes Headway

(II) North - South Corridor

Time of Day	**Headway in Minutes**	**No. of Trains per day**	
		UP	**DN**
5 to 6	10	6	6
6 to 7	6	10	10
7 to 8	**5**	**12**	**12**
8 to 9	**4**	**15**	**15**
9 to 10	**4**	**15**	**15**
10 to 11	**4**	**15**	**15**
11 to12	**5**	**12**	**12**
12 to 13	6	10	10
13 to 14	6	10	10
14 to 15	6	10	10
15 to 16	6	10	10
16 to 17	**5**	**12**	**12**
17 to 18	**4**	**15**	**15**
18 to 19	**4**	**15**	**15**
19 to 20	**4**	**15**	**15**
20 to 21	**5**	**12**	**12**
21 to 22	6	10	10
22 to 23	10	6	6
23 to 24	10	6	6
Total No. of trains per direction per day		**216**	**216**

Rake formation : 6 cars in 2021

3.2.6 Hourly capacity

Based on daily train operation plan, figures of carrying capacity have been worked out for every hour during the initial period of operation (2007) and during the years 2011 and 2021 and are presented in **Table 3.8, Table 3.9 and Table 3.10** respectively.

TABLE 3.8

Hourly Capacity Provided

(YEAR – 2007)

4 Minutes Headway

(I) East - West Corridor

Time of Day	No of Trains per Hour	PHPDT
5 to 6	4	4000
6 to 7	5	5000
7 to 8	**10**	**10000**
8 to 9	**12**	**12000**
9 to 10	**15**	**15000**
10 to 11	**12**	**12000**
11 to12	**10**	**10000**
12 to 13	6	6000
13 to 14	6	6000
14 to 15	6	6000
15 to 16	6	6000
16 to 17	**10**	**10000**
17 to 18	**12**	**12000**
18 to 19	**15**	**15000**
19 to 20	**12**	**12000**
20 to 21	**10**	**10000**
21 to 22	6	6000
22 to 23	5	5000
23 to 24	4	4000

Rake formation : 3 cars

TABLE 3.8

Hourly Capacity Provided

(YEAR – 2007)

4 Minutes Headway

(II) North - South Corridor

Time of Day	No of Trains per Hour	PHPDT
5 to 6	4	4000
6 to 7	5	5000
7 to 8	10	10000
8 to 9	**12**	**12000**
9 to 10	**15**	**15000**
10 to 11	**12**	**12000**
11 to12	**10**	**10000**
12 to 13	6	6000
13 to 14	6	6000
14 to 15	6	6000
15 to 16	6	6000
16 to 17	**10**	**10000**
17 to 18	**12**	**12000**
18 to 19	**15**	**15000**
19 to 20	**12**	**12000**
20 to 21	**10**	**10000**
21 to 22	6	6000
22 to 23	5	5000
23 to 24	4	4000

Rake formation : 3 cars

TABLE 3.9

Hourly Capacity Provided

(YEAR – 2011)

4 Minutes Headway

(I) East - West Corridor

Time of Day	No of Trains per Hour	PHPDT
5 to 6	5	10340
6 to 7	6	12408
7 to 8	**12**	**24816**
8 to 9	**12**	**24816**
9 to 10	**15**	**31020**
10 to 11	**12**	**24816**
11 to12	**12**	**24816**
12 to 13	10	20680
13 to 14	6	12408
14 to 15	6	12408
15 to 16	10	20680
16 to 17	**12**	**24816**
17 to 18	**12**	**24816**
18 to 19	**15**	**31020**
19 to 20	**12**	**24816**
20 to 21	**12**	**24816**
21 to 22	10	20680
22 to 23	6	12408
23 to 24	5	10340

Rake formation : 6 cars in 2011

TABLE 3.9

Hourly Capacity Provided

(YEAR – 2011)

4 Minutes Headway

(II) North - South Corridor

Time of Day	No of Trains per Hour	PHPDT
5 to 6	5	5000
6 to 7	6	6000
7 to 8	**12**	**12000**
8 to 9	**12**	**12000**
9 to 10	**15**	**15000**
10 to 11	**12**	**12000**
11 to12	**12**	**12000**
12 to 13	10	10000
13 to 14	6	6000
14 to 15	6	6000
15 to 16	10	10000
16 to 17	**12**	**12000**
17 to 18	**12**	**12000**
18 to 19	**15**	**15000**
19 to 20	**12**	**12000**
20 to 21	**12**	**12000**
21 to 22	10	10000
22 to 23	6	6000
23 to 24	5	5000

Rake formation : 3 cars in 2011

TABLE 3.10

Hourly Capacity Provided

(YEAR – 2021)

3 Minutes Headway

(I) East - West Corridor

Time of Day	No of Trains per Hour	PHPDT
5 to 6	6	12408
6 to 7	10	20680
7 to 8	**12**	**24816**
8 to 9	**15**	**31020**
9 to 10	**20**	**41360**
10 to 11	**15**	**31020**
11 to12	**12**	**24816**
12 to 13	10	20680
13 to 14	10	20680
14 to 15	10	20680
15 to 16	10	20680
16 to 17	**12**	**24816**
17 to 18	**15**	**31020**
18 to 19	**20**	**41360**
19 to 20	**15**	**31020**
20 to 21	**12**	**24816**
21 to 22	10	20680
22 to 23	6	12408
23 to 24	6	12408

Rake formation : 6 cars in 2021

TABLE 3.10

Hourly Capacity Provided

(YEAR – 2021)

4 Minutes Headway

(II) North - South Corridor

Time of Day	No of Trains per Hour	PHPDT
5 to 6	6	12408
6 to 7	10	20680
7 to 8	**12**	**24816**
8 to 9	**15**	**31020**
9 to 10	**15**	**31020**
10 to 11	**15**	**31020**
11 to12	**12**	**24816**
12 to 13	10	20680
13 to 14	10	20680
14 to 15	10	20680
15 to 16	10	20680
16 to 17	**12**	**24816**
17 to 18	**15**	**31020**
18 to 19	**15**	**31020**
19 to 20	**15**	**31020**
20 to 21	**12**	**24816**
21 to 22	10	20680
22 to 23	6	12408
23 to 24	6	12408

Rake formation : 6 cars in 2021

3.2.6 Vehicle Kilometer

Based on the above planning and assuming 340 days service in a year (after considering maintenance period) Vehicle Kilometers are calculated. Vehicle Kilometers for year 2007,2011 and 2021 is given in **Table 3.11**

TABLE 3.11
Vehicle Kilometers

(I) East - West Corridor

Year	**2007**	**2011**	**2021**
Section Length	17.39	17.39	17.39
No of cars per Train	3	6	6
No of working Days in a year	340	340	340
Number of Trains per day each Way	166	190	226
Daily Train -KM	5773.48	6608.20	7860.28
Annual Train - KM (10^5)	19.63	22.47	26.72
Annual Vehicle - KM (10^5)	**58.89**	**134.81**	**160.35**

Vehicle Kilometers

(II) North - South Corridor

Year	**2007**	**2011**	**2021**
Section Length	14.2	14.2	14.2
No of cars per Train	3	3	6
No of working Days in a year	340	340	340
Number of Trains per day each Way	166	190	216
Daily Train –KM	4714.40	5396.00	6134.40
Annual Train - KM (10^5)	16.03	18.35	20.86
Annual Vehicle - KM (10^5)	**48.09**	**55.04**	**125.14**

3.3 Provision of Emergency cross – overs/ Relief sidings.

Relief sidings and emergency cross over are planned at selected intermediate stations on each corridor with a view to maintaining train services during dislocations caused by technical failures / accidents.

3.4 Operation Control Centre

Train operations will be controlled centrally from operations control center (OCC). The OCC will house :

I. Traffic Control Centre,
II. SCADA System for Traction Power Control and Monitoring,
III. System for Auxiliary Power, VAC, etc. Control and Monitoring,
IV. Telecommunication, CCTV, etc. Control and Monitoring.

3.5 Accident Restoration

Two accident relief trains (ARTs) one each for the North-South & the East-West Corridor have been planned. Flying squads for facilitating normalization of abnormal conditions will be located at important stations.

3.5.1 Station Control

Each station will be headed by a station manager who will be responsible for all facets of operation and commercial activities including proper working and upkeep of facilities / services provided. The SCR (Station Control Room) is the nerve center of the station, which controls and monitors all major activities at the stations and movement of trains.

- Computerized Control of all the points located within the SCR's Zone along with a back up manual control is planned.
- All the announcements on the station are planned to be done from this control room. There should be a facility of making automatic computerized announcement besides the manual emergency announcement. All the displays on station are to be controlled from the SCR.
- Lifts and escalators are also be monitored and communication facility be available with the person in lift with the SCR.
- AFC data is planned to be captured, monitored and analyzed in the SCR.
- All regular and emergency modes of communication are to be provided.
- Digital telephones, radiophones for communication with drivers, handsets for communication with the station staff, tele-conferencing facility etc. to be provided.
- An emergency stop plunger is to be provided in this control room to stop the train in case of some emergency. Fire alarm and control panel is also to be located here.
- For convenience and for giving assistance to sick/disabled person wheel chairs and table stretchers are also to be kept in the SCR.

3.6 Inter corridor Connection

The North-South & the East-West lines will be connected through a link line at Majestic Circle.

3.7 Training

Training is required to be provided to maintenance staff and train operation staff so that they understand the whole system of trains and to familiarize them with maintenance and operation of the trains. As a general guide, training will be based upon a “two-stage” concept:

(i) Stage one will consist of training in the basic concepts and principles. These will include system configuration and specifications, operation and control of all equipments installed in the cars, preventive maintenance procedures, overhaul and repair concepts, fault diagnostic and trouble shooting and emergency procedures. The training will consist of classroom (theory) training; computer-based inter-active training and mock-up training.

(ii) Stage two will consist of “hand-on” site-based practical training on preventive and corrective maintenance and operating procedures.

3.8.1 Maintenance Staff

Training is required to enable engineers, supervisors and staff to achieve following broad objectives:

(i) Full understanding of all aspects of the system design and functions of all the equipment including proprietary and third party equipment, software, etc.

(ii) Full understanding of all aspects of programmed maintenance and overhaul requirements of cars and equipment.

(iii) Procedures to be followed for unscheduled maintenance and repair of cars and equipment.

(iv) Identification of failed components and sub-systems in electronic equipment by use of special test equipment, as necessary.

(v) Modification in the software to extend or modify the control and monitoring functions.

(vi) Maintenance Management Information System and documentation.

(vii) Stores inventory planning and control.

The training of maintenance engineers, supervisor & staff will include direct exposure to actual repair, maintenance and overhaul of similar cars in the Depots and Workshops of an operational Mass Rapid Transit System.

The training will include theoretical as well as practical training so as to enable them to develop skill and expertise necessary for satisfactory maintenance, repairs and overhaul of cars.

3.8.2. Train Operating Staff

The objective of training of train Operating Staff is that the drivers and instructors who will operate the trains are able to run the trains safely under all operating conditions. The training will enable them to acquire full specified duration. The operating staff and instructors will also need training on a cab simulator of a mass transit railway and on a Test Track.

3.8.3 Training Location and Facility

Training will be carried out at such locations as will provide maximum benefit to the trainees. Such locations may be in India, or abroad, at places of manufacture, assembly or testing, or at other locations as may be necessary.

3.9 ROLLING STOCK

The required transport demand forecast is the governing factor for the choice of the Rolling Stock. In a metro city like Bangalore, the projected Peak Hour Peak Direction trips (PHPDT) is as per **Table 3.12**

Table 3.12
FORECASTED (phpdt)

YEAR	2007	20011	2021
FORECASTED PHPDT for East- West Corridor	22442	27398	39838
FORECASTED PHPDT for North South Corridor	19585	22705	31694

The above demand precludes use of Light Rail Vehicles. Considering the future expected population increase in a city like Bangalore, the use of Mass Rapid Transit Rail Vehicles of medium capacity has been considered.

3.10 Optimisation of Rake Formation

To meet the traffic demand as projected above, running trains of 3-car, 6-car, and 8-car with different headways ranging from 2 minutes to 12 minutes has been examined. Longer 8-car trains have following implications: -

- Waiting time for the passengers at station will be high.
- Infrastructure facilities in term of platform dimensions, exit/entry facilities cost more.
- Total number of cars will increase.

With the use of 3-car trains, there is more flexibility to match the traffic capacity and demand through regulation of headways. For the East-West corridor, trains of 3-car length at headways of 4 minutes with a Peak Hour Peak Direction Capacity of 15000 have been planned in the year 2007. The capacity provided by them is less than the peak hour traffic demand on a few sections .The capacity planned has been optimized to avoid excessive under-loading on most of the sections though it may cause slight overcrowding on a few sections. Further increase in capacity to 31020 is possible by running 6-car trains with headway of 4 minutes in the year 2011. In the year 2021, the ultimate peak hour peak direction capacity of 41360 has been planned by running 6-car trains, with headways of 3 minutes. Similarly train operation on the North-South Corridor is planned with 3-car train at a headway of 4 minutes in 2007 and 2011 .The 3-car train capacity with 4 minutes headway is 15000. Peak Hour Peak Direction Capacity of 31020 has been planned in the year 2021 by increasing the rake formation to 6-cars with headway of 4 minutes.

Thus, 3-car formation with a maximum passenger capacity of 1000 per train appears to be ideally suited for the traffic projection.

3.10.1 Optimisation of Coach Size

The East-West corridor and the North-South corridor in Bangalore are mostly on elevated tracks, i.e. 8-10 meter above the ground level. But the alignment also passes through the 6700 meter of underground section. Four stations on the East-West corridor and three stations on the North-South corridor are underground. Tunnel is proposed to be of 5.2 m finished diameter for each track. Sharpest horizontal curve will be of 120 m radius. Maximum gradient on main line will be 4 %. Vertical curves will have a minimum radius of 2500 m. Track shall be ballast-less, laid with 60 kg UIC rails . Considering the clearances and also the space required for ventilation of the tunnel, services and cables etc., following optimum size of the coach has been arrived at **Table 3.13**.

Table 3.13
Size of the coach

	Length	Width	Height
Driver Motor Car	20.9 m	2.88 m	3.8 m
Trailer car	20.5 m	2.88 m	3.8 m

Principal dimensions are shown in **Fig. 3.1 & 3.2**. The Kinematics Envelope has been shown in **Fig. 3.2**.

3.10.2 PASSENGER CARRYING CAPACITY

In order to maximize the passenger carrying capacity, since travelling time is short, longitudinal seating arrangement along with maximum standee area with vestibules shall be adopted. All equipments have been shifted to under frame to maximise the available space. The whole train shall be vestibuled to distribute the passengers evenly in all the coaches and for evacuation from ends in emergency. Criteria for calculation of standing passengers are 3 persons per square meter of standing floor area in normal loading state and 8 persons in crush loading state in peak hours.

Therefore the Rail Vehicle with 20.9 m carbody length, with 2.88 m carbody width and longitudinal seat arrangement conceptually has capacity of 43 seated, 279 standing, i.e. a total of 322 passengers for a driving motor car, and 50 seated, 306 standing i.e. a total of 356 passengers for a trailer car. **Table 3.14** shows these figures

Table 3.14
Carrying Capacity of Mass Rail Vehicles

	Driving Motor car		Trailer car / Non-driving motor car		3-car Train	6-car Train
	Normal	Crush	Normal	Crush	Crush	Crush
Seated	43	43	50	50	136	286
Standing	105	279	115	306	864	1782
Total	148	322	165	356	1000	2068

NORMAL-3 Per/sqm of standee area
CRUSH -8 Per/Sqm of standee area

The train set configuration are shown in **Fig. 3.1**.

3.10.3 WEIGHT

The weights of motor cars and trailers is estimated as in **Table 3.15**, referring to the experiences in Delhi Metro. The average passenger weight has been taken as 60 kg.

Table 3.15
Weight of Mass Rail Vehicles (TONS)

	DMC	**TC**	**MC**	**3-car train**	**6-car train**
TARE	36	32	34	104	204
Passenger					
(Normal)	8.8	9.9	9.9	27.5	57.2
(Crush)	19.3	21.4	21.36	60	124.08
Gross					
(Normal)	44.8	41.9	43.9	131.5	261.2
(Crush)	55.3	53.4	55.36	164	328.08

Heavy rush of passengers, having 10 standees per sq. meter can be experienced occasionally. As done in DMRC, it will be advisable to design the coach with sufficient strength so that even with this overload, the design will not result in overstresses in the coach. Coach and bogie should therefore be designed for 15 T axle load.

For achieving schedule speed of 32 to 35 kmph on the section having average inter-station distance of 900 meters and with dwell time of 30 sec at stations, average running time to cover inter-station distance is in the range of

70 to 75 sec which will give average speed of 45 kmph. To achieve the above performance , the average acceleration should be in the range of 0.5 to 0.6 m/s^2 with braking deceleration of 1.0 m/s^2 . Maximum acceleration should be kept slightly higher to makeup for the time in the event of 1 bogie cutout or 1 motor car cutout.

3.11 Required Power

It would be necessary for the trains to have rather higher acceleration and deceleration, considering the short distance between stations along the line, 2.10 Km as maximum, 0.620 Km minimum and 1.03 Km on average.
To estimate the tractive force required by the three-car train, following preconditions were assumed in consideration of riding comfort and adhesion.
Max. Acceleration : 1.0 m/s^2
Max. Deceleration 1.1 m/s^2 (Normal brake)
More than 1.3 m/s^2 (Emergency brake)

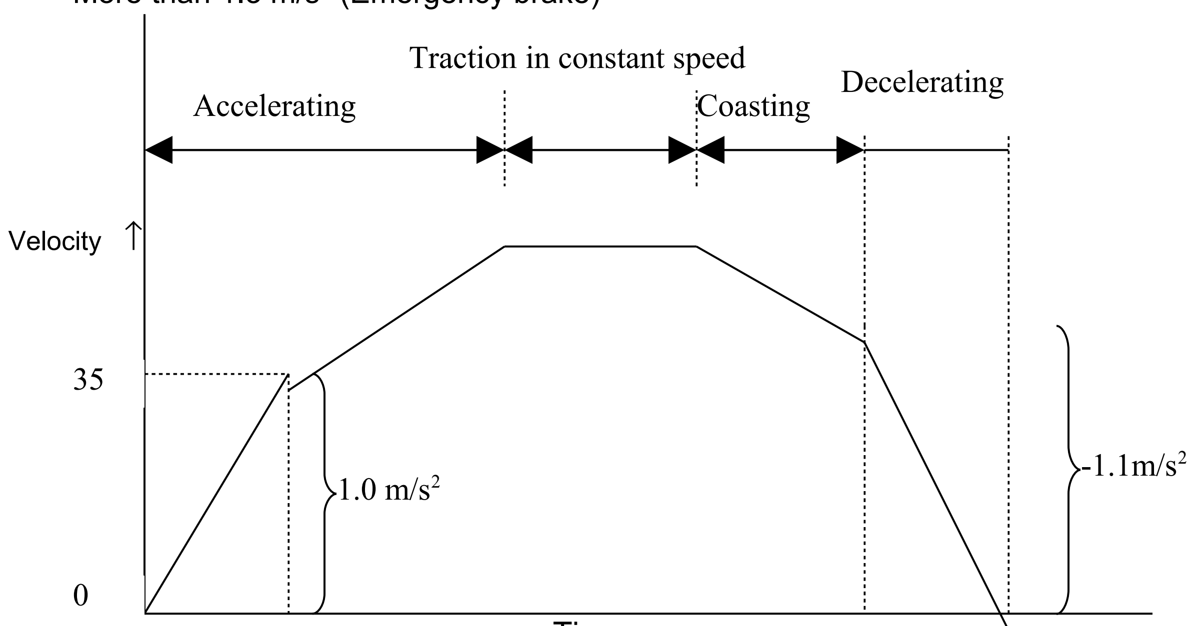


Fig 3.3 - Simplified velocity – time operation curve

Necessary power for a train of about 164 t in gross weight to accelerate in 1.0 m/s^2 , at schedule speed of 32 Km/h, on a level and straight track would be about 1,440 KW.
Since the track on a viaduct could possibly be constructed on level and the traction motors could be operated with overload for a short time, 8 traction motors with about 180 KW installed on a three car train would be enough, even if the equivalent gradients on a curved section of track are considered. It was also assessed that failure of one motor car in a train running on a 4% and 5% grade having a 120 m curvature will still be giving sufficient acceleration to the train to clear the section.

3.12 Coach Design and Basic Parameters

The important criteria for selection of rolling stock are as under :

(i) Proven equipment with high reliability
(ii) Passenger safety feature
(iii) Energy efficiency
(iv) Light weight equipment and coach body
(v) Optimised scheduled speed
(vi) Aesthetically pleasing Interior and Exterior
(vii) Low Life cycle cost
(viii) Flexibility to meet increase in traffic demand

The controlling criteria are reliability, low energy consumption, light weight and high efficiency leading to lower annualized cost of service. The coach should have high rate of acceleration and deceleration.

3.13 Selection of Technology

Low life cycle cost

The Low life cycle cost is achieved by way of reduced scheduled and unscheduled maintenance and high reliability of the sub-systems. It is possible to achieve these objectives by adopting suitable proven technologies. The selection of following Technologies has been adopted to ensure low life cycle cost.

3.13.1 Car body

In the past carbon high tensile steel was invariably used for car bodies. In-fact almost all the coaches built by Indian Railways are of this type. These steel bodied coaches need frequent painting as well corrosion repairs which may have to be carried out up to 4-5 times during the service life of these coaches. It is now a standard practice to adopt stainless steel or aluminum. The car bodies with aluminum require long and complex extruded sections which are still not manufactured in India. Therefore aluminum car body has not been considered for use. Stainless steel sections are available in India and therefore stainless steel car bodies have been specified. No corrosion repair is necessary on stainless steel cars during their service life.

Stainless steel car body leads to energy saving due to its lightweight. It also results in cost saving due to easy maintenance and reduction of repair cost from excellent anti corrosive properties as well as an improvement of riding comfort and safety in case of a crash or fire. Austenitic stainless steel with yield point of 70kg/mm2 has been recommended as in Delhi Metro. For the wall design buffer load of 80 t has been considered as it is a stand-alone system .A design life of 30 years for coach has been recommended.

3.13.2 Bogies

Bolster-less lightweight bogies with rubber springs are now universally adopted in metro cars. These bogies require less maintenance and overhaul interval is also of the order of 4,20,000km. Use of air spring at secondary stage is considered with a view to keep the floor level of the cars constant irrespective of passenger loading unlike those with coil spring. Perturbations from the track are also dampened inside the car body on account of the secondary air spring. Primary suspension system improves the curve running performance by reducing lateral forces through application of conical rubber spring. A smooth curving performance with better ride index is being ensured by provision of above type of bogies.

3.13.3 Braking System

The brake system shall consist of :

(i) An electro-pneumatic (EP) service friction brake.
(ii) A fail safe, pneumatic friction emergency brake.
(iii) A spring applied air-release parking brake.
(iv) An electric regenerative service brake.
(v) Provision of smooth and continuous blending of EP and regenerative braking.

Regenerative braking will be the main brake-power of the train and will regain maximum possible energy and pump it back to the system and thus fully utilize the advantage of 3-phase technology .The regenerative braking should have air supplement control to bear the load of trailer car. In addition, speed sensors mounted on each axle control the braking force of the axles with anti skid valves, prompting re-adhesion in case of a skid .The brake actuator shall operate either a tread brake or a wheel disc brake.

3.13.4 Propulsion System Technology

In the field of Electric Rolling Stock, DC series traction motors have been widely used due to their ideal characteristics and good controllability for traction applications. These motors were adopted because of their high starting tractive effort and simple speed regulation by connecting them in series and series parallel and sequentially short-circuiting the starting resistors on DCEMU/Metro systems and the tap changer contacts in case of ACEMUS. But these motors required intensive maintenance because of commutators and electro-mechanical contactors, resistors etc. With the advent of solid state devices like thyristors/GTOS (Gate Turn off), in power circuits and microprocessor-based control electronics, propulsion technology has undergone significant improvements. Thyristor chopper controls on DC traction system were adopted leading to elimination of starting resistors, contactors, camshaft controller, tap changer, etc. This enabled provision of step-less controls resulting in better riding qualities, reduced energy consumption, easy adoption of electrical re-generative braking etc, but the traction motors continued to be direct current series motors.

The idea of adopting a simple three-phase induction motor for traction remained more or less like a concept and almost in development stage till the seventies. With the development of GTOs and IGBTs, variable voltage variable frequency output from converter - invertor enable smooth control of these induction motors and these have now replaced the D.C. series motors in traction applications. The induction motor, for the same power output, is smaller and lighter in weight and ideally suited for rail-based Mass Rapid Transit applications. The motor tractive effort and speed is regulated by 'Variable Voltage and Variable frequency' control and can be programmed to suit the track profile and operating requirements. Another advantage of 3-phase a.c. drive and VVVF control is that regenerative braking can be introduced by lowering the frequency and the voltage to reverse the power flow and to allow braking to very low speed. The regenerative braking is rather essential in tunnel alignment otherwise heat generated by friction brakes will increase the heat load inside the tunnel and the air-conditioning plant size will go up.

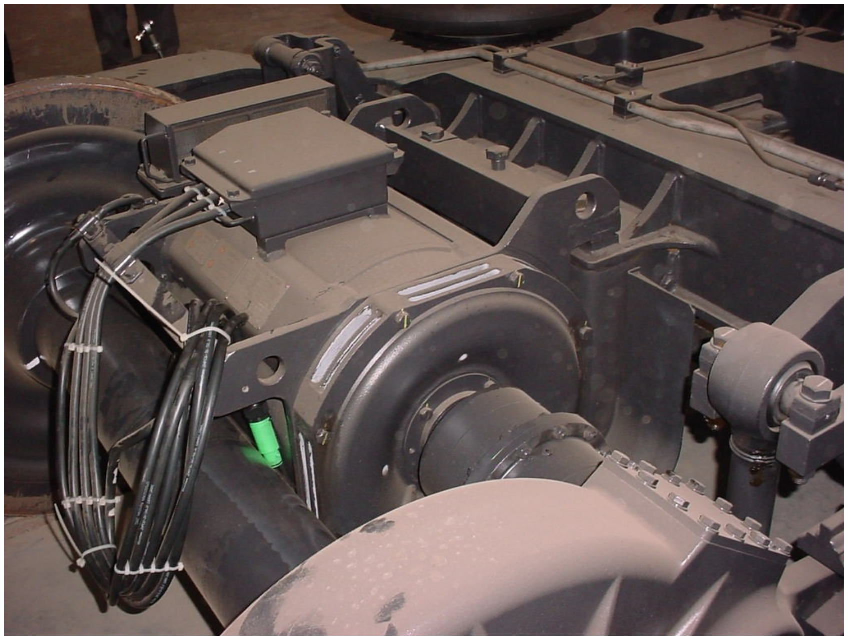


Fig.3.4 Traction Motor

For Bangalore Mass Rapid Transit System, three phase AC traction drive that are self-ventilated, highly reliable, robust construction and back up by slip/slid control have been recommended for adoption.

The DC catenary voltage is stepped up through a ‘STEP up Chopper’ to DC link voltage which feeds Inverter operated with Pulse Width Modulation (PWM) control technology and using insulated Gate Bipolar Transistors (IGBT). Thus three phase variable voltage variable frequency output drives the traction motors for propulsion.

Recently advanced IGBT has been developed for inverter units. The advanced IGBT contains an Insulated Gate Bipolar Transistor (IGBT) and gate drive circuit and protection. The advanced IGBT incorporates its own over current protection, short circuit protection; over temperature protection and low power supply detection. The IGBT has internal protection from over current, short circuit, over temperature and low control voltage.

The inverter unit uses optical fiber cable to connect the control unit to the gate interface. This optical fiber cable transmits the gate signals to drive the advanced IGBT via the gate interface. This optical fiber cable provides electrical isolation between the advanced IGBT and the control unit and is impervious to electrical interference. These are recommended for adoption in trains of Bangalore Metro.

Fig.3.5 CI unit

3.13.5 Why not linear Motor Technology

Possibility of using Linear Motor Technology has been examined for Bangalore Metro. A typical linear motor propelled traction system has its primary member fastened to the under carriage of the vehicle. The secondary reaction rail is held fast on the ground, in alignment with the guide rails, such that primary member faces the secondary member through out the traverse. When excited the primary member will move in the direction of the travelling field at a speed decided by the slip of the system.

In this the driving force is produced directly, without relying on adhesion at the contact surface between the moving object and the stationary member thus, there is no need for maintaining a minimum friction between the wheels and the track for producing pull.

The plus feature of the above systems are :

a. This system of propulsion does not involve the mechanism of adhesion. Hence there is no limit on the tractive effort and possibility of wheel slip or skid.
b. There are no rotary parts in the main motor and gears which has a significant impact on coach weight and maintenance.
c. Steep gradients and sharp curves can be negotiated due to absence of adhesion process and gears. This gives liberty in route selection in respect of grade and curves.
d. Light bogie with reduced height of coaches below the floor level.

The minus features of the system are:-

(a) High air gap and resultant poor efficiency of the Linear-Induction Motor.
(b) Presence of a force of attraction between the primary and secondary which increases loading of the axles.
(c) Need for close monitoring of the air gap and attention to reaction rails.

(d) Pilferability of Aluminium plate if installed in the open under socio-economic conditions prevailing in developing countries.

In addition to above minus features the whole track is to be laid with windings which is extremely expensive and also there should be additional coils along the track for lateral stability. From considerations of reliability, proneness of technology in Indian conditions, economy in initial capital out lay and running expenses, linear motor technology has not been proposed for Bangalore Metro Rail System.

3.13.6 Interior and gang ways

Passenger capacity of a car is maximized in a Metro System by providing longitudinal seats for seating and utilizing the remaining space for standing passenger. Therefore all the equipments are mounted on the under frame for maximum space utilization .The layout of interior panel is blended in such a way that they provide structural integrity to avoid distortion or damage and last the same as the expected life of the train.
The gangways are designed to give a wider comfortable standing space during peak hours along with easy and faster passenger movement especially in case of emergency.

3.13.7 Passenger Doors

For swift evacuation of the passenger in short dwell period, four doors of adequate width, on each side of the coach have been considered. These doors shall be of such dimensions and at such location that all the passengers inside the train are able to evacuate within least possible time without conflicting movement. As the alignment passes through underground tunnel and elevated section at 10 to 12 meters above ground, automatic door closing mechanism is envisaged from consideration of passenger safety. Passenger doors are controlled electrically by a switch in Driver cab. Electrically controlled door operating mechanism has been preferred over pneumatically operated door to avoid cases of air leakage and sluggish operation of doors.
The door shall be of Plug Swing Type as this has the advantage of being flush with coach body when closed giving it a stream line look apart from increasing the available space along width inside the coach.

3.13.8 Air –conditioning

Since the alignment is mostly elevated at 10 to 12 m height above road level with 20% underground section, it is essential to run the trains with doors closed for safety considerations. With heavy passenger loading of 8 persons/m^2 for standee area , doors being closed and with windows being sealed type to avoid transmission of noise, air conditioning of coaches has been considered essential. Each coach shall be provided with two air conditioning units capable of automatically controlling interior temperature throughout the passenger area at 27 °C with 65% RH at all times under varying ambient condition up to full load. For emergency situations such as power failure or both AC failures etc ventilation provision supplied from battery will be made. Provision shall be made to shut off fresh air intake and re-circulate the internal air of the coach, during an emergency condition, such as fire outside the train causing excessive heat and smoke to be drawn in to the coach.


Please mind the gap

3.13.9 Cab Layout and Emergency detrainment door

The modern stylish driver panel shall be FRP moulded which gives maximum comfort and easy accessibility of different monitoring equipments to the driver along with clear visibility .The driver seat has been provided at the left side of the cabin.
An emergency door for easy detrainment of the passenger on the track has been provided at the center of the front side of the each cabin which has a easy operation with one handle type master controller.

3.14 Communication

Driving cab of the cars are provided with continuous communication with base Operational Control Center and station control for easy monitoring of the individual train in all sections at all the time.
Public Address and Passenger Information Display System is provided in the car so that passengers are continuously advised of the next stoppage station, final destination station, interchange station, emergency situations if any, and other messages. The rolling stock is provided with Talk Back Units inside the cars, which permit conversation between passengers and the drivers in case of any emergency.

3.15 Noise and Vibration

The Metro alignment passes through heavily populated urban area. Noise and vibration for a metro railway becomes an important criterion from public acceptance viewpoint. Sources of noise are (i) rail-wheel interaction (ii) noise generated from equipment like blower, compressor, air conditioner, door, Inverter etc., and (iii) traction motor in running train .For elimination and reduction of noise following features are incorporated: -

- Provision of anti drumming floor and noise absorption material.
- Low speed compressor , blower and air conditioner.
- Mounting of under frame equipments on anti-vibration pad.
- Smooth and gradual control of door.
- Provision of GRP baffle on the via-duct for elimination of noise transmission.
- Provision of sound absorbing material in the supply duct and return grill of air conditioner.
- Sealing design to reduce the aspiration of noise through the gap in the sliding doors and piping holes.

The lower vibration level has been achieved by provision of bolster-less type bogies having secondary air spring.

3.16 Passenger Safety Features

(i) ATP/ATO

The rolling stock is provided with Continues Automatic Train Protection and Automatic Train Operation to ensure absolute safety in train operation. It is an accepted fact that 60-70% of accidents take place on account of human error. Adoption of this system ensures freedom from human error. The on-board computerized ATC system compares and verifies the continuous data like speed etc .for safest train control

(ii) Fire

The rolling stock is provided with fire retarding materials having low fire load, low heat release rate, low smoke and toxicity inside the cars. Electric cables used are also normally low smoke zero halogen type which ensures passenger safety in case of fire.

(iii) Emergency door

The rolling stock is provided with emergency doors at both ends of the cab to ensure well directed evacuation of passengers in case of any emergency including fire in the train.

(iv) Crash worthiness features

The rolling stock is provided with inter-car couplers having crashworthiness feature which reduces the severity of injury to the passengers in case of accidents.

(v) Gangways

Broad gangways are provided in between the cars to ensure free passenger movement between cars in case of any emergency.

3.17 Potential source for Design, Manufacturing and Supply of Metro Coaches

Presently Metro Coaches with above-mentioned features are not manufactured in the country. Delhi Metro rail Corporation has placed a contract for 240 Metro Coaches on a consortium of Mitsubishi Corporation/ Japan, Rotem/Korea & Mitsubishi Electric Corporation/Japan .60 coaches are to be manufactured off-shore and 180 are to be manufactured in India with progressive indigenous content .The consortium has tied up with Bharat Earth Movers Limited, Bangalore for setting up facilities to manufacture 180 coaches for Delhi Metro. BEML/Bangalore being a public sector undertaking is to be developed as a centre for absorption of Metro Coaches manufacturing Technology. Already their engineers and technicians have been trained/ are being trained in ROTEM/Korea. The machinery, Jigs/Fixture brought from Korea has been installed/are under installation at BEML /Bangalore. As a result of collaboration with MRM, BEML would be able to develop as manufacturing base for supply of Metro Coaches with modern features to meet the requirement of future Metro projects in India.

3.18 Requirement of Coaches for Bangalore Metro

Requirements of coaches for East – West and North South corridor is calculated based on following assumptions.

Assumptions

1. Train Composition planned as under
   3 Car Train Composition DMC + TC + DMC
   6 Car Train Composition DMC + TC + MC + MC + TC + DMC
2. Train Capacity DMC = 322 (Passengers)
   TC = 356 (passengers)
   3 Car Train = 1000 passengers
   6 Car Train = 2068 passengers
3. Traffic reserve is taken as one train per section for each line to cater to failure of train on line and to make up for operational time lost.
4. Repair and maintenance has been estimated as 8 per cent of total requirement (Bare+Traffic Reserve) based on IOH & POH interval of 3 and 6 years.
5. Coach requirement has been calculated based on headway during paek hours.
6. The calculated number of rakes in fraction is rounded off to next higher number.
7. Schedule speed is taken as 32 Kmph.
8. Turn round time is taken as 3 min at terminal stations.

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