Real time considerations for an airline

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INTRODUCTION

In the 60’s the airlines developed and became the recognized leaders of real time applications of the computer. These applications have been primarily commercial in nature and characterized by small amounts of processing on large amounts of data. In the 70’s the direction and effort will be expanded to include large scale sophisticated mathematical models within the processing.

In no industry are the problems of scheduling as omnipresent as within transportation and particularly within the airlines. In particular the crew scheduling problem has been solved many times using many varied techniques. It has never, however, been completely solved to the satisfaction of all airlines, and certainly not to the degree of rigor that the term solution would imply to a mathematician. The solutions as they exist today represent a varied collection of heuristic approaches to large problems and rigorous approaches to restricted problems.

The problem is a commercial one and constitutes a real time application yet today the solutions remain cumbersome and slow. The real time response to these large computational problems awaits the development of more suitable heuristics and computers with larger capacities and higher speeds. Large scale combinatorial problems depend upon a step by step analysis and nano second speeds are just too slow for the number of steps involved.

REAL TIME APPLICATIONS

The prime impetus to the real time system has been the passenger reservations system. Today there is no commercial airline that does not live off of this system. It is a random request system accessible from a large number of users located at any of a large number of stations. The response time of the system is measured in terms of an unbroken conversation between the prospective customer and the ticket agent.

Development of the communication peripherals have opened the doors to a number of computer systems which possess obvious import to the airlines. Some of the more important at Eastern Airlines include:

Baggage Tracing—This system is so successful that Eastern Airlines handles this function for some 34 other carriers. This also includes a claims central file geared to detect repetitive and possibly fraudulent claims.

Flight Watch—This system collects and displays to dispatchers the position and movement of every flight.

Crew Management—This system collects and displays the activities and events in the histories of crew members. Of particular interest at any time is their eligibility to fly.

In general the characteristics of these information systems are relatively straightforward. In most cases the information deals with inventory. Is some inventory available? Where is the inventory located? The software is not complicated because of the operations performed upon the raw data, but because of the communications and the security aspects of the data. The consequences associated with loss of files and with not being able to access those files in a fast moving environment are obvious.

Of those real time systems which have come into being some possess structured mathematical models. One such is Computer Flight Planning. In producing flight plans, the system takes into consideration the following: (1) altitudes, (2) equipment types, (3) fuel flows, (4) gross weights, (5) Mach numbers, (6) scheduled flight times, and (7) weather data. The vagaries of the weather necessitate real time. Any flight plan which does not meet the performance specifications of the equipment manufacturer is rejected by the computer. In addition, plans which do not allow the flight to arrive on time are rejected unless no plans meet the scheduled time. Under those circumstances those plans
FEDERAL AIR REGULATIONS

- No duty during any rest period
- Do not exceed 30 flying hours in any 7 days
- No more than 8 scheduled hours in any 24 hours without at least 16 hours rest after flying 8 hours
- Deadheading is not considered a rest
- Minimum of 24 hours of consecutive rest during any 7 days

ADDITIONAL FACTORS

- Elapsed time
- Absolute time
- The airport—Rest facilities
- The proximity of airports
- Geography—Customs and clearances
- Connections

PAIRING PAYMENT

- $f$—Flying time
- $d$—Duty time
- $e$—Elapsed time
- $t$—Tour guarantee
- $h$—Deadheading

Pairing Payment = $p(f, d, e, t, h)$

Figure 1—The factors of scheduling which come closest to meeting the scheduled arrival time are selected.

Yet awaiting introduction to the real time system is the crew scheduling problem. The problem is representative of a class of combinatorial problems in which elements of a set are to be ordered or grouped according to some criterion. It is characterized by a large number of possible solutions and is marked by factorial growth in the amount of computation required to carry out that enumeration as problem size increases. The approach taken by most airlines is that of integer programming with 0-1 variables. In contrast, the approach taken by Eastern, the CREATION program is heuristic. The problem is commercially important. The costs associated with flying the flight schedule are difficult to assess. It is necessary to take into account the flight schedule in its entirety. At first thought it would appear that the cost of manning the flights would be a linear combination of the number of flight hours and the unit costs of flying the various types of aircraft. But there is more to it than just that! There are credits which are applicable to the pairings formed and these cannot be determined without completion of the allocation in its entirety. These non-productive costs are appreciable and constitute a major cost of manning the flights.

The flight schedule is constantly changing and at any time there are many flight schedules under investigation. Formulation of the allocation involves specification of the flight schedule and continual liaison between the participating operational groups. The needs and the time responses of each of these participating groups vary at each stage of development and present a formidable real time application.

THE CREW SCHEDULING PROBLEM

The crew schedule is the assemblage of all pairings which satisfy the flight schedule. The pairings are the trips flown by the crews from the time they depart their home base until the time they return home. These pairings must be formulated such that they satisfy governmental regulations and contractual requirements. Collectively the allocation should be executed at least cost to the airline.

There are many factors which must be taken into account in the formation of the pairings as set forth in Figure 1. These are worthy of mention, not because they present an insurmountable challenge, but because together they are indicative of the detail which must be written into the program.

The schedule and time are synonymous. The hours governing the actions of the crew are completely prescribed by the Federal Air Regulations. The principles of safety dictate that the crew not be scheduled for excessively long periods of duty and flying and that the periods of rest are adequate and sufficient. No pairing, no assignment of flying, is acceptable if it does not satisfy these requirements.

Additional requirements are set forth in the contract. The schedule is predicated upon elapsed time, but it is also affected by absolute time. The amounts of permissible duty depend upon the time of day with fewer hours allowable over the evening hours. When periods of rest are prescribed there must be adequate rest facilities available. Some airports possess suitable rooms, some do not. If facilities are not adequate, sufficient additional time must be allotted to travel to proper quarters.

The proximity of some airports, from the viewpoint of scheduling, means they may be treated as one, as co-terminals. It is possible to fly into one airport and depart the other. If the pairing includes such an arrival and departure, sufficient time must be provided to allow for transportation between the airports.

Scheduling depends upon the geography flown. Flights which return from outside of the continental United States must return through customs and an
additional time must be provided to permit this clearance. In the case of connecting flights there must be sufficient time provided to make the connection. And so it goes. Each station, each condition, each special facility, each time zone must be uniquely identified within the program in order to assemble a pairing which satisfies all requirements, a legal pairing.

Rules and regulations set forth the requirements governing the formulation of the pairing. There are other contractual specifications which set forth how the crew is to be paid. The costs associated with the allocation of flying depend upon the actual amount of flying and the non-productive time associated with trips flown. At the end of the pairing the pilot has accumulated an amount of flying time and credits of different forms. In a sense, from the time the pilot starts a trip until the time the trip is completed, a number of clocks are kept in terms of these respective credits. These assure him of some minimum amount of flying for the pairing, a credit for the time he is away from home, and if he is required in the course of his duty to fly as a passenger, a credit for deadheading. Pay for the pairing is a complex formulation which involves all of these factors.

These are some of the considerations which must be taken into account in the formation and evaluation of the single pairing. There are yet others which come into play in the formation of the allocation. For the pairings to be manned there must be a sufficient number of trained personnel to fly the scheduled pairings at each of the designated domiciles. In the Eastern system there are currently 6 domiciles. These are the only locations from which crews can be scheduled to fly and these are the 6 cluster areas in which crews live. Each of these domiciles service some number of different types of aircraft, but not necessarily all of them. In general each type of aircraft is serviced by 2 to 5 domiciles. An allocation to be acceptable must have the assignment of flying in consonance with the domicile apportionment.

These then are the considerations which must be taken into account in the formation of an allocation. As arduous and as complex as the associated bookkeeping may be the heart of the problem is to secure that allocation which can be executed at least cost, with a minimum of nonproductive time to the airline.

The size and scope of the crew allocation problem can be seen in the detailed considerations which go into the formulation of the single pairing, in the many ways in which a pairing can be formed, in the balance of manpower requirements among the domiciles, and in the many, many alternative solutions to the final allocation. The number of possible ways of formulation is indeed so large that it is simply not possible to investigate the entire space of solutions.

THE CREATION PROGRAM

The CREATION program is heuristic and assembles allocations through use of controlled Monte Carlo selections. Within the computer emphasis is upon the allocation in its entirety. At computer speeds thousands of allocations are generated and studied to arrive at the least cost solution.

Input specifications

All data required for the CREATION program are specified in the input. No data are included in the program. A typical data set is shown in Figures 2, 3 and 4. The largest portion of the input consists of the flight segments; there must be an entry for every flight flown.

A review of the input shows the detail previously described concerning the formation of the pairings. Information must be provided concerning the equipment, the allocation of manpower between the contributing domiciles, description concerning the coterminals and the stations. The controls governing the computer run must be specified as well as all of the parameters as specified in the contract. The types of output can be elected.

The program

The CREATION program is shown in Figure 5. The program is heuristic and follows the pattern pursued by the equipment specialist who forms the allocation manually. The procedure is a sequential one. Starting with some flight, additional segments are attempted. If the flight departs the previous arrival site and if it is legal it is added to the sequence. If not another is attempted. This process is continued until the trip finally returns home and can then be considered a complete pairing.

Early in the processing of an allocation there are many degrees of freedom available in the formation of a pairing. As the allocation builds up the degrees of freedom decrease until at the end there may be only one way, if any at all, of putting the last pairing together. In the process of putting the allocation together it is necessary to honor the domicile apportionment and to observe all of the legality checks.

The equipment specialist attempting a solution may pursue several courses. Upon completion of an allocation and noting its quality, he may break up some of the pairings and then reassemble in an effort to improve upon the allocation. He may feel that it is worthwhile to preserve some and to recombine others in a
Figure 2—Input audit listing

more favorable fashion. The effects can not be determined without trial. He can pursue this action time and time again. After some succession of such attempts the equipment specialist may feel that the overall combination has been exhausted. He may elect to start the allocation from scratch if he feels that there is little to be gained through minor perturbations of the originating allocation.

The equivalences of all of these actions can be seen in the flow chart. Prepass indicates the formation of an allocation from scratch. Postpass indicates the reduction of the previous allocation in accordance with prescribed selection criteria. All pairing is based upon random selection from the remaining unassigned flights.

As each allocation is generated, its Figure Of Merit is compared with those of the allocations previously generated. If it is not considered to be a good candidate, it is discarded. If it is considered to be a good candidate, it is saved and the worst of those previously saved is discarded. Throughout the processing some fixed number of allocations is preserved representing the best of the allocations generated. Final selection of the best allocation is made from that reservoir.

The outputs

There are a number of different outputs available from the CREATION program. The basic output is,
of course, the best allocation. The other outputs are optional and relate to the characteristics of all allocations generated within the run. And, of course, there are numbers of various sorts for the convenience of the concerned operating groups.

In Figure 6 is shown a sample printout of a portion of an allocation. All pairings are represented in this common format. Basically the information consists of an identification, a listing of all segments which make up the pairing, departure and arrival data, and a breakout of the respective times and credits. The total pay time and the specific credit, if there is one, are shown.

A typical pairing is ALLNO=1 PR NO=12. This pairing departs JFK and is completed in the co-terminal EWR. This pairing extends over two days with a duty break in MIA. The amount of flying is 13:32. Note that the time away is 42:00. There is an away credit of 1 hour of flying for 3 hours away. This indicates a payment of 14:00, and hence the credit of 28 minutes. In Figure 7 is shown a summary sheet of the pertinent statistics governing the best allocations.

**Timing considerations**

The CREATION program runs on an IBM 360/65. The amount of time required to generate an allocation depends upon the size and characteristics of the fleet. It can be noted that the number of pairings in an allocation may be in the hundreds and the number of allocations attempted in an effort to secure a feasible least cost solution may be in the thousands. A thorough study can involve hours of machine time.

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**Figure 3—Input audit listing**

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**Figure 4—Output controls**

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From the collection of the Computer History Museum (www.computerhistory.org)

The contributions and time responses of the creation system

There are a number of distinct types of requests that must be satisfied by the CREATION program from the time a flight schedule is initiated until the time that the flight schedule is finally implemented. The detail of information and accuracy of information, and the time response in which the response must be made, continually change over the course of the development of the flight schedule. These changes are dictated by the degree of interaction between the participating groups concerned with formulation of the flight schedule.

During the course of development there are four primary groups concerned with production of the ultimate schedule. Fundamental responsibility falls within the Flight Schedule group; theirs is the need of formulating the best schedule from the viewpoint of the traveling public and the operations of the airlines. And for the flights to be flown there must be an airplane available for every scheduled flight; these considera-

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**Figure 4**—A listing of accepted segment records

**Figure 5**—Creation flow chart
Real Time Considerations for an Airline

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Figure 6—Bid information sheet

Itions are treated by the non-manpower groups. On the manpower side, there is the allocations group concerned with the development of the most efficient allocation. And there is the manpower group with the responsibility of assuring that there is sufficient trained manpower available to fly the flights.

There is a great deal of interaction among these participating groups. Each would be pleased if the schedule could be altered to accommodate his own specific needs. Each interact with each other through the flight schedule, and through additional interactions as in the case of manpower requirements defined in the domicile apportionment.

The total cost of manpower depends upon training and transfers of crews at the respective domiciles and the costs of credits. Both of these steady state and transient costs are related to domicile apportionment. Each change to the flight schedule can produce far-reaching consequences to the participating groups and may require a complete analysis of the allocation process.

The allocation can be sensitive to the alteration of but one minute in one flight. Of course, it is possible that a flight can be advanced or delayed a number of minutes and that no change at all will result. But it is also possible that the change may result in the breaking of a pair which will result in the breaking of another until every pair is affected and altered.

The closeness of the relationship of the quality of the flight schedule to the allocation, to the non-manpower requirements, and to the manpower requirements means that each step along the way in the formulation of a new schedule different requirements for information are created which must be satisfied within some permissible time response.

Figure 8 shows a simplified flow chart of the stages

From the collection of the Computer History Museum (www.computerhistory.org)
Figure 7—Summary of flight hours

taken in the formulation of a new schedule. During all of these stages the Allocations group makes some contribution to the formulation and ultimately it generates the final allocation which becomes the basis for assignment of crews to the pairings.

The first step is shown in Stage 1, in which scheduled development originates at the uppermost levels of the planning division. The principal concern at this time is to provide an air transportation service pattern which meets the needs of the traveling and shipping public. Some of the detailed considerations are certificate requirements, market research forecasts, political and civic pressures, competitors’ schedules, equipment availability and support capacity; i.e., terminal and ground handling facilities. Considerations must be given to aircraft procurement and to the size of the pilot pool.

During this stage the schedule is but loosely defined. What is known is the number of flights, where they fly, the number of hours to be flown, and some idea of the equipment to be flown. Less well defined is the departure time to the hour and the minute and the arrival time to the hour and the minute. Yet in the allocation process it is precisely this detailed information that is required.

At this stage of development the requirements imposed upon the Allocations group are for estimates concerning the approximate amounts of non-productive time generated by the proposed schedule. Generation of the initial allocation is more a matter of extrapolating
from overall statistical characteristics as opposed to the generation from the detailed flight specifications. Consistent with the availability of schedule decisions, the need for information response may be measured in weeks or months.

In Stage 2 the objectives of the airline have been reasonably formulated in terms of the flights, the number of equipments flown and the numbers of pilots. It is at this stage that work proceeds to put together a schedule which satisfies these objectives. At this time the emphasis is upon a real detailed schedule, one with realistic departure times and arrival times flown by specific aircraft.

The objective at this time is a real schedule which can be released to the operational groups approximately 6 months prior to the effective date of the schedule. Prior to the release of this advance schedule, whatever is formulated is extremely fluid, and little reliance can be placed upon any of the portions which make up the preliminary estimates. Without some degree of solidification, there is little that can be accomplished definitely by the Allocations group. Again participation by the Allocations group is confined to generalized projections based upon the best though insufficient information available. The time frame for response by the group is not unlike that of Stage 1 and is measured in terms of weeks and months.

Stages 3 and 4 mark the availability of the advance schedule. For the first time the operational groups have made available to them a reasonably fixed schedule that they consider from a detailed point of view. The two stages are marked by the release for publication date. When this time is reached the schedule is deemed fixed. It is during these two stages that the contributions of the Allocations group become most meaningful though in different ways.

In Stage 3 the operational groups examine every detail of each flight in terms of the specific demands imposed upon them. During this time the pace of interchange of information between all of the operational groups and the flight schedulers increases dramatically. There is a constant demand for minute changes to the schedule to bring about important efficiencies to specific groups. Tentative changes must be released as soon as possible to determine if there are adverse effects upon the other participating groups. The result is that changes are released daily.

It is during Stage 3 that the need for detailed information from the Allocations group increases immeasurably. It is at this time that the final schedule begins to take shape and begins to solidify. Each change to the flight schedule must be judged in terms of how it affects the allocation. The evaluation cannot be made in terms of the flights considered by themselves. It is possible that a change may affect the allocation. But it also may be such that it will break a pairing and that the effect will cascade through the allocation in its entirety. With changes taking place daily it is essential that it be possible to generate the allocation daily.

During this Stage 3 the need of the Allocations group is not merely to respond to the demands and changes imposed by the other operational groups. The group itself is the source of changes to the schedule. The schedule must be evaluated in terms of how changes can be secured which can bring about important reductions to the allocation. It is perhaps at this stage that the most important economies can be introduced to the allocation through changes made to the flight schedule.

It is during this stage that the tempo of response increases tremendously and the time frame of management response changes from weeks to a day to day response. It is this stage that makes mandatory computer speeds to permit response in the time frame of management. It is during this stage that there is need for numbers of short bursts upon the computer to evaluate the constantly changing schedule. The emphasis is upon accurate assessments of the effect of the individual changes upon the allocation. The need is for rapid evaluation of not only what is good, but the detection of what is bad in time to permit corrective action in reduction of the overall cost of the final emerging allocation.

Once Stage 3 is closed, as the schedule is released to publication approximately 3 months before the effective date, there is little that can be done to introduce changes to the schedule. At this time the viewpoint of the Allocations group again takes on a new outlook. The objective is to secure the best allocation possible for the now fixed schedule.

In Stage 4 the time response is not so short. The schedule is relatively fixed and the Allocations group is not deluged with a constant flow of changes. Whereas
the emphasis in the preceding stage was to identify pairings which were poor, and to introduce changes to the schedule to ameliorate these bad conditions, the emphasis now is to secure the very best allocation consistent with the now fixed schedule. It is during this stage the final allocation is formulated and comes into being. Each and every pairing is completely specified.

In Stage 5 the allocation is released to the crew bases. At these locations the actual assignments of the specific crews to fly the pairings are made. During this stage the schedule and its implementation is firmly committed and there is little further participation required from the Allocations group.

THE FUTURE

A problem basic to the airlines is the generation of schedules. Flight schedules are in a constant state of flux to accommodate the changing patterns of passenger traffic, the changes of seasons, and the acquisition and retirement of equipment. The problem is compounded due to schedules being predicated upon schedules. The schedules that the crews fly depend upon the flight schedule, the schedules that the equipment fly depend upon the flight schedule, and both crew and equipment schedules depend upon each other.

At present every major carrier is attempting to solve the crew scheduling problem. At best, satisfactory and sufficient solutions are 2 to 3 years away. There are other problems which are composites of the allocation. These involve domicile apportionment and contractual studies. Whereas the generation of the allocation involves hours of machine time these problems involve shifts of machine time. Inclusion of these problem sets into the real time network requires better problem solving capability. The difficulty is not in the processing of information from terminal to computer and from computer to terminal. The bind is within the computer itself.

What is required are computers with larger capacities and higher speeds complemented by the development of better heuristics. Combinatorial problems confined to step by step solutions are so large that increases in speed and capacity alone are not sufficient. Algorithms must be developed which cut across customary methods of solution. Until that time the management information real time system will be sluggish at best.