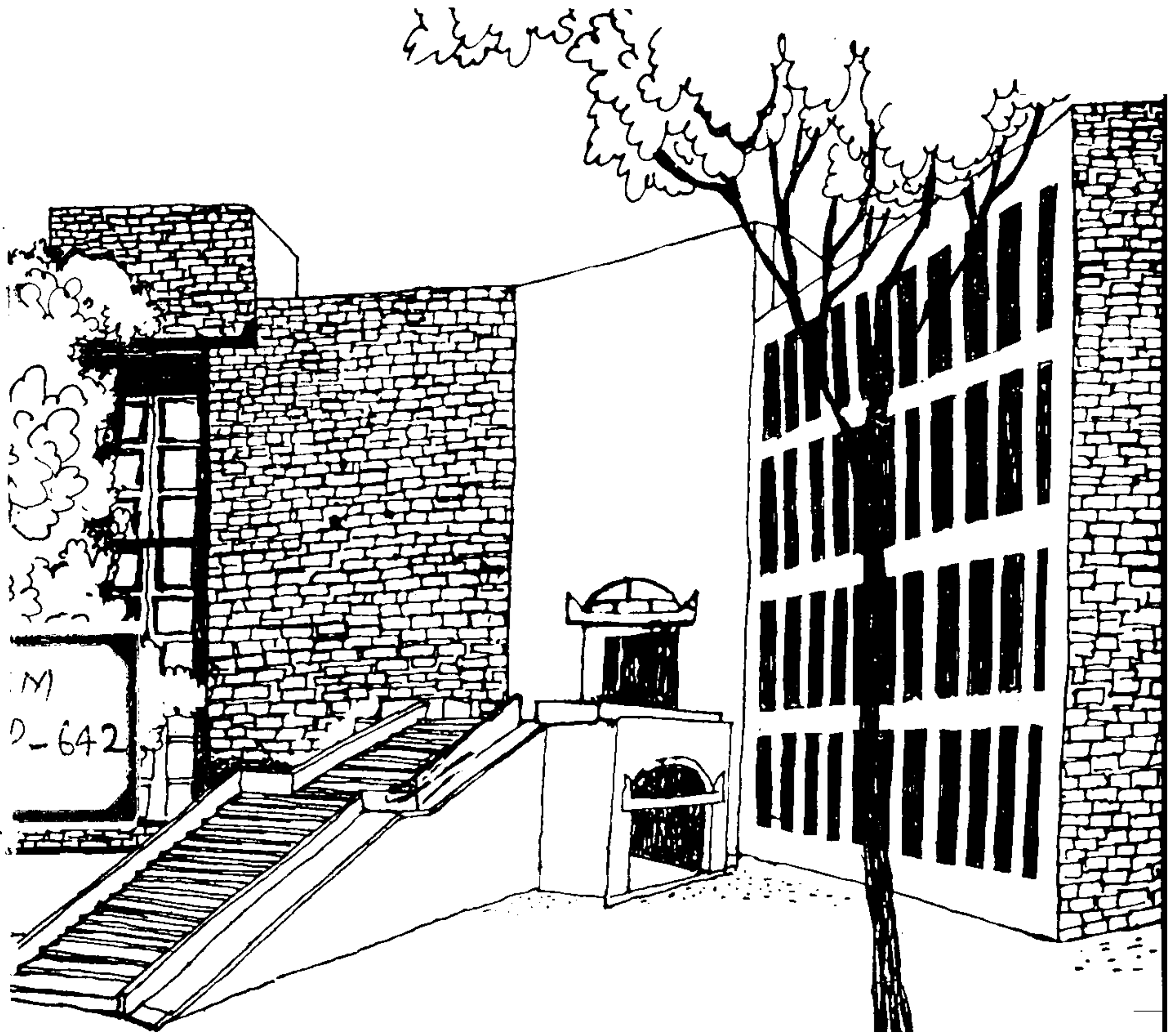
Working Paper



PASSENGER TRAIN CREWS

By

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ABSTRACT

In this paper we discuss the crew scheduling problem in Indian Railways and propose a methodology to minimize crew requirements. In particular, we deal with the scheduling of passenger train crews in Vadodara division of Western Railway.

In Part-I of the paper, we describe the organization of Indian Railways, highlight the decision making process and give a brief description of the crew categories. We end Part-I by giving the regulations relevant for the scheduling decisions and a formulation of the problem as of determining a 'crew link' that requires minimum number of crews.

In Part-II, we describe the 'A-D sequence' methodology and discuss how this is used in evaluating a 'crew link' for the drivers of express trains in Vadodara division. In conclusion, we remark that the methodology is very general and it could be used for scheduling of all category of crews for passenger trains.

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CREW SCHEDULING IN INDIAN RAILWAYS

- A CASE STUDY OF VADODARA DIVISION PASSENGER TRAIN CREWS

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Introduction

In this paper we discuss the crew scheduling problem in Indian Railways and propose a methodology to minimize crew requirements. In particular we deal with the scheduling of passenger train crews in Vadodara division of Western Railway. The methodology, however, is general and is applicable in any railway.

The paper is divided into two parts. In Part-I, we first discuss the crew scheduling problem in general and then cite the example of Vadodara Division. The scheduling procedure as applied to the Vadodara division of Western Railway is presented in Part-II.

Part-I

1. Organization of Indian Railways

Organizationally, the Railway Board is the apex body under the Railway Minister. The Board makes all strategic decisions (decisions having long-term implications) and provides policy guidelines to the nine operating Railways which constitute the Indian Railways. The nine railways are Central, Eastern, Northeastern, Northeast Frontier, Northern, South Central, Southeastern, Southern and

and Western. Each railway further consists of several divisions. For example, Western Railway has eight divisions - Ajmer, Bhavnagar, Bombay, Jaipur, Kota, Rajkot, Ratlam and Vadodara. Tactical decisions (decisions having medium term implications) and coordination among divisions are taken care of at the Railway level. The divisions are the units ultimately responsible for railway operation, making day-to-day operational decisions.

In the context of passenger train crew scheduling, the Board decides on the labour policies and the train services to be provided. Each railway decides on the labour and rolling stock to be employed, and the location of the crew and rolling stock bases. The task of actually scheduling the crew (thereby determining the crew size) is done at the divisional level.

The decision making generally follows a top-down hierarchical approach with the tactical decisions being made, given the strategic decisions, and the operational decisions being made, given the tactical and strategic decisions. It should be kept in mind though that the information flow could be both top-down and bottom-up since decisions at higher levels do depend on consequences at the lower levels.

2. Crew Categories

Stationary and Moving: In the Indian Railways, crews can be categorised as 'stationary' or 'moving'. The stationary crews come back to their base at the end of a working day, for example - gangmen, construction gangs, station staff, office-staff etc. The moving crews move a long with a train and do not necessarily come back to the base at the end of a working day. The account of crew scheduling presented in this paper relates to the moving crews.

Passenger Train and Goods Train: Distinct moving crews are generally used for passenger trains and goods trains. The scheduling approach for these two categories is different since passenger trains are scheduled services, while goods trains are not. We only present the approach for passenger trains.

Passenger Train Crew Categories: There are several categories of crew used in passenger trains. These are:

i) Drivers
ii) Firemen
iii) Motormen
iv) Guards
v) Brakesmen
vi) Conductors
vii) Travelling ticket Examiners
viii) Coach attendents, and
ix) Amenities staff in some of the prestigious trains like safaiwallas, electricians and food service staff.

In this paper, we consider the passenger train drivers of the Vadodara Division (the approach we develop is applicable to the other categories as well).

<u>Driver Categories:</u> Depending upon technical and operational factors of the passenger train services, drivers are categorised into groups. A seperate crew scheduling problem can be posed for each of the groups, though the same approach to crew scheduling can be used for all the groups. The groups are identified based on the following factors:

i. Gauge of the track (Broad, Meter or Narrow)
ii. Type of train (Express/Mail or Passenger), and
iii. Type of traction (Electric, Diesel or Steam).

The drivers considered here are for broad gauge, express/mail trains using electric traction.

3. <u>The Crew Scheduling Problem</u>:

In this section, we define a few necessary terms and then define the problem.

HOER* : Hours of employment regulations. These specify the rules governing the work and rest hours of the crew. The HOER will be elaborated in the next section.

RUN : This is the stretch of a scheduled train service for which a division has to provide the crew. A run may or may not satisfy the HOER, in terms of total continuous hours of duty.

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* The Railways have a document called 'HOER' which specify the rules governing work and rest hours of the crew.

SECTION : This is a part or the whole of run but necessarily satisfying the HOER. If a run satisfies the HOER, then the run is itself a section Otherwise a run has to be cut into sections.

DUTY : This constitutes the continuous working hours for which the crew is paid. It is thus the work period from one rest to another, during which time a crew may have worked over one or more sections.

ASSIGNMENT : This represents, the next duty a crew is asked to perform after completing a given duty at each terminal.

PERIOD : This is the smallest time over which a schedule of train services repeats itself.

CREW LINK : This is a sequence of duties such that:

(a) each duty is assigned to the immediately succeeding duty,

(b) the last duty is assigned to the first, and

(c) the duties together satisfy the HOER.

A crew link may go over many periods. The number of crew required to staff a link is the number of periods that the link goes over.

The crew scheduling problem can be stated as: to determine a set of crew links covering all the considered duties using the minimum crew size.

4. Hours of Employment Regulations (HOER):

The regulations which directly affect the scheduling of drivers have been extracted and interpreted* as follows:

i) The duty hours for a crew includes 'signing on time', 'signing off time', engine attendance time and train attendance time. Such times are specific to each terminal station.

ii) A crew, by plan should not be put on duty for more than 10 hours at a stretch. If the duration of a crew duty happens to exceed 10 hours at a stretch (due to unforeseen circumstances), the crew can claim a rest after working for 12 hours provided a notice of two hours is given for bringing in a relief crew.

iii) Total regular duty hours for a crew should not exceed 104 hours over a two week period. Excess duty hours are paid on overtime basis.

iv) Rest hours should be provided after each duty as follows:

(a) At headquarters (crew base): If the duty has been less than or equal to 8 hours, the crew is eligible for a rest of at least 12 hours. If the duty has exceeded 8 hours, the crew is eligible for a rest of at least 16 hours.

(b) At other stations: The crew is eligible for as much rest as the duty hours that the crew has just had.

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*Rules (ivb) and (vii) are interpretations based on discussions and studying crew link diagrams.

(v) The periodic rest for a crew should be given only at headquarters station and should always include a full night in bed (21.00 hrs to 6.00 hrs). As far as possible it should be given once in ten days. A crew is entitled to five rests of 22 hours or four rests of 30 hours each in a month.

(vi) A crew should not have to work in the night (any time between 21.00 and 6.00) for more than 6 nights consecutively. A crew should come to headquarters at least once in three or four days.

(vii) If a crew is not provided at least one hour rest, then the crew is treated as if on continuous duty.

(viii) If a crew is required for duty before the expiry of the rest period, the crew is entitled for a breach of rest allowance.

5. Crew Scheduling in Practice - Example of Vadodara Division:

Vadodara Division: This is one of the eight divisions of Western Railway. We are concerned with the scheduling problem of drivers of this division, operating broad gauge mail/ express trains using electric traction. Appendix-I gives a currently operating crew schedule, which also happens to be just a single crew link. A topological map of the terminals over which the crews operate is given in Appendix-II.

An important parameter in the crew scheduling problem is the location of the crew's headquarters. This is a major tactical decision with consequences on crew scheduling and crew size. The crews considered in this problem are located at Ahmedabad (ADI).

Identifying the 'Runs': This is usually done at the Railway level. One general principle followed is that the runs for a division should lie within the jurisdiction of the division. Operational economies may not always permit this (since for example the length of a run may be too short). In such situations, a run is allowed to extend into another division; but a suitable exchange is made for the drivers of the other division. From Appendix I & II, we see that all runs going to Valsad (BL) extend into Bombay division beyond Surat (ST). In exchange for this, there are other runs operated by Bombay Division drivers extending to Vadodara and Ahmedabad.

Identifying the 'Sections': All the runs which are being considered also happen to be sections since none of the runs violates the duty hours requirement of the HOER. In fact, it would generally be true that runs and sections are identical since runs are created keeping the divisional jurisdiction in view. A run across most divisions would stay within the HOER.

Identifying the 'Duties' Most sections cannot be combined with other sections to form a duty since either the section is itself too long or a section of proper length may not be immediately available. Thus, in general section themselves would form duties. One exception to this generalization is observable in Appendix-I where:

ST	- BRC	section of 161 Down and
BRC	- ST	section of 162 Up can be combined to form a duty. In fact, this is the current practice.

Period: In the example being considered all trains run daily. Hence, the period is one day.

Assignment: Though Appendix-I does not explicitly state the assignments, we can abstract the same from the crew link. For example: the duty from ADI to BRC by 30 Up is assigned to the duty from BRC to BL by 28 Up and so on.

Crew Link: Currently all the nineteen duties (twenty sections) being considered form part of one link. This link goes over sixteen days, thereby requiring 16 drivers. A general principle followed here is to get long links since then inequalities due to different crew links will be minimized.

PART-II

1. An Approach to solving the Crew Scheduling Problem

The approach to this problem is developed using A-D (arrival-departure) sequence methodology. The output of this methdology should be a set of terminalwise assignments, which amounts to developing a set of crew links.

The A-D sequence methodology can be used in either of the following ways :

(i) to construct an optimal assignment or

(ii) to evaluate a given assignment for optimality and if the same is non-optimal, to improve it to optimality.

The second way is more practical since it is 'incremental' in nature and hence will be used here.

The A-D sequence methodology should be applied at each of the terminals separately.

As regards the HOER, it may not be possible to consider all the regulations initially in the methodology. Once a solution is obtained, we can then (a) examine the same as to whether the other regulations are met and (b) identify marginal changes to satisfy the regulations.

Before we use the A-D sequence methodology, we could analyse the scope for crew reduction. As we see from Appendix-I, sixteen drivers are being used for twenty sections of train runs. The total duty hours of each driver over a period of sixteen days is 106.23.hours. This amounts to 93 hours in a period of two weeks. Five rest periods, each of 22 hours or more in duration have been provided per month. Each of these rest periods include a full night in bed. Given that 16 drivers work for 93 hours each over two weeks, a total of 1488 duty hours have to be provided for in two weeks. Since a driver can work upto 104 hours per week, we would need at least 15 drivers. Thus there is scope to reduce the crew size. The question, therefore, is whether or not we can develop a crew link that satisfies the HOER and uses 15 drivers.

2. <u>A-D Sequence Methodology</u>:

The details of the A-D sequence methodology using the 'incremental' approach are given in the following four steps:

(i) Sequencing the start and finish times: The first step in the analysis is to sequence the 'start' and 'finish' times of the duties at each of the terminals in the order of time over the period of one day. We first define the period to be from 0.00 hours to 24.00 hours at each of the terminals (the period will be redefined in step (iv)).

Start time* is defined such that the crew has time to 'sign on' and attend to engine and train as per requirements before beginning a duty.

Finish time* is defined such that the crew has time to 'sign off' and is then rested so that the crew is ready for another duty.

Considering Surat as an example, from Appendix-I we see that two duties start and finish at Surat (finish on 162 UP and 32 UP and start on 161 DN and 31 DN). Even though 162 UP arrives Surat at 7.16 hours, the crew is effectively available for the next service only after being given 15 minutes to sign off duty and 6 hours and 6 minutes of rest since they would have had to sign on for duty at Surat at 1.25 hours. Consequently, the effective 'finish' time for the duty on 162 UP is 13.22 hours. Similarly for 32 UP the effective 'finish'

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ppendix III gives (i) the total sign on and engine and rain attendance times and (ii) the sign-off times, at he four terminals being considered.

time is 15.00 hours. The effective 'start' time for the duties on 31 DN and 161 DN are 20-20 hours and 1.25 hours respectively. The sequence of 'start' and 'finish' times are shown in figure one.

Developing a Representative Inventory Status: We can consider each duty 'finish' as adding to an "inventory" of crews by one unit and each duty 'start' as depleting the "inventory" by one unit. Giving the value of +1 to each 'finish' and -1 for each 'start' we have a representative inventory status. Figure one shows this for the case of Surat. These figures are only representative of the inventory status while not giving the ideal status. In the specific case of Surat, this is because we are starting the period with a 'start', thereby obtaining a negative status. The inventory status is really not negative as a 'finish' from the previous period would serve this need of a 'start'. We can avoid this problem of a negative status by suitable redefinition of the period (step(iv).

Developing an Ideal Inventory Status: We obtain the ideal inventory status by adding the magnitude of the most negative representative inventory to all the representative inventory figures. In the specific example at Surat, we add one (because -1 is the most negative) to the inventory figures to get the ideal status as seen in figure one.

Figure-1

Train No.	Finish of duty	Start of Duty	Train No.	Representative Inventory Status	Ideal Inventory Status
		1.25	161	-1	0
162	13.22			0	1
32	15.00			1	2
		20.20	31	0	1

The ideal inventory status represents the inventory of crew after each start/finish event, under optimality. For example the inventory of available crew (rested and ready for service) is zero between 1.25 and 13.22 hours The zero inventory has a special meaning since we can view it as 'barrier' dividing the start/finish events.

(iv) Redefinition of the Period and Identifying Blocks: We redefine the period from after the zero of the ideal inventory status. In the Surat example we show the start and finish sequence in the redefined period, in figure two.

Figure - 2

Train No.	Finish of Duty	Start of Duty	Train No.	Ideal Inventory Status	
162	13.22			1	
32	15.00			2	Block
		20.20	31	1	
		1.25	161	0	

The set of start and finish events which are not divided by the barrier caused by a zero, will be called as a "block". As can be seen in figure two, there is one block. It should be noted that in any general example of a termina, there can be more than one block depending upon the actual start-finish sequence and the consequent ideal inventory status.

Now we state an important result without proof*: "A crew assignment is optimal if and only if it does not cross the block barrier". In case the crew assignment crosses the block barrier, then as many additional crew as the number of times the block barrier is crossed will be required.

We can now study the current crew assignment for optimality by seeing whether the assignment crosses the block barriers identified by the start/finish sequences at each of the terminals. Appendices IV, V, VI & VIII demonstrate this at Ahmedabad, Vadodara, Surat and Valsad respectively.

3. Analysis

1. Ahmedabad (Appendix IV): Since the block barrier is crossed once, it seems as though there is a potential saving of one crew. Keeping in mind that we need to provide for the longer rest periods at the headquarters, it can be established that a different crew assignment will not be possible. Thus an additional crew is

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A proof for this result is available in the paper utilisation of Transportation Units: An Optimal Allocation Study, OPSEARCH, Vo.17, No.2 May 1980, by KV Ramani and G Raghuram.

required just to satisfy the periodic rest requirements. The assignment with the '*' marks are the ones where a 22 hours rest has been provided. If the periodic rest requirements can be relaxed marginally, then a crew saving would be possible at Ahmedabad. We do not present this analysis here, but the reader can attempt one.

2. Vadodara (Appendix V) : No crew saving at Vadodara is possible since the assignment does not cross the block barriers.

3. Surat (Appendix VI) : No crew saving is possible at Surat since the assignment does not cross the block barrier.

4. Valsad (Appendix VII) : Since the block barrier is not crossed, no crew saving is possible. But consider the following analysis: We can actually use the crew coming on 28 UP to go out on 9 DN without altering crew requirements. Since this would be done with the crew waiting for almost one period (6.35 hours to 3.05 hours) at Valsad, we can examine whether the 'sections' on 28 UP and 9 DN can be combined into a 'duty'. This saves the crew a day's waiting and consequently one crew is saved. Unfortunately, this 'duty' (Starting at 21.55 hours and finishing at 10.35 hours) violates the 10 hour rule of the HOER. We then push our luck to see if a 'duty' can

be constructed with 28 UP and 27 DN. This 'duty' (starting at 21.55 hours and finishing at 6.40 hours) satisfies the HOER. But the crucial question is whether a crew coming on 28 UP at 1.59 hours can continue work by 27 DN at 2.20 hours. This 'duty' is very dependent on train punctuality. If more slack could be provided by advancing the arrival of 28 UP at Valsad and/or postponing the departure of 27 DN at Valsad, then one crew can be saved.

Conclusions

This methodology allows us to evaluate crew links and identify crew savings. More importantly, it gives insight, into the critical factors that need to be looked into, so that crew savings can be achieved.

The whole procedure outlined in the preceding sections can be computerised. This makes sensitivity analysis on parameters very simple.

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Appendix 1

Schedule of Special A 'Drivers' in Vadodara Division, Western Railway

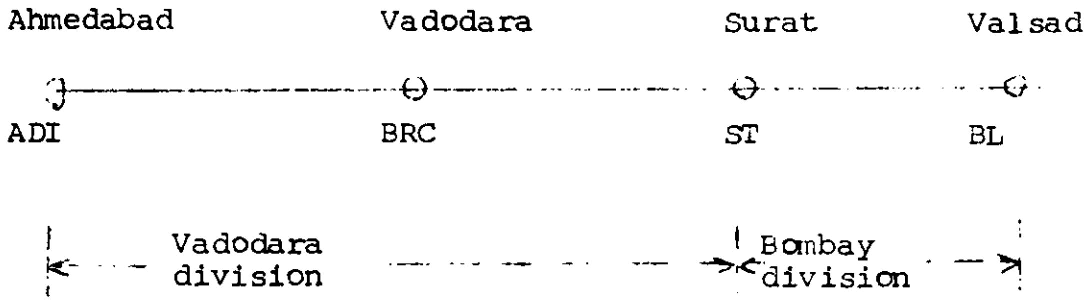
Grade: Rs.550-750
Headquarters at ADI
Section served ADI BRC ST BL

Days	Train No.	Sec. from	On duty	Dep. of train	Sec. to	Time arrived	Time off duty at shed/ stn.	Total duty hrs.	Rest at out stn.	Rest at HQ
1	2	3	4	5	6	7	8	9	10	11
1	30UP	ADI	13-40	14-40	BRC	17.20	17-45	4-05	-	17-00
1/2	28UP	BRC	21-55	22-55	BL	1.59	2.15	4.20	4.05	-
2	15DN	BL	11.45	12.00	ADI	19.35	20.00	8.15	9.30	-
3	10UP	ADI	17.10	18.10	BL	00.15	00.30	7.20	-	21.00
4	11DN	BL	9.20	9.35	ADI	15.50	16.15	6.55	8.50	-
5	6UP	ADI	21.35	22.35	BL	3.36	3.51	6.16	-	29.20*
6	5DN	BL	23.33	23.48	ADI	5.00	5.25	5.52	19.42	-
7	165UP	ADI	19.15	20.15	BRC	22.15	22.45	3.30	-	13.50
8	166DN	BRC	3.55	4.55	ADI	7.10	7.40	3.45	5.10	-
9	12UP	ADI	6.10	7.10	BL	12.32	12.47	6.37	-	22.30*
10	19DN	BL	1.23	1.38	BRC	5.55	5.55	4.32	12.36	-
10	24UP	BRC	12.05	13.05	BL	16.35	16.50	4.45	6.10	-
11	9DN	BL	3.50	4.05	ADI	10.10	10.35	6.45	11.00	17.15
12	32UP	ADI	3.50	4.50	ST	9.10	9.25	5.35		-
13	161DN	ST	1.25	1.40	BRC	3.29			16.00	-
13	162UP	BRC	-	5.15	ST	7.16	7.31	6.06		
13/14	31DN	ST	20.20	20.35	ADI	00.50	1.20	5.00	12.49	-
14	- - - - -	- - -	R E	S T	- - -	- - -	- - -	- - -	- - -	-
15	16UP	ADI	6.40	7.40	BL	14.40	14.55	8.15	-	29.20*
16	27DN	BL	2.05	2.20	BRC	6.10	6.40	4.35	11.10	-
16	29DN	BRC	17.35	17.50	ADI	20.10	20.40	3.05	10.55	-
								106.23	127.12	150.25

1. Total Drivers = 16 Nos.
2. Total Duty hours in a fortnight = 93.00 hrs
3. Total rest more than 22 hrs with NIB = 5 in one month

* Night in bed

Appendix - 2



Appendix - 3

		Sign on +Attendance times	Sign off Time
Ahmedabad	(ADI)	60 minutes	25 minutes
Vadodara	(BRC)	60 minutes	25 minutes
Surat	(ST)	15 minutes	15 minutes
Valsad	(BL)	15 minutes	15 minutes

Appendix - 4

Ahmedabad

Train No.	Finish time	Start time	Train no.	Ideal Inventory status
29	8.40			1
15	12.00			2
31	13.20			3
		13.40	30	2
		17.10	10	1
5	17.25			2
		19.15	165	1
166	19.40			2
		21.35	6	1
9	22.35			2
		3.50	32	1
11	4.15			2
		6.10	12	1
		6.40	16	0

Appendix - 5

Vadodara

Train No.	Finish time	Start time	Train No.	Ideal Inventory status
19	10.27			1
27	11.15			2
		12.05	24	1
		17.35	29	0
30	21.50			1
		21.55	28	0
165	2.15			1
		3.55	166	0

Appendix - 6

Surant

Train No.	Finish time	Start time	Train No.	Ideal Inventory status
162	13.22			1
32	15.00			2
		20.20	31	1
		1.25	161	0

Appendix - 7

Valsad

Train No.	Finish time	Start time	Train No.	Ideal Inventory status
28	6.35			1
10	7.50			2
		9.20	11	1
6	10.07			2
		11.45	15	1
12	19.24			2
24	21.35			3
16	23.10			4
		23.33	5	3
		1.23	19	2
		2.05	27	1
		3.05	9	0