A DECISION SUPPORT SYSTEM FOR IMPROVING RAILWAY LINE CAPACITY

By

G. Raghuram

&

V. Venkata Rao

W P No. 839

December 1989

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INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD-380 056
INDIA

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G.RAGHURAM and V. VENKATA RAO

Indian Institute of Management, Ahmedabad - 380 056

1. INTRODUCTION

In any Railway, high investments are involved in providing additional infrastructure in the form of improved signalling, additional stations, additional tracks at stations, and additional tracks between the stations to improve line capacity. It is therefore essential to determine the existing line capacity and then evaluate rigorously the various investment alternatives for improving it. Determination of the line capacity of a section cannot be done analytically since there are a large number of interacting variables and other operational constraints that determine the capacity.

The traditional approach that Indian Railways use to determine line capacity is train charting. Here all the passenger trains which are pre-scheduled are first depicted graphically, and then as many freight trains as possible are fitted into these charts called Master Charts. This approach is necessitated since the objective of the Railways is to maximize the throughput of freight trains - which earn most of the revenue - for given schedules of passenger trains. Train charting is also used to monitor and control train movements.

This paper describes a Decision Support System (DSS) for determining line capacity in terms of the maximum number of freight trains that can be run for various investment alternatives. This DSS essentially replaces the manual approach of developing a Master Chart with a computer aided approach. The paper highlights the key data structures and the algorithm used and discusses some experimental results obtained using the DSS.

2. DECISION SUPPORT SYSTEM

2.1 Definitions

1. A <u>section</u> is the portion between two major yards of a Railway network. Interactions between trains within a section are significant while those between sections are not significant.
2. A <u>station</u> or a <u>control point</u> is a point in a section where train movements can be regulated.
3. A <u>block</u> is the segment of track between two adjacent stations.
4. <u>Block working time</u> is the time necessary for information and signal exchanges to take place before another train can safely occupy the same block.

2.2 Capabilities of the Decision Support System

The DSS allows a user to input data related to passenger train schedules, stations, and tracks in a section, choose values of several parameters, and then schedule as many freight trains as possible in the section. The parameters that can be experimented with are:

1. Desired starting times of freight trains at major yards
2. Speed of a freight train
3. Block working time
4. Track configuration and operation (single line vs double line)
5. Number and location of sidings and platforms at a station
6. Number and location of stations
7. Schedules of passenger trains.

2.3 Essentials of Data Representation

2.3.1 Representation of stations. The relevant details of a station are represented in the form of a set of three matrices, generated from station diagrams available with the Railways. These matrices contain the following information:

a) Which of the tracks within the station can be accessed from one end, and which from the other end;

b) For each track, whether it is a main line or a siding, whether there is a platform facing it, and in which direction(s) it is signalled.

Appendix-I describes the coding of station diagrams with the help of an example.

2.3.2 Representation of passenger train schedules. Passenger train arrival and departure timings are given for each station along with the track occupied. If the arrival time of a train is equal to its departure time at a station, then the train does not stop there.

2.4 Essentials of the Model

2.4.1 Assumptions.

1. Passenger train timings are fixed
2. All freight trains are identical, and have the same priority
3. A freight train runs at a constant speed. Acceleration and deceleration times are ignored.
4. Passenger trains have absolute priority over freight trains.

2.4.2 How the model schedules a freight train. The freight trains are scheduled by the system one after the other, that is, until the time-path of a freight train from one terminal to the other is determined, the scheduling of another freight train does not begin. The system, while scheduling a train, uses two types of moves called forward move and backward move. To decide the time at which a train can depart from a station, the system uses the concept of a prohibited interval. Further, track occupancy information for each station is stored and updated as the freight trains are scheduled, and is used for selection of tracks by trains.

Prohibited Interval. A prohibited interval in a direction for a station is a time interval in which a freight train cannot depart from the station in the given direction. This is determined by the safety requirement that two trains cannot occupy a block simultaneously. Consider a train departing from station i at time A and and reaching station i+1 at time B as shown in Figure-1. If Ts is the specified block working time, then (B+Ts) = D is the earliest time when another train can be scheduled for departure from i. This forms the upper time limit of the prohibited interval. Similarly, (A-Ts) is the latest time at which a train can reach station i+1. Correspondingly, if TT is the travel time for the freight train between i and i+1, then (A-Ts-TT) = C is the lower time limit of the prohibited interval.

```
i+1  __________________________________________________
                         *|   |      *|
|Distance               * |   |     * |
|                      *  |   |    *  |
|_____               *    |   |   *   |
 Time               *     |   |  *    |
          C  *            |   A *    B    D
i     ____|*__________|___|*_____|___|__________
          |    TT     | Ts | Ts |  | Ts |
          |   Track Release Time>|      |
          |<------Prohibited Interval---->|
```

Figure No. 1

Forward Move. Given the time a freight train is available for departure at the starting station, the first check is to see whether it is in a prohibited interval or not. If it is not the case, the train can move to the next station and the desired arrival time in the next station can be calculated. If the departure time is in a prohibited interval, the ending time of the prohibited interval becomes the departure time and again the desired arrival time at the next station can be calculated. If the desired arrival time at a station occurs when there is no prohibited interval, or during a prohibited interval with track availability, then departure times can be calculated as mentioned above. If the desired arrival time at a particular station occurs during the prohibited interval and at a time at which no tracks are available for admitting the train, then the first possible arrival time into that station is calculated. In such an event, the train has to be re-scheduled at the earlier station for which a backward move has to be done.

Backward Move. Given the first possible arrival (after the desired arrival) at a station, the departure time at the previous station is calculated. If the train can find a track to stay in the previous station from the originally calculated departure time to the newly sought departure time, then the train is rescheduled by holding it in the earlier station. If the train cannot be held in the earlier station until the desired time of departure, then a different arrival time at the previous station has to be calculated. This would then necessitate a backward move once again.

If more than one track is available at a station, then priority is given to a track that is not accessible for train movement in the opposite direction so as not to reduce the flexibility of the movement in the opposite direction. Once a freight train has been scheduled upto the final station, then its schedule is frozen, the prohibited intervals updated, and the scheduling of the next freight train begun. Appendix-II gives the pseudo code with the diagrammatic logic for scheduling a freight train.

3. EXPERIMENTS AND RESULTS

The computerised DSS was used to perform certain experiments on an important section of the Western Railway (a zone of the Indian Railways) between Ahmedabad and Baroda stations. This 100 km section has 18 intermediate control points with an average block length of 5.3 kms. The section is entirely double tracked, except for a 4 km block between control point 14 (Vasad Junction) and control point 15 (Vasad 'A' Cabin) where a river crossing takes place. There are 26 passenger trains running in this section, 13 in each direction.

3.1 Performance Measures

There is an inherent problem with the measurement of the maximum number of freight trains that can be run on the section. Generally, the number of trains can be increased only at the cost of sectional travel time. Thus, along with the number of freight trains, average sectional travel time of the trains could also serve as a performance measure. Accordingly, the capacity of the section could be measured as follows:

i) Number of freight trains that reach the terminals in a given time span (say 24 hours).

ii) Number of freight trains that have their sectional travel times less than or equal to k (k >=1) times a desirable sectional travel time. (The desirable travel time could be based on travel time estimates, or operational constraints like crew changes).

The measure used in the experiments is the first one.

3.2 Firing of Trains

While conducting any experiment with the DSS, the origin and the time at which freight train departures are sought (fired) have to be input. Possible firing rules are:

Time. i) Fire all trains at the same time, say 0 hrs. (The actual departures will automatically be found by the program).

ii) Fire trains immediately after fast moving passenger trains and immediately before slow moving passenger trains (since these are supposed to yield good travel times for the freight trains which are slower than the fast passenger trains and faster than the slow passenger trains). After one freight train is fired for each passenger train, a second could be considered.

The rule used in the experiments is the first one.

Sequence of origins. Trains are fired in sets of k (1 <= k <= maximum number of trains) alternately from each origin. The value of k used in the experiment is k = 1.

3.3 Description of Experiments

Experiment I. The capacity and average travel time over the section have been measured for three values of the average speed (20 kmph, 25 kmph and 30 kmph) and three values of the block working time (2 min, 3min and 4 min). The results are given in the table below for the Ahmedabad-Baroda (AB) and Baroda-Ahmedabad (BA) directions respectively:

Block Working Time (Minutes)	Speed (kmph)	20		25		30	
		AB	BA	AB	BA	AB	BA
2	Max. # of Freight Trains	22	25	31	35	42	48
	Avg. Section Travel Time (Min)	820	702	624	565	563	528
3	Max. # of Freight Trains	20	25	31	35	40	42
	Avg. Section Travel Time (Min)	849	731	666	612	579	571
4	Max. # of Freight Trains	19	23	26	30	33	36
	Avg. Section Travel Time (Min)	863	765	697	647	646	589

Given that the average block length is 5.3 kms, the speeds reflect a travel time which is larger than the block working time. This is established by observing that the impact on capacity and average travel time due to the change in speed is larger than the change in block working time. Further, the impact of change in block working time is more significant at higher speeds. It can also be observed that the BA direction performs consistently better than the AB direction. This could be a reflection of the passenger train schedules and/or the track layouts at the stations favouring train movements in the BA direction.

Experiment II. The capacity and average travel time of the section have been measured by considering the block between Vasad Junction to Vasad 'A' Cabin as (a) single track and (b) double track. The results are as follows:

Speed (kmph) and Block Working Time (Minutes)		Single Track		Double Track	
		AB	BA	AB	BA
[20, 2]	Max. Number of Freight Trains	22	25	24	26
	Avg. Section Travel Time (Min)	820	702	794	728
[20, 4]	Max. Number of Freight Trains	19	23	19	26
	Avg. Section Travel Time (Min)	863	765	838	752

The above results indicate that the double track performs at least as well as the single track with respect to the capacity measure. In cases where the capacity has not improved, the average sectional travel time has reduced. The possible explanation is that the existing single track block operates like an efficient 'server' in a queuing model, so that when the capacity of the server is increased, the effect is felt as reduced waiting times in the section to access the block. This behaviour also reflects the existence of other bottlenecks in the section.

Experiment III. Sectional travel times depend on the departure times since freight trains give priority to passenger trains. It would therefore be useful to identify such freight train departure times that take less travel time over the section, thus aiding despatch decisions. A graph (Appendix III) between the destination arrival time and various departure times at the origin for one freight train has been developed for both the AB and BA directions, with all the passenger trains operating as per schedule. For this experiment, a single freight train was fired and then deleted, every 20 minutes. Good departure times are those where section travel times are less - i.e., those at the end of the flat portions of the graph. For example, in the AB direction, any departure between 00.20 and 03.20 would bring the train into the destination at 07.40. Therefore a departure time around 03.00 is preferable to one around 01.00. The steep portions of the graph indicate that the travel times are highly sensitive to the departures in such portions.

4. LIMITATIONS OF THE STUDY

1. The model's approach of scheduling freight trains is not necessarily an efficient one. A more realistic approach could be to schedule the freight trains concurrently in different parts of the section.
2. Many of the constraints observed by the model are in reality quite flexible, and are violated frequently by the train controllers. For example, online changes are made in emergencies by delaying passenger trains, or by receiving them on tracks not normally nominated. As the model does not permit such flexibilities, it serves only as a planning tool and cannot assist in the real time control of train movements.
3. Trains terminating/originating or leaving/entering the section at intermediate stations are not considered.
4. The experiments presented here reflect only a subset of the range of experiments possible with the model.

5. CONCLUDING REMARKS

1. This model can be used not only for planning line capacity, but also for short term planning of maintenance for tracks, overhead equipment, etc. and planning during disruptions due to accidents.
2. This model has been used for training purposes in programmes for Railway officials.
3. Conceptual developments arising out of working with this model have helped influence the development of a commercial package for line capacity planning.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of Mr. Lil Mohan, Mr. Devarajan, Mr. Binoy George and Mr. Kirit Viradiya in developing the software.

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APPENDIX-I

CODING THE STATION DIAGRAMS

<u>Matrix</u> <u>ACL:</u> Physical accessibility matrix between mainline tracks on the left side of the station and tracks in the station. Each row applies to one track on the left side of the station. Each column applies to one track in the station. A '0' in a cell of the matrix indicates that the corresponding column-track cannot be accessed by the row-track, and a '1' indicates accessibility.

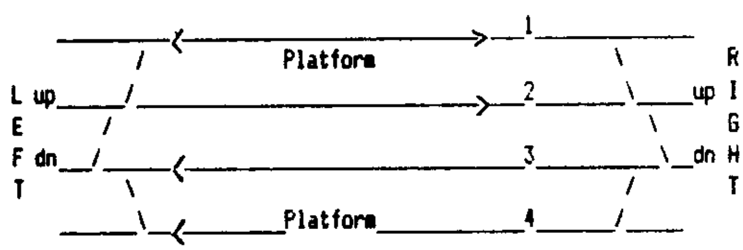
<u>Matrix</u> <u>ACR:</u> This is the same as ACL, except that each row here applies to one track on the right side of the station.

<u>Matrix</u> <u>STR:</u> This has three rows and as many columns as there are tracks in the station. First row indicates for each of the station tracks, whether the track can be operationally accessed by trains going in both directions (value of cell = B), or can be accessed by trains going in up (value = U) or down (value = D) direction alone. The second row indicates whether a track is a siding (value = S), or a mainline track (value = M). The third row indicates whether a track has a platform facing it (value = P), or not (value = N).

The distinction between a mainline track and siding is made because run-through trains using the siding will need more time than while using the main line, in order to safely negotiate the switch. The distinction between a track with a platform facing it and one without it is made to ensure that stopping passenger trains use the tracks with a platform.

<u>Illustration:</u> The above three matrices are shown in detail for an example station whose diagram is given below in Figure 2.

Name of the Station: Utarsanda



Matrix ACL

Track No	1	2	3	4
U	1	1	0	0
D	1	1	1	1

Matrix ACR

Track No	1	2	3	4
U	1	1	0	0
D	1	1	1	1

Matrix STR

Track No	1	2	3	4
	B	U	D	D
	S	M	M	S
	P	P	P	P

Figure No.2

APPENDIX - II

PSEUDOCODE FOR SCHEDULING A FREIGHT TRAIN FROM STATION-1 TO STATION-n

Variable Names:

i . Index of a station. i=1 indicates first station, i=n indicates last station.

TA(i) Time of arrival into station i, sought by the train under consideration.

ST(j) Starting time of the jth prohibited interval in the station under consideration.

ET(j) Ending time of the jth prohibited interval in the station under consideration.

TAF(i) Earliest possible time of arrival into ith station, if TA(i) is not possible.

TT(i-1,i) Time of travel between stations i-1 and i.

TR(j,k) This is the time of availability of track k for interval j and is defined as:
Case (i): The track is available all through the interval: TR(j,k) = latest time before ST(j) at which track k gets released.
Case (ii): The track is occupied partially during the interval: TR(j,k) = latest time before or at ET(j) when track k gets released.

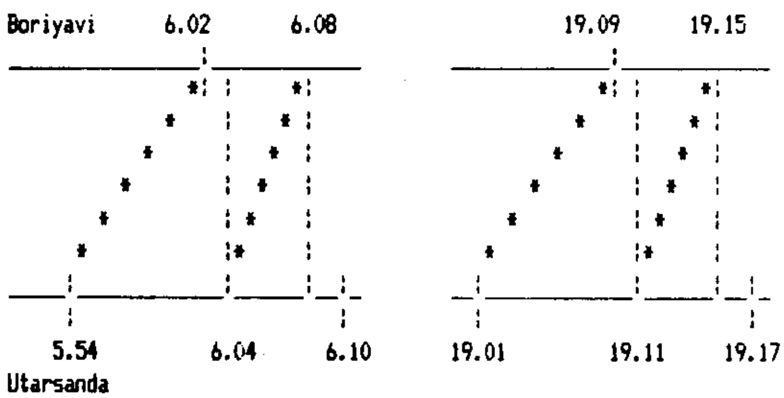
TD(i) Time of first possible departure from station i.

TDF(i) Time of departure sought to suit TAF(i+1) in a backward move.

The ST, ET and TR arrays for a station are shown in Figure 3.

Illustration:

Name of the station: Utarsanda
Travel time for freight train = 8 minutes; Block working time = 2 minutes



Prohibited Interval-j	ST(j)	ET(j)	TR(j,1)	TR(j,2)
1	5.54	6.10	6.06	0
2	19.01	19.17	19.13	0

Figure No. 3

MAIN (FORWARD MOVE) ROUTINE

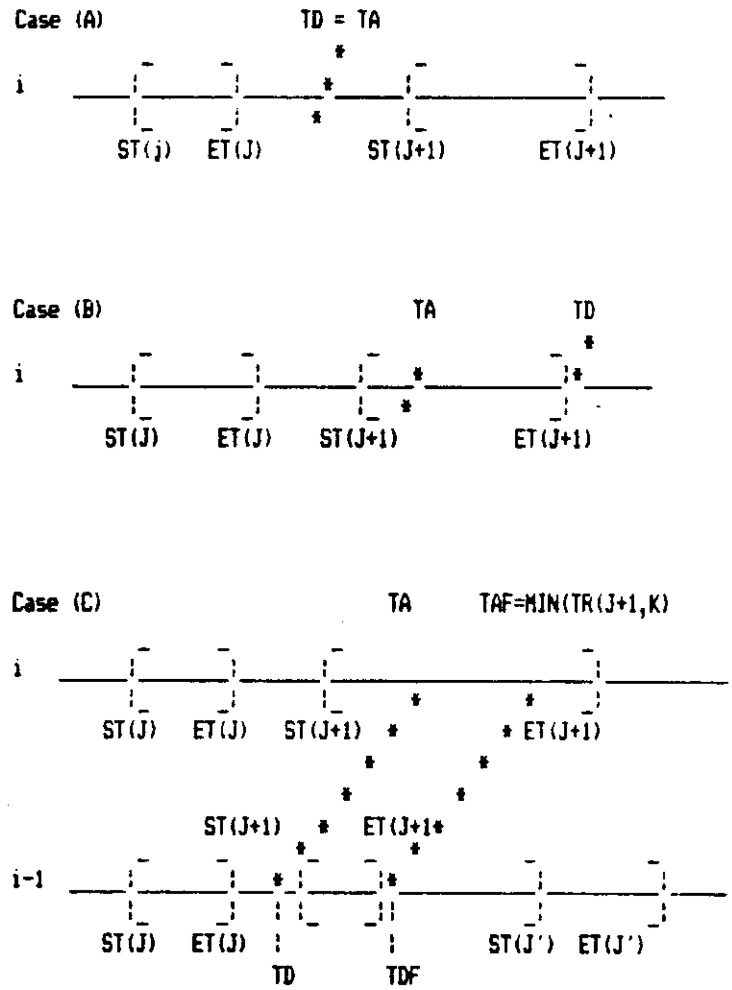
```
BEGIN
    i <-- 1
    WHILE  i <=  n DO
      LET J <-- Arg Max { ET(j):ET(j) <= TA(i) }
                      j
      IF  TA(i)  <  ST(J+1)
      THEN TD(i) <-- TA(i)                          )
             SELECT TRACK                           ) (A)
             i <-- i+1                              )
             TA(i) <-- TD(i-1) + TT(i-1,i)          )
      ELSE
             IF TA(i) >= Min { TR(J+1,k) }
                             k
             THEN  TD(i) <-- ET(J+1)                )
                   SELECT TRACK                     ) (B)
                   i <-- i+1                        )
                   TA(i) <-- TD(i-1) + TT(i-1,i)    )
             ELSE
                   TAF(i) <-- Min { TR(J+1,k) }      )
                                  k                 ) (C)
                   BACKWARD MOVE                    )
             ENDIF
       ENDIF
    ENDWHILE
 Update ST, ET and TR arrays
 END
```

BACKWARD MOVE ROUTINE

```
  BEGIN
     SELECT TRACK
     I <-- i-1
     TDF(i) <-- TAF(i+1) - TT(i,i+1)
     LET J <-- ARG MAX { ET(j):ET(j) <=TD(i)}
                   j
     LET J <-- ARG MIN { ST(j):ST(j)> TDF(i)}
                   j
     IF there exists a k such that TR(j,k)<= ST(J+1)
        for each j belonging to [J+1, J'-1]
     THEN
         TD(i) <-- MAX { TDF(i), ET(J'-1)}          )
         i <-- i+1                                  ) (D)
         TA(i) <-- TD(i-1) + TT(i-1,i)              )
     ELSE
         TAF(i) <-- MIN      MAX       TR(J,k)      )
                     k    J+1<=J<=J'-1              ) (E)
         BACKWARD MOVE                              )
     ENDIF
  END
```

(A) Arrival and immediate departure possible
(B) Arrival, but departure at the end of prohibited interval.
(C) Requested arrival not possible, hence backward move.
(D) Track available for train to stay from arrival to new departure.
(E) Track not available. So backward move again.

Cases (A), (B) and (C) are illustrated in Figure 4.



- If no track is continuously free between TD and TDF, then BACKWARD MOVE again.
- If a track is free, but TDF is in the middle of a prohibited interval, revised TD=ET of prohibited interval.
- Otherwise, revised TD = TDF.

Figure No. 4

APPENDIX - III

ARRIVAL TIME AT DESTINATION
AS A FUNCTION OF
DEPARTURE TIME AT ORIGIN