A computer application to a transport scheduling problem

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The preparation of van drivers' duty schedules for the bulk conveyance of mail in the Central London area is described. The method employed includes a heuristic routine for reducing the idle and empty-running time between jobs.

This paper was presented to the British Joint Computer Conference in May 1966. Since that time there have been a number of changes in the operational requirements and in conditions, not least among them being the effects of the ever-widening restriction of parking facilities in London. The scheme is now based on the more sophisticated Mark II system described in the paper.

The field of application

The Inner Area of the London Postal Region of the Post Office is divided under the control of 9 District Postmasters and 2 Divisional Controllers. Each of these 11 controls has its own fleet of mail vans. Additionally there is a separate fleet, known as the Centrally-Controlled Service (CCS), which caters for the bulk conveyance of mails, mainly between District Offices and the railway termini, and provides support for the local fleets. The CCS fleet is under the control of the Director of the London Postal Region.

The computer system is directed at the scheduling of services for the CCS fleet and aims to provide flexibility of control, improved statistical data and to serve as an operational research tool.

The problem

The CCS fleet comprises 689 vehicles, including reserves and special-purpose vehicles, stationed at 5 garages and driven, on a 3-shift rota, by 1,230 men. The fleet performs about 30,000 services (i.e. individual loaded trips) each week covering some 250,000 miles mainly within a 5 mile circle of Kings Cross. The services are strictly timed because of the need to meet trains and to schedule sorting office work. Each service requirement consists of a start and finish time and place, and may also have a number of timed intermediate calls. The number of terminal points is 360. Of the 30,000 services about 88% are scheduled against known commitments while the remainder are performed on *ad hoc* demand; all *ad hoc* services are controlled from a central operations room at Belgrove Garage near Kings Cross.

The scheduled services are known in advance and operate at varying frequencies within a week. The *ad hoc* services, which operate to special order, vary between approximately 350 and 1,000 services per day. Changes to scheduled services, consequent on alterations in requirements or to railway timetables, vary from about 50 in most weeks to as many as 1,300 in a single week.

The services, which can be scheduled to an individual driver on his tour of duty on a day, are restricted by a number of factors including

(1) Statutory limitations of the Road Traffic Acts which define the number of hours which must not be exceeded before a rest or meal is taken;
(2) Agreements as to conditions of employment which exist between the Post Office and the Union representing the drivers concerning such matters as attendance times and places, duty rotas, meals, overtime, etc.

For the preparation of duty schedules the most difficult restrictions to fulfil are those concerning the duration and location of meals. Meals come within four categories and must be scheduled to be taken at a canteen. There are 18 canteens and each may have different opening hours for each meal category.

Scheduling is a manual operation carried out by clerks in the Transport Branch of the Director's office. The complexity of the task is so great that a full-scale manual overhaul would be out of date in respect of amendments, before it could be implemented. Because of this the tendency is to amend existing schedules piecemeal rather than to attempt overall rearrangements of the services on the schedules.

The present scheduling system is not capable of providing Management easily and regularly with the information necessary for adequate control of the fleet. Because of the constant state of change, major effort is needed to establish the extent of idle time and the points in time and place at which it occurs. The effects of changes in requirements, time-table, and staff conditions or of economic factors in the location of sorting offices, garages and canteens cannot be assessed without a full-scale rescheduling exercise.

The approach

In October 1963 a team was formed to study the problem and to consider whether a computer could be used to produce drivers' schedules, fleet statistics and management control data. (A LEO 326 was scheduled for

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delivery to the Post Office in 1965). The team included the Manager of the CCS Fleet, a Consultant (part-time) and a programmer from English Electric-Leo, and a member of the Computer and Office Services Department of the G.P.O. It was augmented by clerical and further programming assistance later.

Contact with other organizations operating large transport fleets brought the early realization that the P.O. problem was a unique one of timetabling. The scope for economy lay in:

(1) reducing idle time at the end of services;
(2) reducing empty running time between services;
(3) reducing clerical costs by producing for each driver an accurately timed and detailed schedule of all loaded and empty journeys showing the statutory and privileged breaks in duties and the times and places where they should be taken;
(4) the use that could be made of better management information.

The matching of services to schedules should be carried out on the basis of the lowest cost of idle time and empty running time, combined, according to their relative costs, between the service to be added and the last service on the schedule. This rule results in the accumulation of periods of both idle and busy time. While it might not always be desirable to accumulate periods of idle time, in this case it was done to allow for meals to be taken and assistance to be given with the *ad hoc* work.

Detailed fact finding revealed a number of constraints which had to be allowed for in the system:

(1) different periods of daily duty dependent on whether a man is on a 5-day or 6-day rota;
(2) prescribed earliest and latest times that a man on a given shift can be brought on or booked off duty; out of these came the conclusion that the daily cycle started and finished logically at 6 a.m.;
(3) allowances for vehicle service time at the start and finish of each duty;
(4) the location of 18 canteens and the type of meals which they are able to serve at specific times.

After some months of investigation the team concluded that simulation by computer of the working of the entire fleet, trip by trip, day by day, was the most promising approach. Before embarking on such a complex program, however, it was decided to test the theory by a small scale manually operated simulation, to schedule the services currently carried out by vehicles from one of the garages for one day.

The manual simulation exercise consisted of the allocation of 400 services to 50 drivers' schedules and occupied the whole team for 34 days. At the conclusion a set of workable schedules had been prepared and the system had been extensively modified and proved. At this point it was decided to begin programming to produce a Mark I computer system which, although it would fall short of the desired system in terms of refinement, would nevertheless be workable and would form a foundation for development.

While programming proceeded the remainder of the team were occupied in designing and compiling the records of the 26,500 scheduled weekly services and in establishing the various parameters and constraints to be built into the system.

Programming

The number of possible alternative schedules is for practical purposes infinite as each service can be followed by any other with which it does not coincide. A very approximate calculation results in an estimate of $(200)^{24}$ possible combinations for each day. No method of calculation is known which would select the best combination from this number of possibilities within a practicable time span. A step by step approach was therefore necessary which entailed matching each service in turn with the schedule of the driver best able to perform it. This meant the evaluation of 400 alternatives for each of 4,500 services for a single day. The time available to do this on the computer is limited for practical purposes to about 3 hours and it was economically desirable that it should not exceed 30 minutes. Thus, services had to be allocated at the rate of one every 2 seconds maximum, and preferably at 3 or more per second.

Many problems were encountered during the program trials stage. The logic was very complicated and in addition the running time on the computer was far too long. The calculating system used had been designed on the assumption that vehicles became available for further work at random times and places. However, a situation could arise where, at one time and place, up to 50 vehicles became available simultaneously. The computer spent a lot of time trying to distinguish between them as each service was allocated to a schedule. Even worse, at a later stage each schedule was provisionally selected for a service in turn after evaluation of all the others and then rejected because a meal was overdue.

During the scheduling process it is necessary to utilize driving times for all movements. The driving times between the various places visited during a service are known and are part of the input data. The times for journeys between services, and between these and canteens and garages have to be added during the scheduling process. There are 360 terminal points to services 18, canteens and 5 garages. A look-up table of times for all possible combinations would consist of nearly 80,000 items. Not only would there be inadequate storage space in the computer for these, but also realistic times are not available for all of them. Initially, therefore, all such times were calculated as required by applying Pythagoras' Theorem to the Eastings and Northings distances on $2\frac{1}{2}$ in. Ordnance Survey maps to find the straight line distances, multiplying by a constant $(1 \cdot 2)$ to convert to approximate road distance and dividing by the appropriate average speed. Subsequently a look-up table has been incorporated of the times between the 35 most frequently used points, partly because these were known, and partly because, in the Central London traffic condi-

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tions, some of the calculated times were unsatisfactory due to localized congestion, traffic and one-way streets.

When efforts were being made to reduce program running time the program was modified to output the number of distance calculations and the clock time per 50 services processed, thereby enabling the programmer to localize points of difficulty. (At some stages it was found that between 4,000 and 5,000 distance calculations were being made for 50 services.) In attempting to eliminate unnecessary calculations it was found that the Pythagoras results could be closely approximated by the formula:

$$\text{Distance} = 0{\cdot}45\frac{A^2}{B} + B$$ where A and B are the sides containing the right angle and A is the shorter.

The Mark I program demonstrated satisfactorily the ability of a computer system to satisfy the requirements. It was modified a good deal to meet changing requirements, and now meets the minimum satisfactorily.

The Mark I system is, however, very cumbersome, particularly in terms of input and output and the associated clerical functions. As a result of continual evolution of the techniques employed, a new system, known as Mark II, has been devised. The Mark II system makes use of all the experience gained in writing and testing the Mark I system. The suite of programs divides naturally into three sections:

(1) *File maintenance and interrogation*

(*a*) Full details for all garages, canteens and services are stored on a magnetic tape file and the data on this file is updated weekly in the light of changes. All records on the file have a selection pattern associated with them, and data can be selected for a wide variety of scheduling runs according to the control data submitted to the scheduling process. The data on this file for services includes addresses for terminal and intermediate points, all pickup and drop times, service statistics, and any special instructions which the driver may require while performing the service.

(*b*) Details of the services which satisfy parameter controlled conditions may be obtained by the use of an interrogation program. Facilities offered by this program include the printing of services operating over specified routes, or services starting and/or finishing at specified points. The task of fleet management is made a great deal simpler by the use of this program, as questions relating to distribution of work can be answered at extremely short notice.

(2) *Scheduling*

(*a*) The selection of garages, canteens and services for a run is governed by control parameters submitted to the scheduling program at the start of a run. Also submitted are a large number of control values used as parameters within the scheduling process, and a predetermined duty pattern if required. Facilities are provided for the segregation of a parcel and letter mail at specified periods of the day, these periods being controlled by parameters.

(*b*) The input to the scheduling process is in the form of a magnetic tape file on which are stored all the details of garages, canteens and services required. The services are sorted into starting time sequence.

(*c*) Processing commences by forming internal files of garage and canteen details to which continual reference is made during processing for data concerning opening times and map references. Also held internally are parameter records which govern the logic applied during processing, details being held concerning duty patterns and running speeds, time limits and spans for the allocation of meals and overtime. Other parameters are used to eliminate by simple tests a large proportion of the apparent possibilities at each stage leaving only the marginal cases to be fully calculated and explored.

(*d*) An internal file of duty schedule records is maintained in the sequence of the time at which schedules become available for further work. For each schedule details are also held of present map reference, meal relief situation, schedule number and allocated duty span. This file is updated each time a schedule is started or completed and each time a service or meal is allocated to schedule. Schedules are normally only created if it is not possible to allocate the service under consideration to one of those schedules already on duty.

(*e*) A service is read from the service file, access is made to the duty schedule file at the service start time, and schedules are tested individually until one is found which is capable, in terms of time and distance from the start point, of carrying out the service. A simple and approximate test is applied to detect when a meal break is the necessary next move. If the schedule fails it is allocated a meal and testing is resumed with the next schedule. On finding a schedule which is free of meal relief commitments or which has sufficient time available for a meal and still is able to meet the service it is established as the reference schedule. The cost of allocating the service to the schedule is calculated and stored as a reference cost. From the numerical value of this cost, a lower time limit can be calculated beyond which no schedule can be more economical than the reference schedule. Within this time band (from the reference schedule to the lower limit) schedules are tested to determine whether a cheaper match exists; if it does, it becomes the reference schedule and its cost the reference cost. The most economical schedule is put through a main loop of tests in regard to meal reliefs, overtime regulations and permissible duty spans. Provided no rules are transgressed, the service is allocated to the schedule and the schedule file updated. If, however, the cheapest match fails, the testing cycle is repeated with the next cheapest schedule. The cycle is repeated until either the schedule file is exhausted or the service has been allocated.

(*f*) As services are allocated to the most economical schedule where one is available, it follows that some schedules will have periods of idle time between services. This idle time, provided it is of sufficient span to be of use, is converted by the scheduling process into coverage for *ad hoc* work by inserting into the schedules a report

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indicating that the driver should either phone or attend the control point where *ad hoc* services are distributed.

(*g*) Schedules booked on by the program are fitted to the work load, and thus the duty pattern will vary from run to run with the pattern of services submitted. It is a requirement that the patterns of duty attendance for each garage should be identical from day to day, and therefore an alternative procedure is available which provides for fixing an attendance pattern for a garage regardless of the incidence of demand.

(*h*) It is, perhaps, worth mentioning that the scheduling program takes approximately 15 minutes to allocate a day's services to duty schedules.

(3) *Preparation of duty schedules and statistical analyses*

(*a*) The results file from the scheduling process is sorted so that schedule components are in time order within each schedule and each schedule in schedule number order within garage. This file is then used as input to a program which edits the results into the correct format for printing and also compiles comprehensive statistical data about the results of the run.

(*b*) Full operational schedules are printed on hectographic stationery ready for duplication, and management schedules which contain additional details can be printed if required.

(*c*) Information about the time, place and duration of idle time is printed in a suitable form to assist the staff of the control point to cover *ad hoc* requirements.

(*d*) The print output from the suite is governed by control data submitted to the print program and only those details required need be printed.

(*e*) Operation of the Mark II system also gives management a powerful research tool for investigating new concepts in scheduling. The flexibility and sophistication of the suites enables accurate costing of new schemes to be calculated at very short notice and the comprehensive statistical data enables thorough control of the fleet to be exercised by management.

Results

During the development of the Mark I system, the London Postal Region asked for letter and parcel services to be separately scheduled to prevent delays in the parcel services reacting on the letter services, and the program was modified accordingly. The segregation of the services, as might be expected, reduced the savings which would have been achieved with integrated services but management were satisfied that the operational advantages, which could never have been achieved under the manual system, adequately compensated the loss.

At the time of writing, negotiations are in train with the Union representing the drivers to introduce the Mark I system. It can be said with confidence that the savings resulting from the system, despite the segregation of the letter and parcel services, have made the exercise worth while.

The Mark II system will not markedly increase the direct savings, unless its greater flexibility is used to develop a partial integration of letter and parcel services at operationally opportune periods of each day. But the indirect savings resulting from improved management data and the facility for operational research, although not estimable at present, will be considerable.

The future

The Mark II system will be further developed to produce the Christmas pressure schedules which have always been a burden on management and consideration will be given to extending the system to a wider area of London than hitherto and to scheduling similar services in the larger provincial cities.

Book Review

Principles of Automated Information Retrieval, by William F. Williams, 1966; 439 pages. (Elmhurst, Illinois: *The Business Press*, $15.00)

The author of this work sets out to "eradicate an imaginary and rapidly disappearing boundary line between data processing systems and information retrieval systems". Whether he succeeds or not is irrelevant because here is an invaluable compendium of information on both the hardware applicable to retrieval systems and the software of documentation. The problems of the intellectual analysis of information are probably underplayed, with an implication that such problems are diminished by the availability of modern data processing equipment. Nevertheless those parts of the book which deal with information analysis for machine manipulation are a good introduction to the subject for the machine man unfamiliar with this area. The chapters on abstracting, indexing and vocabulary control are particularly useful in this respect, and the treatment of classification is more realistic and more broadly based than the rather too-narrow view which tends to be held by many classificationists.

The data-processing specialist will probably find much of the information on machines superfluous, but there is a great deal of useful description of the equipment designed specifically for information retrieval purposes, particularly the simpler types, with which he may not be familiar. For the documentation specialist the treatment of this aspect of the subject is very useful indeed, particularly as the equipment is dealt with in a context with which he is familiar.

The book contains a useful glossary and a sampling of the definitions produces little with which one could quarrel. The bibliography, though quite substantial, is rather more suspect, for though no doubt it adequately supports the text it seems to be somewhat unbalanced. British writers are conspicuous by their absence, and it is difficult to understand for instance the exclusion of the works of B. C. Vickery.

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