A STUDY OF THE PROBLEM OF IMPROVING THE UTILIZATION OF THE NON-SUBURBAN PASSENGER FLEET IN INDIAN RAILWAYS

G. Raghuram
Public Systems Group
Indian Institute of Management, Ahmedabad
Pin code 380 015 India

1 INTRODUCTION

One of the objectives of the Indian Railways is to provide convenient and comfortable passenger services. There are broadly two categories of passenger services, viz. suburban and non-suburban. Suburban services mostly operate in the five major cities : Bombay, Calcutta, Delhi, Madras and Hyderabad as closed and independent systems. The non-suburban services extend all over the country and can broadly be categorised as follows :

1. Slow moving passenger services, usually running for intermediate distances;
2. Mail/Express services, over intermediate long distances that include a night as part of the journey; and
3. Mail/Express services, over intermediate distances that travel purely by day.

The number of suburban and non-suburban services has been steadily increasing and is expected to follow the trend in the future. The following table gives an idea of the increasing trend.

Table: Quantum of Passenger Services Provided

Year	Suburban (Million)			Non-suburban (Million)		
	Train Kms	Vehicle* Kms	Passenger Kms	Train Kms	Vehicle* Kms	Passenger Kms
1950-51	9.28	119.8	6,551	154.0	2,678	59,966
1960-61	14.05	196.8	11,770	190.0	3,594	65,895
1970-71	23.05	369.4	22,984	225.0	4,636	95,136
1978-79	33.69	566.2	43,439	249.0	5,564	149,506
1979-80	35.05	587.6	38,730	254.0	5,622	159,927
1980-81	35.55	601.5	41,086	258.0	5,582	167,472.
1981-82	36.30	612.2	43,965	255.0	5,599	176,822
1982-83	37.29	631.6	45,789	265.0	5,942	181,142

Source: Facts and Figures (1982-83) Indian Railways (3)

* Numerically, one coach = two vehicle units, though the two terms 'coach' and 'vehicle' are used interchangeably in the rest of the text. Physically, the basic unit is a 'coach', being the general term for an element of the set called 'fleet'.

As of 1982-83, there were about 2,800 coaches used for suburban services and about 35,000 coaches used for non-suburban services. The average utilization of a suburban coach is of the order of 350 kms per day, whereas for a non-suburban coach it is of the order of 260 kms per day (these figures have been arrived at keeping in mind that 14 per cent of the coaches are at any time in major maintenance or kept as spare). There is obviously a difference in the utilization between suburban and non-suburban coaches. Without ruling as to whether the utilization of suburban coaches is optimal or not, one can attribute this difference to the fact that suburban services operate as closed and independent systems with a high frequency of service. The scheduling of vehicles to provide these services is an easy task. As regards non-suburban passenger services, the scheduling of vehicles is not that easy, since such services go over intermediate to long distances across various parts of the country. It is precisely because of this, that the problem of scheduling these vehicles deserves a closer look.

Given that an average life of a coach is 40 years, on the average we would need to replace about 900 coaches a year. Indian Railways provide about 1,200 to 1,300 coaches every year. Thus, the net addition is limited to under 400 coaches, i.e. about 1 per cent of the stock. The constant growth of traffic out-strips the additions provided. Further, even if one were able to manufacture more coaches, the cost per coach ranges any where between 15 to 30 lakhs rupees. Hence, it is important to study ways and means by which utilization of the coaches for non-suburban services can be improved to meet the challenges of catering to an increasing demand for passenger services under tight budget constraints.

The attempt in this paper is to do precisely what is stated above i.e. to study the problem of improving the utilization of the non-suburban passenger fleet. In the next section of the paper, we define the problem and present the three major constraints that influence the utilization of the non-suburban passenger coaches. We follow it up in Section 3 by providing a methodology to improve the utilization, using a model aimed at optimising the fleet utilization. In Section 4, we explore how best to utilize the fact that in our model we get multiple solutions. The conclusions are summarised in Section 5.

2 PROBLEM DEFINITION

Coaches are scheduled to run on advertised train services as part of a "rake", which essentially is a consist of coaches that provides the service, keeping in view the required composition of various types of sleeping/seating accommodation to be provided in the train. A rake may be used to provide more than one service before it returns to an assigned home base for what is called as primary maintenance. It may be essential to use more than one rake to provide this set of services depending upon how many periods it takes for a rake to come back to its home base. For example, if it takes four days for a rake to come back to its home base, and if the services are offered daily, then we would need at least four rakes to keep up the services. The set of services that the rake is used for, until it comes back to its home base and repeats the service pattern, forms a rake link or rake cycle.

The problem of improving coach utilization thus translates to one of developing more efficient rake links. This means that the rakes have to be scheduled over a set of services such that the idle times between two services is made as small as possible. The constraints that would prevent us from making the idle times as small as possible would be

1. the services must be such that the same rake can be used on them keeping in view the composition requirements,

2. maintenance requirements will have to be taken care of, and

3. traffic delays will have to be considered, so that delayed running of a service does not cause delayed running of subsequent services using the same rake.

2.1 Constraints: Past Experience

In the early days, when there were few train services, a rake was used for a to and fro journey between two terminals. This allowed the 'personalization' of the rake composition for each to and fro service.

Further, since a 'well cleaned' rake was considered essential at the start of each trip, sufficient lie -over would be provided between the arrival and departure of each rake, so that maintenance was provided at both ends of the service. If the arrival and departure timings of the associated service did not provide the required lie-over, then an overlapping rake was provided.

Thus, a practice of providing rake compositions specific to each service and maintenance at the end of each trip evolved. The implications of this 'practice' have to be studied objectively, since obviously it imposes constraints on rake utilization.

2.2 Rake Composition

One of the major challenges in achieving improved utilization of coaches is the ability to standardize a rake in terms of its composition. Currently, in the Indian Railways, non-suburban services operate with at least seven types of accommodation (AC class, First class, AC sleeper, AC chaircar, Second class sleeper-three tier, Second class sleeper-two tier and second class ordinary). A combination of different types of accommodation in a single coach raises the number of coach types used on the rakes to at least ten. Two train services with the same number of coaches may have different compositions depending on the combination of coach types used. Further, train services use varying number of coaches, the range being between 5 and 22 coaches over all types of services. Of course, this range is a little exaggerated, since if we do categorise the non-suburban services as previously mentioned, the range figures would look like :

1. Slow moving passenger services : 5 to 15

2. Mail/Express Services (including a night journey) : 10 to 22

3. Mail/Express Services (purely by day) : 8 to 18

It may not be entirely possible to think of one standardized rake for the entire Indian Railways, but one could certainly try to provide a standard rake for each of the above mentioned categories or if need be for sub-categories within the above categories. Provision of such standardized rakes will increase the flexibility of being able to use a given rake type over many services, thus providing scope for improving the utilization.

2.3 Maintenance Requirements

Currently there are three types of maintenance provided while a rake is being used for services.

1. Primary maintenance at the base station to which a rake is allotted: This consists of safety examinations, washing & cleaning, attending to minor repairs and performing 'schedules' of a periodic nature of each of the coaches as per stipulated norms. Most of the schedules follow a quarterly or a six monthly cycle, so that the schedules can be organized over various visits of the rake to its base over the entire period.

2. Secondary maintenance at other major terminals which a rake visits: This consists of safety examinations, washing and cleaning and attending to minor repairs.

3. At major stations along the run, maintenance is provided in the form of safe-to-run examinations and sweeping of the coaches.

While item number three does not directly influence the availability of a rake for improved utilization, the frequency of item numbers one and two has a direct bearing on the rake utilization.

From the point of view of maintenance, there are flaws in the "trip based" maintenance practices as described in section 2.1. Consider the following two examples, both of which are rake links for slow moving passenger services in the Western Railways (10).

Rake Link 1	Vadodara		Mathura	
(1st day)	1820	55	0055	(3rd day)
(4th day)	0935	56	0330	(3rd day)
(4th day)	1820	Repeat	55	

Rake Link 2

	Valsad		Surat	
(1st day)	0750	99	0940	(1st day)
(1st day)	1948	100	1805	(1st day)
(2nd day)	0750		Repeat 99	

In Link 1 the rake runs for nearly 30 hours covering a distance of 851 Kms getting only safe-to-run examination on the way. At the Mathura end, secondary maintenance is provided. The rake then reaches Vadodara after another 30 hours run and gets primary maintenance. The percentage utilization of the coaches on this rake is 83 per cent (this is the highest percentage utilization per coach per day in Western Railways. This figure is obtained as the actual run hours divided by total number of rake hours). Further, maintenance is provided only after every 851 Kms.

In Link 2 the rake runs for 69 Kms in about two hours. The rake is provided primary maintenance at Surat and secondary maintenance at Valsad. The percentage utilization of the coaches on this rake is only about 18 per cent. Maintenance is provided after a run of two hours, once every 69 Kms.

We thus see that there can be a high variance in terms of distance or time if maintenance is to be provided at the end of every trip.

Further, the definition of a trip itself can be questioned from the point of view of Railway Operations. For example : consider the following link (10).

	Lucknow		Kota	
(1st day)	2125	63	1245	(2nd day)
(3rd day)	0540	64	1500	(2nd day)
(3rd day)	2125		Repeat 63	

Primary maintenance is provided at Lucknow and secondary maintenance at Kota. But due to time constraints at Kota, the secondary maintenance cannot be provided to the required standards and effectively only a safe-to-run examination is provided. Thus, maintenance is provided only once in two days and after every (658 + 658) 1,316 Kms. This raises two questions.

(a) Is this a slackening of maintenance that would result in deterioration of the rake? If so, more time has to be made available for the rake at Kota, by some form of relinking, or changing the arrival and departure timings or by providing an overlapping rake.

(b) On the other hand, can we view the two trips: one from Lucknow to Kota and the other from Kota to Lucknow as a Lucknow - Kota - Lucknow trip and maintenance officially provided only at Lucknow. This would imply that maintenance is provided by design only once in two days and after every (658 + 658) 1,316 Kms. In fact, it is not uncommon to find rakes travelling for more than 36 hours over more than 1,500 Kms before either primary or secondary maintenance is provided. In this design, we forego the main advantages of trip-based maintenance which is in our ability to start a trip with a 'washed' clean rake.

With increasing number of services and a genuine constraint in the number of available coaches, it seems possible that maintenance could be slackened just to make the coaches more available for services. On the other hand, we may not be getting the best out of a coach-which is an expensive resource. Thus, there is a real need to state explicitly as to how often maintenance should be provided. The core of the general problem regarding maintenance really comes down to : how often to provide the safety examinations, the minor repairs and the washing and cleaning being done at the primary and secondary maintenance centres. It can be noted that the schedules of the periodic nature would not influence the vehicle utilization since there would be a low probability of constructing rake links wherein a rake visits the base in less frequency than quarterly. Going back to the core question as stated above, the issue really rests on whether such maintenance should be based on (1) number of trips, (2) distance travelled, and (c) run time.

Unfortunately, no scientific answer currently exists to this question. In fact, the answer may not be simple, since any measure of the above indicators from the point of view of providing maintenance could depend upon a host of other factors specific to each run, like

(1) age of the coach,

(2) terrain of the run (steep or flat),

(3) dustiness of the environment of the run, and

(4) attitude towards cleanliness of the travelling public on the run.

Apart from the different types of maintenance, we may also want to define different "quality levels" of maintenance. This could take care of the specific factors as mentioned above. Also, whatever be the time/distance indicators that are specified before maintenance is repeated, it is entirely possible that there are a few runs in the country that exceed such indicators. In such cases, we may have to make exceptions by relaxing the frequency of the maintenance, but suitably compensating with quality. Thus, provision of scientific bases for the frequency and quality of maintenance to be provided will allow proper planning towards improved utilization of passenger vehicles without jeoparadising safety, cleanliness and life of a vehicle.

2.4 Traffic Delays

Possible traffic delays must be considered while scheduling a rake for subsequent runs. This can be done by a statistical analysis of the delay patterns for specific runs, so that we can provide time for traffic delays at a given level of services before a rake is made available for the next run. Further, using a given rake for services that would be similarly affected due to operational constraints should be considered. For example: using a rake as far as possible within a region could be a strategy. This will increase the reliability of services over the entire system since rake links create dependencies between services.

3 OPTIMIZING FLEET UTILIZATION

3.1 Methodology

Having discussed the major constraints that influence the generation of efficient rake links, a methodology can be developed for the same. The steps in this methodology are

(a) identifying the scope for optimum linking for rakes between various arrivals and departures at the various terminals,

(b) studying the current linking pattern to see whether it is optimal or not,

(c) identifying the minimal changes necessary to make the current linking pattern optimal, and

(d) feasibility analysis to examine the feasibility of such links.

A model (5) is used for steps a,b and c. This is described in section 3.2. In section 3.3, we develop the rationale of/framework for the feasibility analysis; we /a do not go through the specifics of such an analysis.

3.2 Description of the model

The first requirement of the model is that it should be applied only on services that are mutually compatible from the point of view of being able to use the same rake type. Hence, it is assumed that the exercise of rake standardization or selection of service for which a given rake type can be used has already been done.

If we assume that empty hauling of the rakes will not be permitted, then the problem of developing optimal linking pattern for a railway network decomposes into a problem of developing an optimum linking pattern at each terminal. The basic concept in this model is to view each terminal as an inventory store where there is an inflow (of a rake) at each arrival and an outflow (of a rake) at each departure. Note that the number of such arrivals must be equal to the number of departures over a period of time. The period after which the arrival and the departure pattern repeats would be the period for analysis.

3.2.1 Identifying the Scope for Optimum Linking

Let us take a specific example - say Bombay Central. We consider three similar (from the point of view of being able to use the same rake type) arrivals and departures, one each from Ahmedabad, Viramgam and Vadodara. The timings of these services at Bombay Central are as given below (10):

Services	Tr.No.	Arrival	Tr.No.	Departure
Ahmedabad - Bombay Central	40	1540	39	1230
Viramgam - Bombay Central	42	0500	41	2155
Vadodara - Bombay Central	46	2040	45	0710

Since the above services are daily, our period of analysis is one day. To identify the scope for optimum linking, we have a four step procedure as follows :

(i) Sequencing the Arrivals and Departures: The first step in the model is to sequence the arrivals and departures in the order of time over the period of one day. Let us take the period to be from 00.00 hours to 24.00 hours.

(ii) Developing a Representative Inventory Status: We can consider each arrival as feeding an inventory and each departure as depleting the 'inventory' by one unit. Giving a value of +1 to each arrival and a value of -1 to each departure, we have a "representative" inventory status. The figures here are only representative of the inventory status, while not giving the ideal status. This is because after the 12.30 departure, we have had one too many departures and so obtained a negative status. The status is really not negative as an arrival from the previous period would service this need of an additional departure. We can avoid this problem of a negative status by suitable redefinition of the period. This is done in step (iv) prior to which we need to develop an ideal inventory status.

(iii) Developing an Ideal Inventory Status (for period redefinition) : We obtain the ideal inventory status by adding the most negative representative inventory to all the representative inventory figures. In the specific example, we add one (because-1 is the most negative) to the inventory figures to get the ideal status.

For the Bombay example, we get the following result after the above steps.

A	D	Representative Inventory Status	Ideal Inventory Status
5.00		1	2
	7.10	0	1
	12.30	-1	0
15.40		0	1
20.40		1	2
	21.55	0	1

The ideal inventory status represents the inventory of rakes after each arrival/departure event, under optimality. For example: the inventory must be zero between 12.30 and 15.40 hours. The zero inventory has a special significance, since we can view it as a barrier dividing the arrival/departure events.

(iv) <u>Redefinition of the Period and Identifying Blocks</u>: We redefine the period from after a zero of the ideal inventory status. In our example, we can show the arrival and departure sequence as follows :

Arrival	Departure	Ideal Inventory Status	
15.40		1	Block
20.40		2	
	21.55	1	
05.00		2	
	07.10	1	
	12.30	0	

The set of arrivals and departures, which are not divided by the barrier caused by a zero, will be called as a 'block', for convenience. It should be noted that in any other example of a terminus, there could be more than one block, depending upon the actual arrival - departure pattern and the consequent ideal inventory status.

We now make an important observation, that "a linking **pattern which** does not cross the block barrier will be optimal". To understand this and to study a given current linking pattern for its optimality, we go to the next step in our methodology.

3.2.2 Studying the Current Linking Pattern for Optimality

Consider two kinds of linking patterns at Bombay: Pattern 1 - which does not cross the block barrier, and Pattern 2 - which is the current linking pattern and crosses the block barrier.

Pattern 1			Pattern 2		
Arrival	Departure	Ideal Inventory Status	Arrival	Departure	Ideal Inventory Status
15.40		1	15.40		1
20.40		2	20.40		2
	21.55	1		21.55	1
05.00		2	05.00		2
	07.10	1		07.10	1
	12.30	0		12.30	0

In Pattern 1, the linking is such that the arrivals linked to departures are from within the same block. In Pattern 2, the linking is such that the block barrier is crossed, because the 5.00 a.m. arrival is linked to the 21.55 departure. The block barrier being crossed implies that the actual inventory at the end of the block is one and not zero, as should be the ideal. The rake idle time at Bombay in either pattern can be calculated as follows :

Pattern 1				Pattern 2			
15.40	-	21.55	6.15	15.40	-	12.30	20.30
20.40	-	07.10	10.30	20.40	-	07.10	10.30
05.00	-	12.30	07.30	05.00	-	21.55	16.55
		Total :	24.15				48.15

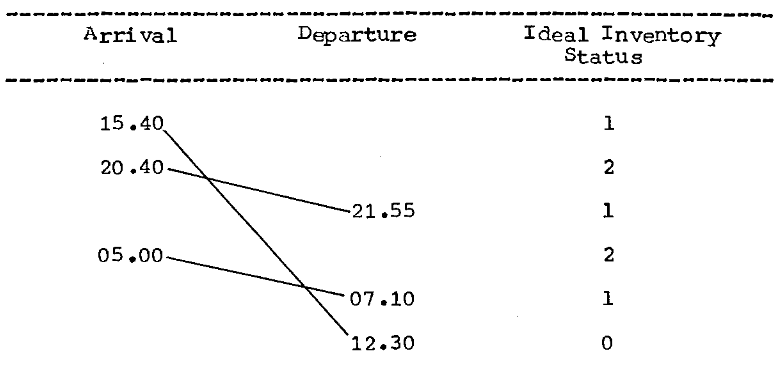
It should be noticed that the total rake idle time in Pattern 2 is exactly 24 hours more - meaning that an additional rake is utilized. This could also have been inferred from the fact that the block barrier has been crossed once. (In fact, to extend the idea: the number of times a specific barrier is crossed gives the number of additional rakes being utilized for meeting the services at any terminal.)

Thus, Pattern 1 is optimal. Pattern 2, the current linking pattern is non-optimal since it crosses the block barrier.

3.2.3 Identifying Minimal Changes Necessary for Optimality

The next step in the methodology is to identify the minimal change necessary to make the solution optimal. This would require us to have a linking pattern that does not cross the block barrier. Consequently the 05.00 - 21.55 link must be broken and reorganized with at least one other link to ensure optimality. There are two ways in this specific problem. One is as suggested in Pattern-1, and the other which we shall call Pattern 3, would be as follows:

<u>Pattern 3</u>



15.40	- 12.30	=	20.50
20.40	- 21.55	=	01.15
05.00	- 07.10	=	02.10
	Total	:	24.15

It can be noted that the idle time of Pattern-3 is the same as that of Pattern 1.

Both Pattern 1 and Pattern 3 require the same number of changes to bring the solution into optimality from Pattern 2.

3.3 Feasibility Analysis

The last step in our methodology is to do a feasibility analysis of the changes necessary to effect the rake saving.

Various criteria could be considered here, but the most important criteria are based on the constraints identified in Section 2 :

(i) Rake Composition: Even though this model is applied to services that are considered mutually compatible in composition, marginal changes may be necessary in composition, depending on which services get linked in the same rake link.

(ii) Maintenance Requirements: For this, we have to study completely, each of the rake links that will be affected/created because of a change in the linking pattern.

(iii) Traffic Delays: This has to be considered in the new pattern since tight service interdependencies could affect the subsequent running of services.

Without even considering the composition or maintenance aspects, we can rule out Pattern-3 from the point of traffic delays, since we are providing as low as one hour and fifteen minutes for a rake to be used between two consecutive services.

Going with Pattern 1 as a possible optimal solution, we can now look at the rake link that results from the linking pattern. Currently we have (under pattern 2):

Rake Link 1

	Bombay Central		Viramgam	
(1st day)	21: 55	41	20:30	(2nd day)
(4th day)	05: 00	42	07:50	(3rd day)
(4th day)	21: 55	Repeat 41		

Rake Link 2

	Bombay Central		Ahmedabad		Anand	
(1st day)	12:30	39	3:55			(2nd day)
(2nd day)			13:30	80	15:50	(2nd day)
(2nd day)			19:00	79	17:05	(2nd day)
(3rd day)	15:40	40	23:25			(2nd day)
(4th day)	12:20	Repeat 39				

In both these links, the rake which provides the first service is available again on the fourth day to repeat the service. Hence, three rakes are necessary to provide these services daily, for each link. This adds up to a total of six rakes for all the services. The average utilization per day for each rake is 55.5 per cent (actual run hours divided by total number of rake hours).

These two links get combined when we adopt linking pattern 1 at Bombay Central :

```
Bombay Central            Viramgam         Ahmedabad           Anand

(1st day)  21:55----41----20:30  (2nd day)
                            |
(4th day)  05:00----42----07:50  (3rd day)
             |
(4th day)  12:30-----------39--------------03:55  (5th day)
                                             |
                     (5th day)             13:30--------80--15:50
                                                            (5th day)
                                                              |
                     (5th day)             19:00--------79--17:05
                                             |              (5th day)
                                             |
(6th day)  15:40-----------40--------------23:25  (5th day)
             |
(6th day)  21:55--------Repeat  41
```

It is easily seen that the total number of rakes needed to provide the same services daily is now five, and the average utilization per day is 66.7 per cent. There is thus a saving of one rake, which results in an increased utilization of 11 per cent.

The new link that is obtained is now ready for analysis from the point of view of being able to (i) use the same rake composition over all the services, (ii) provide maintenance, and (iii) accommodate traffic delays. As already mentioned, we do not present this analysis, since it is beyond the scope of this paper.

4. MULTIPLE OPTIMUM

4.1 Number of Optimum Solutions

In the example considered at Bombay Central (Section 3.3) though pattern 3 is not considered as feasible as pattern 1, the fact remains that there were at least two optimal solutions from the point of view of minimum rake requirements at Bombay Central.

In general, we get many optimal solutions in this kind of a problem wherein we seek to optimize fleet utilization. An 'optimal solution' to this problem consists of a set of rake links that is exhaustive in its coverage of all considered services over the rail network with the minimum number of rakes. If at a given terminal, there are two optimal linking patterns possible, that would lead to at least two optimal solutions. If at another terminal, there are three optimal linking patterns, then we would get at least 2 x 3 = 6 optimal solutions. Thus, the actual number of optimal solutions (when it comes down to different sets of implementable rake links) is given by the product of the number of optimal linking patterns possible at each terminal.

The number of optimal linking patterns at a given terminal now needs to be determined. If before a particular departure, the ideal inventory status is two, then either rake can be used for the departure - hence we would get at least two optimal linking patterns. If before another departure there are again two rakes available, then we would get at least 2 x 2 = 4 optimal linking patterns. Thus the actual number of optimal linking patterns at a terminal is given by the product of the ideal inventory status prior to every departure.

The number of optimal solutions in this problem usually turns out to be large. Hence, one can consider applying a secondary objective function to further select an optimal solution from among the multiple optima.

4.2 Secondary Objective Function

The secondary objective function that we consider is to minimise the maximum number of services for which a rake is utilized. This secondary objective has implications on the maintenance control exercised over the rake. The more number of services that a rake is used for, the greater the dissipation of control and consequently the higher the chance that the rake will be maintained poorly.

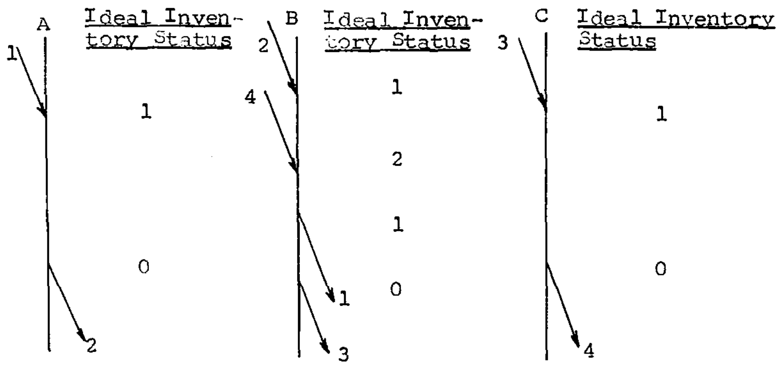
Further, if we minimise the maximum number of services for which a rake is used, then the need for an exact match in terms of rake composition across services also becomes less stringent. Problems due to traffic delays will also be 'contained' over fewer services.

Similarly, we can also consider other secondary objective functions like minimising the maximum distance travelled by a rake before it comes back to the base station or minimising the maximum time spent by a rake before it comes back to the base station. These two secondary objective functions are more difficult to implement considering the ability to obtain a solution in our model. We shall only consider a solution procedure for the secondary objective function of minimising the maximum number of services for which a rake is utilized.

4.3 Solution Procedure

4.3.1 Characterising the Multiple Optima:

Let us consider a simple railway network with three terminals and four services as follows :



Each vertical line represents the time scale, an arrow-in represents an arrival and an arrow-out represents a departure. At terminals A and C, there is just one optimal linking pattern possible. At B, there are two optimal patterns possible. There are thus two optimal solutions to the fleet optimization problem on the above mentioned railway network:

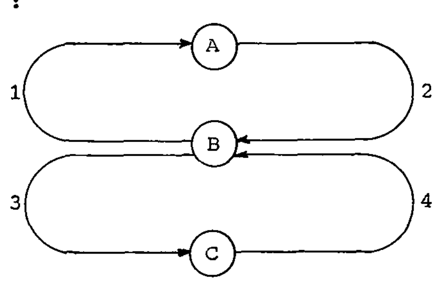
By observation, we can write the two solutions as

(1) Rake Link covering services 1-2-3-4

(2) Two Rake Links covering services 1-2 and 3-4

The first solution is based on the 2-3, 4-1 linking pattern at B. The second solution is based on the other linking pattern which is 4-3, 2-1.

It is possible to characterise the set of optimal solutions to the fleet optimization problem by a network, which captures the optimal linking patterns at each terminal. The terminals are represented by nodes, while the services are represented by arcs. In the above example, the network looks like :



The network captures the fact that at B, either incoming rake (through service 2 or 4) can be used for either outgoing service (1 or 3) .

The two optimal solutions can be obtained as the different ways of decomposing the network into cycles. The network can be decomposed into cycles two ways :

1. 1 - 2 - 3 - 4

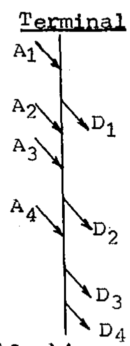
2. 1 - 2, 3 - 4

These are the two sets of optimal rake links.

Thus, determining the optimum set of rake links can be converted to a problem of decomposing a network into (rake) cycles, wherein the network is such that it captures the multiple optimal solutions in the fleet optimization problem

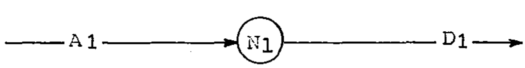
Using the secondary objective function of minimizing the maximum number of services, we select solution number 2. In the next section, we propose an algorithm that generates a solution satisfying the secondary objective function.

The above example is rather simplistic in demonstrating how the possible optimal linking patterns at a terminal are represented. We could consider a move involved example as follows :

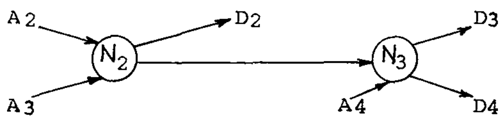


Ideal Inventory Status	
1	Block-1
0	
1	Block-2
2	
1	
2	
1	
0	

A1, A2, A3, A4 are arrivals and D1, D2, D3, D4 are departures sequenced on the time scale represented by the vertical line. The ideal inventory status for this terminal requires that there be two blocks and consequently optimal linking patterns will only be within the blocks. Block 1 will be represented by a single node as follows



In Block 2, we have to capture the fact that though either of the rakes coming as A2 or A3 can be used for the departure D2, only one of them can be carried over and (along with the arrival A4) serve either departure D3 or D4. We thus have a representation as :



Based on the above example, we make the following two observations :

(1) A terminal is represented by n 'directly unconnected' set of nodes, where n is the number of blocks as identified by the ideal inventory status.

We emphasise 'directly unconnected' since the set of nodes may be indirectly connected in the network through nodes representing other terminals.

(2) Each block is represented by (m+1) directly connected nodes where m is the number of occurrences of "an arrival immediately following a departure".

Based on observation (1), it is possible that the network (characterising the multiple optima) itself consists of unconnected sub-networks.

An important property of the nodes is that the indegree (number of arcs directed towards the node) is always equal to the out-degree (number of arcs directed away from the node) .

4.3.2 Algorithm

We propose an algorithm for decomposing a connected network (of the type generated by the procedures described above) into cycles such that we minimize the maximum of arcs over all the cycles.

The connectedness poses no problem since if we do get unconnected sub-networks, then we have to apply the algorithm over each sub-network.

The existence of at least one cycle can be established by the fact that for a connected network, if each node has in degree equal to out-degree, then there exists an 'Euler Path' (which is really a cycle consisting of all arcs of the network) .

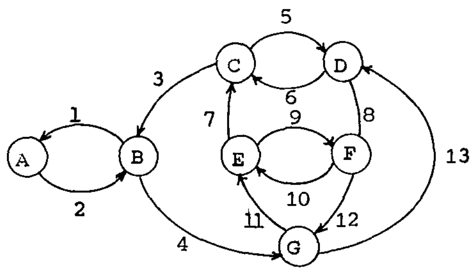
The algorithm has a 'greedy' structure. We do not prove the optimality of the algorithm, though one could conjecture that the algorithm is optimal.

Step-1: If a node has only one arc in and one arc out,

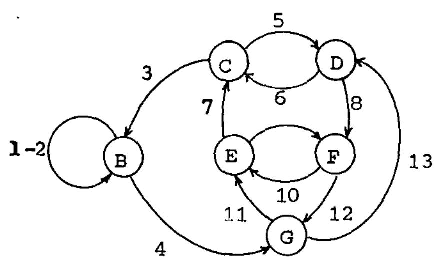
Then remove the node and replace the two arcs by one arc with the proper direction.

Else go to Step-2.

(Consider the following network :)



(After applying step-1 the first time :)



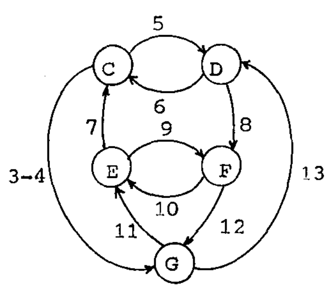
Step-2: If there are cycles of length one

Then remove them from the graph, treating them each separately as part of the desired solution and then go to Step-1.

Else go to Step-3.

(1-2 is a cycle that is removed from the graph, 3-4 becomes a single arc after going back to Step-1:)

1-2;



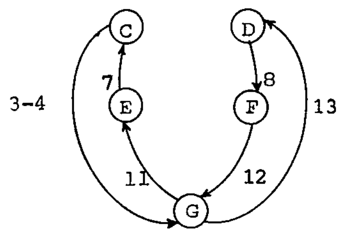
Step-3: If there are cycles of length two

Then remove them from the graph treating them each separately as part of the desired solution and then go to Step-1.

Else go to Step-4.

(After removing cycles of length two, but before going back to Step-1 :)

1-2; 5-6; 9-10;



(After going back to Steps 1 and 2)

1-2; 5-6; 9-10; 3-4-11-7; 8-12-13

Step-4 . . . . For cycles of length 3 . . . .

.

.

.

. and so on until all arcs are exhausted.

In most realistic problems, one would not have to exceed step-3. This does not of course, mean that the maximum number of services in a cycle is two, since we have 'C-D-K-G' - a rake cycle of four services obtained in step-3.

The limitation of this Algorithm is that while programming on a computer, there is a problem of determining cycles. It is visually easier for a human to go through this process than for a computer. This could be good application for a graphic interface, where the computer keeps redrawing the network as the human removes the cycles from the same.

CONCLUSION

1. This paper studies the problem of improving the utili-

zation of the non-suburban passenger fleet of the Indian Railways. The constant growth of the non-suburban passenger traffic outstrips the additions provided to the fleet, which any way is an expensive proposition.

2. The improvement in utilization is sought to be effected by using the fleet more often for the desired services. This is implemented through the development of efficient rake links, wherein the idle times between two services for which a rake is used is made as small as possible.

3. The constraints that would prevent us from making the idle items as small as possible would be (a) rake composition requirements, (b) maintenance requirements and (c) traffic delays.

4. The maintenance requirements pose a major challenge, since currently there are no norms on the frequency of different kinds of maintenance to be provided. While it is certainly possible that excess maintenance is being provided; with increasing number of services and a genuine constraint in the available fleet, maintenance could be slackened (and dangerously so) just to make the fleet more available for services. Thus, there is a real need to study explicitly as to how often maintenance should be provided and whether such maintenance should be based on (a) number of trips (b) distance travelled or (c) run time.

5. The constraints due to rake composition requirements can be relaxed by standardizing the rake composition. It may not be possible to think of one standardized rake for the entire Indian Railways, but one could certainly try to provide a standardized rake for categories of trains.

6. A methodology is proposed to generate efficient rake links with the objective of minimising fleet requirements. Though the methodology uses some sophisticated OR techniques, with proper application it can be used to aid decision making under realistic considerations.

7. While using the OR techniques, usually a number of optimal solutions occur in the problem. This can be exploited by using a secondary objective function to further select a preferred solution from among the optimal solutions of the fleet minimisation problem. The secondary objective function considered in this paper is to minimise the maximum number of services for which a rake is used. The implications of this objective function are from the point of view of better maintenance control exercised over the rake.

8. The entire methodology can be computerized and used as a decision support system for improving the utilization of non-suburban passenger fleet.

9. This paper only proposes a methodology for studying the stated problem of improving the utilization of the non-suburban passenger fleet. The paper does not get into the details of analysis, nor does it provide rigorous proofs for the techniques employed.

10. In summary, the paper motivates the problem (Section 1), defines the problem in order to get implementable solutions (Section 2), highlights the major constraints - especially maintenance requirements (Section 2.3), provides a methodology to generate solutions that improve the utilization (Section 3) and exploits the multiple nature of the improved solutions by using a secondary objective function (Section 4).

REFERENCES

1. Ankolekar SR, Patel NR, and Saha JL (1981), "Optimisation of Vehicle Schedules for a Road Transport Corporation". Published in NK Jaiswal (Ed) Scientific Management of Transportation Systems, North-Holland Publishing Company.

2. Gertsbach I. and Gurevich Yu. (1977), "Constructing an Optimal Fleet for a Transport Schedule" Transportation Science, Volume 11, pp 20-36.

3. Indian Railways, (1982-83), "Facts & Figures", Railway Board, New Delhi.

4. Levin A (1971) "Scheduling and Fleet Routing Models for Transportation Systems", Transportation Science, Vol.5, pp 232-255.

5. Ramani KV and Raghuram G, (1979), "Coaching Stock Utilization in Western Railways", Public Systems Group Monograph No.22, Indian Institute of Management, Ahmedabad.

6. Ramani KV and Raghuram G, (1980), "Utilization of Transportation Units: An Optimal Allocation Study", Opsearch, Vol.17, p 1.

7. Ramani KV (1981), "An Information System for Allocation of Coach Stock of Indian Railways", Interfaces, Vol.11, No.3.

8. Saha JL, (1970) "Algorithm for Bus Scheduling Problems" Operational Research Quarterly, Vol.21, No.4.

9. Simpson RW, (1969) "Scheduling and Routing Models for Airline Systems", NTIS Report, PB 196528, MIT.

10. Western Railway, (1983), "Normal Composition and Marshalling Order and Rake Links of Passenger Trains", Operating Department, Western Railway, Bombay.