Producing train driver shifts by computer

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Abstract

The privatisation of British Rail into twenty-five train operating companies and three freight companies has highlighted the need for each company to have efficient operating schedules. Manpower costs are a significant element in any transport organisation and the ability to minimise these costs is seen as crucial to the well running of these companies. In addition the need to try out different operating strategies is gaining importance as the search for cost cutting measures progresses.

Building on previous experience, a new rail driver scheduling system, TRACS II, has been developed and used for a number of operating companies. Schedules comparable to, or better than, existing ones have been produced, and the system has been used to test several strategies.

1 Introduction

Automatic scheduling of train drivers using computers is rare. This may seem surprising when computer scheduling of bus drivers, which is similar in theory, is already widely practised. Our first insight into the complexity of scheduling train drivers was gained from a project during 1990-91 in collaboration with the Operational Research Unit of British Rail (Wren, Kwan and Parker). In that project, part of the IMPACS (Smith and Wren) bus driver scheduling system was adapted for quickly estimating cost implications associated with options in restructuring driver work rules.

Since September 1994, we have engaged in a two-year project sponsored by the Engineering and Physical Sciences Research Council (EPSRC) in the UK to investigate further the special driver scheduling conditions applicable to train operators with the aim of ultimately producing a system suitable for the privatised rail operators. The system would include some of the processes of the earlier IMPACS system, but these would have to be considerably adapted. The new system has been called TRACS II. The approach of this project is to undertake scheduling problems from a number of UK train operating companies and learn through real scheduling experience with them, thereby
further enhancing the pilot system. These case studies are described later in the paper.

Rather to our surprise, TRACS II was able to produce very early in the case studies driver schedules that were comparable in quality with, and often better than, those being operated. Many train companies appreciate the speed and accuracy of TRACS II, and several of them have recently commissioned projects using it for investigating "what-if" scenarios and for assisting in production of operational driver schedules.

TRACS II is being evolved rapidly to incorporate the experience gained from direct exposure to real train driver scheduling problems, as well as to exploit results of other on-going research at Leeds. Some of the recent developments will be described.

2 TRACS II

Our first bus driver scheduling system, TRACS (Techniques for Running Automatic Crew Scheduling) was developed through the 1970's and used heuristics to build up and then improve a bus driver schedule (Parker and Smith\(^2\)). Unfortunately, it was not sufficiently flexible for adaptation to wide variations in circumstances, and we replaced this by IMPACS (Smith and Wren\(^2\)) which we installed for London Transport Buses in 1984, and is still in use by their successors. Subsequently we expanded it to deal with larger problems by decomposition (Wren and Smith\(^6\)), demonstrating to Greater Manchester Transport that significant savings could be achieved by this process. After installing the system in Manchester we formed a partnership with a firm of consultants with whom we developed the system further; it is now installed in many bus and light rail companies.

Building on the earlier rail work described above, we have been actively developing a new scheduling system, both to combine perceived needs of bus and rail operators, and to improve the inherent heuristic and mathematical processes. This new system, TRACS II, has formed the basis of our current work. In this section TRACS II, as it existed at the start of the project in 1994, is outlined. It consisted of a suite of programs performing separate functions, as described below. Later sections of the paper present enhancements made during the current project.

2.1 System Components

2.1.1 EST estimates whether any potential driver relief opportunity is likely to be critical in forming a good schedule, making a list of such critical opportunities. It also sensibly decomposes particularly large problems. This is bus-oriented, and has not been used in the current work.

2.1.2 SELECT examines the total vehicle work, eliminating many relief opportunities which are unlikely to be useful in a good schedule. It then reinstates any opportunities which were identified as critical by the EST process. Again this is bus-oriented, designed for a closely knit geographical area. It was used tentatively for Company C below and found to be suitable, but it was not used in the other examples.
2.1.3 **BUILD** is the major intelligent process which generates many thousand potential shifts each satisfying all the legal requirements, originally founded on developing sensible chains of meal breaks.

2.1.4 **COMPARE** examines sets of the shifts just built, eliminating any shift which is fully contained in another one. (This means that some shifts may overlap after the later scheduling processes, but such overlaps can be eliminated by the user specifying which of the shifts concerned is to carry out the driving work: the other shift or shifts can then either be reduced in length or the driver booked to travel as passenger.)

2.1.5 **EVEN** was a crude process used in IMPACS to eliminate some shifts whose work was entirely covered by many other shifts. It has been replaced by SIEVE (see 5.2).

2.1.6 **ZIP** is a mathematical process which first gives an accurate estimate of the number of shifts required, and continues from this to produce a workable schedule. The TRACS II version is much superior to the IMPACS version.

2.1.7 **SPRINT** optionally manipulates the schedule to make marginal improvements by swapping halves of shifts or adjusting hand-over times, and prints the result. This may reinstate some shifts eliminated by the COMPARE or SIEVE routines. It may also make improvements in overall quality where costs are identical. It continues by printing the schedule. The optional manipulation has not yet been extended to deal with the complexities of rail operation.

2.1.8 **OVER** is used for large problems which have earlier been decomposed. It accepts a proportion of the shifts in a solution, and carries work of the less efficient shifts forward to be considered with the next sub-problem. The user can specify the percentage of work to be carried forward, and can request that priority be given to carrying the work of certain types of shift (e.g., those on more than two trains).

2.1.9 **COMBINE** is used in decomposed problems to combine the results of all sub-problems into a workable schedule. At this stage SPRINT may be used again to refine the solution further by considering combinations of shifts from different sub-problems although, as noted above, this option within SPRINT has not been extended for rail driver scheduling.

2.2 **Original system applications**

TRACS II and its predecessors have been intensively used to produce many bus driver schedules according to wide ranging conditions. They have consistently produced results comparable to, and usually better than, those obtained by other methods. Most problems have been solved without the need for decomposition, but some users do regularly use an early version of the decomposition process.

3 **Case studies**

Under the terms of our EPSRC contract we undertook to work with at least four train operating companies in order to test our methods as they developed,
and to acquire an understanding of rail-specific driver scheduling conditions which we could build into our system. The Operational Research Unit of British Rail (now Rail Operational Research Ltd. [ROR]), agreed to introduce us to companies covering between them a range of different operating conditions. To these we added two with whom we already had close connections, making a total of six for whom we produced demonstration schedules as part of our research contract. Currently some of this work is confidential, and we therefore discuss this work under the names Company A, Company B, etc. The networks are shown schematically in Figure 1. We hope to be able to identify most of these when presenting the paper.

![Figure 1. The Networks](image)

Driver depots are marked with asterisks. Significant portions of networks D and F are not shown.
Following our initial demonstrations, companies B and D asked us to undertake further work to examine options of different mixes of driver depot locations and alternative scheduling rules. The first of these exercises was carried out within the EPSRC sponsored research, but the second was undertaken as additional work contracted for by the company.

Subsequently we agreed with ROR to undertake joint contracted work with other operating companies. It had become important with the division of British Rail into many separate companies that they should each be able to determine the set of driver scheduling conditions that best met their geographical and operational patterns. We have therefore undertaken in partnership with ROR five further scheduling exercises. In these we have been constrained by having to make available the program suite before it was fully developed in order to meet the urgency with which operating companies have had to change their scheduling practices. In this joint work with ROR the normal pattern has been for ROR to liaise with the client and to undertake the computer scheduling runs, referring to us when, as is natural in a developing system, difficulties arose. We also extended TRACS II at the request of ROR so that it could handle certain complex problems. In the case of the largest company we undertook most of the scheduling work in the University because we had the detailed software system knowledge necessary to expand TRACS II to meet their needs, and to apply it successfully to their very difficult problems.

It should be stressed here that the EPSRC sponsored research project was for a period of two years starting in September 1994, and was intended to result in a prototype system which would require further development before it could be used on real problems. The fact that our earliest experiments resulted in successful schedules meant that we could respond rapidly to company requests for scheduling help. Thus we have been feeding the results of our research into the system while solving urgent problems in advance of our planned system release time. This has inevitably caused difficulties from time to time, but the evolving system has responded well to the demands placed upon it.

It should be noted that in all the case studies, the train schedules have been fixed. It is the normal practice in the UK that driver schedules should be constructed after the train schedules have been agreed. This is particularly the case following the split up of British Rail. The Train Operating Companies first agree their timetables with Railtrack, the infrastructure owner, and only after agreeing the consequent train schedules can driver shifts be produced. The exercises dealt with a single midweek day, apart from one where initially Friday was chosen.

Drivers must return to their 'home' depot at the conclusion of their shifts. It is not sufficient to make an allowance of time for them to do this from wherever they finish their allocated work. In some circumstances because of the distances involved and the relative infrequency of the train service it is necessary to allocate them to particular train journeys. In order to achieve this it is necessary for the driver to travel as a passenger on a nominated train. The way by which ZIP selects shifts from those produced by the BUILD process means that in some cases shifts may overlap (see 2.1.4). The train work assigned in these circumstances is said to be overcovered. This facility is used to return a driver to his 'home' depot by booking him to travel as passenger. Similar circumstances may prevail at the start of a shift.
Companies A and F have a restriction on the total mileage covered in a shift. Currently this is 450 miles. We do not at present have a mechanism for dealing with this sort of restriction and it did not cause a problem in our case studies. However in our experimental work some hard coding was required to ensure that only valid shifts were generated.

A request by most of the operators involved in our case studies was how restrictions on the numbers of drivers at particular depots might be accommodated. Our current work concentrates on restricting the number of shifts having a particular spreadover per schedule, as this is a basic requirement by British Rail. The combination of these two restrictions has yet to be implemented. Another request was how it might be possible to remove a driver depot from the schedule and this is easily handled simply by removing the depot in question from the depot list in the data.

3.1 Company A
This is a long-distance fast operation essentially along a 400 mile track from A1 via A2, A3, A4 to A5. There are spurs from A2 to A6 and A7. For most of the day there are hourly services between A1 and A5 and between A1 and the spur point A6, while there are slower services also hourly between A1 and some of the intermediate points. The fastest trains take about four and a half hours from A1 to A5, and two hours from A1 to A6. Some of the fast trains continue beyond A5 and A6 to a number of other points. The basic routes from A1 to A5 and A6 are electrified, as is one of the extensions from each of A5 and A6, but diesel train sets have to be used on services which continue to the other extensions.

Drivers can operate either diesel or electric units, but two drivers are needed while the electric trains exceed 110 m.p.h. between A1 and A4. There are driver depots at A1, A2, A4, A5 and A6, with train depots one or two miles from each.

The driver schedule falls naturally into two parts because of the way the double manning operation is carried out. The drivers based at A4 who operate exclusively between A1 and A4, between which there is a requirement for double manning, work together as a team throughout the entire course of their shift. Approximately half the drivers based at A1 who also operate exclusively between A1 and A4, work in a similar manner. The remainder of the drivers pair up on an ad hoc basis and need not be based at the same driver depot. The driver schedules were thus constructed separately according to this criterion with the second category being the larger. Another reason for treating these two parts separately is that there are different rules concerning the length of the break in the middle of the shift when there are two drivers compared with just one.

In order to be able to produce a schedule where drivers team up on an arbitrary basis it is necessary to specify all the train work requiring double manning twice and to regard the shifts produced as totally independent of each other. Double manning is only required for the wheel turning part of the shift. Two drivers are not required for preparing the train unit for the subsequent journey or for ensuring that the unit is left in a safe manner at the conclusion of the journey.

In some circumstances a driver may need to travel as passenger on a train which is not present in the train work. In order for this to be done these passenger trips had to be pre-defined and added to the train work. (Later a full facility for passenger travel was added to TRACS II - see 5.1.5.)
This set of train data was interesting in that the opportunities to relieve drivers were remotely spaced both in time and distance, a feature that is quite different to intensive urban bus operation. This had an effect on the allocation of drivers to the five different driver depots and also in the determination of where to place the meal break in the shift. In our work with bus drivers we define two types of break, one where drivers take meals and one where they do not. In this long distance schedule because of the nature of the relief opportunities it is sometimes the case that the second type of break is long enough for a meal. Working within the rules laid down by British Rail as to where in the shift the meal break is to occur showed that our existing BUILD procedure was not always constructing the most appropriate shifts. This was to provide some incentive to establish a new BUILD process (see 5.1). Schedules produced were comparable with those produced manually.

3.2 Company B
This operates over about 150 miles from B1 to B6 via B2, B3, B4 and B5 passing on its own tracks through the centre of a major metropolis (B4). There is a short spur leaving the main line just before B4 to a terminus at B7, and a loop line branching after B4 through B8 to return towards B1. The running time from end to end is about 140 minutes, and there are trains about every 15 minutes over the central section. There are driver and train depots at B1 and B6, and also at B9 which is near B5. To get to or from B9, drivers have to travel as passengers on trains of another company unless they are driving to or from the depot. Drivers from B6 cannot drive between B3 and B1, while drivers from B9 cannot drive between B5 and B6.

This heavily used commuter type problem was tackled at a very early stage of the project before the enhancements discussed in section 5 were implemented. Drivers’ travel times between relief points were estimated and put into a table of ‘standard’ allowances. Route knowledge was simple and did not caused any major concern. Compared with the manual solution of 119 shifts, TRACS II was able to use marginally fewer shifts.

This exercise demonstrated that TRACS II’s solution was able to produce schedules of similar quality to manual schedules, especially on the distribution of work amongst depots. Company B appreciated that TRACS II could provide a very realistic forecast very quickly and they, therefore, requested us to investigate several ‘what-if’ scenarios. Company B hired drivers from two depots and wanted to perform different exercises to predict how the work would be distributed should one or more depots be closed or a new depot opened. These ‘what-if’ exercises were completed in a short period of time and Company B found the results useful in evaluating different strategic options.

Comments from the schedulers were encouraging but they identified a problem in that using standard travel time resulted in some trips not being feasible. The situation was worst during the period 22.00 and 06.00 when the train service is minimal and some vital connection was not available. The problem of drivers’ travel times has since been addressed and resolved satisfactorily (see 5.1.5).

3.3 Company C
This exercise covered a single metropolitan line with trains every two-and-a-half minutes over the busiest period. Trains operate from C1 through C2, C3 and C4 at one end of the line, through the central area to C5, where the line
splits, one branch passing C6 to C7, and the other passing C8 and C9 to C10. C1 to C4 takes 13 minutes, C4 to C5 42 minutes, C5 to C7 and C10 25 and 35 minutes respectively. Thus the end-to-end times are 70 and 80 minutes. C1, C2 and C3 are all used as turning points, while at the other end of the line most trains terminate at C7 or C9. The extension to C10 is only used at peak times. There are train depots at C2 and C6, while six trains are stabled overnight at C8, restarting in the early morning. Driver depots (i.e., reporting points) are at C2, C4, C5 and C6. C5 and C6 are only 4 minutes apart, while drivers taking trains to or from C8 travel by taxi to C5 and C6.

Problem size in TRACS II generally depends on the number of different relief opportunities throughout the day, and on the number of possible shifts which might be generated, which itself depends to a great extent on the number of relief opportunities. At the time this was the largest problem we had ever tackled, with 2500 relief opportunities. There were a number of special conditions which we had never met before; the ability to sign on or sign off at points other than the depots at certain times of day, and a limit on the earliest possible starting time at one of the depots. Although for most of the day the train service was so frequent that sensible estimates could be made of the times required for drivers to travel as passengers between any two points, extra consideration had to be given to late night possibilities. All these special circumstances were handled for this demonstration exercise by hard coding into the routine which checks the validity of shifts.

There were 72 train sets in use daily, of which 18 returned to a depot between the peaks. There were thus 90 train blocks, of which 18 operated for up to five hours over the morning peak, and 18 started before the afternoon peak. The earliest train started at around 0445, and the latest finished around 0130; trains did not necessarily finish work at the depot from which they had started. The current schedule used 169 shifts.

Hitherto the largest problem we had tackled had had about 700 relief opportunities, so it was clear that steps would have to be taken to reduce the problem size. In our bus driver scheduling work we had developed heuristics to eliminate unlikely relief opportunities and to decompose large problems into sensible smaller units (Wren and Smith*), but both had been developed from our specialised knowledge of bus driver scheduling from a single depot and were unlikely to work in the current complex situation. We asked the Company to suggest relief opportunities that were unlikely to be useful, and this resulted in a reduction of about 300 in the early morning and late evening.

We were now faced with decomposing a problem of about 2200 relief opportunities. We first tried the heuristic developed for the bus situation, using both three and four subdivisions and carrying forward inefficiently covered work from one subproblem to the next, but this resulted in solutions with one or two shifts more than in the current schedule. We then formed the train blocks into two groups; blocks which started in the morning at C2 or started in the afternoon anywhere and finished at C2, and the rest (which were associated similarly with C6 or C8). These groups were of approximately equal size, and it was observed that about half the current shifts were entirely on trains from a single group, indicating no significant correlation between driver depot and train depot. We then formed four subproblems; the first consisted of two-thirds of the trains from the first group, the second of three-fifths of the trains from the second group, the third of two-fifths of the trains from the second group, and the fourth from the remaining trains from the first group. Thus the subproblems were of decreasing size; each consisted of similar ratios of peak,
off-peak and evening trains. It would not normally have been necessary to decompose a problem of this size into as many as four sub-problems, but owing to our desire to produce a solution rapidly we did not spend as much time restricting parameters as we might have done. Consequently a very large number of shifts was developed for each sub-problem.

Following the strategy used in bus driver scheduling the first subproblem was solved and the work contained in the least efficient shifts was removed from the solution and merged with the second subproblem. This cascading process was continued automatically by the system through to the fourth subproblem, with about 30% of the work being carried forward each time (the reason for the original subproblems being made progressively smaller). Finally the retained shifts from the first three subproblems were added to the result of the fourth subproblem, yielding a schedule with 167 shifts. This saving of two shifts was accepted in principle by the Company, who, however, pointed out that three shifts required the driver to travel as passenger back to the other end of the line to sign off, which would be unpopular. We therefore added a constraint forbidding this type of shift and obtained a solution with 168 shifts; the Company then accepted that our original solution with 167 was preferable.

3.4 Company D
A wide range of services is operated over a complex network. The longest route is from D1 through D3, D5 and D6 to D7, taking about four hours, with the portion from D5 to D6 having several services providing a total of three trains per hour. A major commuter network is centred on D5, with smaller networks based on D1 and D3-D4.

Initially, as part of the EPSRC project, a study was carried out in which the work currently covered by drivers from depots at D1, D2 and D3 was scheduled. In the study area there are more opportunities to relieve drivers in this network compared to those for Company A but not as many as for Company C. Relief places are closer together both in time and distance. However an extra constraint placed upon the scheduling process is that not all the drivers can drive on all parts of the network. Some existing shifts encompassed work on four or more train units, but this did not cause any problems as the existing BUILD process which limits shifts to work on at most three units produced a suitable schedule saving four shifts in the process. An interesting aspect of this operation was that it was very similar to an exercise which we carried out as part of the 1990-91 project. Since that time a driver depot at D4 has been closed. All early morning trains starting from D4 have thus to be covered by drivers from D3 travelling as passengers on earlier starting trains.

Subsequently, on the strength of these results, we were awarded a contract by the Company to undertake a series of experiments in which the scheduling conditions on this group of services were varied in order to determine a more suitable set of rules. As a result of the success of this exercise, we are about to reschedule the whole system using some of the more likely scenarios so that the Company may select the most suitable for future operation.

3.5 Company E
Intensive services are operated over a system which is broadly H-shaped, with several additional spurs and loops. The legs E1, E2, E3 and E4, E5, E6 are joined between E2 and E5, and are linked by services from E1 through E2 and
E5 to E6. The total number of weekday shifts is 146, from depots at E1, E2, E3 and E5. We have started by scheduling shifts based at E1 and E2, of which there are 108, and will report verbally.

4 Further work commissioned by train companies

Our partners ROR have been commissioned to undertake a range of exercises using TRACS II to examine the effects of varying scheduling rules for many companies. In these the first task has been to produce schedules using the current rules, in order to validate the data and parameters by comparing computer-produced and original schedules. In every case TRACS II has produced schedules at least as efficient as those in operation, and ROR has continued to evaluate other scenarios. In one case, catering staff have been scheduled, while the others concerned drivers.

We have had particular responsibility under this arrangement for Company F which has a mixture of long distance, commuter, rural and branch line traffic. A particular feature here has been the fact that there is a very significant amount of travel as passenger within shifts, and that trains of other companies are sometimes used for this purpose. We therefore had to extend our arrangements for passenger travel (see 5.1.5) to allow the system to read details of trains which it was not going to schedule but might use if appropriate for movement of drivers. It had been decided before the problem was presented to us that the work should be based on Friday schedules, which were rather different from other weekdays.

We first scheduled a part of the Company's operation covering a large, but relatively isolated, geographical area consisting of a main line from F1 to F5 with many branches. This part of the operation was covered principally from seven depots, but we included the work of six shifts which operated into the area in question from three other depots. One further depot in the area was expected to cause difficulties in meeting the relevant conditions, and its work was initially excluded from the schedule. After also removing from consideration the work of two night shifts which consisted of many very short shunting movements which could be well defined in advance, there were 49 shifts in the current schedule.

This was the first problem in which we had to consider shifts operating on more than three trains, and this fact, coupled with the complicated arrangements for passenger travel, and the restriction of drivers from certain depots to certain stretches of line, caused some difficulties at first, but after some changes to the code and correction of the data, a satisfactory schedule was produced using 49 shifts. Experiments were then carried out with a number of alternative scheduling rules.

It was then decided to extend the work to the whole of the company, and initially this was to be divided into three areas, one of which was that already investigated. At this point it was decided to tackle Wednesday rather than Friday, and this required some adjustment to the data. The depot which had previously been excluded was reinstated, and a solution adhering to the current conditions but saving one shift was obtained. Currently the investigation is being extended to the rest of the Company.
5 Recent TRACS II developments

It was always recognised that a significant number of enhancements would have to be made to the system under the EPSRC sponsored research. The contracts with Train Operating Companies added to the urgency of this. In this section we describe the principal adjustments.

5.1 Shift generation

5.1.1 Basic Idea The basic idea of the generation process (BUILD) is to generate a reasonable number of shifts which must satisfy certain union agreements or work practices which are called ‘hard’ rules as well as some efficiency measures which are called ‘soft’ rules. ‘Soft’ rules are used to limit the number of shifts generated.

The new BUILD first looks at the work on each train and marks blocks of train work known as SPELLs. The length of a spell is governed by the above rules. BUILD then transforms these spells into STRETCHes either by using a single spell or combining two spells linked with a gap. This gap must be no shorter than the minimum time required to travel between the relevant points. If there is enough time for a meal, this may be allowed; otherwise the gap is called a joinup. Again, these stretches are governed by ‘hard’ and ‘soft’ rules. These stretches may also be used to form single stretch shifts (see 5.1.2).

BUILD will avoid forming stretches which are obviously inefficient, but will not reject stretches which are included in other stretches. Stretches which are obviously inefficient are those which have two spells belonging to the same train plus a joinup. The reason for not rejecting stretches which are included in other stretches is that these smaller stretches might be used to form some vital combinations with another stretch to form a shift.

After all the possible stretches are formed, each of them, if possible, will be linked with another stretch with a gap to form a valid shift. This gap in the middle is usually a meal break but can also be a joinup. Each shift can cover a maximum of four trains with at least one meal break.

Since the potential number of combinations is enormous, heuristics are used to remove shifts which are inefficient. When there are two shifts containing work on identical trains, and if one of them has a meal break starting later and finishing earlier than the other one, and other things being equal, the shift with a longer meal break will be rejected. Another heuristic cuts down the number of three unit shifts by comparing them with similar two spell shifts.

5.1.2 Single Stretch Shifts Single stretches of work can be turned into shifts provided signing on and signing off times are feasible. These shifts can be considered as ‘part’ shifts. In the present rail practices, part shifts are not allowed. ‘Part’ shifts do exist in reality as they will become a ‘full’ shift if a meal break is allocated either at the front or, more usually, at the end of the shift. ‘Part’ shifts are not as efficient as full ones but they can be useful in completing a schedule.

5.1.3 Meal Break Rules There are some rules governing when a meal break should occur; e.g. it must occur within the third to fifth hour relative to the start of any shifts whose length is less than 8 hours long. These rules differ if the shifts’ spreadover falls into different ranges. In order to overcome these
restrictions, certain intelligence has to be incorporated into BUILD. Some shifts which are crucial in forming a good schedule might be excluded because of these rules. Therefore BUILD allows a driver to sign on earlier than would have been necessary in order to fit the meal break within its allotted period. Sometimes BUILD extends the sign off time instead if it is more beneficial in order to force the shift’s spreadover into a different spreadover range which might have a slightly more relaxed meal break rule.

5.1.4 Spreadover Restrictions It is standard practice in rail operation to restrict the number of shifts over a certain length, i.e. the total number of shifts which are over 8 hours must not be more than 50% of the total number of shifts and the number of shifts over 8½ hours must not be more than 20% of the total. These percentages apply to individual depots. Hence, in the process of removing shifts which are entirely covered by other shifts, BUILD will classify the shifts into spreadover range categories and only remove those within the same category in order to retain more shorter shifts.

5.1.5 Passenger Travel The original system catered for drivers travelling between relief points either by assuming a standard travel time, or by assigning more than one driver to a vehicle as part of a shift; the excess drivers would in fact be passengers. With the lower frequency of train services, and with the need to travel on trains operated by other companies, a special feature had to be added to determine possibilities of travel on timetabled trains, or indeed on other transport modes. As mentioned above in Company B, the use of a standard travelling time is far from ideal.

A new program called TRAVEL has been developed to output a timetable for each relief opportunity. TRAVEL requires train information from the existing problem as well as some journey times operated by other companies or modes, e.g. train times on other networks, underground times, taxi journey etc. TRAVEL produces two different classes of travelling times for each relief opportunity. The first contains the times needed to travel from the relief opportunity to other relief places, the other is the travelling time needed to travel from other relief places to arrive before the time of the relief opportunity. These times will be used by BUILD if the passenger travelling feature is chosen by the user. The calculation of these travelling times follows a simplified shortest path algorithm. When this feature is invoked, there is an option not to calculate the journey time between some places if it is envisaged that travelling between these places is highly unlikely because of the distance or time involved.

5.1.6 Overnight Work Night shifts in bus operation had always been treated by our creating them in advance of the computer process. While this is possible in train operation, it removes some of the flexibility afforded by use of the computer. Initially, we stipulated that vehicle work which was to be included in a night shift should be defined as such by using an extension to the 24-hour clock (e.g., 2600 representing 2 a.m.). This meant that the computer would have the ability of forming late shifts including this work, and would have some flexibility in determining the nature of these shifts. However, we still had to specify which work was to be so treated, and it would have been preferable to allow the computer to choose the work for night shifts. BUILD provides a facility to mark a piece of work so that the computer may consider it as an early piece or a late piece, and to form shifts with it in either position.
5.1.7 Wide Spreadover Ranges Most rail companies would like to assess the effect on their schedules if the possible spreadover ranges are widened. Widening the spreadover ranges will create more combinations and BUILD might take some time to run. To prevent such long execution times, users can generate shifts of different spreadover ranges separately according to different governing parameters. These different sets of shifts are combined by using the program ADDIFO3.

5.1.8 Route Knowledge Rail drivers have to be trained to operate on every track on which they may drive, and have to maintain that knowledge by being assigned frequently to work every line within their domain. For this reason, drivers from any depot are generally restricted to certain sections of the total operating area. These sections overlap, so that it is not possible to subdivide the problem into areas of specific knowledge.

Route knowledge is required for the schedules produced for Companies C and F. The ability to define the nature of the link between consecutive relief opportunities is seen as a major enhancement to the TRACS II system. From information supplied to us by the train company an internal list of routes with route numbers is compiled. These routes relate directly to knowledge pertaining to individual driver depots. For each link between relief opportunities the correct route number is ascribed. For each depot a list is compiled of those routes for which the drivers have no knowledge. When the BUILD process has constructed a potential shift and the depot to which the shift will belong has been determined, each link in each part of the shift is checked against the list of prohibited routes for that depot. If a match is found then the shift must be discarded unless it is suitable for another depot.

5.2 SIEVE
The original TRACS II followed the shift generation process by a process of discarding certain shifts which covered vehicle work, all of which was covered by many other shifts. The process of doing this was rather crude, and there was always a danger that some essential shift might be discarded if we attempted to discard a significant portion of those generated. As we were now dealing with much larger problems in which many more shifts were being generated initially, we sought a new method of sensibly sifting out a large number of shifts which were unlikely to contribute to a good solution.

Each potential shift is ranked using a combination of three attributes: an index formulated to reflect its cost effectiveness, together with the least number and the average number of other shifts covering the individual pieces of work making up the shift. The lowest ranked shifts are discarded and the latter two attributes which affect the rankings are updated continuously, until a prespecified target number of shifts remain. Finally, SIEVE allows some of the discarded shifts to be re-instated because they might be good under some other criteria. The ranking of shifts under those other criteria is simply input as pre-computed indices associated with each shift, and the user may choose to re-instate for example the discarded shifts with indices from 1 to 5.

5.3 ZIP
This is an integer linear programming (ILP) suite for selecting from a large number of potential shifts a subset to form the best schedule. It was originally developed in the 1970s (Ryan⁴), but has since undergone several phases of significant revision and enhancement. Since the development of TRACS II,
the program suite has been restructured and brought up-to-date with the FORTRAN 77 standard. Some on-going research results which improve the algorithms used for solving the ILP have been incorporated. Some adaptations are specific to rail operations, for example facilities for constraining numbers of shifts of particular ranges of lengths. The capability of ZIP for quickly solving large problems has been demonstrated in the recent case studies described above.

Recent PhD research completed by Willers\(^5\) has resulted in improvements to many parts of the ZIP process. That of Fores\(^6\) has developed a powerful column generation strategy. This allows much larger problems to be solved as a single process, and enables better solutions to be found to other problems by forming many more potential shifts in BUILD and retaining a large portion of them through SIEVE. It is hoped soon to incorporate these improvements into the standard TRACS II.

6 Further Work

Further investigations will be on forming shifts with more than 4 trains. In rail operations, train units have to be ‘prepared’ at the start of a day and ‘disposed’ at the end of the day. Also, when a train is stationed at a platform for a short period of time, say 45 minutes, it can be left unattended provided a driver immobilises it before leaving it and a driver then mobilises it just before it becomes operational. All this preparation, disposal, mobilising and immobilising work has to be covered but they are usually very small pieces of work lasting from 5 minutes to about half an hour. Some schedulers tend to group all these small pieces of work into a single night shift.

7 Conclusions

TRACS II has been shown to be capable of producing very good train driver schedules under a wide variety of complicated conditions. All solutions investigated have improved on the previous manual ones while abiding by the same scheduling rules, often saving more than one shift. Some very large problems, with more than ten different driver depots and overlapping work, have been satisfactorily solved.

It has proved a very valuable tool in helping train companies to determine a set of operating rules appropriate to their special circumstances. This has been particularly valuable in the UK where British Rail, with a standard nation-wide operating agreement, has been divided into more than 25 different companies with very different types of operation. As rail operation in the UK is competitive, we are unable to reveal the conclusions reached by the various companies, but we can say that TRACS II generally indicated that significant savings could be made if drivers would work mixtures of long and short days.

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9 References


