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CREATION—A PROGRAM FOR CREW ALLOCATION

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Introduction

CREATION is an acronym for CREw allocATION. The program is heuristic and employs Monte Carlo techniques. It runs on an IBM 360/65 and is used to generate the allocation of crews which man the flights of Eastern Airlines.

The crew allocation 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. Problems such as these can be characterized by the existence, in most cases, of a simply stated algorithm (computational procedure) for enumerating all possible solutions and by a factorial growth in the amount of computation required to carry out the problem.

The program assembles allocations through use of controlled Monte

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Carlo selections. Within the computer emphasis is upon the allocation in its entirety. At computer speeds thousands of allocations are generated and studied in order to arrive at the selection of a satisfactory solution.

In contrast the amount of work to generate allocations manually is measured in weeks of effort and is an effort which does not lend itself to multiple participation. By the very nature of the size of the problem manual emphasis is upon the indivinual pairing and not upon the allocation. Quality of the allocation is easily measurable; the amount of excess credits attributable to crew allocations comes to millions of dollars a year. Any reduction constitutes important savings.

The Pairing

The typical flight schedule of EASTERN involves some 1400 flights which are flown by any of seven different types of airplanes. It is worthy of note that EASTERN flies more flights in their schedule than any

FLT. NO.	FROM	TO	DEP.	ARR.	STOPS	FLT. TIME
1F	JFK	MIA	0400	0630	0	2 : 30
2	MIA	ATL	1030	1230	0	2 : 00
3	ATL	MOB	1300	1300	0	1 : 00
						5 : 30
				$11^1/_2$ on-duty		
4	MOB	ATL	0800	1000	0	1 : 00
5	ATL	ORD	1100	1300	0	3 : 00
6	ORD	MIA	1400	1800	0	3 : 00
7D/H	MIA	NAS	1900	2000	0	: 30
						7 : 30
				12 : 15 on-duty		
8	NAS	BAL	0600	0800	0	2 : 00
9	DCA	EWR	1300	1430	0	1 : 30
						3 : 30
				11 : 15 on-duty		

Total Pay: 30 : 25

Fig. 1. A crew pairing

other carrier with the exception of one. All of these flights must be satisfied by the obvious combination of a crew and an airplane. Both must be available at the time of departure of the flight and both must be deemed adequate to fly the scheduled time of flight.

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 all of them. In general each type of airplane is serviced by 2 to 4 domiciles.

The prime factors of scheduling are those of the considerations of fatigue and the exigencies of time, and a number of explicit rules have been spelled out governing the hours that the crew can be scheduled to fly. In Fig. 1 is shown the characteristics of a trip and is referred to as a pairing. Illustrated are the complexities involved in assembling a crew allocation. This trip is unusual in that it contains nearly all the undersirable features of a pairing. The pairing is then a "bad" trip, a very bad trip. We will refer to it as the LSD trip.

The crew checks in for the trip at 0300. Because of the early hour the crew is limited to $11^1/_2$ hours of duty time for the day. This first flight is a cargo flight. The crew flys for $5^1/_2$ hours the first day and has an overdight rest scheduled in Mobile. However, Mobile does not have adequate sleeping facilities at the airport aud the minimum rest period is extended from 10 hours to 12 hours. The next legal flight departs at 8 o'clock the next day. During the first day the crew flew offshore (JFK-MIA) and some nighttime (0400-0600) for which the crew gets paid a premium.

On tne second day, the crew starts late and can remain on duty longer (13 hour). However, the elapsed flight time approaches the daily limit of 8 hours and the crew's second overnight rest is in Nassau. It is not necessary to extend the usual layover time to allow for customs since the crew is deadheading. The crew receives a premium for foreign, overseas, and night (but not offshore).

On the last day of the trip, the crew goes to Baltimore. The next trip leaves Washington National airport and the crew connects via limousine for the final leg home. If the crew had had an overnight layover in the Baltimore/Washington co-terminal, the minimum time would have been extended by $2^1/_2$ hours or $12^1/_4$ hours. However, in this case an extra two hours connection time was allowed. The crew completed it's trip in EWR, a co-terminal of the New York domicile. Because the crew needs to return to JFK, the on-duty and away times are extended $1^1/_2$ hours. Because the crew was away from home base about 61 hours, a good portion of the crew's pay will be away credit, it being the maximum over on-duty and tour.

Rules and Regulations

The concept of the pair seems reasonable enough. There must be rules and regulations governing the hours that a crew can fly. It is also reasonable that since the pilot may spend considerable time away from home that his pay be determined by considerations other than those of flying time.

Though the number of elapsed hours is a prime factor in determining whether or not the pilot should be permitted to fly, there are numbers of other factors which must be taken into account. These are worthy of mention, not because they present an almost insurmountable challenge, but because they are indicative of the detail which must be taken into account in the assembly of a pairing.

The numbers of factors are many. In addition to the factor of elapsed time there is the factor of absolute time: The rules for night flying are not the same as for day flying. Scheduling depends upon the airport: If the pilot is scheduled for a rest period, there must be facilities at which he can rest. Some airports possess such facilities, others do not. It may be necessary to travel across town to find suitable facilities; the amount of time depends upon distance and the adequacies of transportation. Scheduling depends upon the proximity of adjoining air-

ports: It is possible for a crew to arrive at one airport, travel to and subsequently depart the adjoining airport. Sufficient time must be provided to permit the interchange. Scheduling depends upon the geography flow: Flights which return from outside the continental United States must return through customs and an additional time must be provided to permit this clearance. Each station, each condition, each special facility, each time zone must be uniquely identified in the program in order to assemble a pairing which satisfies the legality requirements.

In addition to these special time requirements, restraints governining trips are as set forth in the Federal Air Regulations and are shown in Fig. 2. Each component of the trip is spelled out in great detail. An example of one constraint is that of the maximum of 8 hours flying in 24 hours. The regulations state:

> An air carrier shall not schedule any flight crew member for duty aloft for more than 8 hours during any 24 consecutive hours, unless he is given an intervening rest period at or before the termination of 8 scheduled hours of duty aloft. Such rest period shall equal twice the number of hours of duty aloft since the last preceeding rest period, and in no case shall the rest period be less than 8 hours.
>
> When a flight crew member has been on duty aloft in excess of 8 hours in any 24 consecutive hours, he shall, upon completion of his assigned flight or series of flights, be given at least 16 hours of rest before assigned any further duty with the air carrier.

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 pay period, the pilot has accumulated an amount of flying time and credits of different forms. In a sense, from

- ○ 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.
- ○ 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.

Fig. 2. Federal air regulations

the time the pilot starts a trip until the time that he returns and 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 each scheduled pairing, a credit for the amount of time that he is on duty and a credit for the amount of time that he is away from home. Also, if he is required, in the course of duty, to fly as a passenger, he is paid for deadheading. The calculation of pay is predicated upon all of these factors. The likelihood is high that the pay of the pilot is made up of credit pay in addition to that associated with actual flying.

CREATION I

CRFATION I, the basic program, is shown in Fig. 3. All of the data to be processed are received in the form of input, and in the main, it consists of flight segment information. A number of different reports are produced of which the main one is the Bid Information Sheet or Crew Allocation.

The Eastern network is primarily oriented to continental United States coverage but does include some flying over international waters. The vastness of the system means that flights are over a number of different time zones. Flight schedules are published in terms of local times, and of course, over the years schedules must be changed to accommodate the changing of times to and from standard. All times read into the program are converted to base time, GMT, to provide an ab-

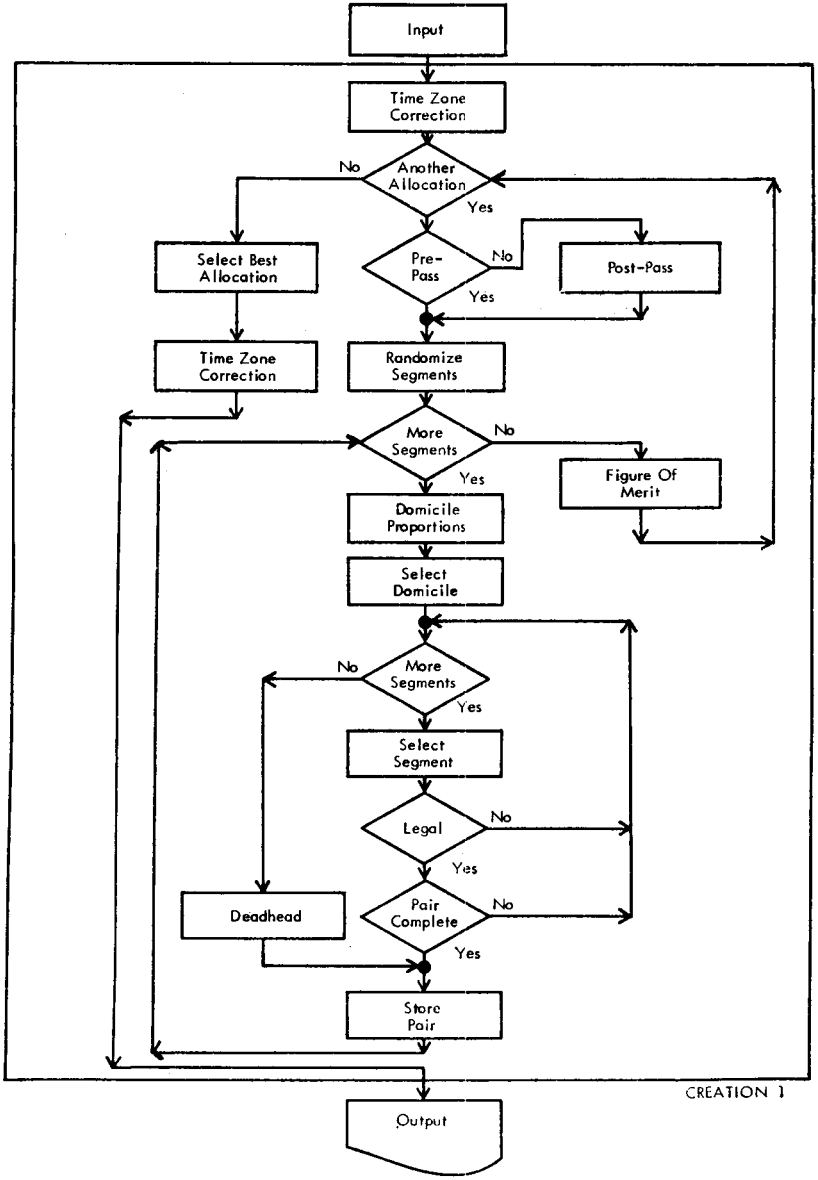

Fig. 3.

solute basis for determining elapsed time. Upon completion of the processing, prior to the printout of the desired allocation, times are converted back to the local times involved.

From the input specifications, information concerning the number of allocations to be generated are determined. This consists of some number of Pre-Pass and Post-Pass runs. By Pre-Pass is meant an allocation which is conducted in accordance with random ordering of the segments to be found in the hopper. By Post-Pass is meant the subsequent processing of segments returned to the hopper as the result of breaking down the allocation generated in the previous Pre-Pass. A Post-Pass specification may read—Return all pairings in the previous allocation to the hopper which have a credit in excess of 50%. Tne subsequent allocation is only upon these segments which result from the pairings which were broken up. The newly formed pairings are, of course, added to those pairings which remained untouched, in the case of the sample specifications, those pairings with credits less than 50%. It is therefore possible to generate allocations from two different approaches: (1) starting from scratch and (2) through modifications of an existing allocation.

A typical computer run consists of a specification of some number of Pre-Passes and some number of Post-Passes. The total number of allocations generated is the product of the two numbers. Regardless of which type of pass, the segments to be found in the hopper are randomized in terms of the existing random number seed. In the Pre-Pass all segments are processed. In the case of the Post-Pass the number of segments is variable and is one which depends upon the quality of the preceeding allocation with respect to the break down criteria.

The specification of the allocation involves some apportionment of the total pay hours among the domiciles servicing the type of aircraft flown. For those airplanes now flown in the Eastern system there are usually 2 to 4 domiciles for each type of airplane. The domicile algorithm continuously calculates the apportionment between the domiciles as the

processing is conducted and selects the next domicile to be initiated in terms of the quality of the apportionment at the time. Quality is specified in terms of the actual specification as it relates to that specified.

A pairing can only be initiated from a domicile. Depending upon the specification of the domicile algorithm, a segment which emmanates from the specified domicile is selected. The next segment to be flown is uniquely determined by the arrival site of the preceeding segment. The list of remaining segments is examined to obtain a segment which departs from the last arrival site. When one is found it is checked to determine if it is a legal addition to the pairing. The proposed adjunct must satisfy the conditions of flying as called forth in the contract which incorporate the Federal Air Regulations. If the segment considered does not satisfy the requirements of legality, it is set aside and another segment is tried until a candidate is found which is a legal addition.

Subsequent to the addition of a new segment a check is made to determine if the pairing has been completed; *i.e.*, the last segment arrives back to the initiating domicile. If this requirement has been satisfied it is possible that the pairing can be considered closed. One of the conditions of the contract is a minium guarantee of a number of hours of flying. If this minimum has not been met additional segments are added to the pairing until the pairing is closed and the minimum bas been met.

It should be noted that as the number of segments remaining in the hopper becomes reduced the point is reached at which it is not possible to complete each pairing attempted. Under these circumstances and those circumstances in which it is not possible to initiate a pairing from a specified domicile it is necessary to deadhead the crew. Both departure and arrival sites are noted and the credits of the pairing calculated in terms of expected deadhead values. Note that the actual flight to be taken by the deadhead crew is not specified. As each pairing is completed, it goes into temporary storage and the process of forming pairings is continued until all of the segments in the hopper are exhausted. Each allocation generated is evaluated in terms of its "Figure of Merit". This

figure is a function of both the hard and soft factors governing the quality of the allocation. The hard factors include the costs of the hours flown as well as the costs associated with credits and deadheading. The soft factors are those which are related although indirectly to costs. A case in point is the quality of the allocation in terms of how well the domicile specification has been met.

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, then it is saved and the worst of the lot previously saved is discarded. Throughout the processing some fixed number of allocations are preserved representing the best of the allocations generated as of that time in the processing. Final selection of the best allocation is made from that reservoir. Upon completion of the computer run the contents remaining in the reservoir are now examined from the viewpoint of the soft factors. Previously the decision as to quality was predicated solely upon the hard factor. Upon conclusion the probability is high that there is a little difference between the allocations from a hard point of view. Of those allocations in the final selection, they are the best from the hard point of view and the best of all is that one from the soft point of view. As was noted initially the determination of the appropriate elapsed times is based upon GMT. Prior to the printing out of the best allocation all times are converted back into the local times of the cities in question. The best allocation is then printed out as well as ancilliary reports.

Input Specifications

All data required for the CREATION program are specified in the input. No data are included in the program. There are a number of different types of data to be input and these are shown in Fig. 4. The largest portion of the deck is made up of flight segment cards, one of which is shown in Fig. 5.

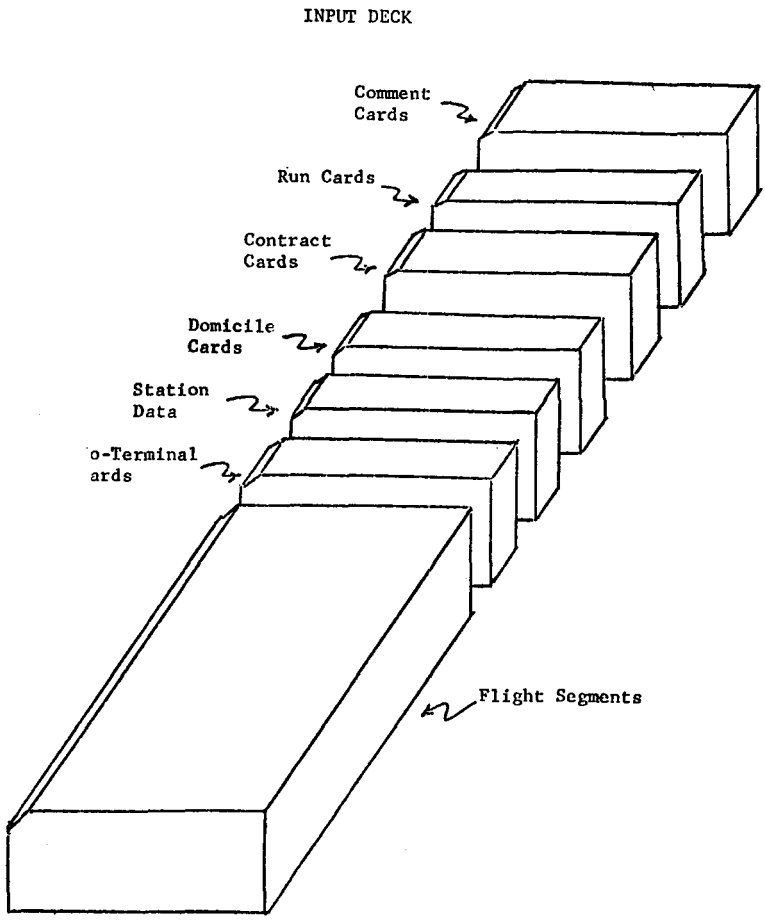

Fig. 4.

Each flight segment is defined in terms of its type of aircraft. Specified is its flight number, departure place and time, arrival place and time, the amount of flying, the number of stops and the flight number that the airplane will turn to. There must be a card for every flight scheduled.

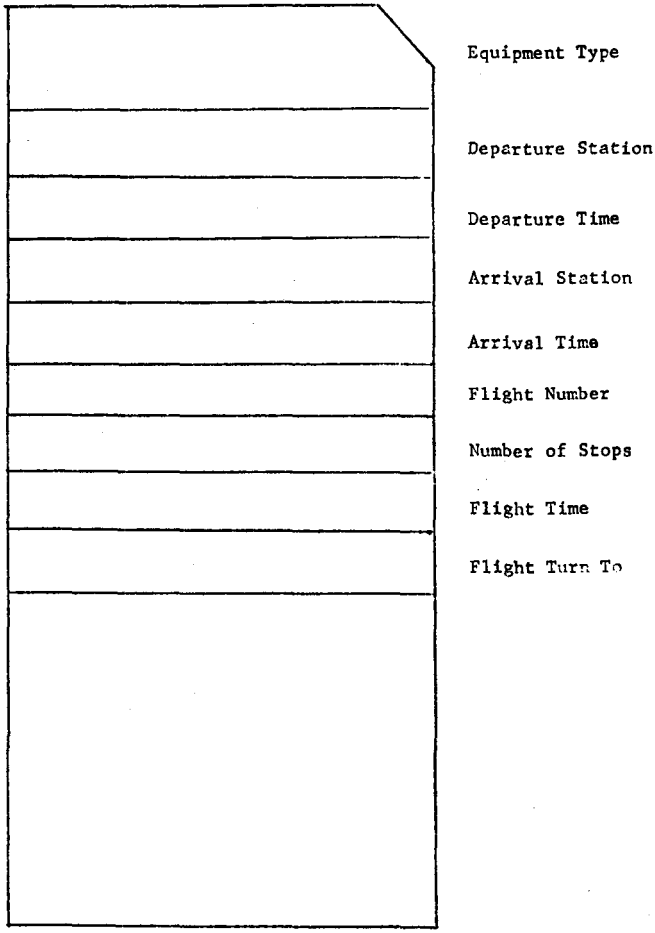

Fig. 5.

There are a number of other types of data which must be specified. In the order shown these include:

Co-Terminal Cards—Some airports due to their proximity can be treated as one; e.g., JEK and EWR. A crew can be permitted to arrive at one and depart from the other. Sufficient time must be provided for

this interchange. Depending upon distance and the adequacies of transporation this-time is a variable for different co-terminals.

Station Data Cards—Each airport must be specified in terms of time zone and preclearance times.

Domicile Cards—For each type of aircraft flown there is some apportionment of manpower among the servicing domiciles. This specification is called for on these cards.

Contractual Cards—Numbers of parameters are called forth in the contract. Each value must be set forth in these cards.

Run Parameters—These cards deal with the parameters governing the computer run and include the random number seed, the number of Pre-Passes and the number of Post-Passes.

Comment Cards—Identifying information governing the run can be specified. This may specify the flight schedule processed or the name of some managerial study.

The Outputs

A number of different outputs is generated by the CREATION program. Of primary importace is the Bid Allocation Sheet which consists of all the pairings generated in terms of identifying information and the credits associated with the pairing. The Bid Information Sheet contains the above information ordered by domicle. Within eacn domicile sequences are ordered by equipment types.

There are a number of ancilliary reports which are produced which break out in convenient from the information called forth in the Bid Allocation Sheet. These include summaries on crew expenses, company crew rooms, the allocations among the domiciles, credits and deadheads.

Another report of import is the statistical output which consists of a listing of all of the allocations generated and a description of the credits and the quality of the allocations attempted. This sheet permits definition of the quality of the allocation obtained in terms of the number of allocations attempted. From the relationship it is possible to

determine the probability of obtaining a still better allocation in terms of additional computer runs.

Program Size and Timing

The CREATION I packge runs under the CAT (Compile Audit Test) system. The CAT system functions to maintain and to update source programs and can be used to compile, test and list computer programs. Programs submitted to the system are built into a "job stream" or queue and the jobs processed in accordance with assigned priorities.

The CAT system uses the MVT (Multiple Program Vartiable Tasks) processing mode. It uses a standard core limitation of 100 K bytes and can process up to 15 programs simultaneously. Only one program at a time can seize the CPU (Central Processing Unit).

Timing for processing depends upon the size of the flight schedule, the mode of operation (Pre-Pass or Post-Pass), and the priority queuing at the time of the computer run. An average rate of processing for an allocation is on the order of 10,000 allocations per hour.

CREATION II

Additional capabilities and refinements are being programmed for the CREATION package. When combined with basic package it will bear the name of CREATION II. The composite diagram of this development is shown in Fig. 6.

The first module to be processed is referred to as the Priority module. In the processing of any flight schedule there is some a priori feeling as to how the schedule is to be processed. In the case when the changes to the flight schedule are considerd to be but a slight modification of the preceeding one and this is the usual case, then there can well be a strong feeling that the new allocation should be similar to the old one. Under these circumstances the first allocation to be generated should be as similar as possible to that generated for the previous schedule. In the case of a major schedule change, less is know as to what is a good

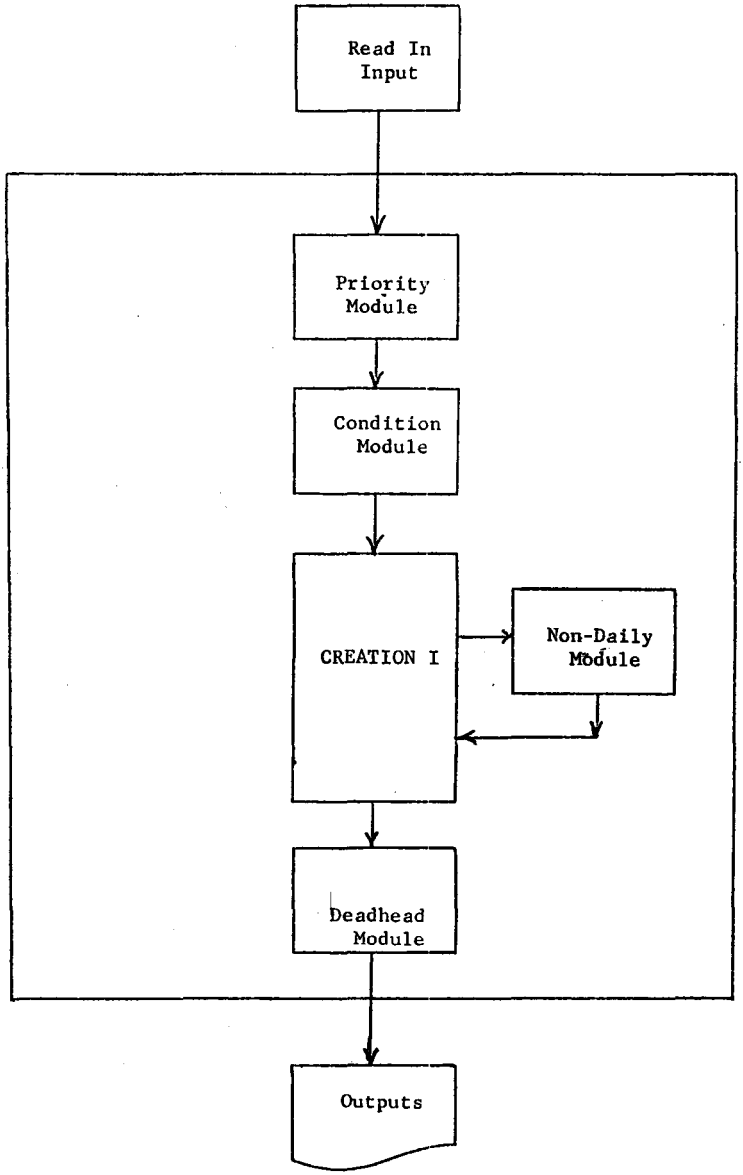

Fig. 6.

allocation, but here too, this is a matter of degree.

There are a number of different reasons for the assignment of a priority condition to a pairing. Past experience may show that certain segment should always be combined in a certain way and that they should always be combined when possible. For whatever reason if it is deemed worth-while to preserve a pairing this can be accomplished. Under priority control, it is possible to break up only that portion of the flight schedule which does not include priority pairings.

The amount of break up is a variable and can be specified as either a constant or as a functional relationship.

The specifications of run control in the basic CREATION package are primarily of an absolute nature. In CREATION II it is possible to state controls which are conditional and which depend upon the quality of the allocations generated in the computer run. Rather than a computer run specified in terms of some number of Pre-Passes and some number of Post-Passes, specification can be in terms of the quality of the allocation desired. Conditions can be specified in terms of the rate of achievement as well as the absolute quality achieved.

A most important extension of the CREATION ability is the provision for the handling of non-daily flights. Processing in the main program has been confined to daily flights. This new module extends the capacity of the package greatly. Some of the non-daily flights are irregulars and some are infrequents. Irregulars occur with the same periodicity week in and week out; e.g., flights which fly each week end. Infrequents may take place as in the case of flights which are scheduled over a holiday or but with the exception of a holiday. These additional considerations are handled in this new module. There is considerable amount of bookkeeping associated the processing of the non-daily flights, and an effort is made to keep the number of non daily pairings as small as possible.

In the basic program pairings are completed in terms of the credits dictated by deadheading although the actual flight to be deadheaded is

not explicitly specified. This does not impose any difficulty in the evaluation of the allocations, but it does leave the final crew allocation sheet incomplete in that those pairings which include deadheads do not have the deadheads specified. Additional manual work is required to provide the flight numbers of the flights to be taken. The new deadhead module is called into play after selection of the best allocation. Each pairing is examined to determine if a headhead is required. If so the entire flight schedule is examined to determine the logical flight to be taken by the deadheaded crew. At this time the credits are recalculated in terms of the actual times flown instead of the expected values used previously.

Is should be noted that the inclusion of the headhead module extends greatly the size of core storage required. Whereas in the normal processing of an allocation the processing is confined to a given type of aircraft, in the case of deadheading the entire flight schedule can be called forth since there is no restriction to a given type of airplane in deadheading.

Managerial Studies

The primary output of the CREATION package is the Bid Information Sheet and its associated reports. The use of the package is not limited to the generation of these reports. There are numbers of managerial studies which can be conducted using the CRFATION program. These studies differ considerably and no standard approach lends itself to treatment. Some of the applications illustrative of these studies are as follows : Contractual exercises, domicile exercises, and schedule changes.

Contractual Exercises

Numbers of different parameters are required to describe the regulations of the contract. These involve the various credits, clearance times, duty times, deadhead times, layovers and flight limitations. In a contractual study it is relatively simple manner to alter the values of parameter since all data are specified in the input. Contrasts between

different sets of parameters can be made to determine the effects of the parametric values. The differential costs associated with any set of contractual parameters can be determined accordingly.

One of the more significant gains to be achieved through the use of the package is the speed with which the program can be run. Turn around time using the program is measured in hours whereas the conduct of such analyses without use of the computer involves weeks of effort. The speed of the package makes possible analysis in the time frame of the negotiation.

Domicile Exercises

There are two types of domicile exercises to be conducted. The first has to do with the modifications of the manpower apportionment between existing domiciles for a given type of airplane. The second has to do with the addition or deletion of domiciles for a given fleet.

Changes of domiciles or modifications to the domicile apportionment are easily accomplished by altering the input specification. Runs conducted using different input values provide the essential contrasts to determine the sensitivity of crew allocation to domicile apportionment.

Schedule Changes

The crew allocation as it is generated is based upon the general flight schedule which includes all types of aircraft flown, and of course, there is a separate allocation for each type of aircraft. The possibility exists that economic gains could result from having different flights flown by different types of aircraft. This problem crosses a number of considerations external to the scope of the CREATION program.

In the assignment of aircraft consideration is given to number of passengers carried; these data are not entered directly or indirectly into CREATION. Nevertheless the CREATION program can be used as a vital addition to such studies. Without analysis which can be conducted within the time frame that the schedule is to be created it is not posi-

ble to treat crew allocation considerations. At computer speed it is posible to provide a new feedback.

Conclusions

The CREATION program is representative of a more sophisticated level of processing required to handle the complexities of large scale managerial applications. These problems are characterized by the large numbers of factors which must be considered in their many combinations. Without the large scale computer it is physically impossible to attempt to deal with these problems in terms of real parametric values.

The progam makes it possible for EASTERN management to pose interesting alternatives of operation dealing with future schedules and to evaluate and compare these potential actions in terms of each other and in terms of their economic worth. Of utmost importance is the speed with which these problems can be evaluated. For the first time the computer is beginning to play a role in making management theory an implementable tool in the timetable of decision making.