Appendix I

A. Calculation of line capacity of trains running with same speed & with two types of trains running with speed differential.

Line Capacity = 24 / Time taken to clear section in Hr

Block length - 20 KM

Case 1

All trains running with speeds of 120 KMPH

Line Capacity = 24 / (20/120)

= 144

Case 2

All trains running with speeds of 70 KMPH

Line Capacity = 24 / (17.1/60)

= 84

Case 3

Equal mix of trains running at 120 KMPH & 70 KMPH

First train clears section in 10 mins

Second train clears section in 17.1 mins

Combined for one set 27.1 mins

Line capacity = 2x 24x 60/27.1

= 106

whereas

Line capacity by average speed (95 KMPH) = 24/ (10/95) = 114

B. Calculation of Loss of Time with a hypothetical Case of 2 train Mix with higher & lower speeds.

Length of the section 20 KM

Senction in KM	Train A	Train B
Speed in KMPH	120	70
Time in Min	10	17.1
Line cap	144	84

Train Mix %	50	33.3	25	20	10	0
A Fast Train	1	2	3	4	9	1
B Slow Train	1	1	1	1	1	0
t1+t2	27	37	47	57	107	120
Line Cap	106	116	122	126	134	288
Av Speed	95	103	108	110	115	120
t at Av. Speed	12.6	11.6	11.2	10.9	10.4	5.0
line cap	114	124	129	132	138	288
Los Loss in line cap w.r.t. average speed	7.9	7.7	6.8	6.0	3.6	0.0
% Loss in line cap	6.9	6.2	5.3	4.5	2.6	0.0

Results For 120, 50 KMPH Train Mix

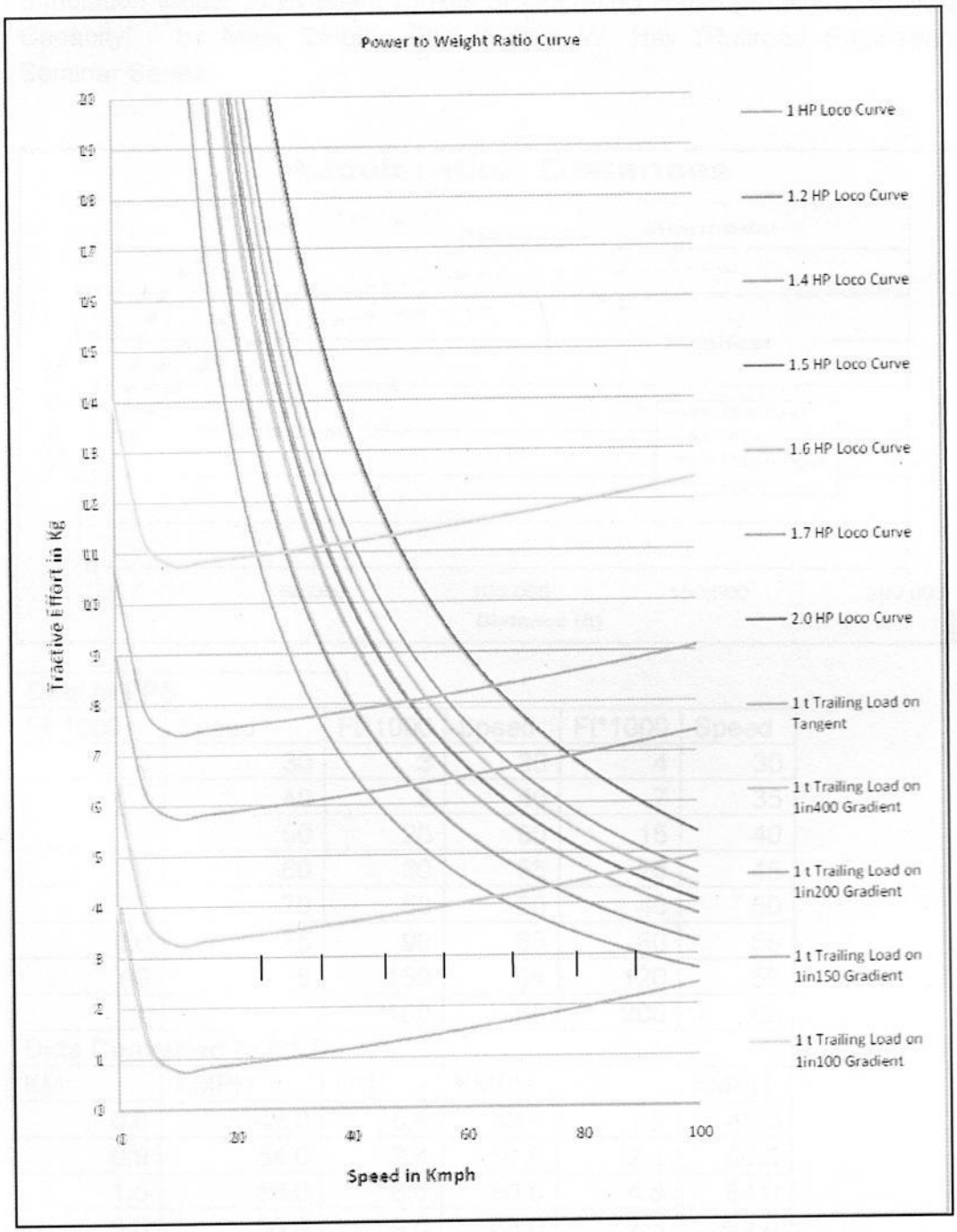
% Loss in line cap	16.9	15.3	13.2	11.5	6.8	0

Results For 120, 70 KMPH Train Mix with 10 KM block

% Loss in line cap	6.9	6.2	5.3	4.5	2.6	0.0

Appendix II

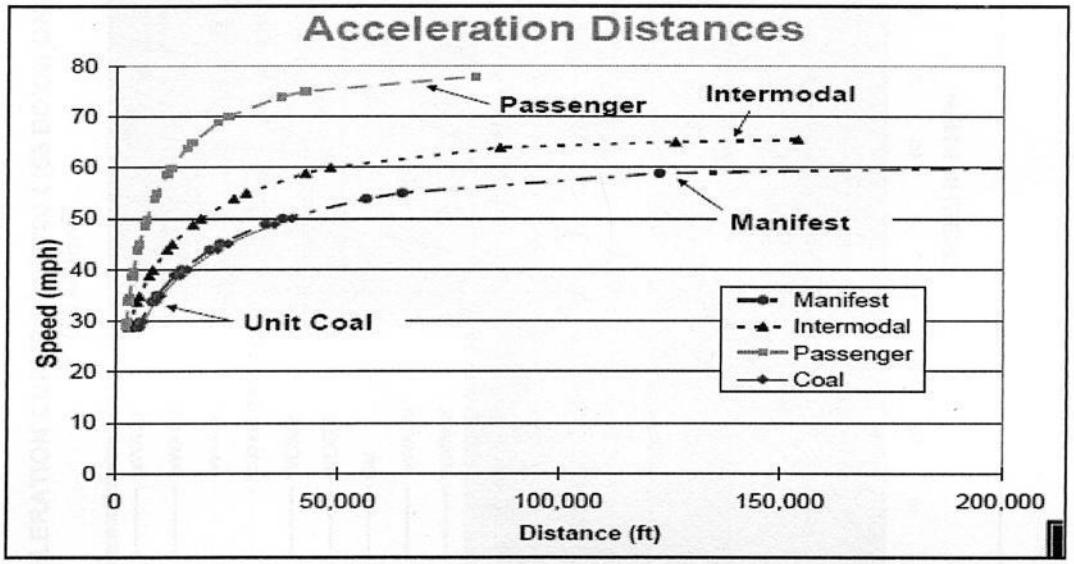
Power to Wight Ratio Curves



Source: Electric Directorate, Railway Board Rail Bhawan, Ministry of Railway

Appendix III

Acceleration Distance Curve at Different HP/TL Ratio of Passenger & Freight trains adapted from study from of American Railroad "Using the RTC Simulation Model to Evaluate Effects of Operating Heterogeneity on Railway Capacity", by Mark Dingler, The William W. Hay (Railroad Engineering Seminar Series)



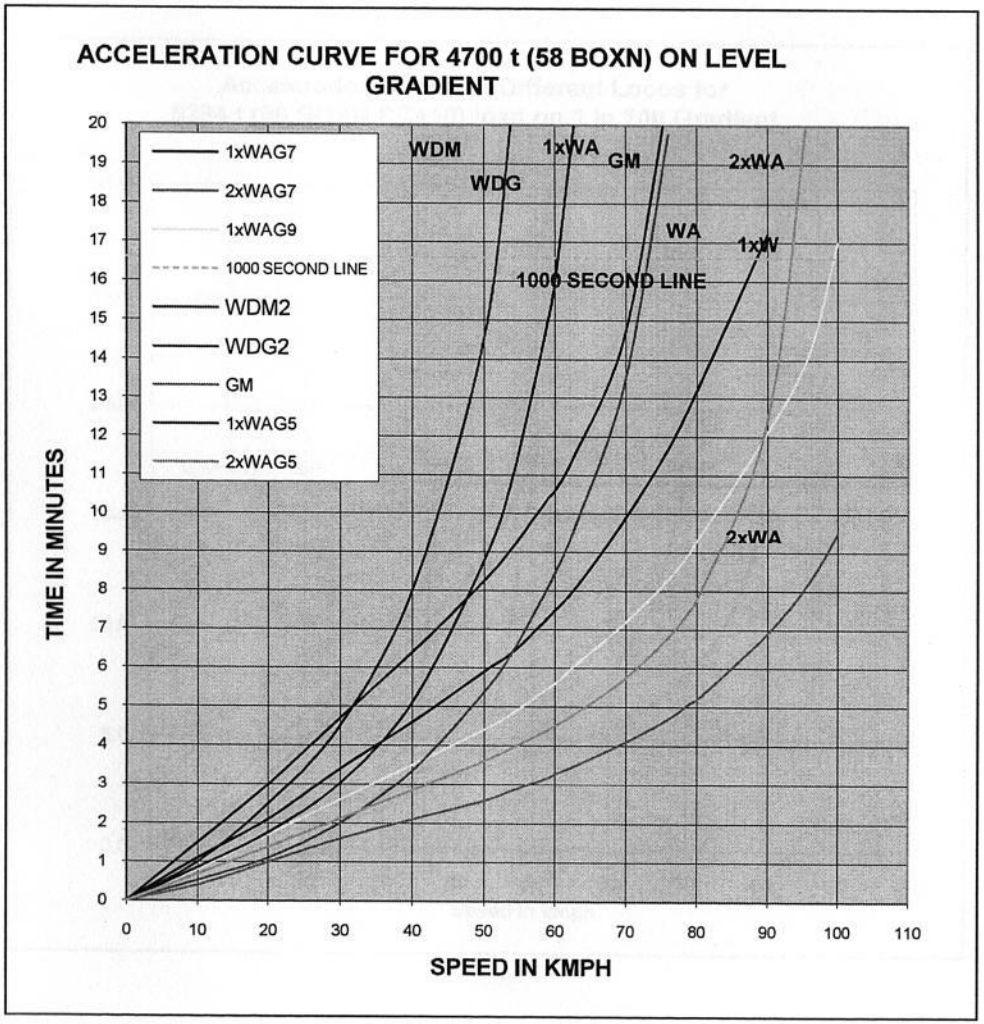
Data in FPS					
Ft*1000	Speed	Ft*1000	Speed	Ft*1000	Speed
2	30	3	30	4	30
3	40	8	40	7	35
5	50	20	50	15	40
10	60	30	55	25	45
25	70	50	60	40	50
50	75	90	63	60	55
90	78	130	64	120	58
		160	65	200	60
Data Converted to MKS					
KM	KMPH	KM	KMPH	KM	KMPH
0.6	48.0	0.9	48.0	1.2	48.0
0.9	64.0	2.4	64.0	2.1	56.0
1.5	80.0	6.0	80.0	4.5	64.0
3.0	96.0	9.0	88.0	7.5	72.0
7.5	112.0	15.0	96.0	12.0	80.0
15.0	120.0	27.0	100.8	18.0	88.0
27.0	124.8	39.0	102.4	36.0	92.8

Appendix IV

(a)Speed Time Data For 4700 T load on flat Gradient

SPEED	1WAG7	2WAG7	1WAG9	WDM2	WDG2	GM	WAG5	2WAG5
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1.1	0.4	0.8	1.0	0.9	0.5	1.5	0.7
20	2.1	1.0	1.7	2.5	1.8	1.1	3.0	1.4
30	3.4	1.6	2.6	4.5	3.0	2.0	4.7	2.1
40	4.6	2.1	3.5	8.0	5.1	3.4	6.4	2.9
50	5.9	2.6	4.4	14.5	8.8	5.4	8.3	3.6
54	6.4	2.9	4.8	20.3	10.9	6.4	9.1	3.9
59	7.3	3.2	5.5		15.0	8.1	10.4	4.4
60	7.5	3.3	5.6		16.0	8.5	10.6	4.5
63	8.1	3.5	6.1		20.4	9.7	11.6	4.9
70	9.9	4.1	7.2			13.5	14.7	5.8
76	11.7	4.7	8.3			19.8	20.8	6.8
79	12.8	5.1	9.0					7.5
80	13.2	5.2	9.3					7.8
90	17.2	6.9	12.1					12.4
96		8.3	14.2					20.8
100		9.5	17.0					
82	29.0							

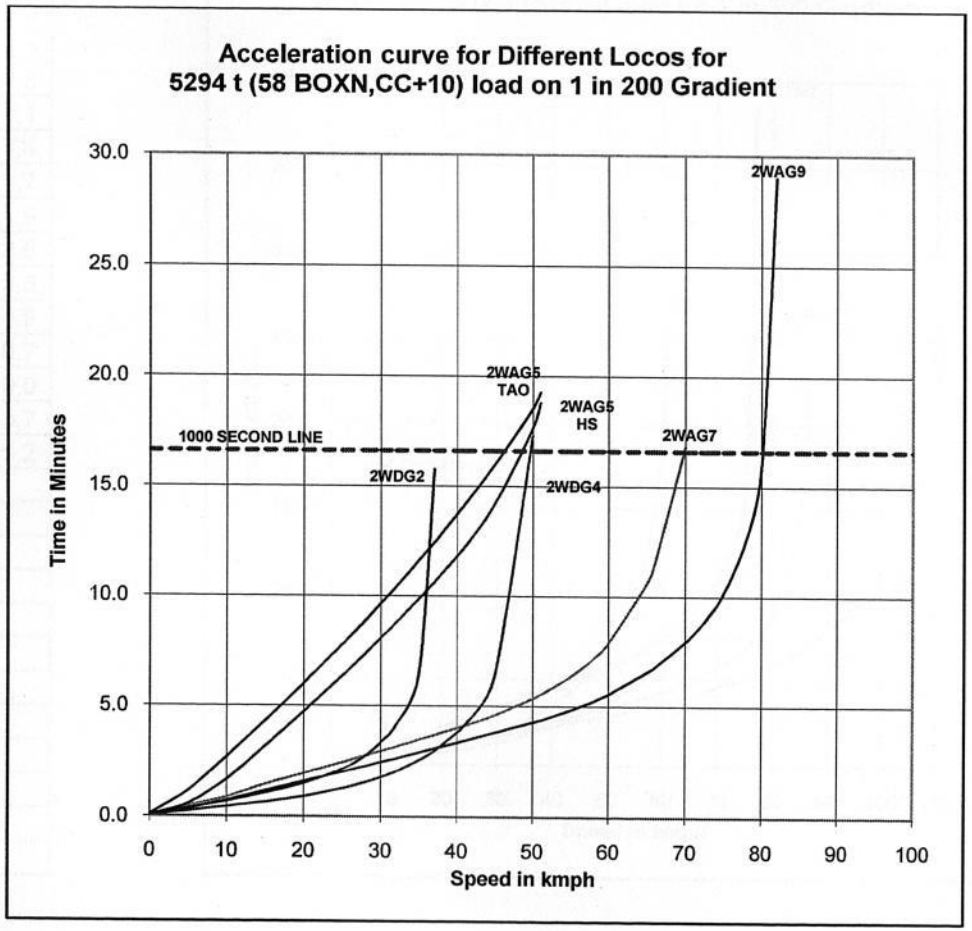
Source of all Appendix IV data: Time Speed Data of RDSO



Appendix IV (b)

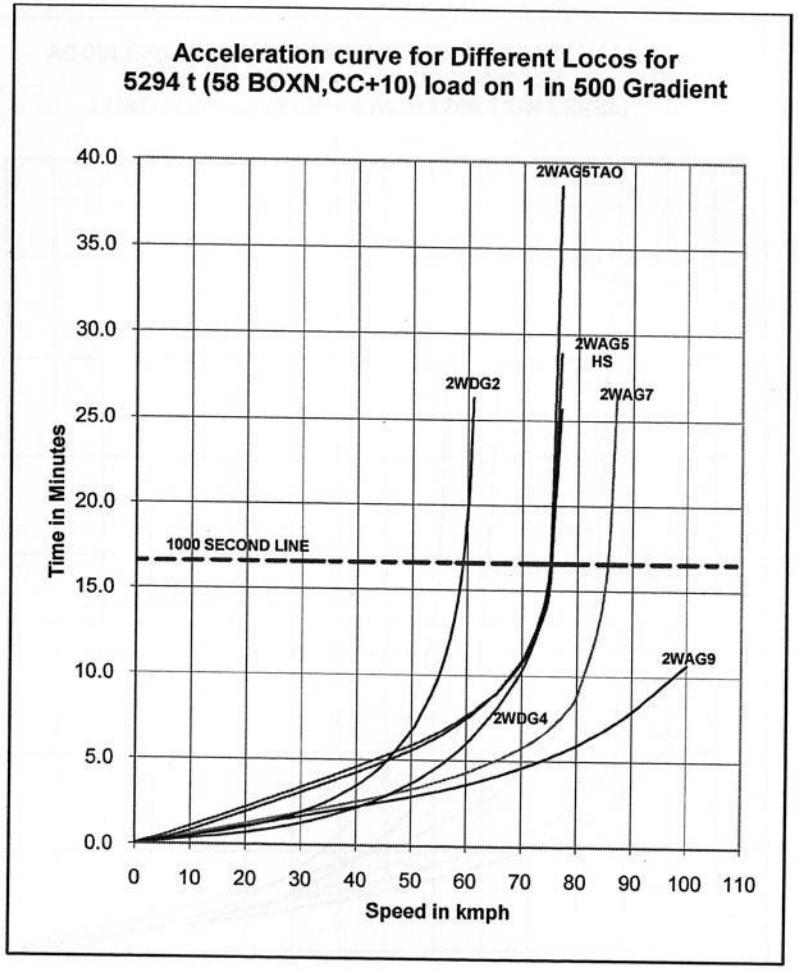
Speed Time Data For 5294 T (CC+10) load on 1 in 200 Gradient

SPEED	2WAG9	2WAG7	2WAG5A	2WAG5H	2WDG4	2WDG2
0	0.0	0.1	0.1	0.1	0.0	0.1
5	0.3	0.5	1.2	0.6	0.2	0.4
10	0.7	0.9	2.7	1.7	0.4	0.7
15	1.1	1.4	4.3	3.2	0.6	1.0
20	1.6	1.9	6.0	4.7	0.9	1.5
25	2.0	2.4	7.8	6.3	1.3	2.1
28	2.3	2.8	8.9	7.4	1.5	2.7
30	2.4	3.0	9.6	8.0	1.8	3.3
32	2.6	3.2	10.4	8.8	2.0	4.1
35	2.9	3.5	11.6	9.9	2.5	6.4
37	3.1	3.7	12.4	10.6	3.0	15.8
40	3.3	4.0	13.7	11.8	3.8	
45	3.8	4.6	16.0	14.2	6.3	
50	4.3	5.4	18.5	17.6	17.3	
51	4.4	5.5	19.3	18.8		
55	4.8	6.4				
58	5.3	7.2				
60	5.6	7.9				
65	6.6	10.6				
66	6.8	11.5				
70	7.9	16.8				
72	8.7					
75	10.1					
78	12.6					
80	15.8					



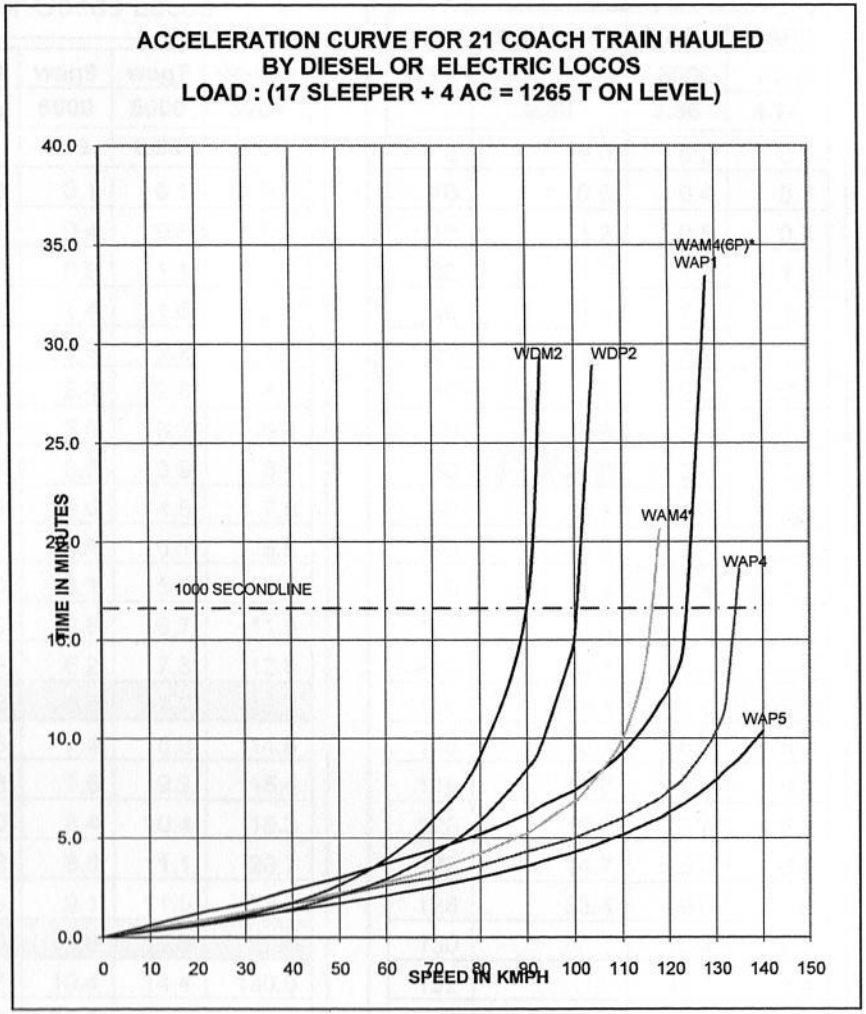
Appendix IV (c) Speed Time Data for 5294 (CC+10) T load on 1 in 500 Gradient

SPEED	2WAG9	2WAG7	2WAG5A	2WAG5H	2WDG4	2WDG2
0	0.0	0.0	0.1	0.1	0.0	0.0
5	0.3	0.3	0.5	0.4	0.2	0.3
10	0.5	0.6	1.1	0.8	0.4	0.5
15	0.8	0.9	1.6	1.4	0.5	0.8
20	1.1	1.3	2.2	1.9	0.7	1.1
25	1.4	1.6	2.8	2.5	1.0	1.4
28	1.6	1.8	3.1	2.8	1.2	1.7
30	1.7	1.9	3.4	3.1	1.3	1.9
35	2.0	2.2	4.0	3.7	1.7	2.6
40	2.3	2.6	4.6	4.3	2.2	3.5
45	2.6	2.9	5.2	4.9	2.8	4.8
50	2.9	3.3	5.9	5.6	3.6	6.7
55	3.2	3.8	6.6	6.4	4.7	10.0
58	3.4	4.1	7.2	7.0	5.4	13.7
60	3.6	4.3	7.6	7.5	6.0	19.2
65	4.1	5.0	8.9	8.8	7.9	
70	4.6	5.8	10.9	10.8	10.3	
72	4.8	6.1	12.2	11.9	11.8	
75	5.2	6.9	16.0	15.2	16.2	
77	5.5	7.5	38.6	28.9	25.7	
78	5.6	7.8				
80	5.9	8.8				
85	6.8	15.0				
87	7.2	26.3				
90	7.9					
95	9.3					
100	10.7					



Appendix IV (d) Speed Time Data for 1265 T passenger train on Level track

SPEED	WAM4(6P)	WAP4	WAP5	WAM4	WDP2	WDM2
0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.6	0.4	0.3	0.4	0.3	0.3
20	1.2	0.8	0.7	0.8	0.6	0.7
30	1.7	1.2	1.0	1.3	1.0	1.1
40	2.4	1.7	1.4	1.8	1.4	1.7
50	3.0	2.1	1.7	2.2	2.1	2.6
60	3.7	2.6	2.1	2.8	2.9	3.9
70	4.4	3.0	2.5	3.4	4.2	5.9
80	5.2	3.6	3.0	4.2	5.9	9.1
90	6.2	4.3	3.6	5.3	8.5	16.6
93	6.6	4.5	3.8	5.7	9.6	29.4
99	7.3	4.9	4.2	6.7	14.0	
100	7.4	5.0	4.3	6.8	15.0	
104	8.1	5.4	4.6	7.9	28.9	
110	9.3	6.0	5.2	10.0		
115	10.7	6.6	5.7	13.9		
118	11.8	7.0	6.0	20.6		
120	12.6	7.4	6.3			
123	14.7	8.0	6.7			
128	33.4	9.6	7.6			
130		10.4	7.9			
132		11.7	8.4			
135		18.6	9.0			
140			10.4			



Appendix IV (e) Electric Loco Speed Time Data with HP/TL ratio on flat track

For Goods Locos

Speed	WAG5	1WAG7	1WAG9	2WAG5	1WAG9
4700	3900	5000	6000	7800	6000
	0.83	1.06	1.28	1.66	2.13
0	0.0	0.0	0.0	0.0	0.0
10	1.5	1.1	0.8	0.7	0.4
20	3.0	2.1	1.7	1.4	1.0
30	4.7	3.4	2.6	2.1	1.6
40	6.4	4.6	3.5	2.9	2.1
50	8.3	5.9	4.4	3.6	2.6
54	9.1	6.4	4.8	3.9	2.9
59	10.4	7.3	5.5	4.4	3.2
60	10.6	7.5	5.6	4.5	3.3
63	11.6	8.1	6.1	4.9	3.5
70	14.7	9.9	7.2	5.8	4.1
76	20.8	11.7	8.3	6.8	4.7
79		12.8	9.0	7.5	5.1
80		13.2	9.3	7.8	5.2
90		17.2	12.1	12.4	6.9
96			14.2	20.8	8.3
100			17.0		9.5

Source: Speed time data in Appendix IV (a) to (d)

For Goods Locos

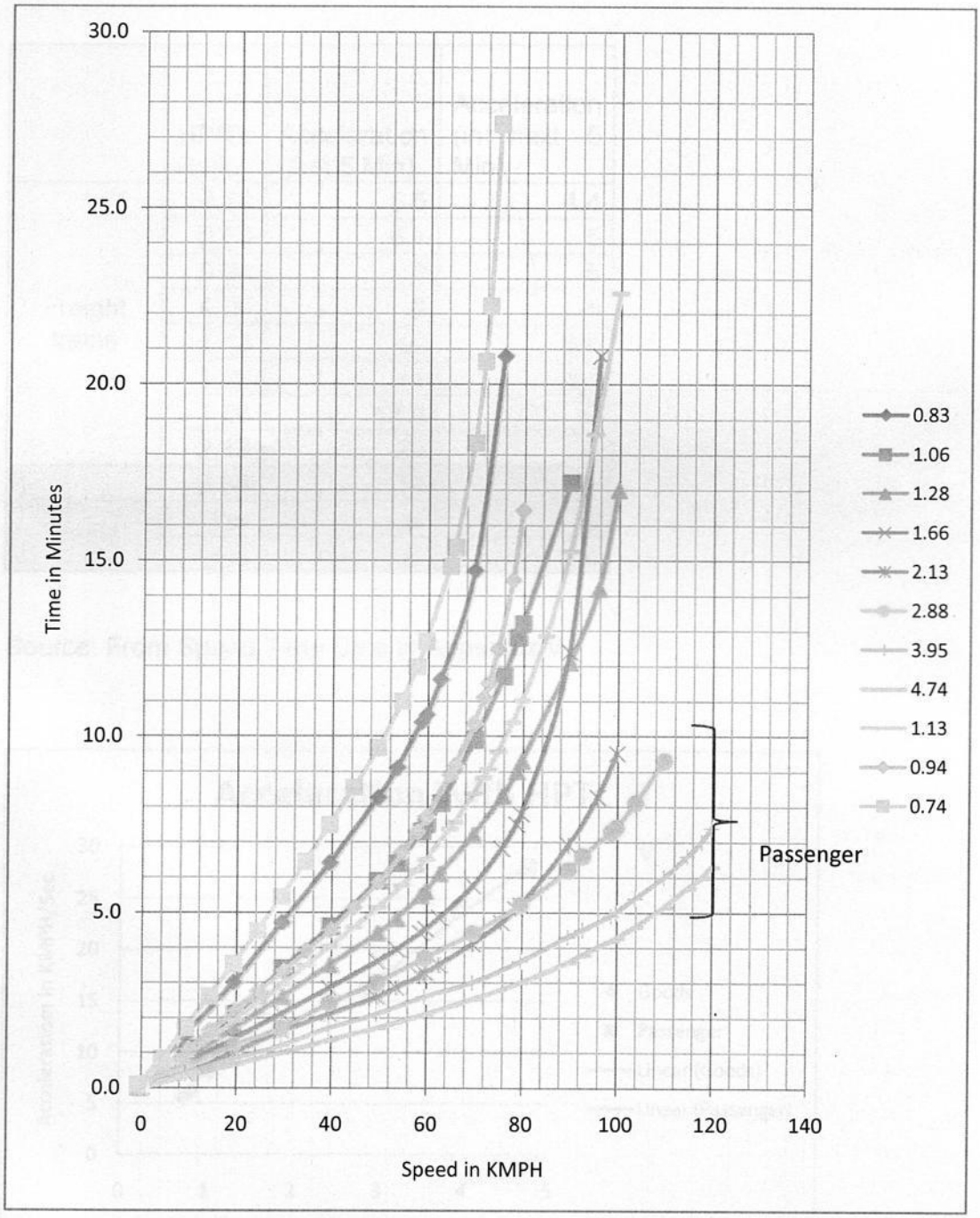
Speed	wag9	wag7	wag5a
5294	6000	5000	3900
	1.13	0.94	0.74
0	0.1	0.1	0.1
5	0.4	0.6	0.8
10	0.9	1.1	1.7
15	1.4	1.6	2.6
20	1.9	2.2	3.5
25	2.4	2.8	4.5
30	3.0	3.3	5.4
35	3.5	3.9	6.4
40	4.0	4.5	7.5
45	4.6	5.1	8.5
50	5.1	5.9	9.7
55	5.8	6.7	11.0
58	6.2	7.3	12.0
60	6.5	7.7	12.7
65	7.4	8.9	14.8
66	7.5	9.2	15.4
70	8.4	10.4	18.3
72	8.8	11.1	20.7
73	9.1	11.5	22.2
75	9.6	12.5	27.4
78	10.4	14.4	190.0
80	11.0	16.4	
85	12.8		

For Passenger

	WAM4(6P)	WAP4	WAP5
1265	3640	5000	6000
	2.88	3.95	4.74
0	0.0	0.0	0.0
10	0.6	0.4	0.3
20	1.2	0.8	0.7
30	1.7	1.2	1.0
40	2.4	1.7	1.4
50	3.0	2.1	1.7
60	3.7	2.6	2.1
70	4.4	3.0	2.5
80	5.2	3.6	3.0
90	6.2	4.3	3.6
93	6.6	4.5	3.8
99	7.3	4.9	4.2
100	7.4	5.0	4.3
104	8.1	5.4	4.6
110	9.3	6.0	5.2
115	10.7	6.6	5.7
118	11.8	7.0	6.0
120	12.6	7.4	6.3
123	14.7	8.0	6.7
128	33.4	9.6	7.6
130		10.4	7.9
132		11.7	8.4
135		18.6	9.0
140			10.4

Appendix IV (f)

Combined Electric Loco Speed Time Curve for different HP/TL Ratio on flat track



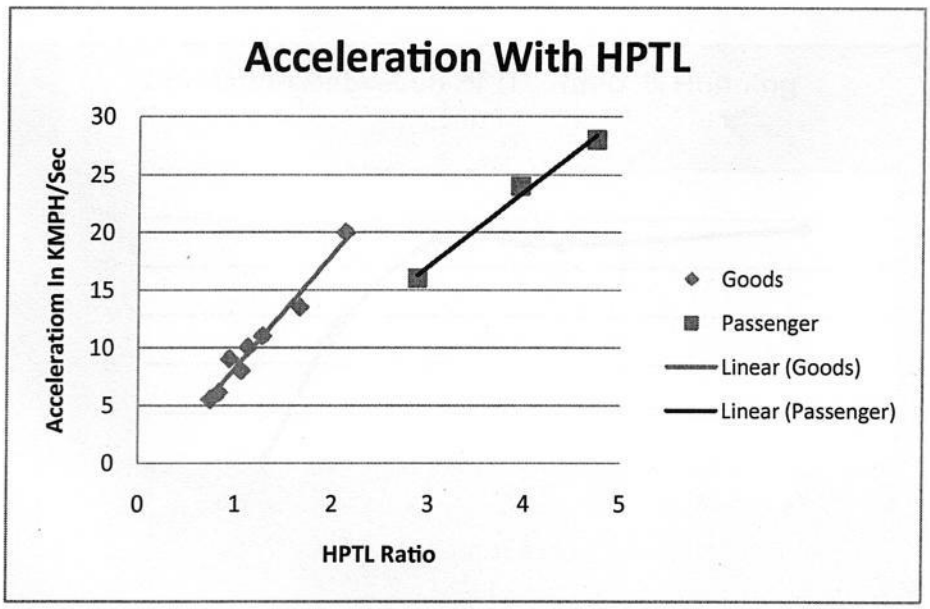
Source : Drawn from data from Appendix IV(e)

Appendix V

Correlation between Acceleration & HP/TL Ratio

	HP/TL Ratio	Acceleration (first 5 Min)	Acceleration (in next 5 Min)
Freight trains	0.74	5.5	4.4
	0.83	6.1	5
	0.94	9	5
	1.06	8	5
	1.13	10	5.6
	1.28	11	5.4
	1.66	13.5	4
	2.13	20	4
Passenger Trains	2.88	16	11
	3.95	24	0
	4.74	28	0

Source: From Speed Time Data in Appendix V



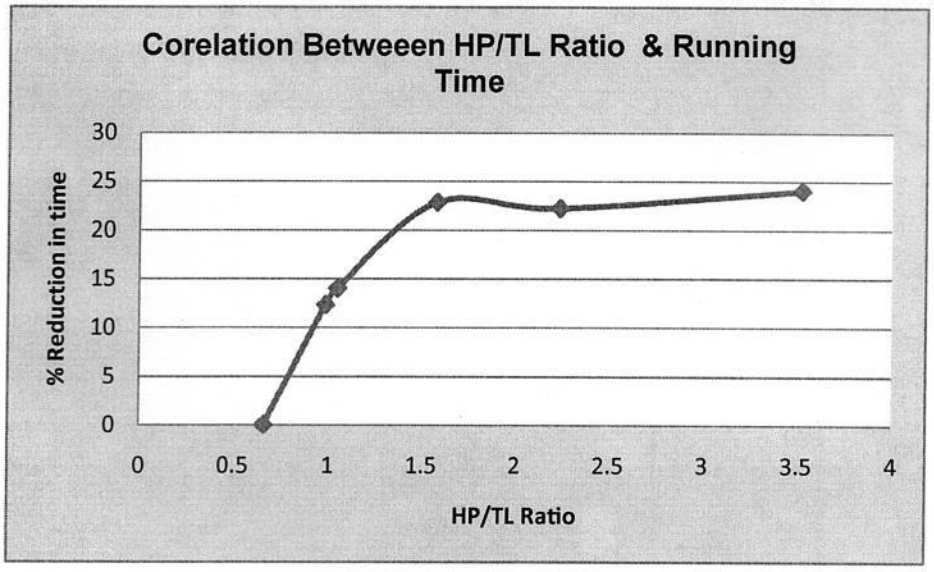
Source: drawn from data above

Appendix VI

Correlation between the HP/TL ratio and reduction in transit time.

Impact of HP/TL ratios on transit times					
Motive Power	Load	HP/TL	Transit Time (minutes)	Reduction in Transit Time (minutes)	% Reduction in Transit Time
1 WDG-2	57 loaded BOXN	0.661	171	0	0
2 WDG-2	57 loaded BOXN	0.985	150	21	12.3
1 WAG-7	57 loaded BOXN	1.048	147	24	14
2 WAG-7	57 loaded BOXN	1.576	132	39	22.8
1 WDG-2	57 empty BOXN	2.235	133	38	22.2
1 WAG-7	57 empty BOXN	3.524	130	41	24

Source: Multidisciplinary Team, *Throughput Enhancement, Railway Board, 2008*



Source: Drawn from data above

Appendix VII

Details of wagons used over IR

Sr. No.	Type of Wagon	No. of Units	Tare Wt (t)	Volume (m3)	Speed (kmph)	Commodity
1	BOX	8885	25	56.3	75	Centre discharge wagons used for carrying coal and other bulk commodities.
2	BOXN	64,469	22.47	56.3	80	Centre discharge wagons for movement of bulk commodities like coal, iron ore, stone, etc.
3	BOXNHS		22.47	56.3	100	Centre discharge wagons for movement of bulk commodities like coal, iron ore, stone, etc.
4	BOBR		25.6	57.2	80	Centre discharge wagons used for carrying coal to thermal power plants, track ballast, stone, etc.
5	BOBRN		25.6	57.2	100	Centre discharge wagons used for carrying coal to thermal power plants, track ballast, stone, etc.
6	BOY (vacuum brake)	900	20.7		50/65	Iron ore
7	BOBS	1,542	30.4	34	100	Ballast and ores
8	BOST		25			Open discharge wagons used for carrying finished steel products and also for coal, stone, etc.
9	BCN	42,957	25.9	104	75	Water-tight covered bogies for cement, foodgrains, and fertilizers
10	BCNA		24.5	106.5	80	Water-tight covered bogies for cement, foodgrains, and fertilizers
11	BCNAHS		24.5	106.5	100	Modified BCNA wagons for carrying cement, foodgrains or fertilizers
12	BCX (vacuum brake)		9,208	27.2	104	Cement, foodgrains, etc.

Source: G. Raghuram and Niraja Shukla, *'Turnaround' of Indian Railways: Increasing the Axle Loading*

Appendix VIII

A. Calculation of requirement of additional locomotives to convert all DUs to multi &

Key data

Traction	Holding	% of Milti DUs
Electric	2502	25%
Diesel	2000	30%

Additional Loco required for Multi

Driving Unit	Single	Multi	% Multi of total DU	Total DU	Additional Loco to convert single to multi	Adding maint. spare (15%)	present Holding	Addition Requir-ement in %
Electric	1237	412	25%	1649	1237	**1422**	2502	64.3
Diesel	875	375	30%	1250	875	**1006**	2000	57.8

B. Saving in WTR due to increased freight average speeds

Freight Lead	Av Speed in KMPH	Transit time both ways way	Loading Unloading time	WTR Days	% reducti on in WTR	Factoring in alredy 25% multi op	Additiona l 5% for operatio nal reliability	Running Time gain from LRDSS report
661	25	2.20	3.00	5.2				171
661	50	1.10	3.00	4.10	21.19	15.89	20.89	132

C. Saving in Transit Time & loco due to increased freight average speeds

	Av Speed	Transit time for av. Freight lead Days	Add half day for wastages & attaching etc	Saving in loco requirement %	Factoring in alredy 25% multi op	Additional 5% for operationa l reliability
Now	25	2.20	2.70			
Proposed (all Multi)	50	1.10	1.60	40.8	30.6	35.56

Appendix IX

Calculation of Requirement of additional Locomotives to operate multiple Driving Units in Different scenario of savings

Approach 1: Factoring WTR improvement on present DU translating into savings of 20% (see appendix VIII for details)

Driving Unit	DU After reduction 20%	Multi Available	Additional Multi required	Single loco available	multi converted from present holding	Additional loco required for remaining multi	Additional loco required adding 15% spare	present Holding	Addition Requirement %
Electric	1319	413	906	1237	618	576	662	2502	26.5%
Diesel	1000	382	618	875	438	361	415	2000	20.8%

Approach 2: Factoring Wagon transit time reduction improvement translating in savings of 35% (see appendix VIII for details)

Driving Unit	DU After reduction 35%	Multi Available	Additional Multi required	Single loco available	multi converted from present single	Additional loco required for remaining multi	Additional loco required adding 15% spare	present Holding	Addition Requirement %
Electric	1072	413	659	1237	618	81	93	2502	3.7%
Diesel	813	382	431	875	438	-14	-16	2000	-0.8%

Approach 3:

A. Working out loco requirement from "no of rakes run" with increased Efficiency at 30%

	Av. Daily Trains run	Trains reduced due to 30% saving	DU required + 5% wastage	Factor Taken: LOCO/DU	Locos Required	Add 15% Maintenance spare	Additional Locos required
Electric							
BOXN	1000	700	735	2.1	1544	1775	
BCN	600	420	441	2	882	1014	
Total	**1600**	**1120**	**1176**		**2426**	2789	287
Diesel							
BOXN	750	525	551	2.2	1213	1395	
BCN	500	350	368	2.1	772	888	
Total	**1250**	875	919		**1985**	**2282**	282

B. Working out loco requirement from "no of rakes run" with increased Efficiency at 20%

	Av. Daily Trains run	Trains reduced due to 20% savings	DU required + 5% wastage	Factor Taken: LOCO/DU	Locos Required	Add 15% Maintenance spare	Additional
Electric							
BOXN	1000	800	840	2.1	1764	2029	
BCN	600	480	504	2	1008	1159	
Total	**1600**	**1280**	**1344**		**2772**	3188	686
Diesel							
BOXN	750	600	630	2.2	1386	1594	
BCN	500	400	420	2.1	882	1014	
Total	**1250**	875	919		**2268**	**2608**	608

Approach 4: Running BOXN with Multi & BCN with single Loco

a. With accounting for increased Efficiency at 30%

	Av. Daily Trains run	Trains reduced due to new WTR	DU required + 5% wastage	Factor Taken: LOCO/DU	Locos Required	Add 15% Maintenance spare	Additional
Electric							
BOXN	1000	700	735	2.1	1544	1775	
BCN	600	420	441	1	441	507	
Total	**1600**	**1120**	**1176**		**1985**	2282	-220
Diesel							
BOXN	750	525	551	2.2	1213	1395	
BCN	500	350	368	1.0	368	423	
Total	**1250**	875	919		**1580**	**1817**	-183

b. With accounting for increased Efficiency at 20%

	Av. Daily Trains run	Trains reduced due to new WTR	DU required + 5% wastage	Factor Taken: LOCO/DU	Locos Required	Add 15% Maintenance spare	Additional
Electric							
BOXN	1000	800	840	2.1	1764	2029	
BCN	600	480	504	1	504	580	
Total	**1600**	**1280**	**1344**		**2268**	2608	106
Diesel							
BOXN	750	600	630	2.2	1386	1594	
BCN	500	400	420	1.0	420	483	
Total	**1250**	875	919		**1806**	**2077**	77

Appendix X

Impact of Running Multiple locomotives on The Line Haul Cost

Line Haul Cost Breakup

		Cost#	% of LH cost
Repair & Maint Cost		677857	18.3
Energy Cost		2288165	61.8
Crew Cost		358215	9.7
	Total	**3324237**	**89.8**
Depreciation Charges		257482	7.0
Interest Charges		118654	3.2
	Total	376136	**10.2**
Total		**3700373**	**100.0**
x1000 GTKM		59208.639	
LH cost per GTKM in Paise		**75.00**	

Sample line haul cost of Electric Locomotives for the Northern Railways 2000-01 (Taken from NR, Head Quarter)

Calculation Table

Item		Single	Multi	Actual
Ratio of Single & Milti DU		0.75	0.25	
Repair & Maint Cost	PU cost factor	1	1.8	
Energy Cost		1	2.1	
Crew Cost		1	1	
Total		3	4.9	
Deprecation Charges		1	2	
Interest Charges		1	2	
Total		2	4	
G. Total		5	8.9	
PU of T Cost-En.cost of DU		4	6.8	
(PU of cost-En of DU)*%of DU		3	1.7	
part of LHC-E		24.36	13.80	38.16
PU Extra Energy Cost (5% of Actual)		0.00	3.09	61.84
Total		24.36	16.90	41.26
PU Factor of GTKM moved		1.00	1.20	
PU LHC After moving fact		24.36	14.08	
part of the LHC-E (total)		26.14	15.11	41.26
for each DU		**34.86**	**60.45**	
% of Cost of running 2 locos in multi				173.40
% saving in Cost of turning 2 locos into multi/loco		LHC without Energy		86.70

Calculation of the Cost increase/decrease in different scenarios

Saving Scenario	Total driving Units	Break up	DU	LH Cost of each DU (without Energy)	Operational cost without Energy (1x2)	Energy Cost **	Total 3+5	% Increase or decrease
			1	2	3	4	5	
Present	1600	multi	400	60.45	24178			
		single	1200	34.86	41831			
					66009	93991	160000	
30% Savings with all Multi	1120	multi	1120	60.45	67698	93991	161689	1.06%
		single						
with all Multi	1280	multi	1280	60.45	77370	93991	171360	7.10%
		single						
Running BCN with single & BOX with Multi								
30% Savings	1000	multi	700	60.45	42312			
	600	single	420	34.86	14641			
					56952	93991	150943	-5.66%
20% Savings	1000	multi	800	60.45	48356			
	600	single	480	34.86	16732			
					65088	93991	159079	-0.58%

** Energy Cost 95% of 61.8 x 1600 (5% already accounted for in multi cost)

REMARKS

Assumptions

1. By multiple operation Maintenance cost will come down by 10% due to reduction in wear & tear.

2. SEC due to multi operation will rise by 5%.

3. Cost breakup structure is taken for the Northern Railway, for IR it could vary.

4. These calculations are illustrative and indicate trend. Actual cost may differ.

Appendix XI

Calculation of Loco requirement

Year	Freight target	Loco holding at Present rate	Additional loco for growth	Total with multi	elect %	additional for Elect	Total holding	Yearly additional requirement	For condemnation	Total yearly additional requirement
2010	896	2500		2500	66		2500			
2011	963	2700	438	3238	70	130	3367	867	150	1017
2012	1036	2900	211	3448	75	302	3750	383	150	533
2013	1114	3100	227	3675	78	412	4087	337	180	517
2014	1198	3300	244	3919	80	491	4409	322	180	502
2015	1288	3500	262	4181	82	574	4755	346	180	526
2016	1385	3700	282	4463	83	619	5082	327	180	507
2017	1489	3900	202	4665	84	665	5330	249	180	429
2018	1601	4100	217	4882	85	714	5597	266	180	446
2019	1722	4300	234	5116		714	5830	234	180	414
2020	1850	4500	249	5365		714	6079	249	180	429
								3579	**1740**	**5319**

Source: Calculated based on the data collected from Electrical Directorate of Railway Board (MoR)

Appendix XII

Year	Normal Growth Pattern (30 Mill MT per year)	Recent Initiatives (CC+10) & others	Normal with recent Initiatives	Additional capacity added by Eastern DFCC	Total	Target
1991	318		318		318	318
2001	473		473		473	473
2003	518		518		518	518
2004	557	0	557		557	557
2005	602	0	602		602	602
2006	632	34	666		666	666
2007	662	65	727		727	727
2008	692	102	794		794	794
2009	722	111	833		833	833
2010	752	101	853		853	896
2011	782	101	883		883	963
2012	812	101	913		913	1036
2013	842	101	943		943	1114
2014	872	101	973		973	1198
2015	902	101	1003		1003	1288
2016	932	101	1033		1033	1385
2017	962	101	1063	235	1298	1489
2018	992	101	1093	235	1328	1601
2019	1022	101	1123	235	1358	1722
2020	1052	101	1153	235	1388	1850

Data from Vision 2020 & various department of Railway Board