RESEARCH INTO A METHOD OF CREW SCHEDULING FOR SUBURBAN RAIL TRANSPORT USING HEURISTIC AND LINEAR PROGRAMMING TECHNIQUES

Andrew Neville Comrie

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DECLARATION

I declare that this project report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

A.N. Comrie

The 13th day of November 1989

ABSTRACT

Crew schedules on the South African Transport Services are done by roster compilers at depots. A method that uses heuristic and mathematical programming algorithms was developed to replace existing hand methods.

It is a two stage method that will use a microcomputer to assist roster compilers to draw up crew schedules. Initially timetables are subdivided into shifts and then they are combined into crew schedules.

The solution, which produces a significant improvement compared with an existing crew schedule and an existing method, has been accepted in principle and computer programming has begun.

In Appendix E another heuristic for the scheduling of league matches is described.

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1.1 TERMINOLOGY

A *train trip* is a train journey that has a specific departure point and destination at a specific time.

A *train set* is a set of coaches that undertakes train trips.

A *timetable* is all the train trips undertaken by all train sets on a single day.

A *crew schedule* is all the train trips that a crew undertakes on a single day.

A *shift* is a group of train trips that a crew undertakes on a single train set. One or more shifts make up a crew schedule.

Peak times are those times of the day when the most train sets are operating. There is a morning peak time and an afternoon peak time.

A *peak shift* is a shift at a peak time.

A *non-peak shift* is a shift out of peak time.

A *spreadover* is a crew schedule where the crew books off after completing one or more shifts and then books on again on at a later time on the same day to complete the crew schedule.

A *depot* is where a crew books on and off at the beginning and end of a crew schedule.

A *relief station* is a station where a crew may begin or end a shift.

A *transport trip* is a trip taken by train or road vehicle to transport a crew between a depot and a relief station at the beginning and end of a shift.

1 INTRODUCTION

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1.2 STATEMENT OF THE PROBLEM

Present methods of constructing timetables to meet passenger and vehicle requirements of suburban rail transport are done in the head office of the South African Transport Services (SATS). Solutions are integrated with other train services.

Crews, however, are scheduled by roster compilers at the depots because the requirements of crews are complicated and need special knowledge of local conditions. These often fall short of optimum as they are done by hand.

A new method of crew scheduling was required to assist the roster compilers in their tasks. The requirements of the method were :

- Programming must be developed on a microcomputer so that all depots are able to use the method.
- It must be flexible enough for adaption to local conditions.
- The solution must be acceptable to the crews.
- The method was to be originally used for crews of train drivers. It would then be adapted later to crews of conductors.
- The programming would be extended to include the compilation of the daily duty roster where unmanned crew schedules are split up and allocated to other crew schedules.

The purpose of the research was to examine the feasibility of computer scheduling. The method has been accepted in principle and computer programming has begun. The method will be subjected to further tests on other timetables once the programming is completed.

1.3 BACKGROUND TO COMPUTER SCHEDULING

The development of a timetables and schedules consider four facets :

- the passengers who determine the number and times of train trips.
- the vehicles which make up the vehicle schedules.
- the crews who undertake crew schedules.
- and the daily duty roster which adapts the crew schedules for daily use.

The particular problem addressed by this project report is the crew scheduling and the first two facets serve as data to the solution to the problem.

Wren[1] mentions three solution approaches : heuristic, mathematical programming and interactive. Most methods use a combination of these methods with the mathematical programming often being used to refine the solutions.

The mathematical algorithms use matching methods, the set partitoning approach or the set covering approach.

In the matching algorithms, two lists of part schedules are formed and are paired together by minimising cost. This allows the use of the Hungarian method of solving the Assignment problem.[2] This is an extremely efficient algorithm.

The set partitioning and set covering approach lead to the formation of large matrices that require large computing power to solve.

The publication of literature on crew scheduling has declined in recent years and that which is available is dated and may have been superseded. Wren,[3] however, commented in 1975 that " the lack of references ... in the formal literature reflects no lack of research in the field, but rather a paucity of work brought to a successful conclusion, owing to the extreme practical difficulties of the problem."

1.4 APPROACH TO THE PROBLEM

"All known algorithms for crew/vehicle scheduling solve the problem as a sequence of subproblems. The purpose of these decompositions is that each of the subproblems can be solved by a reasonably efficient solution algorithm."[4] Solutions can thus never be regarded as optimum.

The Johannesburg Municipality[5] had investigated a fully computerised system from Leeds University in the early 1980's but found that the system was too inflexible.

It was decided that an interactive system supported by heuristics and mathematical algorithms using matching methods would best meet the requirements.

Why is it now necessary to develop a new algorithm for scheduling ? There is really no standard method of crew scheduling as each enterprise has its own special set of rules. Programming that is available from overseas would be expensive and would need to be altered. Furthermore, changes in the rules for crew scheduling can be expected from time to time.

The approach to the problem differs in the following ways from what is proposed in the literature:

- The subdividing of the timetables into shifts is completely separated from the combining of shifts into crew schedules. The separation is necessary because a roster compiler's expertise is required to provide the times for walking, shunting, preparation and staging at the beginning and end of shifts.

- Both peaks are handled simultaneously when shifts are combined into crew schedules. This allows the shifts near midnight to be combined to either to an afternoon or morning peak shift.

1.5 METHOD

The method employed on the project was:

- the analysis of an existing timetable and crew schedule of one of the bigger depots in the SATS to develop crew scheduling rules.

- the development of a heuristic for the subdividing of the timetable into shifts.

- the use of a mathematical algorithm to combine shifts into schedules and

- the results of the method.

Each of these are handled in a separate chapter in the report.

2 ANALYSIS OF EXISTING CREW SCHEDULES

2.1 ANALYSIS OF THE TEST DATA

The analysis was done on the existing timetable and crew schedule for train drivers at the Germiston depot. The train sets were those for Dunswart, Germiston (excluding train trips to Vereeniging), Kwesine, Leralla and a few train sets between Pretoria and Braamfontein, all of which are controlled by the Germiston roster office. The data consisted of 31 train sets undertaking 448 train trips.

The distribution of train trips during a 24 hour period is shown in Figure 2.1. The morning and afternooon peaks are approximately 12 hours apart.

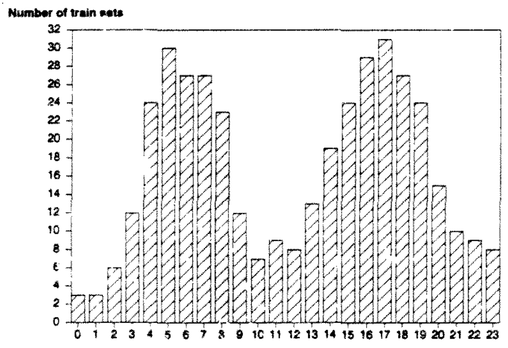

Figure 2.1 Distribution of train sets over 24 hours

There are a total of 60 crew schedules in the existing timetable and the longest schedule of 14 hours and 35 minutes. The overtime is 250 hours and 8 minutes per day for all crew schedules.

Analysis showed that 27,2% of the time is spent on trains. The low figure is greatly influenced by the relief time as a train set may not be left unattended except when it is staged in a yard. This percentage is misleading and the solutions generated will be expressed in terms of the number of schedules and the hours of overtime per day for all crew schedules.

The result of the limitation on the relief time mentioned in the previous paragraph is that a new crew must take over the train set when the previous shift ends. Wren[1] defines this as a Class C problem. The characteristic of this type of problem is that a crew cannot operate the same train set on two adjacent shifts as no break time is possible.

The analysis of the data proved to be more difficult than was first anticipated as walking, shunting, preparation and staging times are not shown in the crew schedule. Times for these movements could not be regarded as standard as they depend on a variety of factors such as whether the train trip has passengers, how many crews are operating the train set, the distance of the rest rooms from the platform or road vehicle and the number of shunting movements etc. All times for walking, preparation and staging of the train set and shunting movements had to be added to the train trip data.

A crew schedule consists of one to four shifts. By far the majority of these schedules have two or three shifts. Typically a schedule has one long shift of three to four hours and one or two shorter shifts of one to three hours. This construction allows for an efficient utilisation of paid working hours.

No spreadovers are allowed for the train driver crews.

2.2 ESTABLISHMENT OF RULES FOR CREW SCHEDULING

The following set of rules were drawn up from the analysis of the Germiston crew schedule and from discussions with personnel from the Southern Transvaal Region of SATS. The figures in brackets represent the standard time for train drivers at present. These parameters can sometimes be exceeded and this is left to the discretion of the roster compiler.

2.2.1 Rules for subdividing of timetables

2.2.1.1 The nominal length of the longest shift in a crew schedule. (4 hours)

2.2.1.2 The nominal length of other shifts in a crew schedule. (2,5 hours)

Rule 2.2.1.1 is the official maximum length of a shift. Rule 2.2.1.2 was introduced from the analysis of the test data and to ensure that the majority of two shift schedules would be less than the paid working hours.

2.2.2 Rules for combining shifts into schedules

2.2.2.1 The booking on time. (20 minutes)

2.2.2.2 The booking off time. (15 minutes)

2.2.2.3 The maximum length of a crew schedule. (14 hours)

2.2.2.4 The minimum length of a crew schedule (paid working hours). (8 hours)

2.2.2.5 The maximum number of shifts in a crew schedule. (4)

2.2.2.6 The maximum length of a crew schedule with no meal break. (5 hours)

2.2.2.7 The maximum length of a crew schedule with only one meal break. (10 hours)

2.2.2.8 The minimum time allowed for a meal break. (30 minutes)

2.2.2.9 The minimum time allowed between shifts. (10 minutes)

2.2.2.10 The maximum rest period in a crew schedule. (3 hours)

All the rules except Rule 2.2.2.10 were used in the programming. This rule is usually circumvented by allocating office work to a crew schedule.

3 SUBDIVIDING TIMETABLES INTO SHIFTS

The approach is to subdivide the timetable by a heuristic method which will serve as a guideline to roster compilers, who then ensure that the shifts all form cohesive units.

Timetables do not vary much during the week. All train trips that occur on a week day are placed in one 24 hour timetable for subdividing. Saturday and Sunday timetables are handled separately.

The principle behind the heuristic is to provide shifts where there is a reasonable amount of work done before a break and on spreading the work load evenly. As most crews should work either the morning or afternoon peak, Rule 2.2.1.1 was applied to shifts at the morning and afternoon peaks while Rule 2.2.1.2 applied to other shifts.

The roster compiler then :

- alters the shifts to tie in with transport trips of the full train service.
- assigns time for walking, shunting movements, preparation and staging of train sets.
- assigns two crews to train trips (one at each end of the train) on some lines late at night. This is a safety measure that eliminates walking to the motorised vehicle at the other end of the train set on the return trip.
- assigns two crews for short shunting movements at or near the depot when it is more efficient than using one crew.
- assigns transport trips at the beginning and end of shifts to and from relief points out of the existing train service or from the availability of road vehicles. These trips have a great influence on the solution.

3.1 DETAILED DESCRIPTION OF THE ALGORITHM

3.1.0.1 A preliminary subdivision of each train set's trips into blocks is done first. A new block starts when the time difference between an arrival and the next departure is more than a meal break.

3.1.0.2 The morning peak time and the afternoon peak time are determined.

3.1.0.3 A theoretical number of shifts is calculated from the blocks generated in 3.1.0.1 using Rules 2.2.1.1 and 2.2.1.2. Theoretical subdivision times are then calculated. If the block is over a peak time, the peak shift is positioned so that the middle of the shift is closest to the peak time.

3.1.0.4 The computer subdivides the blocks by comparing the theoretical subdivision times with the arrival times at depots and relief stations.

3.1.0.5 The roster compiler now examines the subdivision and makes alterations where required.

3.1.0.6 Walking, shunting, preparation and staging times are then added.

3.1.0.7 The transport trips for those shifts that begin or end at a relief station are finally added in case they are necessary. (The transport trip will not be used if the next shift begins at the same relief station.)

3.2 GENERATED DATA SETS

Three sets of data for testing the method were generated :

[A] the shifts of the existing crew schedule (151 shifts).

[B] the use of standard times for Rules 2.2.1.1 and 2.2.1.2
123 shifts were generated.

[C] the reduction of the time for Rule 2.2.1.2 to 1,5 hours.
141 shifts were generated.

The new data sets, [B] and [C] have less shifts than [A] because the shifts at peak times have been kept as long as possible.

4 COMBINING SHIFTS INTO CREW SCHEDULES

The approach is to use the Assignment algorithm to match and combine shifts into crew schedules. This is a two stage procedure that is based on the article by Ball, Bodin and Dial.[4]

- Shifts are assigned to crew schedules to find the minimum number of schedules. This gives an unsmoothed solution.

- The unsmoothed solution is improved upon by reallocating the beginning and end shifts of each schedule to reduce overtime and even out the work load.

4.1 FORMULATION OF THE MATHEMATICAL MODEL

The formulation consists of three main components :

- the compilation of list A and list B part schedules

- the feasibility subroutine and

- the matching subroutine.

A part schedule consists of one or more shifts that have already been combined.

In general, the list A part schedules cannot be feasibly be joined to another list A schedule to form a full schedule. List B part schedules can be joined to at least one list A part schedule. A more detailed explanation of the compilation of these lists is described in section 4.3.

The feasibility subroutine tests whether a part schedule in list A can be feasibly joined to a part schedule in list B. An optimisation parameter is calculated. If the part schedules cannot be feasibly joined the optimisation parameter is set equal to a large number.

The matching subroutine assigns the List B part schedules to the list A part schedules by minimising the optimisation parameters.

Let there be m part schedules in list A and n part schedules in list B.

For $i = 1,2,3,...,m$ and $j = 1,2,3,...,n$

Minimise : $Z = \sum_i \sum_j t_{ij} x_{ij}$

where t_{ij} = the optimisation parameter. This is expressed in units of time.

subject to : $\sum_i x_{ij} = 1$

$\sum_j x_{ij} = 1$

$x_{ij} = 1$ if the ith part schedule in list A is assigned to the jth part schedule in list B.

$x_{ij} = 0$ if there is no assignment.

4.2 ALTERNATIVES TESTED

4.2.1 The unsmoothed solution

The order in which the shifts are combined into a schedule is critical to the effectiveness of the algorithm and several models were tested.

4.2.1.1 The 1988 model

The first model placed all the shifts that occur at at the greatest peak and all shifts that could not feasibly be joined to them in list A. List B shifts were those that were feasible to at least one shift in list A and there were far more of them. Part schedules were formed by matching over a number of iterations. With each iteration the list B shifts became less and the unsmoothed solution terminated when list B was empty.

4.2.1.2 The three dimensional model

Shifts were classified into three groups: peak shifts (morning and afternoon), inner shifts (midday shifts which lie between the peaks) and outer shifts (early morning and late night shifts). The idea was to match both an inner and an outer shift to a peak shift simultaneously.

The size of the matrix for the three dimensional problem was approximately 225 000 values. This is too big to handle by normal branch-and-bound algorithms and methods of simplifying the problem were investigated. The literature survey revealed many articles on the subject.[6,7,8,9,10]

The technique of Langrangian relaxation brought the problem back to solving in two dimensions and when it became clear that the smoothing algorithms would not be eliminated, the additional computation required was not warranted and the model was abandoned.

4.2.1.3 The 1989 model

Analysis of the solution of the 1988 model showed that classifying the shifts into two groups (peak and non-peak) was insufficient.

Initially, five groups of shifts were created : peak shifts and two sets of inner and outer shifts each. The first sets of inner and outer shifts were just before or after one of the two peaks. The second sets were those inner shifts that could be feasibly be joined to other inner shifts and those outer shifts that could be feasibly be joined to other outer shifts.

Different orders of matching were tried and compared against each other. The model that consistently gave the best answers for the unsmoothed solution (which is described in more detail later) was:

- Build part schedules out of the peak and outer shifts.
- Use the 1988 model on these part schedules and the inner shifts.

This procedure is indirectly confirmed by Hoffstad[1] who in his algorithm develops early morning shifts first followed by spreadovers. Afternoon schedules are handled last.

Maisey[5] who uses an interactive computer aided process with no mathematical algorithm also handles his early morning and late night shifts first. An additional reason for this is that his crews are not prepared to work a one shift schedule at those times.

4.2.2 The smoothed solution

Four ways of separating the first and last shifts from each schedule were tried :

4.2.2.1 all first shifts.

4.2.2.2 all last shifts.

4.2.2.3 all first and last shifts from the morning peak to the afternoon peak.

4.2.2.4 all first and last shifts from the afternoon peak to the morning peak on the following day.

For 4.2.2.3 and 4.2.2.4 were suggested in the literature[4]. The composition of the list B schedules tended to be the same as those developed in the list B schedules used in the unsmoothed solution. Using 4.2.2.1 and 4.2.2.2, gave a better answer as this allowed overnight schedules to be generated.

4.2.3 The optimisation parameter

Time instead of cost was used in the optimisation parameter as all crew schedules under the paid working hours have the same cost and overtime is paid on the time worked in excess of the paid working hours.

Different parameters were required for the unsmoothed and smoothed solutions as the object of these two stages of the procedure differ.

In the unsmoothed solution, the object is to generate the minimum number of schedules without any consideration to the overtime. Three optimisation parameters were tried :

- *the length of the schedule.*
- the length of the break between the list A part schedule and the list B part schedule including transport time.
- the length of the break between the list A part schedule and the list B part schedule excluding transport time.

The second and third optimisation parameters were better than the first but there was very little difference between them in the final solution. (This may, however, change with other data.) The third parameter was decided upon as to eliminate cases where the part schedules are far apart and are selected as their transport trips are suited to each other.

In the smoothed solution, the object is to minimise overtime. Many of the schedules, however, do not have any overtime and a secondary optimisation parameter to balance the work load was added. A composite optimisation parameter was thus chosen : **1000 x overtime + ABS (time on trains - average time on trains per schedule) [minutes].**

4.3 DETAILED DESCRIPTION OF THE ALGORITHM

4.3.1 Weekday programme

Shifts are classified into three groups: peak shifts (morning and afternoon), inner shifts (midday shifts which lie between the peaks) and outer shifts (early morning and late night shifts).

The shifts are combined into crew schedules as follows :

4.3.1.1 List A part schedules : select all peak shifts.

List B part schedules : select all outer shifts except those around midnight that can be feasibly be joined to earlier or later outer shifts.

Optimisation parameter : The time between the part schedules, excluding any transport time.

4.3.1.2 List A part schedules : select part schedules from 4.3.1.1.

List B part schedules : select all outer shifts excluded in 4.3.1.1.

Optimisation parameter : The time between the part schedules, excluding any transport time.

4.3.1.3 List A part schedules : select part schedules that span the biggest peak and all part schedules that cannot be feasibly joined to them.

List B part schedules : select all part schedules (including inner shifts) that can be feasibly joined to a List A schedule.

Optimisation parameter : The time between the part schedules, excluding any transport time.

4.3.1.3 is iterated until all part schedules fall in List A. This produces the unsmoothed solution with the minimum number of crew schedules.

4.3.1.4 List B part schedules : select the first shift of each crew schedule formed in 4.3.1.3 that has more than one shift.

List A part schedules : select the balance of the crew schedules left over from list B.

Optimisation parameter : 1000 x overtime + ABS (time on trains - average time on trains per schedule) [minutes].

4.3.1.5 List B part schedules : select the last shift of each crew schedule formed in 4.3.1.4 that has more than one shift.

List A part schedules : select the balance of the crew schedules left over from list B.

Optimisation parameter : 1000 x overtime + ABS (time on trains - average time on trains per schedule) [minutes].

4.3.2 Weekend programme

The shifts from the Friday and Sunday overnight schedules from the the weekday programme are added to the Saturday and Sunday shifts. A 72 hour period is used.

4.3.2.1 List A part schedules : find the shift that has the earliest completion time. Select all shifts that begin before this shift ends.

List B part schedules : find the shift that is not in list A that has the earliest completion time. Select all shifts that are not in list A that begin before this shift ends.

Optimisation parameter : The time between the part schedules, excluding any transport time.

4.3.2.2 List A part schedules : select part schedules already generated.

List B part schedules : find the shift that is not in list A that has the earliest completion time. Select all shifts that are not in list A that begin before this shift ends.

Optimisation parameter : The time between the part schedules, excluding any transport time.

4.3.2.2 is iterated until the end of the period is reached. This produces the unsmoothed solution with the minimum number of crew schedules.

Find the Saturday and Sunday morning and afternoon peaks.

4.3.2.3 List B part schedules : using two adjacent peaks, select the last shift from the crew schedules of the first peak that have more than one shift and select the first shift from the crew schedules of the second peak that have more than one shift.

List A part schedules : select the balance of the crew schedules from the two adjacent peaks.

Optimisation parameter : 1000 x overtime + ABS (time on trains - average time on trains per schedule) [minutes].

5 RESULTS

The results presented are based sole' ` ` the development of the weekday programme. An example of a crew sche. . produced by the 1989 algorithm is given in Appendix B.

5.1 COMPARISON BETWEEN TH. 8 AND 1989 MODELS

A detailed comparison of the answers from the two models is given in the Appendix C1. The reduction in the number of shifts for all three data sets using the standard crew scheduling rules varies between three and six shifts. The newer model is thus a significant improvement.

5.2 COMPARISON BETWEEN THE EXISTING SCHEDULE AND THE 1989 MODEL

Although the maximum length of a crew schedule is 14 hours, the roster compiler had in five cases exceeded the limit with a maximum of 14:35 hours. Using data set [A] and the standard rules, the 1989 algorithm generates the same number of crew schedules but the overtime is reduced by 37,5 %.

Setting the maximum length of a crew schedule to 14:35 hours there is a saving of seven crew schedules with overtime reduced by 9 %.

A detailed comparison of the answers is in Appendix C2.

5.3 SENSITIVITY ANALYSIS ON RULES

5.3.1 MAXIMUM LENGTH OF CREW SCHEDULE (RULE 2.2.2.3).

In Appendix C3 and in Figure 5.1, the best answer from the three data sets was selected. There was always very little difference between the answers of data set [B] and [C], indicating that the nominal length of the shorter shifts in a schedule is probably not critical.

Data set [A] gave between two and five more schedules than the best answer for all maximum schedule lengths. The policy of having all the longer shifts at the same time (i.e. at the peak times) pays.

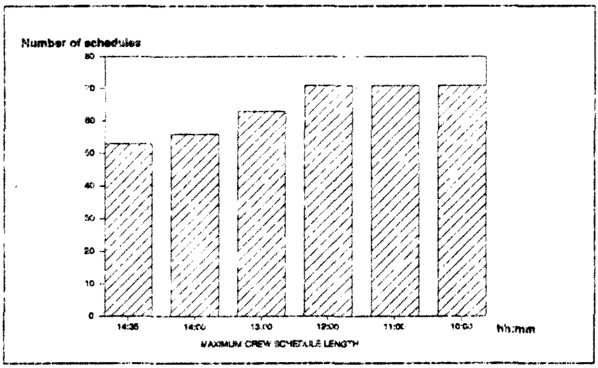

Figure 5.1 The effect of the maximum crew schedule length

The same number of crew schedules (71) is generated for the maximum schedule length of 12, 13 and 14 hours. The solution is, however, not the same and the overtime varies between 21 and 30 hours. This shows that the solution is not optimum. This is within acceptable limits as the average length of a crew schedule does not vary by more than ten minutes or 2,2%.

5.3.2 MINIMUM LENGTHS OF MEAL BREAKS AND SHORT BREAKS (RULES 2.2.2.8 AND 2.2.2.9).

Appendix C4 gives details of the analysis and Appendix D shows a schematic diagram of how well the 1989 algorithm matches the shifts.

Increasing the meal break to 45 minutes would be a reasonable step to take and this would only increase the crew schedules by two. The overtime remains approximately the same. Note that the number of crew schedules is still less than the 60 of the existing crew schedule.

Increasing the short break to 20 minutes would also be a reasonable step to take as it can be considered as a safety factor for delays. The effect is that overtime is increased by 5,7 %.

Table 5.1 shows why increasing the minimum lengths of meal breaks and short breaks has little effect on the number of crew schedules. (i.e. the breaks are well above the minimum).

	EXISTING	1989 ALGORITHM	
DATA SET	[A]	[B]	[C]
MAXIMUM SCHEDULE LENGTH	14:35	14:00	14:35
NUMBER OF SCHEDULES	60	56	53
Break length [hh:mm]	Percentage of total breaks		
0:00 to 0:30	4,5	12,5	7,2
0:30 to 1:00	9,1	31,9	33,3
1:00 to 3:00	55,7	16,7	20,3
3:00 +	30,7	38,9	39,1
	100,0	100,0	100,0

Table 5.1 Comparison of break lengths between shifts

The reason for the large breaks can be attributed to the requirement that the train set must not be left unattended and the crews are forced to operate different train sets from shift to shift.

It is interesting to note that the existing crew schedule has the majority of breaks concentrated between one and three hours while in the mathematical algorithm increases the percentage of breaks in all the other three ranges.

At least 30 % of the crew schedules in both the existing and computerised method have breaks of longer than three hours. By allowing 25% of crew schedules as spreadovers the time on duty can be reduced by approximately 90 hours on all crew schedules.

6 CONCLUSION

The method developed has significant benefit in both the reduction of shifts and overtime on the test timetable, although it has not yet been accepted by the crews themselves.

The reduction of the crew schedules by 7 using the actual maximum schedule length of 14 hours and 35 minutes would lead to a saving at the Germiston depot of R 415 000 per year if staff could be reduced. The schedules, however are extremely long and would probably be unacceptable to the crews.

A better solution is to design the schedules strictly to the standard rules and only allow crew schedules up to 14 hours. If the number of crew schedules is kept at 60 a saving of R 365 000 per year in overtime will result.

The major benefit of the method is that the scheduling rules (i.e. policy adjustment in the letter in Appendix A) can be altered and a monetary value can immediately be placed on it. If spreadovers were allowed on 25% of the schedules (i.e. the crews were not paid for the longest rest period) a further saving of R 235 000 per year would then be possible.

Bodin et.al.[4] states that "the general experience has been that computerized methods have saved a relatively small percentage of costs...(although this) can amount to a large sum of money. ...(However) computerized scheduling has saved transit agency planners and schedulers considerable time in developing new schedules and considerable time and effort training new schedulers." Timetables can be changed in a matter of weeks, rather than months, a requirement that will become necessary as SATS moves toward privatisation.

The feasibility of the method has been established, although the results obtained can be improved upon with the help of a roster compiler. By examining the schematic diagram in Annexure D, which is produced on a microcomputer minor improvements can be also made.

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APPENDIX A

70/21/MC

SASDRUK/SARPRINT

37/57691 (7/82)

SUID-AFRIKAANSE VERVOERDIENSTE – SOUTH AFRICAN TRANSPORT SERVICES

RIG ALLE MEDEDELINGS AAN DIE HOOFBESTUURDER

ADDRESS ALL COMMUNICATIONS TO THE GENERAL MANAGER

KABELGRAMME/CABLES
TELEGRAMME/TELEGRAMS } SAR

TELEFOON/TELEPHONE
VERWYSING/REFERENCE

HOOFBESTUURDER SE KANTOOR
GENERAL MANAGER'S OFFICE
Privaatsak/Private Bag X47
JOHANNESBURG
2000

1989 -10- 3 0

TO WHOM IT MAY CONCERN

The Assistant General Manager (Operating) of the South African Transport Services (SATS) commissioned Mr A N Comrie of the Productivity Bureau to develop a method of crew scheduling. Visits to the USA and Europe revealed no standard software that could be used by SATS for crew schedules.

The method was applied within the existing parameters and showed a substantial reduction in the working hours and the number of crew schedules required.

Mr Comrie's approach represents an advancement in the practical application of scheduling methodologies in the railway environment. The results are currently being assessed with a view to policy adjustment and further improvement prior to implementation.

DIRECTOR (OPERATING), SATS

APPENDIX B

CREW SCHEDULE FOR A MAXIMUM SCHEDULE LENGTH OF 14 HOURS

KEY

BSTP	=	Walking time from a depot before a transport trip.
ESTP	=	Walking time to a depot after a transport trip.
LOSA	=	Relief time.
PASS	=	A transport trip time.
RANG	=	Shunting time.
STAL	=	Staging time (including the time for the shunting movement).
SSTP	=	Walking time to a depot or relief station after a shift.
VSTP	=	Walking time from a depot or relief station before a shift.
VOOR	=	Preparation time.

CREW SCHEDULE 1

TRAIN SET G02

0036	VSTP	GMR - GMR	0041
0041	VOOR 1601	GMR - GMR	0056
0056	RANG	GMR - GMR	0105
0105	1601	GMR - OLF	0132
0145	1602	OLF - GMR	0224
0224	SSTP	GMR - GMR	0229

TRAIN SET D01

0404	BSTP	GMR - GMR	0409
0409	PASS 0017	GMR - DUN	0427
0502	VSTP	DUN - DUN	0513
0513	VOOR 8815	DUN - DUN	0531
0531	8815	DUN - DAV	0553
0601	8816	DAV - DUN	0623
0631	8823	DUN - DAV	0653
0701	8824	DAV - DUN	0723
0723	SSTP	DUN - DUN	0726
0745	PASS 0066	DUN - GMR	0801
0801	ESTP	GMR - GMR	0806

CREW SCHEDULE 2

TRAIN SET K01

0151	VSTP	GMR - GMR	0156
0156	VOOR 7600	GMR - GMR	0214
0214	7600	GMR - KUT	0219
0228	7601	KUT - GMR	0233
0234	7803	GMR - KWE	0306
0315	7602	KWE - GMR	0345
0345	SSTP	GMR - GMR	0350

TRAIN SET K07

0425	BSTP	GMR - GMR	0430
0430	PASS KOMBI	GMR - KUT	0440
0451	VSTP	KUT - KUT	0458
0458	VOOR 7613	KUT - KUT	0516
0516	7613	KUT - KWE	0535
0545	7508	KWE - KUT	0610
0621	7623	KUT - KWE	0644
0655	7722	KWE - SIM	0724
0724	STAL 7722	SIM - SIM	0745
0745	SSTP	SIM - SIM	0753
0820	PASS 1116	SIM - GMR	0825
0825	ESTP	GMR - GMR	0833

CREW SCHEDULE 3

TRAIN SET L07

0153	BSTP	GMR - GMR	0158
0158	PASS 1603	GMR - EFT	0209
0216	VSTP	EFT - EFT	0224
0224	VOOR 0501	EFT - EFT	0242
0242	RANG	EFT - EFT	0306
0306	0501	EFT - LRA	0336
0346	0502	LRA - GMR	0428
0428	SSTP	GMR - GMR	0433

TRAIN SET K03

0522	VSTP	GMR - GMR	0527
0527	LOSA 7806	GMR - GMR	0529
0529	7613	GMR - KWE	055.
0606	7510	KWE - KUT	0631
0641	7625	KUT - KWE	0704
0716	7734	KWE - GMR	0745
0746	7830	GMR - BRR	0807
0807	STAL 7830	BRR - BRR	0831
0831	SSTP	BRR - BRR	0852
0923	PASS 7625	BRR - GMR	0928
0928	ESTP	GMR - GMR	0933

TRAIN SET D03

1104	BSTP	GMR - GMR	1109
1109	PASS 0091	GMR - DUN	1127
1155	VSTP	DUN - DUN	1158
1158	LOSA 8844	DUN - DUN	1206
1206	8843	DUN - DAV	1228
1236	8846	DAV - DUN	1258
1306	8847	DUN - DAV	1328
1336	8848	DAV - DUN	1358
1358	STAL 8848	DUN - DUN	1406
1406	SSTP	DUN - DUN	1418
1426	PASS 0104	DUN - GMR	1445
1445	ESTP	GMR - GMR	1450

CREW SCHEDULE 4

TRAIN SET G02

0219	VSTP	GMR - GMR	0224
0224	LOSA 1602	GMR - GMR	0225
0225	1602	GMR - BRR	0250
0302	1607	BRR - GMR	0322
0322	STAL 1607	GMR - GMR	0339
0339	SSTP	GMR - GMR	0344

TRAIN SET L07

0423	VSTP	GMR - GMR	0428
0428	LOSA 0502	GMR - GMR	0444
0444	0507	GMR - LRA	0524
0533	0518	LRA - EFT	0604
0615	0517	EFT - LRA	0645
0657	0538	LRA - GMR	0739
0743	0538	GMR - IDI	0745
0745	SSTP	IDI - IDI	0745
0756	PASS 1825	IDI - GMR	0800
0800	ESTP	GMR - GMR	0805

CREW SCHEDULE 5

TRAIN SET L02

0247	BSTP	GMR - GMR	0252
0252	PASS 1605	GMR - KAF	0320
0426	VSTP	KAF - KAF	0434
0434	VOOR 1811	KAF - KAF	0452
0452	1811	KAF - LRA	0505
0521	0516	LRA - EFT	0552
0605	0515	EFT - LRA	0635
0644	0534	LRA - EFT	0715
0750	0535	EFT - LRA	0820
0829	1804	LRA - KAF	0841
0841	SSTP	KAF - KAF	0906
0917	PASS 0636	KAF - GMR	0947
0947	ESTP	GMR - GMR	0952

TRAIN SET K02

1322	VSTP	GMR - GMR	1327
1327	LOSA 7860	GMR - GMR	1330
1330	7657	GMR - KWE	1358
1408	7864	KWE - GMR	1442
1445	7663	GMR - KWE	1513
1524	7648	KWE - GMR	1554
1554	SSTP	GMR - GMR	1559

CREW SCHEDULE 6

TRAIN SET D04

0304	BSTP	GMR - GMR	0309
0309	PASS 0013	GMR - DUN	0327
0332	VSTP	DUN - DUN	0343
0343	VOOR 8803	DUN - DUN	0401
0401	8803	DUN - DAV	0423
0431	8804	DAV - DUN	0453
0501	8811	DUN - DAV	0523
0531	8812	DAV - DUN	0553
0553	SSTP	DUN - DUN	0556

TRAIN SET D03

0635	VSTP	DUN - DUN	0638
0646	8825	DUN - DAV	0708
0716	8826	DAV - DUN	0738
0738	LOSA 8826	DUN - DUN	0746
0746	8833	DUN - DAV	0808
0816	8834	DAV - DUN	0838
0901	8837	DUN - DAV	0923
0936	8838	DAV - DUN	0958
0958	SSTP	DUN - DUN	1001
1026	PASS 0084	DUN - GMR	1046
1046	ESTP	GMR - GMR	1051

CREW SCHEDULE 7

TRAIN SET D02

0304	BSTP	GMR - GMR	0309
0309	PASS 0013	GMR - DUN	0327
0350	VSTP	DUN - DUN	0353
0353	VOOR 8805	DUN - DUN	0411
0411	8805	DUN - DAV	0433
0441	8806	DAV - DUN	0503
0503	SSTP	DUN - DUN	0506

TRAIN SET D04

0542	VSTP	DUN - DUN	0553
0553	LOSA 8812	DUN - DUN	0601
0601	8819	DUN - DAV	062°
0631	8820	DAV - DUN	0653
0701	8827	DUN - DAV	0723
0731	8828	DAV - DUN	0753
0801	8835	DUN - DAV	0823

0831	8836	DAV - DUN	0853
0853	STAL 8836	DUN - DUN	0906
0906	SSTP	DUN - DUN	0918
0926	PASS 0080	DUN - GMR	0945
0945	ESTP	GMR - GMR	0950

TRAIN SET L03

1215	BSTP	GMR - GMR	1220
1220	PASS 0639	GMR - KAF	1248
1315	VSTP	KAF - KAF	1323
1323	VOOR 1843	KAF - KAF	1341
1341	RANG 1843	KAF - KAF	1405
1405	1843	KAF - LRA	1418
1428	0554	LRA - EFT	1459
1459	SSTP	EFT - EFT	1502
1609	PASS 0664	EFT - GMR	1620
1620	ESTP	GMR - GMR	1625

CREW SCHEDULE 8

TRAIN SET G03

0329	VSTP	GMR - GMR	0334
0334	VOOR 1105	GMR - GMR	0349
0349	RANG	GMR - GMR	0358
0358	1105	GMR - KPR	0423
0434	1106	KPR - GMR	0519
0519	SSTP	GMR - GMR	0524

TRAIN SET G04

0601	VSTP	GMR - GMR	0606
0606	LOSA 1108	GMR - GMR	0649
0649	1115	GMR - KPR	0732
0741	1116	KPR - GMR	0825
0825	STAL 1116	GMR - GMR	0830
0830	SSTP	GMR - GMR	0835

TRAIN SET D03

0904	BSTP	GMR - GMR	0909
0909	PASS [illegible]000	GMR - DUN	0927
0955	VSTP	DUN - DUN	0958
0958	LOSA 8838	DUN - DUN	1006
1006	8841	DUN - DAV	1028
1036	8842	DAV - DUN	1058
1106	8843	DUN - DAV	1128
1136	8844	DAV - DUN	1158
1158	SSTP	DUN - DUN	1201

TRAIN SET D04

1332	VSTP	DUN - DUN	1343
1343	VOOR 8849	DUN - DUN	1401
1401	8849	DUN - DAV	1423
1431	8850	DAV - DUN	1453
1515	8857	DUN - DAV	1537
1545	8858	DAV - DUN	1607
1607	SSTP	DUN - DUN	1610
1626	PASS 0136	DUN - GMR	1646
1646	ESTP	GMR - GMR	1651

CREW SCHEDULE 9

TRAIN SET L06

0336	BSTP	GMR - GMR	0341
0341	PASS 0503	GMR - KAF	0410
0420	VSTP	KAF - KAF	0428
0428	VOOR 1807	KAF - KAF	0446
0446	1807	KAF - LRA	0457
0506	0512	LRA - EFT	0537
0551	0513	EFT - LRA	0619
0629	0532	LRA - EFT	0700
0712	0527	EFT - KAF	0725
0725	STAL 0527	KAF - KAF	0754
0754	SSTP	KAF - KAF	0802
0819	PASS 0632	KAF - GMR	0847
0847	ESTP	GMR - GMR	0852

TRAIN SET K02

1053	VSTP	GMR - GMR	1058
1058	LOSA 7850	GMR - GMR	1100
1100	7647	GMR - KWE	1128
1139	7854	KWE - GMR	1213
1215	7651	GMR - KWE	1243
1253	7860	KWE - GMR	1327
1327	SSTP	GMR - GMR	1332

CREW SCHEDULE 10

TRAIN SET K02

0345	BSTP	GMR - GMR	0345
0345	PASS KOMBI	GMR - KUT	0355
0425	VSTP	KUT - KUT	0432
0432	VOOR 7611	KUT - KUT	0450
0450	7611	KUT - KWE	0513
0524	7810	KWE - GMR	0558
0600	7621	GMR - KWE	0628
0639	7822	KWE - GMR	0713
0715	7631	GMR - KWE	0743
0754	7834	KWE - GMR	0828
0828	SSTP	GMR - GMR	0833

TRAIN SET K05

1241	BSTP	GMR - GMR	1246
1246	PASS 0096	GMR - BRR	1319
1322	VSTP	BRR - BRR	1352
1352	VOOR 7659	BRR - BRR	1410
1410	7659	BRR - KUT	1437
1437	STAL 7659	KUT - KUT	1442
1442	SSTP	KUT - KUT	1445
1538	PASS 7646	KUT - GMR	1543
1543	ESTP	GMR - GMR	1548

CREW SCHEDULE 11

TRAIN SET R28

0414	VSTP	GMR - GMR	0419
0419	LOSA 1606	GMR - GMR	0420
0420	1606	GMR - BRR	0445
0445	SSTP	BRR - BRR	0504
0506	PASS 0029	BRR - GMR	0539
0539	ESTP	GMR - GMR	0544

TRAIN SET L05

0554	VSTP	GMR - GMR	0559
0559	LOSA 0514	GMR - GMR	0616
0616	0521	GMR - LRA	0658
0714	0544	LRA - GMR	0756
0756	RANG	GMR - IDI	0800
0802	LOSA 0541	IDI - IDI	0816
0816	0544	IDI - GMR	0820
0820	STAL 0544	GMR - GMR	0828
0828	SSTP	GMR - GMR	0837

TRAIN SET G04

1059	VSTP	GMR - GMR	1104
1104	VOOR 1121	GMR - GMR	1119
1119	1121	GMR - KPR	1202
1216	1122	KPR - GMR	1300
1300	STAL 1122	GMR - GMR	1314
1314	SSTP	GMR - GMR	1319

CREW SCHEDULE 12

TRAIN SET L04

0415	BSTP	GMR - GMR	0420
0420	PASS 0503	GMR - KAF	0448
0517	VSTP	KAF - KAF	0525
0525	VOOR 1819	KAF - KAF	0543
0543	1819	KAF - LRA	0554
0603	0524	LRA - EFT	0634
0643	0523	EFT - LRA	0707
0725	0546	LRA - GMR	0807
0809	0546	GMR - IDI	0813
0822	0571	IDI - GMR	0826
0826	STAL 0826	GMR - GMR	0834
0834	SSTP	GMR - GMR	0843

TRAIN SET L02

0915	BSTP	GMR - GMR	0920
0920	PASS 0629	GMR - KAF	0948
1032	VSTP	KAF - KAF	1040
1040	LOSA 1812	KAF - KAF	1105
1105	1831	KAF - LRA	11[illegible]
1128	1816	LRA - KAF	1148
1205	1835	KAF - LRA	1218
1228	1820	LRA - KAF	1240
1305	1839	KAF - LRA	1318
1328	1824	LRA - KAF	1340
1340	STAL 1824	KAF - KAF	1345
1345	SSTP	KAF - KAF	1403
1450	PASS 0652	KAF - GMR	[illegible]320
1520	ESTP	GMR - [illegible]	1525

CREW SCHEDULE 13

TRAIN SET L0[illegible]

0415	BSTP	GMR - GMR	0420
0420	PASS [illegible]3	GMR - KAF	0448
0459	VSTP	KAF - KAF	0507
0507	VOOR 1817	KAF - KAF	0525
0525	1817	KAF - LRA	0536
0545	0520	LRA - EFT	0616
0627	0519	EFT - LRA	0651
0703	0540	LRA - EFT	0734
0745	0533	EFT - KAF	0758
0758	STAL 0533	KAF - KAF	0818
0818	SSTP	KAF - KAF	0826
0850	PASS 0634	KAF - GMR	0920
0920	ESTP	GMR - GMR	0925

TRAIN SET K04

1153	VSTP	GMR - GMR	1158
1158	LOSA 7630	GMR - GMR	1201
1201	7841	GMR - KWE	1233
1243	7636	KWE - GMR	1313
1315	7847	GMR - KWE	1347
1358	7640	KWE - GMR	1428
1428	SSTP	GMR - GMR	1433

CREW SCHEDULE 14

TRAIN SET G05

0431	VSTP	GMR - GMR	0436
0436	VOOR 1109	GMR - GMR	0451
0451	RANG	GMR - GMR	0500
0500	1109	GMR - KPR	0543
0552	1110	KPR - GMR	0637
0642	0040	GMR - BRR	0708
0708	STAL 0040	BRR - BRR	0732
0732	SSTP	BRR - BRR	0753
0808	PASS 0071	BRR - GMR	0839
0839	ESTP	GMR - GMR	0844

TRAIN SET D02

1304	BSTP	GMR - GMR	1309
1309	PASS 0101	GMR - DUN	1327
1403	VSTP	DUN - DUN	1414
1414	VOOR 8851	DUN - DUN	1432
1432	8851	DUN - DAV	1454
1502	8852	DAV - DUN	1524
1532	8859	DUN - DAV	1554
1602	8860	DAV - DUN	1624
1624	SSTP	DUN - DUN	1627
1641	PASS 0144	DUN - GMR	1700
1700	ESTP	GMR - GMR	1705

CREW SCHEDULE 15

TRAIN SET D02

0434	BSTP	GMR - GMR	0439
0439	PASS 0021	GMR - DUN	0457
0503	VSTP	DUN - DUN	0506
0506	LOSA 8808	DUN - DUN	0511
0511	8813	DUN - DAV	0533
0541	8814	DAV - DUN	0603
0611	8821	DUN - DAV	0633
0641	8822	DAV - DUN	0703
0711	8829	DUN - DAV	0733
0741	8830	DAV - DUN	0803
0803	STAL 8830	DUN - DUN	0811
0811	SSTP	DUN - DUN	0823
0856	PASS 0078	DUN - GMR	0916
0916	ESTP	GMR - GMR	0921

TRAIN SET L01

1141	BSTP	GMR - GMR	1146
1146	PASS 0088	GMR - BRR	1219
1246	VSTP	BRR - BRR	1305
1305	VOOR 0547	BRR - BRR	1323
1323	0547	BRR - GMR	1343
1413	0547	GMR - LRA	1455
1505	0556	LRA - GMR	1547
1547	SSTP	GMR - GMR	1552

CREW SCHEDULE 16

TRAIN SET G01

0448	VSTP	GMR - GMR	0453
0453	VOOR 1007	GMR - GMR	0508
0508	1007	GMR - ALB	0521
0526	1008	ALB - GMR	0540
0545	1009	GMR - ALB	0558
0603	1010	ALB - GMR	0617
0622	1011	GMR - ALB	0635
0640	1012	ALB - GMR	0654
0708	1013	GMR - ALB	0721
0726	1014	ALB - GMR	0740
0740	STAL 1014	GMR - GMR	0754
0754	SSTP	GMR - GMR	0759

TRAIN SET G04

1410	VSTP	GMR - GMR	1415
1415	VOOR 1123	GMR - GMR	1430
1430	1123	GMR - KPR	1513
1522	1124	KPR - GMR	1607
1758	SSTP	GMR - GMR	1803

CREW SCHEDULE 17

TRAIN SET G03

0514	VSTP	GMR - GMR	0519
0519	LOSA 1106	GMR - GMR	0520
0520	RANG 1113	GMR - GMR	0550
0550	1113	GMR - KPR	0633
0645	1114	KPR - GMR	0730
0730	STAL 1114	GMR - GMR	0744
0744	SSTP	GMR - GMR	0749

TRAIN SET K04

1423	VSTP	GMR - GMR	1428
1428	LOSA 7640	GMR - GMR	1430
1430	7853	GMR - KWE	1502
1513	7546	KWE - GMR	1543
1545	7857	GMR - KWE	1617
1628	7654	KWE - GMR	1658
1701	7867	GMR - KWE	1733
1743	7666	KWE - GMR	1813
1813	SSTP	GMR - GMR	1818

CREW SCHEDULE 18

TRAIN SET K06

0545	BSTP	GMR - GMR	0550
0550	PASS 1113	GMR - SIM	0555
0557	VSTP	SIM - SIM	0604
0604	LOSA 7712	SIM - SIM	0613
0613	7819	SIM - KWE	0636
0645	7714	KWE - SIM	0714
0725	7825	SIM - KWE	0753
0804	7728	KWE - SIM	0833
0833	STAL 7728	SIM - SIM	0854
0854	SSTP	SIM - SIM	0902

TRAIN SET K06

1545	VSTP	SIM - SIM	1552
1552	VOOR 7861	SIM - SIM	1610
1610	7861	SIM - KWE	1638
1647	7732	KWE - SIM	1716
1725	7871	SIM - KWE	1753
1803	7738	KWE - SIM	1832
1832	SSTP	SIM - SIM	1835
1835	ESTP	SIM - GMR	1848

CREW SCHEDULE 19

TRAIN SET L08

0615	BSTP	GMR - GMR	0620
0620	PASS 0615	GMR - EFT	0631
0642	VSTP	EFT - EFT	0647
0647	LOSA 0528	EFT - EFT	0658
0658	0525	EFT - LRA	0722
0733	0550	LRA - EFT	0804
0804	STAL 0550	EFT - EFT	0824
0824	SSTP	EFT - EFT	0832
0909	PASS 0636	EFT - GMR	0920
0920	ESTP	GMR - GMR	0925

TRAIN SET K01

1508	VSTP	GMR - GMR	1513
1513	LOSA 7644	GMR - GMR	1515
1515	7855	GMR - KWE	1547
1556	7650	KWE - GMR	1628
1630	7863	GMR - KWE	1702
1713	7662	KWE - GMR	1743
1745	7873	GMR - KWE	1817
1828	7674	KWE - GMR	1858
1858	SSTP	GMR - GMR	1903

CREW SCHEDULE 20

TRAIN SET L01

0632	VSTP	GMR - GMR	0637
0637	LOSA 0522	GMR - GMR	0638
0638	0522	GMR - BRR	0711
0711	STAL 0522	BRR - BRR	0735
0735	SSTP	BRR - BRR	0756
0808	PASS 0071	BRR - GMR	0839
0839	ESTP	GMR - GMR	0844

TRAIN SET K05

1325	BSTP	GMR - GMR	1330
1330	PASS 7657	GMR - KUT	1335
1430	VSTP	KUT - KUT	1437
1437	RANG 7659	KUT - KUT	1442
1512	VOOR 7667	KUT - KUT	1530
1530	7667	KUT - KWE	1553
1602	7552	KWE - KUT	1627
1636	7673	KUT - KWE	1659
1708	7560	KWE - KUT	1733
1742	7677	KUT - KWE	1805
1816	7572	KWE - KUT	1841
1841	STAL 7572	KUT - KUT	1910
1910	SSTP	KUT - KUT	1917
1923	PASS 7676	KUT - GMR	1928
1928	ESTP	GMR - GMR	1933

CREW SCHEDULE 21

TRAIN SET K05

0644	VSTP	GMR - GMR	0649
0649	LOSA 7816	GMR - GMR	0651
0651	7627	GMR - KWE	0719
0730	7618	KWE - GMR	0800
0803	7637	GMR - BRR	0824
0824	STAL 7637	BRR - BRR	0848
0848	SSTP	BRR - BRR	0859
0908	PASS 0083	BRR - GMR	0939
0939	ESTP	GMR - GMR	0944

TRAIN SET L07

1516	BSTP	GMR - GMR	1521
1521	PASS 0653	GMR - EFT	1532
1545	VSTP	EFT - EFT	1553
1553	RANG	EFT - EFT	1617
1617	VOOR 0565	EFT - EFT	1635
1635	0565	EFT - OLF	1701
1710	0574	OLF - EFT	1738
1752	0581	EFT - LRA	1822
1831	0588	LRA - EFT	1902
1902	STAL 0588	EFT - EFT	1907
1907	SSTP	EFT - EFT	1910
1936	PASS 0684	EFT - GMR	1947
1947	ESTP	GMR - GMR	1952

CREW SCHEDULE 22

TRAIN SET D01

0649	BSTP	GMR - GMR	0654
0654	PASS 0039	GMR - DUN	0712
0720	VSTP	DUN - DUN	0723
0723	LOSA 8824	DUN - DUN	0731
0731	8831	DUN - DAV	0753
0801	8832	DAV - GMR	0840
0841	8832	GMR - BRR	0906
0906	STAL 8832	BRR - BRR	0930
0930	SSTP	BRR - BRR	0951
1013	PASS 0087	BRR - GMR	1044
1044	ESTP	GMR - GMR	1049

TRAIN SET D04

1534	BSTP	GMR - GMR	1539
1539	PASS 0115	GMR - DUN	1557
1604	VSTP	DUN - DUN	1607
1607	LOSA 8858	DUN - DUN	1615
1615	8863	DUN - DAV	1637
1645	8864	DAV - DUN	1707
1715	8871	DUN - DAV	1737
1745	8872	DAV - DUN	1807
1815	8879	DUN - DAV	1837
1845	8880	DAV - DUN	1907
1907	SSTP	DUN - DUN	1910
1926	PASS 0160	DUN - GMR	1946
1946	ESTP	GMR - GMR	1951

CREW SCHEDULE 23

TRAIN SET L03

0659	VSTP	GMR - GMR	0704
0704	LOSA 7820	GMR - GMR	0710
0710	0531	GMR - LRA	0752
0803	0552	LRA - EFT	0834
0844	1823	EFT - KAF	0857
0858	1823	KAF - LRA	0911
0921	1808	LRA - KAF	0933
0933	STAL 1808	KAF - KAF	0944
0944	SSTP	KAF - KAF	0952
1117	PASS 0642	KAF - GMR	1144
1144	ESTP	GMR - GMR	1149

TRAIN SET D02

1534	BSTP	GMR - GMR	1539
1539	PASS 0115	GMR - DUN	1556
1621	VSTP	DUN - DUN	1624
1624	LOSA 8860	DUN - DUN	1632
1632	8867	DUN - DAV	1654
1702	8868	DAV - DUN	1724
1745	8875	DUN - DAV	1807
1815	8876	DAV - DUN	1837
1837	SSTP	DUN - DUN	1840
1856	PASS 0162	DUN - GMR	1915
1915	ESTP	GMR - GMR	1920

CREW SCHEDULE 24

TRAIN SET L07

0736	VSTP	GMR - GMR	0741
0741	0538	GMR - IDI	0745
0745	LOSA 0538	IDI - IDI	0746
0756	1825	IDI - GMR	0800
0800	RANG	GMR - GMR	0824
0845	1825	GMR - EFT	0853
0853	STAL 1825	EFT - EFT	0858
0858	SSTP	EFT - EFT	0906
0936	PASS 0636	EFT - GMR	0947
0947	ESTP	GMR - GMR	0952

TRAIN SET R13

1442	BSTP	GMR - GMR	1447
1447	PASS 0104	GMR - BRR	1519
1522	VSTP	BRR - BRR	1552
1552	VOOR 1335	BRR - BRR	1610
1610	1635	BRR - GMR	1642
1643	1635	GMR - OLF	1735
1745	1636	OLF - BRR	1844

1844	STAL 1636	BRR - BRR	1908
1908	SSTP	BRR - BRR	1927
1938	PASS 0167	BRR - GMR	2009
2009	ESTP	GMR - GMR	2014

CREW SCHEDULE 25

TRAIN SET K01

0738	VSTP	GMR - GMR	0743
0743	LOSA 7616	GMR - GMR	0745
0745	7827	GMR - KWE	0817
0828	7624	KWE - GMR	0858
0858	STAL 7624	GMR - GMR	0927
0927	SSTP	GMR - GMR	0932

TRAIN SET K03

1414	BSTP	GMR - GMR	1419
1419	PASS 0102	GMR - BRR	1449
1450	VSTP	BRR - BRR	1520
1520	VOOR 7669	BRR - BRR	1538
1538	7669	BRR - KUT	1605
1610	7671	KUT - KWE	1633
1650	7558	KWE - KUT	1715
1734	7575	KUT - KWE	1757
1806	7570	KWE - KUT	1831
2007	SSTP	KUT - KUT	2014
2038	PASS 7686	KUT - GMR	2043
2043	ESTP	GMR - GMR	2048

CREW SCHEDULE 26

TRAIN SET L02

0745	BSTP	GMR - GMR	0750
0750	PASS 0611	GMR - KAF	0818
0822	VSTP	KAF - KAF	0830
0830	RANG	KAF - KAF	0841
0841	LOSA	KAF - KAF	1005
1005	1827	KAF - LRA	1018
1028	1812	LRA - KAF	1040
1040	SSTP	KAF - KAF	1048
1150	PASS 0646	KAF - GMR	1220
1220	ESTP	GMR - GMR	1225

TRAIN SET L09

1418	BSTP	GMR - GMR	1423
1423	PASS 0647	GMR - KAF	1451
1516	VSTP	KAF - KAF	1524
1524	VOOR 1832	KAF - KAF	1542
[illegible]	1832	KAF - EFT	1555
[illegible]	0557	EFT - LRA	1642
1651	0568	LRA - EFT	[illegible]
1738	0577	EFT - LRA	1809
1818	0586	LRA - EFT	1845
1845	SSTP	EFT - EFT	1848
1909	PASS 0682	EFT - GMR	1920
1920	ESTP	GMR - GMR	1925

CREW SCHEDULE 27

TRAIN SET L05

[illegible]	[illegible]	GMR - GMR	0756
[illegible]	LOSA 0544	GMR - GMR	0758
[illegible]	0544	GMR - IDI	0802
[illegible]	SSTP	IDI - IDI	0805
0816	PASS 0541	IDI - GMR	0820
0820	ESTP	GMR - GMR	0825

TRAIN SET G05

1422	VSTP	GMR - GMR	1427
1427	LOSA 0361	GMR - GMR	1512
1512	1125	GMR - KPR	1556
1605	1126	KPR - GMR	1647
1647	RANG 1126	GMR - GMR	1705
1715	1131	GMR - NAS	1742
1751	1132	NAS - GMR	1820
1820	STAL 1132	GMR - GMR	1844
1844	SSTP	GMR - GMR	1849

CREW SCHEDULE 28

TRAIN SET K04

0808	VSTP	GMR - GMR	0813
0813	LOSA 7620	GMR - GMR	0815
0815	7831	GMR - KWE	0847
0858	7626	KWE - GMR	0928
0930	7835	GMR - KWE	1002
1013	7628	KWE - GMR	1043
1043	SSTP	GMR - GMR	1048

TRAIN SET L08

1418	BSTP	GMR - GMR	1423
1423	PASS 0647	GMR - EFT	1434
1603	VSTP	EFT - EFT	1615
1615	VOOR 0569	EFT - EFT	1633
1633	RANG	EFT - EFT	1657
1657	0569	EFT - TEM	1719
1728	0578	TEM - EFT	1748
1805	0583	EFT - LRA	1835
1844	1844	LRA - KAF	1855
1855	STAL 1844	KAF - KAF	1900
1900	SSTP	KAF - KAF	1908
1917	PASS 0684	KAF - GMR	1947
1947	ESTP	GMR - GMR	1952

CREW SCHEDULE 29

TRAIN SET K02

0823	VSTP	GMR - GMR	0828
0828	LOSA 7834	GMR - GMR	0830
0830	7639	GMR - KWE	0858
0907	7844	KWE - GMR	0941
0943	7643	GMR - KWE	1011
1024	7853	KWE - GMR	1056
1058	SSTP	GMR - GMR	1103

TRAIN SET L06

1418	BSTP	GMR - GMR	1423
1423	PASS 0647	GMR - KAF	1451
1519	VSTP	KAF - KAF	1527
1527	VOOR 1834	KAF - KAF	1545
1545	1834	KAF - EFT	1556
1619	0559	EFT - LRA	1649
1700	0570	LRA - EFT	1731
1810	0585	EFT - LRA	1840
1850	1846	LRA - KAF	1901
1901	STAL 1846	KAF - KAF	1906
1906	SSTP	KAF - KAF	1914
1950	PASS 0686	KAF - GMR	2020
2020	ESTP	GMR - GMR	2025

CREW SCHEDULE 30

TRAIN SET G01

1138	VSTP	GMR - GMR	1143
1143	VOOR 1023	GMR - GMR	1158
1158	1023	GMR - ALB	1211
1216	1024	ALB - GMR	1230
1258	1025	GMR - ALB	1311
1316	1026	ALB - GMR	1330
1330	STAL 1026	GMR - GMR	1343
1343	SSTP	GMR - GMR	1350

TRAIN SET G01

1426	VSTP	GMR - GMR	1436
1436	VOOR 1029	GMR - GMR	1451
1451	RANG	GMR - GMR	1500
1500	1029	GMR - ALB	1513
1610	1030	ALB - GMR	1624
1636	1031	GMR - ALB	1649
1654	1032	ALB - GMR	1708
1712	1033	GMR - ALB	1725
1730	1034	ALB - GMR	1744
1749	1035	GMR - ALB	1802
1808	1036	ALB - GMR	1822
1822	STAL 1036	GMR - GMR	1830
1830	SSTP	GMR - GMR	1835

TRAIN SET G06

1915	VSTP	GMR - GMR	1920
1920	LOSA 1134	GMR - GMR	2000
2000	1137	GMR - KPR	2041
2053	1138	KPR - GMR	2137
2137	STAL 1138	GMR - GMR	2151
2151	SSTP	GMR - GMR	2156

TRAIN SET K02

2225	VSTP	GMR - GMR	2230
2230	7695	GMR - KWE	2256
2307	7696	KWE - GMR	2334
2334	STAL 7696	GMR - GMR	2339
2339	SSTP	GMR - GMR	2344

CREW SCHEDULE 31

TRAIN SET G05

1211	BSTP	GMR - GMR	1216
1216	PASS 0092	GMR - BRR	1249
1308	VSTP	BRR - BRR	1338
1338	VOOR 0361	BRR - BRR	1353
1353	0361	BRR - GMR	1415
1415	RANG 0361	GMR - GMR	1427
1427	SSTP	GMR - GMR	1432

TRAIN SET L01

1542	VSTP	GMR - GMR	1547
1547	LOSA 0556	GMR - GMR	1616
1616	0563	GMR - LRA	1656
1708	0576	LRA - GMR	1750
1808	0587	GMR - LRA	1850
1900	0590	LRA - EFT	1931
1931	STAL 0590	EFT - EFT	1936
1936	SSTP	EFT - EFT	1939
2009	PASS 0686	EFT - GMR	2022
2022	ESTP	GMR - GMR	2027

CREW SCHEDULE 32

TRAIN SET K01

1222	VSTP	GMR - GMR	1227
1227	VOOR 7845	GMR - GMR	1245
1245	7845	GMR - KWE	1317
1328	7638	KWE - GMR	1358
1400	7851	GMR - KWE	1432
1443	7644	KWE - GMR	1513
1513	SSTP	GMR - GMR	1518

TRAIN SET G02

1550	VSTP	GMR - GMR	1555
1555	LOSA 1737	GMR - GMR	1559
1559	1740/1	GMR - BOY	1624
1636	1743/4	BOY - GMR	1701
1711	RANG 1746	GMR - GMR	1735
1735	1746	GMR - BOY	1800
1810	1751	BOY - GMR	1835
1835	STAL 1751	GMR - GMR	1849
1849	SSTP	GMR - GMR	1854

CREW SCHEDULE 33

TRAIN SET G02

1241	BSTP	GMR - GMR	1246
1246	PASS 0096	GMR - BRR	1319
1336	VSTP	BRR - BRR	1348
1348	VOOR 0367	BRR - BRR	1403
1403	0367	BRR - GMR	1425
1425	STAL 0367	GMR - GMR	1437
1445	1734	GMR - BOY	1510
1530	1737	BOY - GMR	1555
1555	SSTP	GMR - GMR	1600

TRAIN SET K07

1612	BSTP	GMR - GMR	1617
1617	PASS 1129	GMR - SIM	1621
1635	VSTP	SIM - SIM	1642
1642	VOOR 7865	SIM - SIM	1700

1700	7865	SIM - KWE	1728
1739	7736	KWE - SIM	1808
1823	7579	SIM - KWE	1851
1902	7578	KWE - KUT	1932
1932	STAL 7578	KUT - KUT	1939
1948	SSTP	KUT - KUT	1954
2008	PASS 7864	KUT - GMR	2013
2013	ESTP	GMR - GMR	2018

TRAIN SET K02

2053	VSTP	GMR - GMR	2058
2058	LOSA 7692	GMR - GMR	2100
2100	7693	GMR - KWE	2128
2139	7896	KWE - GMR	2213
2230	7695	GMR - KWE	2258
2307	7696	KWE - GMR	2334
2334	STAL 7696	GMR - GMR	2355
2355	SSTP	GMR - GMR	0000

CREW SCHEDULE 34

TRAIN SET D03

1334	BSTP	GMR - GMR	1339
1339	PASS 0105	GMR - DUN	1358
1437	VSTP	DUN - DUN	1448
1448	VOOR 8855	DUN - DUN	1506
1506	8855	DUN - DAV	1528
1536	8856	DAV - DUN	1558
1606	8861	DUN - DAV	1628
1636	8862	DAV - DUN	1658
1658	SSTP	DUN - DUN	1701
1711	PASS 0148	DUN - GMR	1730
1730	ESTP	GMR - GMR	1735

TRAIN SET K04

1808	VSTP	GMR - GMR	1813
1813	LOSA 7666	GMR - GMR	1815
1815	7877	GMR - KWE	1847
1858	7676	KWE - GMR	1926
1930	7887	GMR - KWE	2002
2013	7686	KWE - GMR	2043
2043	SSTP	GMR - GMR	2048

CREW SCHEDULE 35

TRAIN SET P10

1345	VSTP	GMR - GMR	1350
1350	LOSA 0645	GMR - GMR	1351
1351	0645	GMR - PRR	1455
1455	STAL 0645	PRR - PRR	1500
1500	SSTP	PRR - PRR	1509

TRAIN SET P08

1618	VSTP	PRR - PRR	1621
1621	VOOR 0672	PRR - PRR	1642
1642	RANG	PRR - PRR	1645
1645	0672	PRR - GMR	1753
1754	0672	GMR - BRR	1818
1818	STAL 0672	BRR - BRR	1823
1823	SSTP	BRR - BRR	1823

TRAIN SET P08

1934	VSTP	BRR - BRR	1934
1934	VOOR 0685	BRR - BRR	1955
1955	0685	BRR - GMR	2020
2021	0685	GMR - PRR	2124
2124	STAL 0685	PRR - PRR	2129
2129	SSTP	PRR - PRR	2138

TRAIN SET P06

2143	VSTP	PRR - PRR	2148
2148	VOOR 0692	PRR - PRR	2209
2209	RANG	PRR - PRR	[illegible]
2212	0692	PRR - GMR	2320
2321	[illegible]	GMR - BRR	2345
2345	STAL 0692	BRR - BRR	0009
0009	SSTP	BRR - BRR	0028
0028	PASS [illegible]	BRR - GMR	0049
0049	ESTP	GMR - GMR	0054

CREW SCHEDULE 36

TRAIN SET L02

1346	BSTP	GMR - GMR	1351
1351	PASS 0645	GMR - KAF	1419
1439	VSTP	KAF - KAF	1447
1447	VOOR 1847	KAF - KAF	1505
1505	1847	KAF - LRA	1518
1528	0562	LRA - GMR	1610
1617	0562	GMR - IDI	1621
1632	0567	IDI - GMR	1636
1636	SSTP	GMR - GMR	1641

TRAIN SET L05

1713	VSTP	GMR - GMR	1718
1718	VOOR 0579	GMR - GMR	1736
1736	0579	GMR - LRA	1818
1827	1842	LRA - KAF	1838
1838	STAL 1842	KAF - KAF	1843
1843	SSTP	KAF - KAF	1851
1917	PASS 0684	KAF - GMR	1947
1947	ESTP	GMR - GMR	1952

CREW SCHEDULE 37

TRAIN SET K01

1353	VSTP	GMR - GMR	1358
1400	7851	GMR - KWE	1432
1443	7644	KWE - GMR	1513
1513	SSTP	GMR - GMR	1518

TRAIN SET K02

1549	VSTP	GMR - GMR	1554
1554	LOSA 7648	GMR - GMR	1556
1556	7859	GMR - KWE	1628
1644	7656	KWE - GMR	1714
1716	7869	GMR - KWE	1748
1759	7568	KWE - KUT	1824
1835	7681	KUT - KWE	1858
1909	7884	KWE - GMR	1943
1943	SSTP	GMR - GMR	1948

TRAIN SET K04

2038	VSTP	GMR - GMR	2043
2043	LOSA 7686	GMR - GMR	2045
2045	7893	GMR - KWE	2117
2128	7692	KWE - GMR	2158
2200	7895	GMR - KWE	2232
2241	7594	KWE - KUT	2302
2302	STAL 7594	KUT - KUT	2307
2307	SSTP	KUT - KUT	2314
2338	PASS KOMBI	KUT - GMR	2348
2348	ESTP	GMR - GMR	2348

CREW SCHEDULE 38

TRAIN SET D01

1416	BSTP	GMR - GMR	1421
1421	PASS 0656	GMR - BRR	1445
1539	VSTP	BRR - BRR	1609
1609	VOOR 8873	BRR - BRR	1627
1627	8873	BRR - DAV	1757
1802	8874	DAV - DUN	1824
1832	8881	DUN - DAV	1854
1902	8882	DAV - DUN	1924
1924	STAL 8882	DUN - DUN	1932
1932	SSTP	DUN - DUN	1944

TRAIN SET D04

2104	VSTP	DUN - DUN	2107
2107	LOSA 8894	DUN - DUN	2115
2115	8895	DUN - DAV	2137
2145	8896	DAV - DUN	2207
2235	8897	DUN - DAV	2257
2305	8898	DAV - DUN	2327
2327	STAL 8898	DUN - DUN	2348
2348	SSTP	DUN - DUN	2351
2355	PASS 1408	DUN - GMR	0009
0009	ESTP	GMR - GMR	0014

CREW SCHEDULE 39

TRAIN SET L03

1418	BSTP	GMR - GMR	1423
1423	PASS 0647	GMR - EFT	1434
1454	VSTP	EFT - EFT	1459
1459	LOSA 0554	EFT - EFT	1542
1542	0551	EFT - LRA	1612
1630	0564	LRA - EFT	1701
1723	0575	EFT - LRA	1751
1800	0584	LRA - GMR	1842
1844	0584	GMR - IDI	1848
1856	0595	IDI - GMR	1903
1903	SSTP	GMR - GMR	1908

TRAIN SET K02

1938	VSTP	GMR - GMR	1943
1943	LOSA 7884	GMR - GMR	1945
1945	7687	GMR - KWE	2013
2024	7892	KWE - GMR	2058
2058	SSTP	GMR - GMR	2103

TRAIN SET K04

2156	VSTP	GMR - GMR	2200
2200	7895	GMR - KWE	2232
2241	7594	KWE - KUT	2302
2302	STAL 7594	KUT - KUT	2307
2307	SSTP	KUT - KUT	2314
2338	PASS KOMBI	KUT - GMR	2343
2343	ESTP	GMR - GMR	2343

CREW SCHEDULE 40

TRAIN SET G03

1528	VSTP	GMR - GMR	1538
1538	VOOR 1127	GMR - GMR	1553
1553	1127	GMR - KPR	1636
1645	1128	KPR - GMR	1728
1728	STAL 1128	GMR - GMR	1745
1745	SSTP	GMR - GMR	1750

TRAIN SET L09

1822	BSTP	GMR - GMR	1827
1827	PASS 0679	GMR - EFT	1838
1842	VSTP	EFT - EFT	1845
1845	LOSA 0586	EFT - EFT	1901
1901	0593	EFT - LRA	1931
1940	1850	LRA - KAF	1951
1951	STAL 1850	KAF - KAF	1956
1956	SSTP	KAF - KAF	1959
2050	PASS 0688	KAF - GMR	2120
2120	ESTP	GMR - GMR	2125

CREW SCHEDULE 41

TRAIN SET G04

1602	VSTP	GMR - GMR	1607
1607	LOSA 1124	GMR - GMR	1617
1617	1129	GMR - KPR	1700
1709	1130	KPR - GMR	1753
1753	STAL 1130	GMR - GMR	1758
1758	SSTP	GMR - GMR	1803

TRAIN SET D04

1834	BSTP	GMR - GMR	1839
1839	PASS 0143	GMR - DUN	1857
1904	VSTP	DUN - DUN	1907
1907	LOSA 8880	DUN - DUN	1915
1915	8887	DUN - DAV	1937
1945	8888	DAV - DUN	2007
2015	8893	DUN - DAV	2037
2045	8894	DAV - DUN	2107
2107	SSTP	DUN - DUN	2110
2156	PASS 0176	DUN - GMR	2215
2215	ESTP	GMR - GMR	2220

CREW SCHEDULE 42

TRAIN SET L04

1621	VSTP	GMR - GMR	1626
1626	VOOR 0571	GMR - GMR	1644
1644	RANG	GMR - GMR	1656
1656	0571	GMR - LRA	1738
1754	0582	LRA - EFT	1825
1847	0591	EFT - LRA	1917
1930	1848	LRA - KAF	1942
1942	STAL 1848	KAF - KAF	1959
1959	SSTP	KAF - KAF	2007
2050	PASS 0688	KAF - GMR	2120
2120	ESTP	GMR - GMR	2125

TRAIN SET R32

0405	VSTP	GMR - GMR	0410
0412	0329	GMR - DUN	0428
0429	8807	DUN - DAV	0451
0459	0712	DAV - GMR	0541
0541	SSTP	GMR - GMR	0546

CREW SCHEDULE 43

TRAIN SET D03

1626	BSTP	GMR - GMR	1629
1629	PASS 0121	GMR - DUN	1647
1655	VSTP	DUN - DUN	1658
1658	LOSA 8862	DUN - DUN	1706
1706	8869	DUN - DAV	1728
1736	8870	DAV - DUN	1758
1806	8877	DUN - DAV	1828
1836	8878	DAV - DUN	1858
1906	8885	DUN - DAV	1928
1936	8886	DAV - DUN	1958
1958	STAL 8886	DUN - DUN	2006
2006	SSTP	DUN - DUN	2018
2026	PASS 0172	DUN - GMR	2046
2046	ESTP	GMR - GMR	2051

TRAIN SET K03

0345	BSTP	GMR - GMR	0345
0345	PASS KOMBI	GMR - KUT	0355
0358	VSTP	KUT - KUT	0405
0405	VOOR 7607	KUT - KUT	0423
0423	7607	KUT - KWE	0442
0453	7606	KWE - GMR	0527
0527	SSTP	GMR - GMR	0532

CREW SCHEDULE 44

TRAIN SET L02

1631	VSTP	GMR - GMR	1636
1636	LOSA 0567	GMR - GMR	1639
1639	0567	GMR - LRA	1720
1733	0580	LRA - GMR	1815
1815	SSTP	GMR - GMR	1820

TRAIN SET K01

1855	VSTP	GMR - GMR	1858
1858	LOSA 7674	GMR - GMR	1900
1900	7683	GMR - KWE	1932
1943	7684	KWE - GMR	2013
2013	STAL 7684	GMR - GMR	2042
2042	SSTP	GMR - GMR	2047

CREW SCHEDULE 45

TRAIN SET G06

1713	VSTP	GMR - GMR	1718
1718	VOOR 1133	GMR - GMR	1733
1733	1133	GMR - KPR	1817
1836	1134	KPR - GMR	1920
1920	SSTP	GMR - GMR	1925

TRAIN SET G04

0351	VSTP	GMR - GMR	0358
0358	VOOR 1107	GMR - GMR	0413
0413	1107	GMR - KPR	0456
0505	1108	KPR - GMR	0550
0550	RANG 1108	GMR - GMR	0606
0606	SSTP	GMR - GMR	0611

CREW SCHEDULE 46

TRAIN SET K03

1725	BSTP	GMR - GMR	1730
1730	PASS 0102	GMR - KUT	1735
1826	VSTP	KUT - KUT	1831
1831	LOSA 7570	KUT - KUT	1841
1841	7683	KUT - KWE	1904
1913	7580	KWE - KUT	1938
1938	STAL 7500	KUT - KUT	2007
2007	SSTP	KUT - KUT	2014
2038	PASS 7686	KUT - GMR	2043
2043	ESTP	GMR - GMR	2048

TRAIN SET L01

0318	VSTP	GMR - GMR	0323
0323	VOOR 0503	GMR - GMR	0341
0341	0503	GMR - LRA	0423
0436	0506	LRA - EFT	0507
0521	0509	EFT - LRA	0549
0559	0522	LRA - GMR	0637
0637	SSTP	GMR - GMR	0642

CREW SCHEDULE 47

TRAIN SET D02

18[illegible]	[illegible]TP	GMR - GMR	1809
18[illegible]	[illegible]SS 0153	GMR - DUN	1827
1834	[illegible]STP	DUN - DUN	1837
1837	[illegible]A 8876	DUN - DUN	1845
1845	8883	DUN - DAV	1907
1915	8884	DAV - DUN	1937
1945	8891	DUN - DAV	2007
2015	8892	DAV - DUN	2037
2037	STAL 8892	DUN - DUN	2058
2058	SSTP	DUN - DUN	2101
2156	PASS 0175	DUN - GMR	2215
2215	ESTP	GMR - GMR	2220

TRAIN SET K06

0318	BSTP	GMR - GMR	0318
0318	PASS KOMBI	GMR - KUT	0328
0331	VSTP	KUT - KUT	0338
0338	VOOR 7603	KUT - KUT	0356
0356	7603	KUT - KWE	0415
0425	7702	KWE - SIM	0454
0503	7811	SIM - KWE	0526
0535	7712	KWE - SIM	0604
0604	SSTP	SIM - SIM	0607
0607	ESTP	SIM - GMR	0620

CREW SCHEDULE 48

TRAIN SET L02

1810	VSTP	GMR - GMR	1815
1824	0589	GMR - LRA	1901
1913	0592	LRA - KAF	1925
1925	SSTP	KAF - KAF	1933
1950	PASS 0686	KAF - GMR	2021
2021	ESTP	GMR - GMR	2026

TRAIN SET K05

0318	BSTP	GMR - GMR	0318
0318	PASS KOMBI	GMR - KUT	0328
0405	VSTP	KUT - KUT	0412
0412	VOOR 7609	KUT - KUT	0430
0430	7609	KUT - KWE	0449
0500	7710	KWE - SIM	0529
0538	7815	SIM - KWE	0606
0615	7816	KWE - GMR	0649
0649	SSTP	GMR - GMR	0654

CREW SCHEDULE 49

TRAIN SET L02

1810	VSTP	GMR - GMR	1815
1815	LOSA 0580	GMR - GMR	1824
1824	0589	GMR - LRA	1901
1913	0592	LRA - KAF	1925
1925	SSTP	KAF - KAF	1933
1951	PASS 0386	KAF - GMR	2020
2020	ESTP	GMR - GMR	2025

TRAIN SET L08

0247	BSTP	GMR - GMR	0252
0252	PASS 1605	GMR - KAF	0320
0412	VSTP	KAF - KAF	0420
0420	VOOR 1805	KAF - KAF	0438
0438	1805	KAF - LRA	0449
0458	0508	LRA - EFT	0529
0543	0511	EFT - LRA	0611
06[illegible]	0528	LRA - EFT	0647
0647	SSTP	EFT - EFT	0650
0705	PASS 0620	EFT - GMR	0713
0713	ESTP	GMR - GMR	0718

CREW SCHEDULE 50

TRAIN SET G04

1813	VSTP	GMR - GMR	1818
1818	VOOR 1135	GMR - GMR	1833
1833	1135	GMR - KPR	1916
1925	1136	KPR - GMR	2009
2009	STAL 1136	GMR - GMR	2023
2023	SSTP	GMR - GMR	2028

TRAIN SET G06

0447	VSTP	GMR - GMR	0452
0452	VOOR 1111	GMR - GMR	0507
0507	RANG	GMR - GMR	0519
0519	1111	GMR - KPR	0602
0611	1112	KPR - GMR	0656
0656	STAL 1112	GMR - GMR	0713
0713	SSTP	GMR - GMR	0718

CREW SCHEDULE 51

TRAIN SET K06

1817	BSTP	GMR - SIM	1829
1829	VSTP	SIM - SIM	1832
1832	LOSA 7738	SIM - SIM	1841
1841	7881	SIM - KWE	1909
1920	7746	KWE - SIM	1949
2000	7889	SIM - KWE	2028
2037	7588	KWE - KUT	2102
2102	STAL 7588	KUT - KUT	2107
2107	SSTP	KUT - KUT	2114
2153	PASS 7692	KUT - GMR	2158
2158	ESTP	GMR - GMR	2203

TRAIN SET L03

0336	BSTP	GMR - GMR	0341
0341	PASS 0503	GMR - KAF	0410
0429	VSTP	KAF - KAF	0437
0437	VOOR 1813	KAF - KAF	0455
0455	1813	KAF - TEM	0500
0509	0510	TEM - GMR	0544
0553	7619	GMR - KWE	0621
0630	7820	KWE - GMR	0704
0704	SSTP	GMR - GMR	0709

CREW SCHEDULE 52

TRAIN SET L03

1819	BSTP	GMR - GMR	1824
1824	PASS 0589	GMR - KAF	1848
1858	VSTP	KAF - KAF	1903
1903	LOSA 0595	KAF - KAF	1930
1959	0595	KAF - LRA	2012
2023	1862	LRA - KAF	2035
2035	STAL 1852	KAF - KAF	2040
2059	SSTP	KAF - KAF	2107
2150	PASS 0690	KAF - GMR	2220
2220	ESTP	GMR - GMR	2225

TRAIN SET D03

2303	BSTP	GMR - GMR	2308
2308	PASS 0177	GMR - DUN	2327
0317	VSTP	DUN - DUN	0328
0328	VOOR 8801	DUN - DUN	0346
0346	8801	DUN - DAV	0408
0416	8802	DAV - DUN	0438
0446	8809	DUN - DAV	0508
0516	8810	DAV - DUN	0538
0546	8817	DUN - DAV	0608
0616	8818	DAV - DUN	0638
0638	SSTP	DUN - DUN	0641
0643	PASS 0048	DUN - GMR	0704
0704	ESTP	GMR - GMR	0709

CREW SCHEDULE 53

TRAIN SET L02

1828	BSTP	GMR - GMR	1833
1833	PASS 78081	GMR - KAF	1855
1917	VSTP	KAF - KAF	1925
1925	LOSA 0592	KAF - KAF	2059
2059	1849	KAF - LRA	2112
2123	1854	LRA - KAF	2135
2153	1851	KAF - LRA	2212
2223	1856	LRA - KAF	2235
2259	1853	KAF - LRA	2312
2321	0598	LRA - GMR	0003
0003	STAL 0598	GMR - GMR	0008
0008	SSTP	GMR - GMR	0013

TRAIN SET L05

0247	BSTP	GMR - GMR	0252
0252	PASS 1605	GMR - EFT	0303
0357	VSTP	EFT - EFT	0400
0400	VOOR 0505	EFT - EFT	0418
0418	RANG	EFT - EFT	0442
0442	0505	EFT - OLF	0508
0520	0514	OLF - GMR	0559
0559	SSTP	GMR - GMR	0604

CREW SCHEDULE 54

TRAIN SET L02

1828	BSTP	GMR - GMR	1833
1833	PASS 78081	GMR - KAF	1855
1917	VSTP	KAF - KAF	1925
1925	LOSA	KAF - KAF	2059
2059	1849	KAF - LRA	2112
2123	1854	LRA - KAF	2135
2159	1851	KAF - LRA	2212
2223	1856	LRA - KAF	2235
2259	1853	KAF - LRA	2312
2321	0598	LRA - GMR	0003
0003	STAL 0598	GMR - GMR	0008
0008	SSTP	GMR - GMR	0013

TRAIN SET K01

0340	VSTP	GMR - GMR	0345
0345	LOSA 7602	GMR - GMR	0400
0400	7807	GMR - KWE	0432
0443	7604	KWE - GMR	0513
0515	7813	GMR - KWE	0547
0556	7610	KWE - GMR	0626
0628	7821	GMR - KWE	0700
0713	7616	KWE - GMR	0743
0743	SSTP	GMR - GMR	0748

CREW SCHEDULE 55

TRAIN SET L03

1858	VSTP	GMR - GMR	1903
1903	LOSA 0595	GMR - GMR	1930
1930	0595	GMR - LRA	2012
2023	1852	LRA - KAF	2035
2035	STAL 1852	KAF - KAF	2059
2059	SSTP	KAF - KAF	2107
2150	PASS 0690	KAF - GMR	2220
2220	ESTP	GMR - GMR	2225

TRAIN SET K04

0407	VSTP	GMR - GMR	0412
0412	VOOR 7806	GMR - GMR	0430
0430	7809	GMR - KWE	0502
0511	7606	KWE - GMR	0541
0543	7817	GMR - KWE	0615
0624	7515	KWE - KUT	0649
0709	7629	KUT - KWE	0732
0743	7620	KWE - GMR	0813
0813	SSTP	GMR - GMR	0818

CREW SCHEDULE 56

TRAIN SET R28

2329	BSTP	GMR - GMR	2334
2334	PASS 0698	GMR - BRR	2357
0148	VSTP	BRR - BRR	0207
0207	VOOR 1605	BRR - BRR	0225
0225	1605	BRR - OLF	0323
0340	1606	OLF - GMR	0419
0419	SSTP	GMR - GMR	0424

TRAIN SET G02

0512	VSTP	GMR - GMR	0517
0517	VOOR 1722	GMR - GMR	0532
0532	1722/3	GMR - BOY	0557
0602	1725/6	BOY - GMR	0627
0645	1728/9	GMR - BOY	0710
0716	1731/2	BOY - GMR	0743
0757	0358	GMR - BRR	0818
0818	STAL 0358	BRR - BRR	0842
0842	SSTP	BRR - BRR	0903
0908	PASS 0083	BRR - GMR	0939
0939	ESTP	GMR - GMR	0944

TRAIN SET K04

1038	VSTP	GMR - GMR	1043
1043	LOSA 7628	GMR - GMR	1045
1045	7839	GMR - KWE	1117
1128	7630	KWE - GMR	1158
1158	SSTP	GMR - GMR	1203

APPENDIX C1

COMPARISON BETWEEN THE 1988 AND 1989 MODELS

Nominal length of the longest shift	4:00	4:00	4:00	4:00	4:00	4:00
Nominal length of the other shifts	2:30	2:30	2:30	2:30	1:30	1:30
Booking on time	0:20	0:20	0:20	0:20	0:20	0:20
Booking off time	0:15	0:15	0:15	0:15	0:15	0:15
Maximum length of a schedule	14:00	14:00	14:00	14:00	14:00	14:00
Minimum length of a schedule	8:00	8:00	8:00	8:00	8:00	8:00
Maximum number of shifts in a schedule	4	4	4	4	4	4
Maximum schedule length with no meal break	5:00	5:00	5:00	5:00	5:00	5:00
Maximum schedule length with one meal break	10:00	10:00	10:00	10:00	10:00	10:00
Minimum time allowed for a meal break	0:30	0:30	0:30	0:30	0:30	0:30
Minimum time between shifts (short break)	0:10	0:10	0:10	0:10	0:10	0:10
Maximum rest period in a schedule	3:00	3:00	3:00	3:00	3:00	3:00

Model	**1988**	**1989**	**1988**	**1989**	**1988**	**1989**
Data set	**[A]**	**[A]**	**[B]**	**[B]**	**[C]**	**[C]**
Number of schedules	**63**	**60**	**62**	**56**	**59**	**56**
A. Time on trains	198:14	198:14	198:14	198:14	198:14	198:14
B. Booking on/off times	36:45	35:00	36:10	32:40	34:25	32:40
C. Walking time	44:18	43:43	38:18	37:58	41:23	40:[illegible]
D. Transport time	42:05	39:27	38:11	36:06	37:30	33:40
E. Meal/short break time	34:20	34:10	28:40	30:10	33:00	32:40
F. Time between trains	205:43	219:24	190:31	281:39	212:28	291:11
G. Preparation time	17:21	17:21	17:21	17:21	17:21	17:21
H. Shunting/staging time	20:29	20:29	20:29	20:29	20:29	20:29
I. Time on duty	599:15	607:48	567:54	654:37	594:50	666:58
J. Time to 8 hours	34:47	28:31	30:26	10:29	24:34	12:16
K. Total schedule time	634:02	636:19	598:20	665:06	619:24	67[illegible]:14
L. Total idle time	240:18	247:43	220:57	292:08	237:02	303:27
M. Overtime	130:02	156:19	102:20	217:06	147:24	231:14

I = A + B + C + D + E + F + G + H ; K = I + J ; L = F + J

Maximum time on trains	06:25	06:16	05:10	05:53	06:20	06:32
Minimum time on trains	01:13	01:00	01:37	01:56	01:20	01:54
Average time on trains	03:08	03:18	03:11	03:32	03:21	03:32
Standard deviation	01:05	01:13	00:54	00:53	00:52	00:56
Maximum time on duty	13:59	14:00	13:58	14:00	14:00	14:00
Minimum time on duty	04:04	03:33	04:58	04:51	04:49	04:40
Average time on duty	09:30	10:07	09:09	11:41	10:04	11:5[illegible]
Standard deviation	03:00	02:58	02:41	02:32	02:56	02:33

APPENDIX C2

COMPARISON OF 1989 MODEL WITH EXISTING SCHEDULE

The existing crew appears in the first column.

Nominal length of the longest shift	4:00	4:00	4:00	4:00	4:00
Nominal length of the other shifts	2:30	2:30	2:30	2:30	1:30
Booking on time	0:20	0:20	0:20	0:20	0.20
Booking off time	0:15	0:15	0:15	0:15	0:15
Maximum length of a schedule	14:35	14:00	14:35	14:35	14:35
Minimum length of a schedule	8:00	8:00	8:00	8:00	8:00
Maximum number of shifts in a schedule	4	4	4	4	4
Maximum schedule length with no meal break	5:00	5:00	5:00	5:00	5:00
Maximum schedule length with one meal break	10:00	10:00	10:00	10:00	10:00
Minimum time allowed for a meal break	0:30	0:30	0.30	0:30	0:30
Minimum time between shifts (short break)	0:10	0:10	0:10	0:10	0:10
Maximum rest period in a schedule	3:00	3:00	3:00	3:00	3:00
Data set	[A]	[A]	[A]	[B]	[C]
Number of schedules	60	60	57	54	53
A. Time on trains	198:14	198:14	198:14	198:14	198:14
B. Booking on/off times	35:00	35:00	33:15	31:30	30:55
C. Walking time	43:28	43:43	43:18	37:48	40:43
D. Transport time	38:25	39:27	39:34	34:46	34:17
E. Meal/short break time	32:40	34:10	34:00	29:20	32:30
F. Time between trains	335:14	219:24	240:22	256:22	273:27
G. Preparation time	17:21	17:21	17:21	17:21	17:21
H. Shunting/staging time	20:29	20:29	20:29	20:29	20:29
I. Time on duty	720:51	607:48	626:33	625:50	647:56
J. Time to 8 hours	09:17	28:31	17:27	09:56	03:31
K. Total schedule time	720:51	636:19	644:00	635:46	651:27
L. Total idle time	344:31	247:43	257:37	266:18	276:58
M. Overtime	250:08	156:19	188:00	203:46	227:27

I = A + B + C + D + E + F + G + H; K = I + J; L = F + J

Maximum time on trains	05:31	06:16	05:50	07:03	05:55
Minimum time on trains	00:41	01:00	01:27	01:53	01:56
Average time on trains	03:18	03:18	03:28	03:40	03:44
Standard deviation	00:59	01:13	01:06	01:00	00:56
Maximum time on duty	14:35	14:00	14:34	14:35	14:34
Minimum time on duty	03:38	03:33	04:31	05:14	06:41
Average time on duty	12:00	10:07	10:59	11:35	12:13
Standard deviation	02:09	02:58	02:54	02:57	02:21

APPENDIX C3

SENSIVITY ANALYSIS ON THE MAXIMUM CREW SCHEDULE LENGTH

Nominal length of the longest shift	4:00	4:00	4:00	4:00	4:00	4:00
Nominal length of the other shifts	1:30	2:30	1:30	2:30	1:30	1:30
Booking on time	0:20	0:20	0:20	0:20	0:20	0:20
Booking off time	0:15	0:15	0:15	0:15	0:15	0:15
Maximum length of a schedule	**14:35**	**14:00**	**13:00**	**12.00**	**11:00**	**10:00**
Minimum length of a schedule	8:00	8:00	8:00	8:00	8:00	8:00
Maximum number of shifts in a schedule	4	4	4	4	4	4
Maximum schedule length with no meal break	5:00	5:00	5:00	[illegible]	5:00	5:00
Maximum schedule length with one meal break	10:00	10:00	10:00	10:00	10:00	10:00
Minimum time allowed for a meal break	0:30	0:30	0:30	0.30	0:30	0:30
Minimum time between shifts (short break)	0:10	0:10	0:10	0:10	0:10	0:10
Maximum rest period in a schedule	3:00	3:00	3:00	3:00	3:00	3:00
Data set	**[C]**	**[B]**	**[C]**	**[B]**	**[C]**	**[C]**
Number of schedules	**53**	**56**	**63**	**71**	**71**	**71**
A. Time on trains	198:14	198:14	198:14	198:14	198:14	198:14
B. Booking on/off times	30:55	32:40	36:45	41:25	41:25	41:25
C. Walking time	40:43	37:58	40:53	38:28	41:23	41:23
D. Transport time	34:17	36:06	34:36	40:34	38:25	36:53
E. Meal/short break time	32:30	30:10	34:10	26:20	32:10	32:30
F. Time between trains	273:27	281:39	257:28	156:23	161:10	157:23
G. Preparation time	17:21	17:21	17:21	17:21	17:21	17:21
H. Shunting/staging time	20:29	20:29	20:29	20:29	20:29	20:29
I. Time on duty	647:56	654:37	639:56	539:14	550:37	545:38
J. Time to 8 hours	03:31	10:29	09:58	58:26	42:56	43:49
K. Total schedule time	651:27	665:06	649:54	597:40	593:33	589:27
L. Total idle time	276:58	292:08	267:26	214:49	204:06	201:12
M. Overtime	**227:27**	**217:06**	**145:54**	**29:40**	**25:33**	**21:27**

I = A + B + C + D + E + F + G + H; K = I + J; L = F + J

Maximum time on trains	05:55	05:53	04:58	05:10	04:51	04:51
Minimum time on trains	01:56	01:56	01:20	01:16	01:15	01:15
Average time on trains	03:44	03:32	03:08	02:47	02:47	02:47
Standard deviation	00:50	00:53	00:46	00:49	00:45	00:44

Maximum time on duty	14:34	14:00	12:59	11:39	10:17	09:57
Minimum time on duty	06:41	04:51	06:21	04:17	04:58	04:58
Average time on duty	12:13	11:41	10:09	07:35	07:45	07:41
Standard deviation	02:21	02:32	02:08	01.34	01:13	01:09

APPENDIX C4

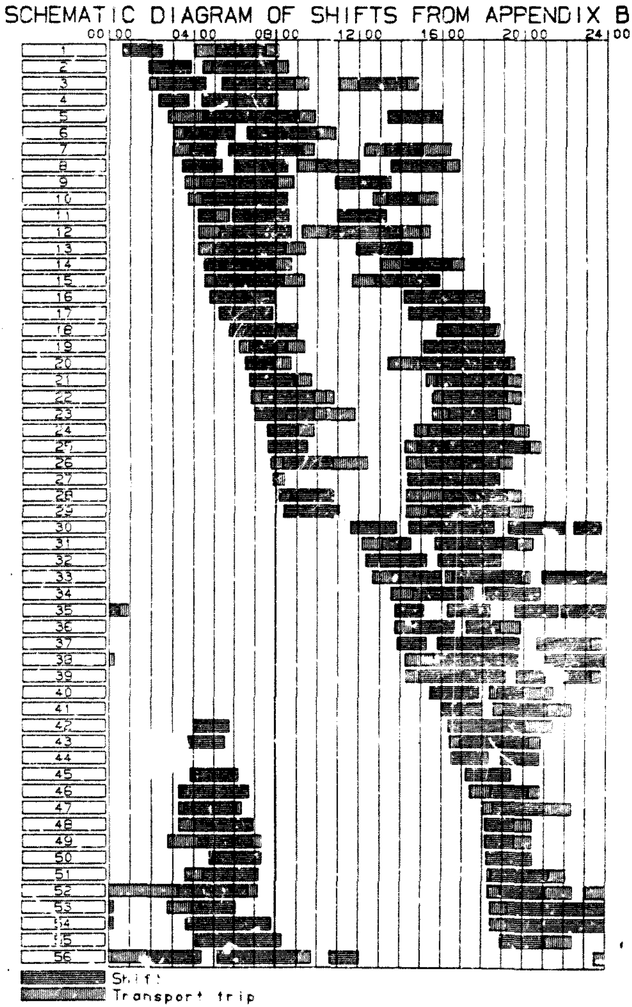
SENSITIVITY ANALYSIS ON THE MEAL BREAKS AND SHORT BREAKS

Nominal length of the longest shift	**4:00**	**4:00**	**4:00**
Nominal length of the other shifts	**2:30**	**2:30**	**2:30**
Booking on time	**0:20**	**0:20**	**0:20**
Booking off time	**0:15**	**0:15**	**0:15**
Maximum length of a schedule	**14:00**	**14:00**	**14:00**
Minimum length of a schedule	**8:00**	**8:00**	**8:00**
Maximum number of shifts in a schedule	**4**	**4**	**4**
Maximum schedule length with no meal break	**5:00**	**5:00**	**5:00**
Maximum schedule length with one meal break	**10:00**	**10:00**	**10:00**
Minimum time allowed for a meal break	**0:30**	**0:30**	**0:45**
Minimum time between shifts (short break)	**0:10**	**0:20**	**0:10**
Maximum rest period in a schedule	**3:00**	**3:00**	**3:00**
Data set	**[B]**	**[B]**	**[B]**
Number of schedules	**56**	**56**	**58**
A. Time on trains	198:14	198:14	198:14
B. Booking on/off times	32:40	32:40	33:50
C. Walking time	37:58	38:03	37:38
D. Transport time	36:06	37:33	34:59
E. Meal/short break time	30:10	29:50	30:10
F. Time between trains	281:39	292:55	294:00
G. Preparation time	17:21	17:21	17:21
H. Shunting/staging time	20:29	20:29	20:29
I. Time on duty	654:37	667:05	666:41
J. Time to 8 hours	10:29	10:18	07:36
K. Total schedule time	665:06	677:23	674:17
L. Total idle time	292:08	303:13	301:36
M. Overtime	**217:06**	**229:23**	**210:17**

I = A + B + C + D + E + F + G + H ; K = I + J ; L = F + J

Maximum time on trains	05:53	06:18	05:53
Minimum time on trains	01:56	01:48	01:32
Average time on trains	03:32	03:32	03:25
Standard deviation	00:53	01:01	00:54
Maximum time on duty	14:00	14:00	14:00
Minimum time on duty	04:51	04:51	04:13
Average time on duty	11:41	11:54	11:29
Standard deviation	02:32	02:30	02:27

APPENDIX D


SCHEMATIC DIAGRAM OF SHIFTS FROM APPENDIX B
00:00
04:00
08:00
12:00
16:00
20:00
24:00
1
2
3
4
5
6
7
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46
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48
49
50
51
52
53
54
55
56
Shift
Transport trip

APPENDIX E

A SIMPLE HEURISTIC FOR

SCHEDULING OF LEAGUE FIXTURES

1 THE SCHEDULING OF HOME AND AWAY MATCHES

1.1 INTRODUCTION

The Southern Transvaal Tennis Association arranges four tennis leagues in the year. The biggest of these is the men's Sunday league which in 1989 consisted of 320 teams fro[illegible] 10[illegible] tennis clubs. The league is divided into 41 sections of seven or eight teams that play each other on a round robin basis over 7 weeks. The scheduling of the fixtures requires that in each week, the home and away matches for each club be balanced.

This scheduling was originally done by hand and took three [illegible]r weeks to do. This heuristic was developed so that each league cou[illegible] done on a microcomputer within a matter of hours and has been in use for the last three years.

1.2 ORDER OF PLAY

A new order of play for the seven weeks was developed as follows:

WEEK	1	2	3	4	5	6	7
	1 vs 2	5 vs 1	1 vs 4	7 vs 1	3 vs 1	1 vs. 6	1 vs 8
	3 vs 4	2 vs 3	3 vs 7	5 vs.3	2 vs 4	4 vs. 7	5 vs 4
	8 vs 5	7 vs 8	8 vs 2	4 vs 8	7 vs 5	5 vs. 2	7 vs 2
	6 vs 7	4 vs 6	6 vs 5	2 vs 6	6 vs 8	8 vs. 3	3 vs 5

The numbers refer to *places* that are allocated to teams in each section. Places on the left are the home teams and places on the right are the away teams.

Features of this order of play are:

- The odd-numbered places have four home matches and three away matches, and the even-numbered places have three home matches and four away matches.

- If there is a bye in a section (i.e. there are seven teams in the section), the place 1 is allocated to the bye. Each team then has three home and three away matches.

- The places 1 and 2, 3 and 4, 5 and 6, and 7 and 8 form *place pairs*. If one of the place pairs has a home match, the other has an away match.

- If a club has two teams in the same section, the pair place 1 and 2, or if that is not possible, the pair place 3 and 4 are allocated to th[illegible]ms. The teams each have four home matches and play each oth[illegible]he first week of the league. This reduces the chances of one of the teams losing their match against the other deliberately so that the other wins the league.

- In the top section of the league, the teams must be *seeded* so that the best teams do not play against each other immediately. Places 1, 3, 6 and 8 (or places 2, 4, 5 an 7) play against from the fifth week on.

1.3 HAND METHOD

The hand method begins at the top section and allocates place pairs to teams of the same club. Not only does this process take a long time by hand, the method is unsatisfactory for the following reasons:

- Difficulty in being able to allocate pair places begins when ten to fifteen sections of the allocation is completed. It is then extremely difficult to go back to the beginning and re- allocate pair places.

- The rule for the byes often gets broken in order to do the allocation.

- Clubs prefer to have their first and second teams paired so both teams can take advantage of the best courts at their club. This cannot be always managed with the hand method.

1.4 NEW ALGORITHM

1.4.1 Pairing

1.4.1.1 Pair any two teams from the same club that are in the same section.

1.4.1.2 Pair the rest of the club teams. If the club has an odd number of teams the lowest team is not paired. These teams are grouped as together as odd teams.

1.4.1.3 Pair the byes with an odd team in the same section.

If there is no such odd team, pair the bye with an odd team so that there is a matching pair with teams in the same sections.

For the 1989 men's Sunday league 139 sets of pair teams were formed and there were 50 odd teams.

1.4.2 Level allocation.

A new concept of a *level* is now introduced: level 1 has places 1 and 2; level 2 has places 3 and 4; level 3 has places 5 and 6; and level 4 has places 7 and 8.

Pair teams must be allocated on the same level for home and away matches to be balanced. One team will then later be allocated the odd-numbered place while its pair will be allocated the even- numbered place.

1.4.2.1 Place all pair teams in the following order for allocation:

- Bye pair teams.
- Pair teams with one or more teams in the seeded section.
- *Pair teams that are in the same section.*
- Pair teams from clubs with an even number of teams.

- Pair teams from clubs with an odd number of teams.

1.4.2.2 Allocate pairs from 1.4.1.1 and 1.4.1.2 specific levels and places.

1.4.2.3 Allocate the rest of the pair teams to the lowest feasible level. Only two teams in each section can be allocated to a level.

If there is no feasible level, find a level which is feasible to one of the pair. Re-allocate a second pair team to a higher level so that the original pair can be allocated to the first level.

If no re-allocation can be feasibly done, replace one of the pair with the odd team from the same club. The need for such a changing the teams in a pair is unlikely and has only been necessary in three of the twelve leagues done so far. It has never been necessary to change more than two pair teams in any schedule.

1.4.2.4 When all the pair teams are allocated, fill the levels with the odd teams so that every level has two teams. Pair all odd teams with another odd team on the same level. All teams now have a pair.

1.4.3 Place allocation

The place allocations for the byes and the seeds have already been done (see 1.4.2.2).

1.4.3.1 Select any team that has not been allocated a place and note on what level it has been allocated. Allocate the odd-numbered place associated with the level to the team (level 1 has places 1 and 2; level 2 has places 3 and 4; level 3 has places 5 and 6; and level 4 has places 7 and 8).

1.4.3.2 Allocate the even-numbered place to its pair team.

1.4.3.3 Find the other team in the same section that is on the same level as the team in 1.4.3.2 and allocate to it the odd-numbered place associated with the level. Its pair will then be allocated the even-numbered place.

1.4.3.4 Continue allocating teams until the allocation returns to the section of the original team. A closed loop has now been formed.

1.4.3.5 Repeat 1.4.3.1 to 1.4.3.4 until all teams have been allocated a place.

1.5 PRACTICAL EXAMPLE

When there are less than ten sections, the scheduling of home and away matches can just as easily be done by the hand method. Consider, however, the following example with only three sections to illustrate the computer method. No seeding of the top section has been done.

1.5.1 Initial data

Section 1	Section 2	Section 3
Johannesburg A	Johannesburg C	Johannesburg D
Johannesburg B	Jeppe B	Jeppe C
Jeppe A	Parkwood B	Jeppe D
Parkwood A	Parkwood C	Wanderers C
Wanderers A	Wanderers B	Honeydew C
Honeydew A	Honeydew B	Observatory B
Observatory A	Bedfordview A	Greenside A
Witwatersrand A	BYE	BYE

1.5.2 Pair teams in order of allocation

	Level allocated
BYE and Bedfordview A	1 (bye teams)
BYE and Greenside A	1 (bye teams)
Johannesburg A and B	1 (same section)
Parkwood B and C	2 (same section)
Jeppe C and D	2 (same section)
Observatory A and B	3
Johannesburg C and D	3
Jeppe A and B	3
Wanderers A and B	2
Honeydew A and B	4

1.5.3 Odd teams in order of allocation

	Level allocated
Parkwood A	2
Witwatersrand A	2
Wanderers C	4
Honeydew C	4

1.5.4 Place allocations (closed loops)

1.	BYE (1)	Bedfordview A (2)
2.	BYE (1)	Greenside A (2)
3.	Johannesburg A (1)	Johannesburg B (2)
4.	Parkwood B (3)	Parkwood C (4)
5.	Jeppe C (3)	Jeppe D (4)
6.	Observatory A (5) Johannesburg D (5) Jeppe B (5)	Observatory B (6) Johannesburg (C) (6) Jeppe A (6)
7.	Wanderers A (7) Honeydew B (7)	Wanderers B (8) Honeydew A (8)
8.	Witwatersrand A (3)	Parkwood A (4)
9.	Wanderers C (7)	Honeydew C (8)

1.5.5 Final order

Place	Section 1	Section 2	Section 3
1	Johannesburg A	BYE	BYE
2	Johannesburg B	Bedfordview A	Greenside A
3	Witwatersrand A	Parkwood B	Jeppe C
4	Parkwood A	Parkwood C	Jeppe D
5	Observatory A	Jeppe B	Johannesburg D
6	Jeppe A	Johannesburg C	Observatory B
7	Wanderers A	Honeydew B	Wanderers C
3	Honeydew A	Wanderers B	Honeydew C

1.6 FURTHER DEVELOPMENTS

- An order of play has been prepared for sections of six, seven and eight teams. The round robin of matches for sections of only six teams is completed after five weeks.

- If a club cannot accommodate all its quota of home matches as a result of a shortage of courts, its teams are paired with clubs that have more than sufficient courts or with clubs that have only one team in the league. These pair teams are allocated different levels and home matches in the order of play are then swopped around by hand.

- The fixture data is transferred to a desk top publishing package from where A6 pages are produced. The publisher of the fixture book then photographs the pages for inclusion in the book. This eliminates costly type setting and the errors that occur with it.