CO-OPERATION IN PROBLEM SOLUTION - A PRACTICAL ILLUSTRATION

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ABSTRACT: *The solutions to many problems are often difficult to find, particularly for the layman practical operator or manager without the specialised academic skills necessary to tackle such problems. Not infrequently the difficult problem will be placed in the "too hard" basket together with the hope that, by some stroke of good fortune, it will disappear. A more practical approach is available to the operator as is shown in this paper which illustrates how, by the use of skills made available from outside its own organisation, the then Municipal Tramways Trust, now the Bus and Tram Division of the State Transport Authority in South Australia, was able to carry out a successful investigation into a difficult problem of a highly complex nature dealing with the preparation of timetables and duty rosters.*

INTRODUCTION

There are many areas, including the field of transport, where people with highly developed and specialised skills can help the practical operator or manager to find solutions to problems, with considerable benefit not only to the specialist and the operator, but also to the community in general by way of improved services or working conditions, reduced costs and the like. It would seem however, that many of these benefits will not be achieved because of the limited line of communication which at present exists between specialist and layman. Many a problem, awaiting solution, will remain unanswered because the specialist is not aware that the problem exists while, on the other hand, the operator or manager is, in many cases, ignorant of the facilities which could be made available from consultants, Government institutes, and those largely untapped sources, the various centres of learning such as universities.

A somewhat different communication problem must be overcome even after the initial approach has been made and contact established between specialist and operator. It is difficult for the specialist to understand the true complexity and nature of the exercise, partly because of a lack of experience on the operating side and partly because the practical operator is not able to explain or define the problem properly. On the other hand, a layman practical operator or manager has difficulty in fully understanding the type of help obtainable from the specialist - this may be caused by a lack of appreciation of the techniques available even in the very broadest sense. Particular problems at times require particular specialist treatment, and it can be seen that, because of this communication problem, there is a real risk that a specialist may become involved with an investigation for which a quite different skill is required. This is frustrating to both specialist and operator and has, no doubt,

been the cause of some disenchantment, and a reduction in enthusiasm for cooperation in the future.

The foregoing has painted a somewhat gloomy picture of the cooperation scene between academic specialist and practical operator, but despite the difficulties, the authors quite firmly believe that, by application of enterprise, enthusiasm, patience and understanding, many of the problems, now considered to be a veritable way of life, could be solved if only the specialist and operator could break through this barrier of communication. In support of this contention, this paper presents an illustration of what can be achieved by cooperation, in describing in fairly broad outline, a project carried out by the then Municipal Tramways Trust in Adelaide with the cooperation of academic staff from the University of Adelaide and a local firm of consultants, for the solution to problems associated with bus operation in the Adelaide metropolitan area.

INITIAL APPROACH

This project was probably initiated in 1964 when Professor Renfrey Potts (Professor of Applied Mathematics, University of Adelaide) approached the Municipal Tramways Trust, among other organisations, to see whether the Trust had any practical problems to be solved. The Professor, very wisely, wanted to find practical problems for his mathematics students rather than have them try out their skills on hypothetical ones.

This approach was followed by the setting up of weekly sessions at which students, practical operators and other interested parties posed practical problems and discussed possible theoretical approaches to their solution. Among those present at these sessions were Professor Potts, Mr. P.G. Pak Poy

(now of P.G. Pak Poy and Associates, a local firm specialising in operations research with a background knowledge of the public transport industry), several students who later joined the staff of P.G. Pak Poy and Associates, and the Trust's Traffic Manager, Mr. R.P. Wilson, who outlined problems faced by the Municipal Tramways Trust in the areas of timetabling, crew rostering and other aspects of bus operation. Subsequent weekly sessions indicated that solutions to the Trust's problems were, at least, theoretically possible.

PROJECT OUTLINE

P.G. Pak Poy and Associates then approached the Municipal Tramways Trust with a proposal to investigate the automation of certain of the rostering procedures. This proposal was accepted and led to further investigations aimed at achieving an integrated system for the preparation of time-tables, rosters and payrolls for traffic crews. After a survey of the project, the consultants suggested that, because of the size and complexity of the problem, the best approach was to divide the overall procedure into steps and to attempt to devise the optimal solution by using a mathematical modelling technique, and then write a computer programme for each step. Because of the probability of finding an early solution in some areas of crew rostering, it was decided to tackle this section of the total project first, and the agreed philosophy was for the consultants to study the Trust's manual methods and develop these rather than seek a completely new solution.

THE ROSTER PROBLEM

This can be stated as the production, from pre-determined timetable data, of a set of duty schedules or man-

shifts which exactly covers all duty, and the arrangement of these daily shifts into fortnightly duty rosters for traffic crews. The duty schedules and fortnightly rosters must be compiled so as to comply with a complex industrial award and other agreed conditions and to achieve, as far as practicable, optimal economy.

In a preliminary discussion between the consultants and our operations staff to formulate a study plan, it was agreed that the total rostering problem should be broken down into three major phases, each of which could be the subject of a separate investigation. It was intended that the three phases would be combined subsequently to form one complete procedure capable of integration with existing or proposed procedures for the compilation of timetables and payrolls for traffic crews. The rostering phases to be investigated were as follow:

Phase I - The initial compilation of duty shifts to cover all duty exactly.

Phase II - The re-arrangement of morning and afternoon portions of broken shifts compiled in Phase I to produce an optimal or near-optimal economic result.

Phase III - The construction of the fortnightly duty roster for traffic crews.

PROCEDURE FOR THE PREPARATION OF DUTY ROSTERS

As has already been stated, the agreed philosophy was, in general terms, to develop the manual methods then in current use, with the aim of using automation as a means of reducing production time and ensure, as far as possible, optimal

economy. Procedures for the compilation of shifts (Phase I) vary between Sunday, Saturday and weekday duty because of the different service conditions which apply on each day. The flow diagram on Page 6 and the description of the outlined procedure which follows, relates to the preparation of weekday shifts only.

The flow diagram also shows how the procedures for timetable, roster and payroll preparation have been integrated. The output from timetable data provides input for roster preparation while roster output is used to produce input data for the automated payroll procedure.

Basic Information

The basic information necessary for the production of rosters comprises:

The times at which buses depart from and return to depot and pass the points along each route at which crews can be relieved. These times are extracted from working timetable data.

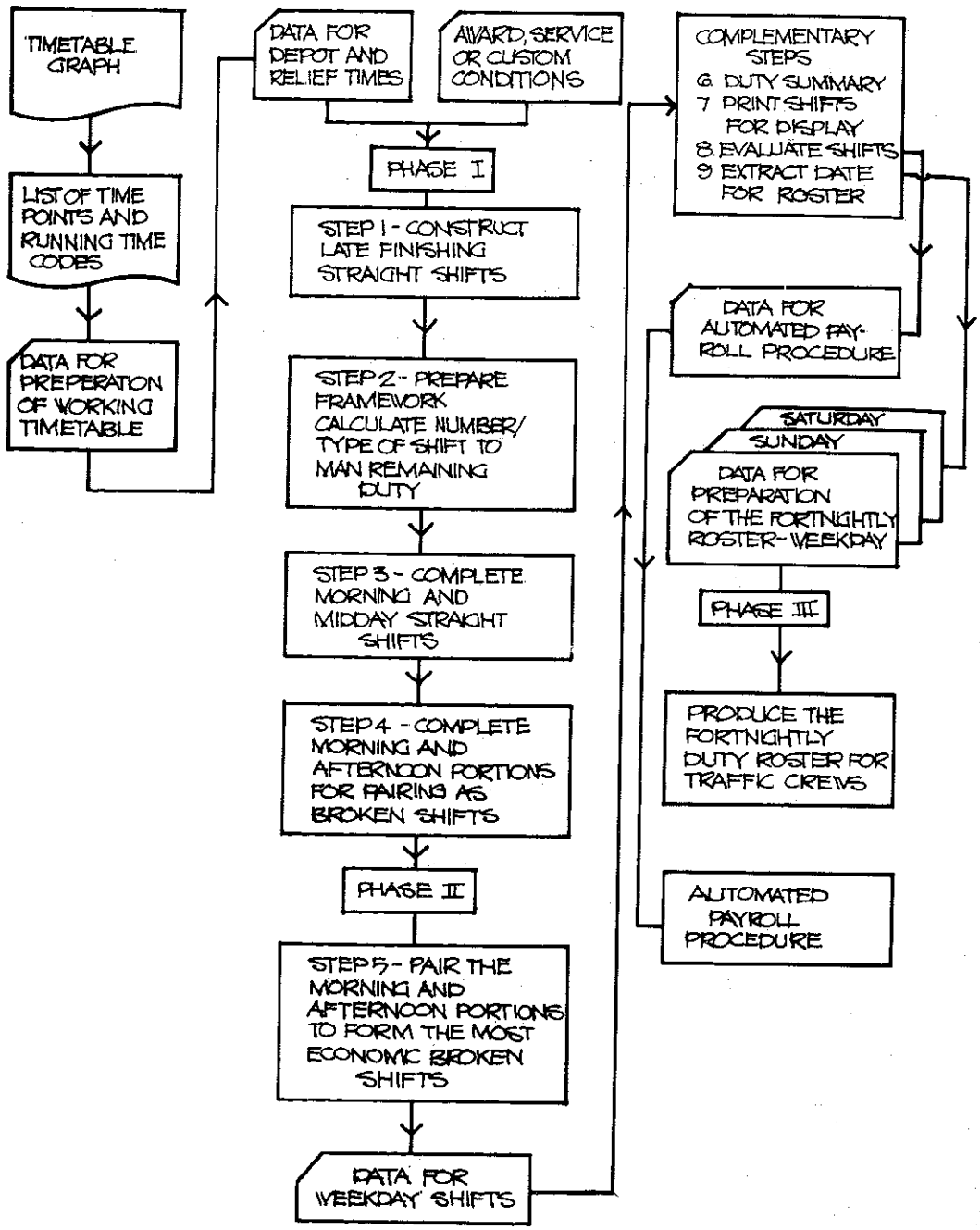
The award conditions, custom and service requirements which must be complied with.

The depots and classification of staff for which the rosters are required.

Rostering Procedure in Outline

Roster preparation can be conveniently divided into the following phases:

Phase I - Cut runs and combine portions of duty to form



FLOW DIAGRAM - DUTY ROSTER PREPERATION

man-shifts. Having determined the bus trips required, and the times at which these should run to cater for the needs of patrons, it is then necessary to cut these runs into pieces of work which can be combined to form man-shifts. This involves providing time allowances for signing on or off, travelling to and from relief points, providing reliefs for meals and the like. This phase can be sub-divided into the following steps -

Step 1 : Construct late finishing straight shifts.

Step 2 : Prepare a framework to calculate the minimum numbers and type of shift required to man duty remaining after Step 1.

Step 3 : Complete morning straight and midday straight shifts.

Step 4 : Complete morning and afternoon duty portions to subsequently form broken shifts.

Phase II - Step 5 : Pair the morning and afternoon duty portions prepared in Phase I to form broken shifts giving optimal economic results.

Complementary procedures -

Step 6 : Prepare a summary which shows the allocation of runs or portions of runs to shifts. This is known as the block roster and may be used to ensure visually that all duty has been included.

Step 7 : Print, for display purposes, the shifts for crews based at each depot.

Step 8 : Evaluate each shift for payroll preparation by calculating minutes of duty, penalties and allowances. This information forms the basis for an automated payroll procedure and for the compilation of cost and statistical records.

Step 9 : Extract the data necessary for the construction of the fortnightly duty roster for traffic crews. This information is collated with similar information relating to Saturday and Sunday shifts.

Phase III - Step 10 : Construct fortnightly duty rosters. The data extracted in Step 9 is combined into a fortnightly duty roster based on five days duty and two days off each week for each employee.

DEVELOPMENT IN AUTOMATION OF THE ROSTER PROCEDURES

The three automation Phases I, II and III were expected to be complex, to require a large capacity computer and also be capable of integration with each other. It was decided, therefore, that the programmes should be written to run on the CDC 6400 machine owned by the University of Adelaide.

Phase I - Although the first stage in preparing duty rosters from timetables, the compilation of shifts (or run-cutting) is the most complex and time consuming aspect of all scheduling procedures and for this reason the investigation of the automation of this phase was left until completion of the automation of Phases II and III.

The basic problem consists of cutting runs into

pieces of work which can be formed into man-shifts and which comply with complex award conditions. The procedure is divided into the four steps outlined previously.

The consultants proposed to mechanise the existing manual procedures used to carry out this phase of roster work as it was not thought possible to devise a mathematical technique which would ensure optimum results. It was considered, however, that any inefficiencies in this phase would be largely offset by optimisation of the subsequent Phases II and III.

During the course of the investigation, it became evident that, because of the varied service and award conditions applicable on weekdays, Saturdays, Sundays and public holidays, separate automated procedures would need to be developed for each of these days. For economic reasons, it was decided to restrict the investigation to the compilation of weekday shifts only. The subsequent decision to convert the Trust's services to full time one-man operation further limited the investigation to the automation of the run-cutting procedures required for one-man bus operators.

The investigation, which took approximately 3½ years, was completed in 1970. Tests using the new procedures and programmes indicated that complete automation of run-cutting was not achieved, but with a relatively small proportion of the work performed manually - representing up to about 2% of the duty to be scheduled - a computerised solution to the run-cutting

problem could be obtained. It was then considered that further investigation to pursue complete automation of the procedures would be uneconomical.

The automated technique does not provide the optimum solution in all circumstances and test evaluations have shown that the computerised shifts represent a slight increase in traffic wage costs when compared with shifts compiled manually by an experienced schedule builder. For this reason, it was decided to use the fully automated procedures on a selective basis with particular application to schedule construction required for periods of short duration, thus limiting the effect of the increased wage costs but retaining the benefit of rapid construction. The procedure can also be used to compile shifts for the quick evaluation of alterations to service or industrial award conditions as data for such changes to service or award conditions can be easily introduced into the programmes.

The automated procedure has been arranged in sections, each capable of independent application for use, if required, in conjunction with manual procedures. This flexibility provides the means by which efficient duty shifts can be produced for operation over extended periods in approximately one-third of the construction time necessary when using fully manual methods.

Because of the potential economic benefit and other advantages gained by a saving in schedule construction time, the investigation into the automation and run-cutting procedures has been well worthwhile.

Phase II - As it was considered less complex than Phase I and III, the decision was made to investigate the automation of Phase II - the pairing of broken shift portions - as the first stage of the total roster automation project. The basic problem in this phase is to find the pairings which comply with the award provisions and provide the lowest cost combinations.

The consultants constructed a mathematical model using a small amount of data to obtain the optimum solution to this problem and then prepared a computer programme capable of applying the same technique to the much larger volume of actual data.

The technique used ensures that the pairings finally selected comply with three basic award conditions and give the lowest possible cost. In practice there are some hundreds of broken shifts each weekday so that the numbers of possible pairings is extremely large. There are decided advantages, therefore, in being able to determine the exact solution quickly.

The computer programme for this phase of the roster work was completed in March 1965 and checks made at that time showed that the automated procedure did improve the results which were being achieved by the manual procedure. This programme has been used in the preparation of all new rosters since 1965 and has proved its reliability in practice.

The principal advantages of this automated procedure are that optimum results are guaranteed and the time of preparation is substantially reduced.

Phase III - Having achieved the automation of Phase II, it was decided next to automate the procedures used for the construction of fortnightly duty rosters for traffic crews. The basic problem in Phase III is to arrange the daily shifts to form weekly and fortnightly periods of work in a way which complies with the award conditions and local customs and which incurs minimum cost.

For this problem, an optimal assignment programme was used to evaluate each line of work according to a predetermined score system. The process used ensures that a near-optimum solution, consistent with award and local custom requirements, is achieved.

This computer programme was completed in November 1966 and checks made showed that the automated procedure provided a solution superior to that being achieved manually. The programme has been used to prepare all new fortnightly rosters since the beginning of 1967 and has provided advantages for both management and traffic crews - management benefits by the guarantee of a near-optimum minimum cost roster, and traffic crews have their work arranged with more identical or similar starting times than was achieved under the manual system. The time required to prepare a new fortnightly duty roster has been reduced from three weeks to one day.

Complementary procedures -

In October 1966, the Municipal Tramways Trust took delivery of its own IBM System 360 Model 20 computer which was to be used principally for processing

payrolls and accounting work. The Trust's own computer programmers and schedules staff have since collaborated in preparing programmes to automate Steps 6, 7, 8 and 9 of the duty roster procedure using the 360/20 computer. These programmes, which have been integrated with those designed to run on the C.D.C. 6400 computer, have proved effective in practice and have further reduced the time required for preparing new rosters.

AUTOMATION OF TIMETABLING PROCEDURES

The first real approach to this problem was made in 1963 when staff from I.B.M. Australia Limited, in cooperation with Trust officers, compiled a computer programme which, by the use of a basic start time in conjunction with codes for standard running times and time point patterns, produced a printed working timetable and a "run card". The printed output from this programme was introduced into use for a trial period but was found to be unsatisfactory in operations. Following the purchase of an I.B.M. 360/20 computer in 1966, this programme was revised by the Trust's own programmers, and a satisfactory solution to the problem of the printed output was found. Not only was the tedious and time-consuming work of handwriting draft timetables for reproduction eliminated, but the output from the programme could readily be used for the production of input for roster preparation.

In 1969, following a series of discussions with Trust officers, P.G. Pak Poy and Associates, currently involved in the roster automation problem, carried out an investigation into the feasibility of developing computer programmes for the preparation of bus timetables. As a result of this preliminary study, it was decided that, because of the relatively constant

nature of the off-peak services, the investigation would be limited to the development of automated procedures which would design optimum peak hour services using the minimum number of vehicles based on load statistics and any specified standard of service. The new peak hour services were then to be automatically combined with existing or pre-determined off-peak services to produce complete timetables. Because of the complexity of the task it was further decided to carry out the project in two stages - firstly the preparation of time-tables for a relatively simply service along a single route without branches and if success was achieved, this would be followed by a more complex problem involving multiple services operating over a common trunk with any or all of the services having branches.

The consultants completed their investigations and developed an automated procedure which was capable of producing timetables of a simple nature. However, the results were not entirely satisfactory as the timetables produced were not as efficient or economic as those produced manually, mainly because of the greater flexibility of the manual methods, and for this reason, it was decided not to proceed with the second stage of the investigation. Although the results of the study were some-what disappointing, the fact that the computer-produced time-table was functional and met most of the Trust's requirements was a significant achievement.

LESSONS

The investigations, briefly outlined in the foregoing pages, took place over a period of some six or seven years and provided a number of lessons which the authors believe could be used to avoid or at least reduce waste of time, effort and

frustration, with the consequential benefit of a more confident approach to cooperative ventures of this nature on future occasions. These lessons may be summarised as follows:

Availability of Help

As a result of its experience, the Trust became far more aware of the specialist assistance available from outside the organisation and that there was no real need to place difficult problems in the "too hard basket" merely because internal resources were unable to find the solutions.

Communication

Probably the most important lesson arising from the investigation project was that communication, or rather lack of communication, between layman and specialist was a major obstacle in the path of progress. In the early stages of the investigation, discussions between specialists and Trust officers were conducted on fairly broad terms and this occasionally resulted in either a misunderstanding by the specialist or by the layman officer, of the nature of a particular problem. The lessons from this experience were that -

The purpose of the investigation and any relevant terms of reference had to be fully understood by both the operator and the specialist.

Each problem, major and minor, had to be exactly defined and understood by both parties.

Because of the danger of mis-interpretation, it was necessary that both parties clearly understood the precise meaning of all terms or expressions used, either in posing problems or giving solutions.

It was found that precise documentation of these matters very considerably reduced the extent of the misunderstandings which subsequently occurred. The act of committing statements of aims and problems to paper led to more consideration of the subject matter by the operator and gave an improved study opportunity to the specialist. A very important advantage of proper documentation, especially in a major investigation over a long period of time, was that basic information could be more readily and accurately passed on in the event of the almost inevitable changes in staff which take place.

Division of the Problem

During the preliminary study of the proposal to automate procedures for the preparation of timetables and rosters, it was recognised that because the total problem was too large and complex to attempt as a single project, separate investigations would be necessary for timetable preparation and roster preparation. Again, in considering the roster problem, it was found that a division into three separate phases not only reduced the complexity of the problem but also presented an opportunity of providing benefits more quickly. The system of dividing a major problem into a number of smaller, separate problems for solution and subsequent amalgamation had proved successful and was continued during the more detailed examination of the procedures for roster preparation.

The breakdown into smaller steps provided an ability to test each progressive step, and to find and correct errors which would otherwise have created difficulties in subsequent stages of the investigation.

COOPERATION IN PROBLEM SOLUTION

"In-house" Specialists

The Trust's experience indicated that there could be advantages if "in-house" specialist staff were used in investigation projects of this nature. The background knowledge of the industry together with the more readily available contact with practical operating staff would, in the opinion of the authors, have reduced the communication problem considerably. It must be appreciated however, that a major investigation such as the timetables and roster project would have tied up an "in-house" team for a long period of time therefore limiting the team's availablity for other important projects. As a matter of interest, the Trust has provided some measure of "in-house" specialist capacity by the employment of a science graduate, with majors in mathematics and computing, to carry out studies and investigations.

Suitability of the Procedures for Use in Other Areas

The procedures and programmes produced were based on requirments which applied in Adelaide. Because of the effect which these local conditions had on the techniques which were used, it is probable that these procedures would not be suitable, in their present form, for operation in other public transport organisations.

BENEFITS

From a management point of view, the investigation into the automation of timetables and duty rosters for traffic crews was worthwhile and has yielded the following benefits:

Top management obtained a means of effective control over traffic costs which was not previously available

in that -

Rosters could now be prepared on a near minimum cost basis.
The new procedures allowed a quick evaluation to be made of the effect of changes or proposed changes in industrial working conditions.
More accurate estimates of the effect of service adjustments, extensions of service or the introduction of new services could be obtained.

The time required to prepare timetables and duty rosters was considerably reduced, enabling more frequent reviews of both timetables and rosters to be made.

The Trust's roster staff have been required to define clearly the problems they are attempting to solve and to detail, in writing, the procedures used, thereby clarifying these matters and giving a more critical outlook on their work.

The reduction in timetable and roster preparation time has encouraged flexibility in approach and facilitates experimentation to test new ideas to achieve better results.

There are benefits to traffic crews in the form of better arrangement of duty schedules.

FUTURE STUDIES

As far as the Municipal Tramways Trust, now the Bus and Tram Division of the State Transport Authority in South Australia, is concerned, there are further areas on the physical

operations level where specialist services can be used to provide improved techniques and procedures, or to suggest more suitable equipment which would achieve a better result from existing procedures. Some of these areas, described in broad terms only, are:

Sign-On and Sign-Off Procedures for Traffic Crews

At present, traffic crews commencing duty are required to register attendance, collect a daily journal or work sheet, pick up a fare collection outfit, walk to the bus park and prepare the bus for traffic. On completion of the shift, a like but reverse procedure is carried out when traffic staff must, in addition, peruse rosters and note details of duty for the next shift. These activities occupy considerable periods of time and involve traffic crews in the transcription of the daily duties to be performed. It is believed that an investigation into the automation of some of these procedures could provide substantial benefit to both management and traffic crews.

Bus and Tram Passenger Counts

Statistics relating to the numbers of passengers carried are based generally on visual checks carried out by supervisory staff at particular times and at particular locations depending upon the requirement. Although this system provides an indication of the need for a change in or retention of existing bus and tram services, the information is, understandably, not always sufficiently accurate to determine the precise extent of the alteration necessary. A study of the use of specialised counting equipment in combination with automated procedures could result in the availability of relevant information more quickly and accurately.

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Bus and Tram Destination Signs

The diversity of bus services in Adelaide has resulted in an intensive, complicated system for the display of route destinations on buses. There is considerable difficulty in finding sufficient space on bus destination sign rollers, and in providing traffic crews with a simple method of arranging for the display of the correct destination sign at each of the destination sign boxes. Although the problem could partly be solved by the allocation of particular buses to particular routes, this would drastically reduce the overall flexibility of the bus fleet and result in economic disadvantage. This seems to be a further area where a study of the use of specialised equipment could yield worthwhile benefits.

ACKNOWLEDGEMENTS

The investigation into the automation of procedures for preparing timetables and rosters for traffic crews produced results which have been of tremendous benefit to this organisation. The automated roster procedures created considerable interest and were considered to be of world-wide significance in the field of public transport. The authors acknowledge, with gratitude, the skills, expertise and sheer hard work exercised by the specialist investigators and thank them for the patient understanding with which they cooperated with those layman members of the Trust's staff with whom they worked. A special acknowledgement is made to Professor Renfrey Potts, Mr. P.G. Pak Poy, Dr. Brian Bennetts, Mr. Graham Dunne and to the other members of the staff of P.G. Pak Poy and Associates who contributed to such a successful and worthwhile exercise in cooperation. Reference to the various reports dealing with this project is made in the bibliography which follows:

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