A DECISION SUPPORT SYSTEM FOR RAKE LINKING AND RELATED OPERATIONAL DECISIONS[+]

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1 INTRODUCTION

Rake linking is the term used for the decision of assigning physical rakes to certain sets of scheduled services on a regular basis. The particular rake linking patterns that are chosen depend on a number of factors. In passenger operations, the time-table of scheduled services is the target, which has to be met. Certain constraints such as availability of maintenance facilities, safety considerations and norms of operation can be considered to be primary ones, while maximising reliability of services and increasing operational flexibility can be considered as secondary considerations. Subject to these, efficient rake utilisation is an objective, which can be reasonably tackled. This issue is presented in its realistic operational complexity, with a suggested methodology for evaluating certain rake linking options.

The issue of rake linking is seen in its inter-relationship with the three critical operating databases of the Indian Railways: the *time table*, which represents the demand side, the *rake link*, which captures the supply allocation of the rolling stock by listing the rake links and the *platform and maintenance line occupancy charts* which provide information on the allocation of terminal facilities. In view of the complex nature of the decisions involved, a need was felt to provide some kind of management support. This would allow the decision maker to understand the totality of the situation in more concrete terms. An attempt has been made in this direction by implementing a prototype Decision Support System (DSS) termed TRIMS (Terminal Rake Information and Maintenance Scheduling). TRIMS captures the relevant information by integrating the timetable, rake link book, platform and maintenance line occupancy charts.

The objective is to ultimately provide a user with a comprehensive analysis of coaching stock allocation, over the entire system. TRIMS consist of two modules - *RakeInfo* and *Scheduler*. By integrating the operating databases, *RakeInfo* provides comprehensive information about services and rake cycles. *Scheduler* allows the user to schedule all the stipulated services on the available platform and maintenance lines. Further, the schedule thus arrived is represented in a visual format (Gantt Chart). TRIMS has been implemented in C in a UNIX environment on X- Windows.

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We focus on long distance Mail Express trains and their linking patterns in this study. An earlier study by K. V. Ramani and G. Raghuram is the foundation for this analysis. Their report illustrates the ideas that are discussed with examples from Central and Western Railway operations in Mumbai. We note that the timetable on Indian Railways is an evolving document and many train numbers and timings referred to here, are no longer valid. The principles discussed here continue to be valid.

2 MAJOR CONSIDERATIONS

We briefly discuss the major considerations in the preparation of a rake link as part of the timetabling exercise, seen as a whole.

2.1 TIMETABLE:

The timetable provides a schedule of regular services and the type of service (rake composition) provided in each case. If we treat this as given, the first consideration in rake linking is that a service can be linked to another service at a certain terminal, provided a suitable time gap exists between the arrival of one and the departure of the other. Sometimes, departure times of services are not fixed *a priori* and are actually synchronised with that of the linking train. This is especially true in rake links involving short inter-city runs.

2.2 MAINTENANCE NORMS:

A thumb rule, which emerges from an analysis of different rake links in different zonal railways, is that, for Mail/Express operations, after an upper limit of 2500 kms a rake must get a minimum time of 6 hrs for Primary Maintenance (PM). Similarly after a distance of 1500 kms, it must get a minimum of 1 to 1.5 hrs. of Secondary Maintenance (SM). For trains running beyond 2500 kms., more primary maintenance time would be required. It is generally observed that a long distance train idles for a minimum of 5 hours before it begins another service. During this time, it could undergo primary or secondary maintenance, depending partly on the maintenance facilities available at that terminal. Ideally, maintenance activity should be viewed in the context of a rake cycle rather than associating it with each individual service. Refer Appendix A for a summary of these empirical observations.

Given an average speed of Mail Express trains, a simple relationship can be stated which links the maintenance norms depending on distance, the running times and maintenance times. This results from the fact that an average of about 25% of the total rake cycle time is available for maintenance. A convenient ratio is that maintenance time is 1/3 of the total run time.

These figures have been arrived at, after analysis of different rake cycles. A closer look at the rake cycles would reveal that there is substantial variation in terms of the frequency of maintenance. (Example: In case of Trivandrum - Guwahati Express PM is provided after a run of 3582 kms. and 65 hrs, on the other hand in the Mumbai –Pune-Mumbai sector, it is approximately 400 kms. and 8 hrs.)

2.3 MAINTENANCE FACILITIES:

Especially at congested metropolitan terminals, availability of specific maintenance facilities is a major consideration in rake linking.

1. Primary Maintenance (PM) , is done at the base station to which a train is allotted. This requires a pit line for the scheduled time. Primary maintenance involves technical services such as checking of the axle boxes and repairing or oiling them if necessary. Besides these there are certain checks, which are common with secondary maintenance like checking of the trolley defects and spring cracks. Brakes are also checked to ensure that the brake efficiency is close to 100%. It is considered desirable from safety considerations that primary maintenance is done during daytime hours, wherever possible.

2. Secondary Maintenance (SM) , is done at the major terminal where a rake visits. This may require an empty siding for the scheduled time. Other than checks on the brake springs etc., it also involves services like cleaning and washing of rakes.

3. Ready to Run Inspection (RRI), is done at major stations along the run which sometimes requires platform availability for the scheduled duration. For PM and SM, shunting time has to be provided for the rake to be hauled to the yard. Primary maintenance facilities are limited and rake linking is sometimes done specifically with the scheduling of such facilities (refer Class (C)-(ii), (iii) and (iv) in Section 1.5 below).

2.4 RAKE COMPOSITION

Rake Composition refers to the number and the type of coaches (AC, Second Class etc.) in a rake. Train services use varying number of coaches. Further, two services having the same number of coaches may have different rake composition depending on the combination of coach type used. One of the major challenges in achieving improved utilisation of coaches is the ability to standardise a rake in terms of its composition. To link up some particular arrival service at a terminal to a departure, it is desirable that both these services should have identical rakes. In the absence of identical rakes, linking will still be possible but some shunting will be required i.e. it may be required to attach or detach some coaches from a particular rake. Thus, in many coaches saving may not be possible in terms of rakes but in terms of coaches. However, standardisation of rakes (i.e. all the services on a particular network have the same rake composition) facilitates rake linking.

3 OTHER CONSIDERATIONS

Two other relevant considerations are discussed here, of a qualitative nature, the reliability of services that are planned in a timetable, and the operational flexibility that a rake linking decision provides.

3.1 RELIABILITY OF SERVICES

Rake links often have to acknowledge the fact that uncertainty of operations are sometimes chronic, and till such time as the reliability of certain services improves, there might have to be special provisions for maintaining punctual services. This results in certain services being linked to other services (usually the same service in the reverse direction) after almost 24 hours. Essentially, a standby rake is provided on such services. Refer Class (C)-(ii) in Section 4 below.

3.2 OPERATIONAL FLEXIBILITY

A consideration similar to (2.1) above is that operational delays are often direction specific (e.g. due to disruptions on a particular line). This suggests that rake links, which connect services along the same line, are better for operational flexibility. The reasoning is that if services on different lines are linked, then there are possible cascading effects of delays and disruptions on different lines. If, on the contrary, services on the same line are linked, then no more than the unavoidable delays of services on that line alone are incurred. See Classes C - (iii) and C - (iv) in Section 4 below for examples of these two types of links.

Other operational strategies for better reliability are discussed in Appendix B

4 RAKE UTILISATION

We now come to a major concern of rake linking, from a supply perspective. This is the objective of meeting the service obligations with as few rakes as possible. This is clearly desirable from the point of view of asset utilisation. As has been clearly pointed out by Ramani and Raghuram, the most desirable strategy from this perspective is to link each service at each terminal with the first available service that meets maintenance and other major constraints. This may be referred to as the FCFS policy. (The analysis by Ramani and Raghuram goes further, suggesting linking even when rake compositions are not exactly the same, in cases where the costs of some shunting operations may be far outweighed by the gains in terms of fewer coaches used, system wide.)

Let us now suppose that rakes are allotted to services (in some linked manner, based on the FCFS logic or any other scheme). We can think of a number of ways to proceed beyond this stage:

i) The introduction of new services with the same rake supply can be considered. This has indeed lead to a number of inter city services, which make effective use of the layover of longer distance trains. (See example in Section 4: (B)-(iii) (a) for an example of this.)

ii) The directional consideration in 2.2 above, or other considerations can be used to exploit the fact that there are, in fact a number of schemes (other than the first come -first feasible served scheme), which in fact use the same number of rakes.

iii) Minor changes in the time table can be considered fo r rake linking effectiveness (the example in Section 4: (C)-(iii)-(a) has resulted from a minor change in the earlier timetable, to make this particular link possible.)

5 RAKE LINK CLASSIFICATION

This section enumerates in a somewhat exhaustive manner, d ifferent types of rake linking strategies used allover the Indian Railways. The attempt is to systematically indicate various possibilities in rake linking of different types of trains. These can be used to generate new possibilities, and can then be evalu ated for operational feasibility and other considerations (like availability of maintenance facilities and estimates of reliability). A suggested procedure for doing this at a strategic level is indicated in the following section (1.6). Refer to Appendix B for notes on the rake linking strategies illustrated below.

In what follows, a (symmetric) timetable for a train refers to the fact that the arrival and day times of the train at a station are symmetrically timed at a station are symmetrically timed around a reference time (approximately 1.00 P.M. or 1. A.M.). This is a general principle of timetabling that is largely followed on Indian Railways. Among other things, if all train timings are symmetric, it ensures that a suitable time path in one direction e nsures a path in the other direction as well. It is convenient for planning overnight, commute and most day distance services.

A) DAY SERVICES

i) ***Symmetric timetable***

a) Deccan Queen (Mumbai-Pune) -1 rake

b) Karnavati Express (Mumbai-Ahmebadad) -1 rake

```
BCT                 ADI
1340 ------->-------- 2125
:       2933      :
:                     :
1245 -------<-------- 0510
        2934
```

c) Tapovan Express (Mumbai-Pune) -2 rakes

ii) Symmetric linking of two day trains (same destinations)

a) Indrayani Express (Mumbai-Pune) / Deccan Express (Mumbai-Pune)

This is a crossover strategy, described in Appendix B.

iii) Symmetric linking of two day trains (different destinations)

a) Pallavan Express (Madras-Tiruchirapalli) / Vaigai Express (Madras–Madurai)

This is also a crossover strategy.

iv) Asymmetric timetable

a) Gujarat Express (Mumbai-Ahmedabad) -2 rakes
BCT ADI
0545 -------->-------- 1510
: 9011 :
: :
25 ------< ------------ 0715
9012

B) OVERNIGHT SERVICES

i) Self-linking

a) Gujarat Mail (Mumbai-Ahmedabad) – 2 rakes

BCT ADI
2125------→---------0630
: 9101 :
: :
0645-------←---------2200
9102

b) Siddheshwar Express (Mumbai - Solapur) – 2 rakes

ii) Night train-day train link

Madras Bangalore Mail – 2 rakes, integrated with Madras Bangalore Express
MAS SBC
2200---------→-----------0515
: 6007 :
: :
1430----------←----------0730
6024
AND
SBC MAS
2200---------→-----------0515
: 6008 :
: :
:
1430----------←----------0730
6023

Note that of the approximately 9 hr 45 min idle time a major chunk of it is provided at one place in each cycle, in Madras in the first cycle and Bangalore in the other. This permits the primary maintenance activities to be done.

iv) Night train with intercity daytime run

a) Ahmedabad Janata Express (Mumbai-Ahmedabad) -2 rakes, integrated with Ahmedabad Vadodara inter city Express

```
BCT          BRC                        ADI
1935 --------→---------------- 0435
                9007                       :
:                                          :
:
1630-------←------1425
:                  :
:                  :
                 1800------→--------
                   :                         :
                   :                         :
                 0625--------←------2115
                                 9008
```

b) Vadodara Express (Mumbai-Vadodara) -Sayaji Nagari Express (Bandra-Vadodara) and Kutch Express (Mumbai-Gandhidham)

```
BCT    BDTS                       BRC              GIM
2330 --------->------------ 0615
                        2927          :
                                      :
                 1400 ------←------- 0725
                   :         9056
                   :
                 1500 ------>--------- 2145
                            9055             :
                                      :
0535 -----------------←--------- 2300
:                       2928
:
1710--------------------→----------------------0750
                            9031                          :
                                                          :
1145--------←---------------------------------2045
  :           9032
  :
2330--------→-------------Repeat
                2927
```

In addition to using the daytime slot at Vadodara for an intercity run. (Sayaji Nagari) the Kutch express – Vadodara Express link uses the cross over strategy described in (A) -(ii) and (iii) and Appendix B.

C) Long Distance Services

i) Self linking (symmetric timetable)

a) Mumbai Howrah Mail (via Nagpur)

```
BBVT                  HWH
2015   --------→---------0815
:          8001            :
:                          :
0740 ----------←---------- 1925
           8002
```

b) Udyan Express (Mumbai - Bangalore)

c) Avantika Express (Bandra Terminus-Indore)

ii) Self linking (asymmetric timetable)

a) Konark Express (Mumbai-Bhabaneshwar)

```
BBVT                    BBS
1120------→---------0400
:          1019           :
:                         :
0400 ----------←-----1230
           1020
```

b) Mahanagari Express (Mumbai- Varanasi)

```
BBVT                        BSB
2330 ---------→--------------0400
    :          1093             :
    :                           :
1515-----------←-------------1120
               1094
```

The pit line maintenance of these two services at Mumbai can be scheduled on the same facility. For this train, a stand by rake is provided at Mumbai to maintain reliability of departure timings, in face of chronic delays of the pairing service.

iii) Non-self linking (directional)

a) Mumbai-Madras Mail / Mumbai Madras Express

```
BBVT                        MAS
1400------->------------1635
:           6511            :
:                           :
 0450-------←-----------2220
               6010
```

AND

```
BBVT                        MAS
2315----------->-------- 0545
```

```
:              6009              :
:
1505---------←--------1145
                    6512
```

This pattern is a typical one of the up and down services being part of different rake cycles. The general strategy is that of as crossover, described in Appendix B. T he maintenance pit line at VT/Mazagaon is occupied by the arriving Madras Mail rake in the first half of the day and the arriving Madras Express rake in the second half of the day.

b) Mumbai -Hyderabad Express / Hussainsagar Express (Mumbai -Hyderabad). T his is another case where two rake cycles together provide a mix of (in this example) two services. The maintenance pit line scheduling is similar to the earlier example.

iv) Non - self linking (non-directional)

a) Dadar Amritsar Express integrated with Sewagra m (Dadar -Nagpur Express. Along with this rake linking, the maintenance pit line at Dadar is also scheduled to serve the rake arriving from Amritsar during the morning hours and the rake from Nagpur in the second half of the day, following the pattern above.

D) NON-DAILY SERVICES

a) Chambal Express (Gwalior - Howrah) integrated with Lashkar Express (Dadar - Agra CanttiGwalior) integrated with Shramshakti Express (Dadar -Muzaffarpur). The rake cycle is as follows-

```
AGC                  DR               MFP
FRI 2050   SAT 2205
------→------------
                :
                :
 SUN 0755          MON 2015
  -------->-------
:
:
  --------←------
 WED 2205          TUE 0900
     :
     :
FRI 0850   THU 0755
--------←---------
```

A rake linking similar to the one at Dadar is followed at Gwalior between Chambal Express and Lashkar Express.

6 SOFTWARE SUPPORT

Rake linking decisions have to be inter-related with time – tabling platform and maintenance line occupancy. In view of the complex and unstructured nature of the problem a need was felt to provide some kind of software support for easy access and analysis of the time table, rake link and platform and maintenance line occupancy information. An initial attempt has been made in this direction by implementing a conceptual DSS, TRIMS (Time Table, Rake Information and Maintenance Scheduling). The two modules are RakeInfo and Scheduler.

6.1 RakeInfo

RakeInfo integrates the three key operating databases. It is a database of the Indian Railway services -providing comprehensive information about services and rake cycles. For a service RakeInfo provides the arrival time, departure time, arrival terminal, departure terminal, platform and maintenance occupancy times, nature of maintenance (ready to run/primary/secondary). Further, for a rake cycle RakeInfo evaluates parameters: such as total travel time, idle time, percentage rake utilisation and number of rakes required. Along with the standard input file, the user has the option to evaluate other options by making the necessary changes in the rake links or/and platform and maintenance line times.

RakeInfo provides the user with the following options:

1. Service Information: provides arrival time, departure time, arrival terminal, departure terminal, platform and maintenance occupancy times, nature of maintenance (ready to run/primary / secondary)
2. Rake Cycle: provides the rake cycle for the specified service.
3. Rake Composition: provides the number and the type of coaches.
4. Rake Cycle Analysis: for the rake cycle of the specified service this provides the total travel time, idle time, percentage rake utilisation and number of rakes required.
5. Platform Line Occupancy: for the specified terminal provides this provides the occupancy intervals.
6. Maintenance Line Occupancy: for the specified terminal provides this provides the maintenance line occupancy intervals.
7. Update the input file: allows the user to update the input file on a temporary/permanent basis and evaluate alternative options.
8. Help: provides help to the user to update the input file along with the service listings.
9. Exit: allows the user to return to the main menu of TRIM

6.2 Scheduler

Scheduler, the second arm of the prototype DSS-TRIMS, deals with platform and maintenance line scheduling. It allows the user to schedule all the services at a particular terminal on the available platform and maintenance lines. Overnight services and non-daily services are also considered. The latter is done by individually keeping track of each of the platform/maintenance line on each day of the week. The schedule thus arrived is then represented in a visual format (Gantt Chart). For the visual representation the 3D graphics library has been used. This library has been written using C and Xlib and is meant for making simple drawings and animation in an X windows environment.

The scheduler provides the user with the following options

1) Platform Line Scheduling.
2) Maintenance Line Scheduling
3) Exit.

7 PROCEDURE FOR RAKE LINKING

A study of the above examples highlights a number of interesting features, which can be encapsulated in the procedure given below. A rigorous analysis of the issue is briefly hinted at, in Appendix C. All patterns refer to the checklist of examples in above Section.

This procedure requires two main databases:

1) The timetable at various terminii, to show the arrival and departure times of various services. In congested destinations, where a number of terminii are present, the consolidated list of arrivals and departures must be considered (e.g. New Delhi-H.Nizamuddin-Delhi, or Bombay Central-Bandra Terminus).

2) The number of maintenance lines at the various terminii and the scheduled occupation on each one. Other information like platform availability etc can be checked separately. Of course, if one is willing to admit timetable changes, there are a number of parameters like time paths, which need to be checked. We do not consider that issue in detail here.

i) Consider the run of a particular train. If a day train, see if patterns in (A)-(i),(ii),(iii) above are relevant. [See Appendix B-1 for notes on such strategies.]
A policy followed by the railways seems to be that short distance (upto 5 hours) trains serving commuters are usually not linked with long distance trains. For other day trains, carry over of maintenance timings and linking with other trains as part of a longer cycle is a possibility.

ii) If an overnight train, see if patterns (B)-(i) and (B)-(ii) are applicable. Self linking is particularly appropriate for trains with a run of about 16 hours, since the maintenance time ratio is near the norm, without carrying it over to another service and the link is ideal from the point of view of compatibility, reliability, etc. [Example: (C)-(i)-(c)]

iii) For a 18-24 hour service between two cities, look for a matching service between the same pair of cities. This is ideal from the point of view of operational flexibility. For linking a train with another train, look for candidates in the following order of priority:

- Departures after sufficient time, allowing for maintenance can be considered. [A simple rule is that we can consider carry-over maintenance for medium distance trains (less than 24 hours or so).]
- Departures in the direction of the arriving train may be considered for linking, among the eligible trains.
- Departures of trains to any destination may be considered.
- If it is decided to link the train with itself, the possibility of a short inter-city can be considered. This is especially possible if the primary maintenance of the rake is planned at the other end of the long-distance run.

References:

1) Raghuram,G. and Ramani,K.V., "Coaching Stock Utilisation in Western Railway", Public systems Group, I.I.M., Ahmedabad, 1979.
2) Rake link book, Western Railway, July 1993.
3) Rake link book, Western Railway, July 1994.
4) Railway time table, Central Railway, July 1995.
5) Railway time table, Western Railway, July 1995.

APPENDICES

APPENDIX A:

Maintenance times and run times:

An early and comprehensive analysis of maintenance time norms vis a vis run times of trains was done in the report of Raghuram and Ramani (1979) on Western Railway operations. The following tabulation is along similar lines and uses more recent timetable information.

The cycle performed by a rake is the set of services the rake performs before repeating the same pattern. The length of a cycle is directly connected with the number of rakes required to provide all the services in the cycle. If we think of rake cycle time lengths, this is obvious (i.e. a rake cycle of three days means that -for a daily service - three rakes are required). The following table gives an approximate chart in terms of distance, which is related to the fact that the normal average speed of a Mail/Express train is no more than 50-60 kmph, and allowing for maintenance time of some 6 hours a day (at least).

Cycle distance (kms.)	Length of rake cycle
0-600	1 rake cycle
600-1000	1 or 2 rake cycle
1000-1700	2 rake cycle
1700-3000	3 rake cycle
3000- 4000	4 rake cycle
4000-5000	5 rake cycle

For different cycles, an examination of the average run time is tabulated. The remaining time is idle time, which is technically available for maintenance and other related operations. The conclusion from the table below is simple, namely, about a third of the time is provided or actually spent on maintenance related activities. However, there is wide variation as to how often this maintenance time is actually provided or utilized. It is clear that major maintenance activities are more a function of distance traveled rather than trips made. In other words, it is not at all essential to provide full maintenance services at the end of each rake turn around and maintenance can be easily "carried over" to other convenient times on the rake cycle.

Sr. No.	Rake cycle	Av.Maint. time	Av. Maint. time per day	% of time spent on maintenance
1	2	17h 12m	8h 36m	35.83
2	3	21h 22m	7h 07m	29.65
3	4	26h 11m	6h 08m	27.27
4	5	30h 09m	6h 02m	25.13
5	6	38h 47m	6h 28m	26.9
6	7	50h 02m	7h 08m	29.75
7	14 day cycle	91h 40m	6h 30m	27.28

Average Maintenance time per day of all cycles=6h 51m
Average % of time spent on maintenance=28.82

APPENDIX B:

We discuss various strategies in rake linking. The most useful strategy is that of a crossover, where the arrival of train A is linked to the departure of train B and vice versa.

B-1) If a mid-day arrival/departure of one train is linked with the late night departure/early morning arrival of another train [Examples (C)-(iii)] or if the late morning arrival/late afternoon departure of one train is linked with the early afternoon departure/mid-day arrival, a rake (or more) is saved over the self linking of the individual trains. [Examples: (A)-(iii) in Section 4.]

B-2) If an evening departure/late morning arrival is linked with an early morning arrival /late night departure [Example (B)-(iv)] or a midday arrival/departure is linked with a late morning/early evening arrival departure [Examples: (A)-(ii)] then the reliability of services increases, because a larger buffer is provided for the tight link of one train.

B-3). If a daytime run of a train back and forth is linked to the arrival/departure of an overnight service, a separate rake is not required for the daytime service. This presumes that the primary maintenance of the rake is at the other end of the overnight service. This also means that there is a choice of terminals of the overnight service at which the linking to another train can be done. [Example: (B)-(iii) in Section 4].

As an illustration, consider the following options:

Example 1: Vadodara Express and Kutch Express

Option 1: Vadodara Express linked to itself at Bombay Central and Kutch Express linked to itself at Bombay Central; and

Option 2: Vadodara Express linked to Kutch Express at Bombay Central. In both cases, the number of rakes required remains the same, but the slacks avai lable at Bombay Central are as follows:

	Option 1	Option 2
Vadodara Express	18 hr	11 hr 45 min
Kutch Express	5 hr	25 min 11 hr 25min

The second option is better, as it provides for more combined reliability of the two services.

Example 2: Vadodara E xpress (Mumbai -Vadodara) -Sayaji Nagar Express (Bandra - Vadodara) and Kutch Express (Mumbai-Gandhidham)

	Run Time	Idle Time	Rakes	%Rake Util.
Option 1	56h 20m	39h 40m	4	41.3
Option 2	56h 20m	63h 40m	4,1	44.79,55.5
Option 3	56h 20m	36h 15m	2,2	55.5,61.8
Option 4	56h 20m	63h 40m	2,1,2	27.7,55.5,61.8

		BCT	BDTS	BRC	GIM
Option1	P	4h	1h	2h 25m	2h
	M	9h 15m	-	-	10h 15m
Option2	P	4h	-,1h	2h,2h	2h, -
	M	9h 15m,-	-,-	14h15m,7h10m	10h15m,-
Option3	P	2h	1h,-	2h25m,-	-,2h
	M	14h15m,4h10m	-,-	-,-	-,10h15m
Option4	P	2h,-,2h	-,1h,-	2h,2h,-	-,-,2h
	M	14h15m,-,4h10m	-,-,-	7h10m,7h10m,-	-,-,10h15m

APPENDIX C:

In this section, the issue of rake linking is posed in its *most* general *form.* Consider a network with each terminal as a node in the network. The different services *from* nodes to other nodes can be represented as links in the network. There are a number of possibilities of linking arrivals at terminals (or a group of terminals) *to* departures at those terminals. These links together with the travel links will eventually *form* cycles (since there are only a finite number of links). These cycles will have properties such as

i) Length of the rake cycle
ii) Directional spread of the rake cycle
iii) Time intervals provided formaintenance and slack

The cycle decomposition taken as a whole will have certain properties such as maintenance line occupation at certain terminals, spread of run times and maintenance times over different cycles and the total number of rakes utilised. A desirable decomposition into cycles can be attempted using a procedure based on mathematical programming or some heuristic techniques. The problem in its entirety is quite a large one given the whole Indian Railway network, but a large part of it can perhaps be solved at a localised level, as well, with some standardized practices.