A system for computing university examination timetables

By D. C. Wood*

A comprehensive system for constructing large university examination timetables using the Atlas computer is described. The method has produced timetables involving well over 1,000 subjects which are superior to those constructed manually.

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The arrangement of events subject to constraints is the common feature of all scheduling problems. The events may be hours of duty for staff or journeys between places by vehicles. The constraints can be such items as the minimum number of staff, the permitted distribution of shifts, or the availability of vehicles. In view of the similarities of various scheduling problems, one may endeavour to find a general method which would permit a computer solution. Since the real benefit of computer techniques is in the solution of large-scale problems, a generalized formulation of the information, for example as an integer programming problem, would produce a problem which could not be solved economically. It is preferable, and often necessary, to take full advantage of any characteristics of the particular large scale problem which simplify the computing, although the basic principles of obtaining the solution may be widely used.

This is the philosophy adapted in scheduling more than 1000 examination papers taken by some 6000 students. Although a fundamental method is employed in constructing the timetable, maximum advantage of the features of the problem and its constraints accelerate the solution enormously. A timetable is obtained which is superior to that produced manually, yet requires only several minutes computing time on Atlas. The scheduling, although the major computing problem, is only part of a fully integrated system which enables all the data processing to be performed.

Examination timetables

In constructing an examination timetable the fundamental requirement is that no candidate is required to sit two examinations at the same time. Places must also be provided for the candidates to take their examinations. An examination room can only accommodate a certain number of seats and where several rooms are used it is usual that all the candidates taking the same examination paper should be in the same room. Finally, it is generally preferred that students should have their examinations distributed so that they do not occur too closely together.

Cole (1964) describes a method for preparing examination timetables using a small-store computer, with the emphasis on economy of storage. A binary matrix is used to indicate whether pairs of subjects conflict, i.e. whether someone takes both subjects. The total number of other subjects conflicting with each subject is counted up and used as the first criterion in arranging the subjects in a well-determined order. The timetable is then developed one period at a time until all subjects have been scheduled. Certain conditions can be imposed on the ordering of papers, but it is impossible to spread candidates' papers as is generally preferred. Further, fitting all the candidates for the same paper into one room when a number of rooms are used can be as difficult as selecting the period.

Broder (1964) also begins by rearranging the subjects according to their total number of conflicts, but he stores the number of conflicts in full in the matrix. The number of periods is fixed and the subjects are assigned sequentially to a period which minimizes the number of student conflicts, i.e. the number of students required to sit two examinations at the same time. When more than one equally good period is available, a random selection can be made, or distribution of candidates' papers can be optimized.

How far does this method go towards satisfying the requirements at Manchester University? In 1967, 1323 examination papers took place in 15 days. A particular paper, such as "Introduction to Psychology" may be taken by candidates from the Faculties of Science, Arts, Economics and Medicine. This means that in choosing a time for this paper one may have to take into account many of the subjects being taken in each of these faculties. To store the conflict matrix in full for 1000 subjects would require 499,500 locations, which is clearly prohibitive. Various techniques have to be employed to economize on the space required to store the conflict matrix without losing any vital information.

Finding sufficient suitable places for the students to take their examinations is also a problem. A timetable has to contend not only with the wide combinations of courses open to students, but also with the physical limitations of the rooms in which the examinations are held. In 1967 the greatest number of candidates to be seated on any occasion was 1515. In accommodating the growing numbers there is very little spare room, and as many as 20 rooms have to be used. All the candidates for a paper must be in the same room, although each room, of course, can only accommodate a certain number

* *Department of Mathematics, Computation Division, The University of Manchester Institute of Science and Technology, Manchester*, 1.

of seats. Consequently, when a subject is assigned to a period, a room must also be found in which the candidates can be accommodated.

The organization of examinations at present keeps three administrators and three clerical assistants busy for most of the year. Work starts in November on the timetable for the June examinations: two provisional copies are published so that difficulties can be reported, and the final version is produced by the end of April. Enormous tables of conflicts are drawn up by hand and each addition or alteration to the timetable is checked systematically to ensure that a student conflict is not introduced. It is impossible to consider the rooms at this stage: all that can be done is to restrict the total number of candidates for each period to about 85% of the places, and hope the subjects can be fitted into the rooms afterwards.

Candidates must register for the examinations by 12 February, since the registration by courses which takes place at the beginning of the academic year does not account for the alternative subjects which may frequently be selected. After the entries are received, lists of candidates for each subject must be compiled, typed and checked: an extremely tedious process.

Examination timetables constructed by computer in this country have all been on a relatively small scale. The problems tackled could quite well have been solved by hand. However, at Manchester the existing system is stretched to its limits with the increasing number of students and complexity of courses. There is little advantage to the administrators in using a computer to do parts of the timetable. The real success of applying computers to examination timetables rests on the ability to schedule the whole university comprehensively. Thus the system must be capable of handling well over 1000 subjects. This presents a considerable amount of data handling as well as a complex timetabling problem.

The main purpose in adopting the system described in this paper would be to relieve the administrators of months of difficult work constructing the timetable, and to produce a superior timetable in the process. In addition, the system would eliminate several months of clerical time spent checking for student conflicts and typing lists of candidates. Now, however, the data could be punched and verified by three operators in a week. The cost of the computer time would, of course, also have to be considered.

Organization of data

The basic information is provided by the forms on which candidates register for the examinations. This includes the student's name and the subjects for which he is entered.

The Faculty of Economics already uses a three-digit number to represent each course, the first digit indicating the year of the course. The numbering of courses has been extended to other faculties in a similar way. As the data for each faculty is separate, the full range of three-digit numbers can be used in each case without ambiguity. In this way the numbers can be kept to three digits, which are simpler to work with, whilst still giving some significance to the first digit. A list of subject numbers and titles is provided as data:

```
101 ECONOMICS    1
102 GOVERNMENT 1
103 SOCIOLOGY    1
. . .
```

A directory is constructed from this list so that subjects are renumbered on imput into a single consecutive sequence and converted back on output with a letter to indicate the faculty. The full titles are stored on magnetic tape for use in the final lists.

The students' data is represented as a list of students' names and the numbers of the subjects taken.

```
SMITH M W    101  102  103  104
BROWN A J    101  102  103  105
ALLEN R M    101  102  103  107
. . .
```

The subject numbers are used by the candidates when completing the registration forms, so that the data can be punched straight from the forms, preferably on cards, using one card per student.

As each student's list of subjects is read in, two sets of information are built up. The number of candidates for each subject is accumulated in an array n:

$$n(s) = \text{number of candidates for subject } s.$$

A conflict matrix cft is built up where

$$cft(i, j) = \text{number of candidates taking both subjects } i \text{ and } j.$$

The manner in which the conflicts are stored is described in the next section.

A subject, as represented by one number, usually represents a single paper requiring either a morning (9.45 to 12.45) or an afternoon (2.00 to 5.00) session. Where, however, two papers of a subject are always taken by all candidates, and cannot be taken separately, they can be represented by one number. Such subjects require a morning and afternoon of the same day.

Before construction of the timetable can start, the number of periods and the rooms available must be known. The data and time for each period is presented in the following form:

```
MONDAY 5 JUNE 9.45
MONDAY 5 JUNE 2.00
. . .
```

The name and capacity of each room also needs to be stated:

```
McDOUGALL    300
WHIT HALL    200
. . .
```

Method of storing conflicts

Clearly the conflict matrix will be symmetrical, so only the upper triangular half need be stored. For 1000 subjects this will require 499,500 locations. Since a word in Atlas consists of 48 binary digits or bits, a saving can be made by approximating each number by a 6-bit character. This means that the maximum number that can be stored is 63, but this is sufficient to indicate that two subjects are highly incompatible. Approximately 62,500 words, however, are still required.

If the matrix is divided by faculties (or departments) into blocks, there will be very few non-zero elements in the off-diagonal blocks, since very few candidates take subjects from more than one faculty. If subjects which are taken in more than one faculty are repeated in each faculty in which they occur, the elements outside the diagonal blocks can be removed completely, so only the triangular diagonal blocks need be stored (**Fig. 1**). These are stored in a one-dimensional array, and another array "row" is used to point to the position corresponding to the diagonal element of each row, in the same way as a 2-dimensional array is stored by the Atlas Autocode compiler. In this way the amount of storage occupied by the conflicts can be further reduced, but its effectiveness depends on the extent to which the subjects can be partitioned into nearly conflict-free groups. In practice the largest faculty contains over 500 subjects which cannot readily be divided. Each block of the conflict matrix can, however, be accumulated in the store separately from the data for the faculty.

In order to construct the timetable, all the blocks of the conflict matrix are required, and in practice this makes excessive demands upon the store. Since the majority of the elements in the conflict matrix are zero, once the matrix has been accumulated it can be stored much more efficiently as lists. That is, for each subject, a list is formed of the subjects with which it clashes and the number of student conflicts. In matrix terms, for each row, the list consists of the positions of those columns containing non-zero elements and the values of those elements. The subject number can be represented by 18 bits and the number of conflicts is already represented by 6 bits, so each conflict can be held in a half-word. As the average number of conflicts per subject is about 15, the lists for 1000 subjects now require only 7500 words.

The conflict lists for those subjects which are repeated in more than one faculty can now be merged. Similarly if two or more subjects are required to take place simultaneously they can be treated as a single subject by merging their conflict lists. The list of conflicts for each subject is printed out and can be useful in making pre-assignments or late alterations to the timetable.

It may be considered preferable to build up conflict lists in the first place, using chain lists, instead of constructing the matrix. This is particularly likely if the subjects cannot be readily partitioned such that the matrix will fit into the store. More computing time will, however, be required as it will involve looking along the conflict lists for each subject taken by each student. The way in which the conflict lists are formed is therefore a compromise between computing time and storage.

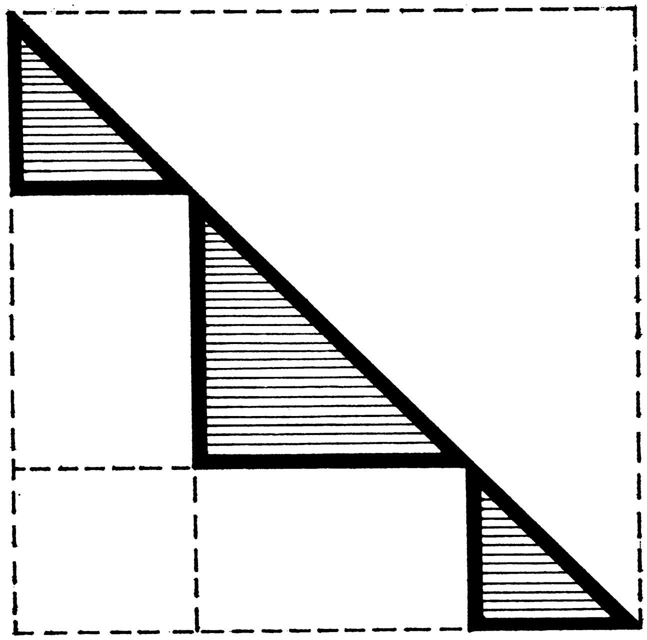

Fig. 1. Partitioning of conflict matrix

Timetable construction

In constructing the timetable there are three fundamental conditions that have to be satisfied.

(1) No candidate is required to sit two examinations at the same time.
(2) All candidates for a subject must be in the same room.
(3) Each room can only accommodate a certain number of seats.
(4) The number of occasions on which candidates have two examinations within 24 hours is kept to a minimum. When it is necessary, an afternoon and the following morning are selected in preference to the morning and afternoon of the same day.

The subjects are first rearranged into an order which takes into account all factors affecting their placement in the timetable: number of candidates, number of clashes, size of rooms. Each subject in turn is then allocated to a carefully chosen period in the timetable and a room. The period is selected so as to maintain the distribution of candidates' examinations as defined in (4) above, and also to restrict the periods available for other subjects as little as possible.

Two factors have to be considered in determining the order in which the subjects are fitted into the timetable. The number of clashes of a subject is a good indication of the difficulty of finding a suitable period; the number of candidates restricts the rooms which are possible. These criteria are combined in ordering the subjects.

Those subjects are first selected which must take place in the largest room. They are then placed in descending order of the number of subject clashes. Next those subjects are taken which could be held in the second largest room, and again placed in descending order of clashes, and so on. The subjects are then assigned in this sequence to the timetable. A further advantage of this ordering is that it reduces work at a later stage.

Selection of period

To be able to assign subject s to period p two conditions must be satisfied:

(1) subject s must not clash with another subject already assigned to that period,
(2) there must be a room with sufficient seats.

The answer to each of these questions can be recorded by a binary digit:

$$0 = \text{condition satisfied,}$$
$$1 = \text{condition not satisfied.}$$

One word is used to indicate the periods which are conflict-free and another to indicate the periods with a room available for each subject, with the pth bit corresponding to period p. When allocating a subject, the two binary words are inspected for those periods which are available for the subject.

The ideal choice of period is one for which the subject is conflict-free for both the preceding and following periods, since this implies that no candidate for the subject has another examination which takes place in these periods. If there is more than one such period, a secondary criterion is used which aims to minimize the effect of this assignment on the choice of periods available for later subjects. This is achieved by counting up the number of unallocated subjects which could at present be assigned to each of the possible periods and which conflict with the subject under consideration. Since the period chosen will no longer be available for such periods, the period with the minimum total is selected.

If there are no periods without conflicts on both sides, those without any the same day are sought. The period is selected which minimizes the number of conflicts in the adjacent period. Finally, if neither of these types can be found, the period is selected with the least number of candidates taking another examination on the same day.

In the case of subjects requiring a whole day, this is preferably chosen so that the preceding afternoon and following morning are conflict-free for the subject. Again, as a secondary criterion, the day is selected which interferes least with the availabilities for other subjects. If there are no days with conflict-free adjacent periods, the day is selected which minimizes the number of such conflicts.

The examinations last three weeks, which means there are 15 days, i.e. 30 periods. It is often preferable that as many examinations as possible are held in the first two weeks, or 20 periods, to provide more time for marking, etc. In this case these periods are tried first when assigning subjects.

Selection of room

Having selected a period for a particular subject, the next step is to choose a room. This is done by selecting the room with the least number of vacant seats above the number required. The number of empty seats for each room r and period p is recorded in a matrix. For example, if rooms with 100, 68 and 30 seats are available, a subject with 65 candidates is put in the 68 seat room. This ensures that the largest number of seats are left in one room.

If the examinations are concentrated in the first two weeks, a lot of seats will not be required during the third week. With the above method of allocation, several small rooms might be used while a large one remained empty, which is uneconomical on supervisors. This is another instance where the ordering of subjects is utilized. Once all the subjects requiring a certain room size have been allocated, rooms of that size are used in preference to smaller ones. In the above example, the 100 seat room would be selected if all subjects with more than 68 candidates had been allocated.

Updating binary arrays

Having allocated a subject s to a period p and room r, the binary arrays have to be updated accordingly. Any subject t which conflicts with s can no longer take place in period p, so the pth bit of the word indicating conflict-free periods for subject t must now be 1. All the unallocated subjects in the conflict list for s must be checked in this way.

The room availability bits for period p must also be inspected and a 1 inserted for any subject which can no longer be fitted into that period. The only subjects which need be tested are those in the same room size group as s, since a larger room than necessary is only used if all the subjects requiring it have been allocated, whilst subjects which can be accommodated in a smaller room are not affected. Furthermore, as only unallocated subjects need be checked, only those subjects after s in the same room size group need be tested. Thus the computing is greatly reduced by virtue of the subject ordering.

When a 1 is inserted in one of the binary arrays, say for subject s, period p, the total number of periods available for subject s is checked. If the other bit for period p, subject s, already contains a 1, the total is unaffected. Otherwise the total availability is reduced by 1 for single paper subjects. For other subjects, the bits for the other half day have to be considered. If the total number of periods available for a subject is reduced to one, the subject is allocated to that period immediately.

Output of timetables

As each subject is allocated to the timetable, the two binary words, indicating periods which are conflict-free and for which room is available, are printed out together with the period and room selected **(Fig. 2)**. This gives a good insight into the changing situation as the construction of the timetable proceeds.

SUBJECT	0 = CONFLICT-FREE	0 = ROOM AVAILABLE	PERIODS	ROOM
E 103	000000000000000000000000000000	000000000000000000000000000000	1	MC DOUGALL
E 102	100000000000000000000000000000	100000000000000000000000000000	3	MC DOUGALL
E 229	101000000000000000000000000000	101000000000000000000000000000	5 6	MC DOUGALL MC DOUGALL
E 101	101011000000000000000000000000	101011000000000000000000000000	8	MC DOUGALL
A 138	100011000000000000000000000000	000000000000000000000000000000	9 10	MC DOUGALL MC DOUGALL
A 144	101011001110000000000000000000	000000000000000000000000000000	12	MC DOUGALL
A 228	100000001100000000000000000000	000000000000000000000000000000	5	WHIT HALL
E 203	000011010000000000000000000000	000010000000000000000000000000	1	WHIT HALL
E 202	100011010001000000000000000000	100010000000000000000000000000	3	WHIT HALL
A 671	000000001100000000000000000000	101010000000000000000000000000	6	WHIT HALL
E 201	101000000001000000000000000000	101011000000000000000000000000	8	WHIT HALL
S 316	000000000000000000000000000000	101011010000000000000000000000	2	MC DOUGALL

Fig. 2. Construction of timetables

U N I V E R S I T Y   O F   M A N C H E S T E R

F A C U L T Y   O F   E C O N O M I C S

SUBJECT		DATE	ROOM	
E 101	THURSDAY	8 JUNE 2-00	MC DOUGALL	ECONOMICS I
E 102	TUESDAY	6 JUNE 9-45	MC DOUGALL	GOVERNMENT I
E 103	MONDAY	5 JUNE 9-45	MC DOUGALL	SOCIAL ANTHROPOLOGY AND SOCIOLOGY I
E 104	THURSDAY	15 JUNE 2-00	MC DOUGALL	ECONOMIC HISTORY I
E 105	TUESDAY	13 JUNE 2-00	ARTS TH	MATHEMATICS FOR ECONOMISTS
E 106	WEDNESDAY	7 JUNE 2-00	ROSCOE 123	MATHEMATICS MT 101
E 107	FRIDAY	9 JUNE 2-00	ROSCOE 423	ELEMENTS OF ACCOUNTING
E 201	THURSDAY	8 JUNE 2-00	WHIT HALL	ECONOMICS II
E 202	TUESDAY	6 JUNE 9-45	WHIT HALL	GOVERNMENT II
E 203	MONDAY	5 JUNE 9-45	WHIT HALL	SOCIOLOGY AND SOCIAL ANTHROPOLOGY II
E 204	THURSDAY	15 JUNE 2-00	OWENS PARK	SOCIAL SYSTEMS OF INDUSTRIAL SOCIETY
E 205	FRIDAY	9 JUNE 2-00	ROSCOE 523	SOCIAL SYSTEMS OF PRE INDUSTRIAL SOCIETY

Fig. 3. Final timetable

U N I V E R S I T Y   O F   M A N C H E S T E R

THURSDAY 8 JUNE 9-45

ROOM	SUBJECT		CANDIDATES	TOTAL	VACANT
MC DOUGALL	S 195	THERMODYNAMICS (HONS AND ORD CIVIL MECH AND AERO)	152		
	S 308	GEOLOGY I	1		
	S 319	PURE MATHS MT 106	147	300	0
WHIT HALL	E 420	DISTRIBUTIVE TRADES	1		
	E 801	EDUCATION	143		
	A 203	AMERICAN LITERATURE	66	210	0
OWENS PARK	A 247	ITALIAN	20		
	S 337	MATHEMATICS MT 212	105	125	0
ARTS TH	E 435	POLITICS OF W AFRICA	1		
	A 421	INTROD TO HISTORY OF FRENCH LANGUAGE	91		
	A 668 *	PHILOSOPHY OF LANGUAGE	6		
	S 484 *	PHILOSOPHY OF LANGUAGE	2	100	0

* INDICATES COMMON PAPERS

Fig. 4. Room timetable

Once the timetable has been computed, it can be printed out as desired. The main timetable consists of a list of the subjects in numerical order with the time and place of each (**Fig. 3**). From this a candidate can immediately find when and where his examinations are held. Lists are also produced showing the state of every room for each period (**Fig. 4**). These enable the administrators to send the appropriate papers to each room, and can be displayed in the room to indicate the seats allocated to each subject.

Production of name lists

The names of the candidates are not actually needed for the construction of the timetable. However, by including them in the data, lists can be produced of the candidates taking each subject, as required at the time of the examination for checking purposes and later by the examiners for recording their marks.

Each symbol in the students' names is represented on input by an integer in the range 0 to 63 so that it can be stored as a 6-bit character. Three words, i.e. 24

characters, are allowed for a name; a long name which is truncated at 24 characters will certainly be unique. If each list is to be stored conventionally in consecutive store registers, it is necessary to estimate its size in order to allocate an appropriate area in the store. Since the lists vary for different subjects, to allocate a safe maximum area to each would be wasteful. Chain lists are therefore used, whereby the items of each list are not stored consecutively but are connected by means of a link and can be extended as required. For each item two consecutive storage registers are used: the item itself is recorded in the first, and the second is reserved for the address of the pair of registers containing the next item. The names themselves are stored consecutively in a list occupying three words each. The position of a name in this list is stored as the item in a half-word in the chain, the other half-word containing the position of the next item of the chain. A chain list of three items is shown diagrammatically in **Fig. 5.**

Once all the data has been read in, the chain lists can be used to collect together the names of the candidates for each subject. The names are then sorted into alphabetical order and printed out in the desired format **(Fig. 6).**

Implementation

The method described has been programmed for the Manchester University Atlas and a complete trial of the system has been carried out for the 1967 examinations alongside the existing organization. This involved 5730 students taking 1323 different papers. The examinations had to be scheduled in 30 periods using up to 18 rooms.

The subjects were split into four blocks as follows:

Economics and Education	250 subjects
Arts and Music	560 subjects
Science	399 subjects
Law, Medicine and Theology	114 subjects

The data for each group was used to form conflict matrices which were then rearranged as lists. This organization of the data altogether occupied about five minutes computing time.

Construction of the timetable took approximately ten minutes, over half of which was taken up transferring information between the drums and the core store. Although drum transfers are controlled by the Atlas

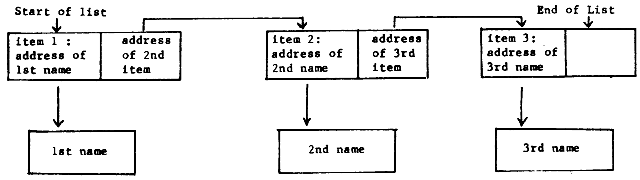

Fig. 5. Chain list for three names

supervisor, the core store of 16,000 words was considerably smaller than the area of store which was frequently accessed.

The production of the name lists also required about ten minutes computing, the printing being performed off-line. These lists were of great value as they were available much sooner than was previously possible.

The computed timetable compares favourably with the manual version in two respects. The rooms can be filled much more efficiently by computer, over 99% of the places being occupied, whereas by hand not more than 85% of the seats are used. Secondly the distribution of candidates' examinations is improved. The number of occasions on which candidates take two examinations in 24 hours is halved, with an even greater reduction in the number of students sitting two examinations in one day.

Various practical details must of course be allowed for in the computed timetable. It is important to be able to preassign subjects to fixed periods and to preclude subjects taking place in certain periods; different examination papers may have to be scheduled simultaneously because of common questions; certain subjects may exceed the capacity of the largest room, and so on.

The effect on the timetable of varying the number of periods or rooms can be studied. Various timetables were successfully computed when as few as 24 periods were specified. It is considered quite an achievement to produce a timetable manually using 30 periods, and fewer periods could not be considered. This shows that it is unnecessary to extend the examinations in the near future as had been feared.

It was possible to make maximum use of the accommodation during the first two weeks by filling 99% of the places. This is desirable since it brings forward the marking and results as much as possible. More significantly, since it it demonstrated that the rooms can be

U N I V E R S I T Y   O F   M A N C H E S T E R

E 104 ECONOMIC HISTORY I — 30 CANDIDATES

ADAM CAROLINE S	FOX K J	LEPIANKIEWICZ BARBARA K	SANDLER JUDITH H
ANDERSON SHEILA M	GREEN BRENDA	MERRIN R A	SIMON MARILYN
ANSDELL J R W	HALL MARGARET A	MILLSTED A J	SMITH M W
BOSWORTH CLIVE	HAWORTH CHRISTINE	O NEILL TERESA	SPENCE K J
BURTON WYNNE	HERZBERG SUSANNA T	PAGE JUDITH A	THOMAS MARION C
DAVIES MAUREEN	HOWARD-GOODCHILD STELLA	PLATT STEPHEN	WALLS MARY H
DAVIES N J	JACQUES MARTIN	RICHARDSON JENNIFER	WILDING MARGARET
FOGG SYLVIA A	JORDAN NICOLAS		

Fig. 6. List of candidates

used to capacity, additional buildings cannot be justified solely for examination requirements while the existing accommodation provides the total number of places required over the duration of the examinations.

If during construction a subject is encountered which cannot be fitted into the timetable, the binary words for the subject are printed and the program terminated. Inspection of the binary arrays printed as the construction proceeded, and the list of conflicts printed initially, clearly reveal the subjects which cause the difficulty. The best hope is to preassign such subjects and restart construction of the timetable.

When 24 periods were specified, a group of subjects could not be fitted into the timetable, mainly those requiring a complete day. This was overcome by carefully preassigning the 12 most difficult subjects and restarting the construction of the timetable which then proceeded without interruption.

From the timetables obtained it can be concluded that the method described is a practical and efficient way of producing large examination timetables on a high-speed digital computer. Accommodation is utilized more efficiently, the number of periods can be reduced and the distribution of candidates' papers is improved.

Acknowledgements

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Correspondence (*Continued from p.* 120)

To the Editor
The Computer Journal

Marking of multiple choice question papers

Sir,

The marking of multiple choice question papers has been a natural application for computers for some time and programs exist with facilities different from those described by P. D. Groves (this *Journal*, Vol. 10, pp. 365–7). It is useful to be able to allow different numbers of alternatives for the questions on a paper and, more important, to allow some, all, or none of them to be selected by the candidates, and for the alternatives to be marked separately. Such a structure of the marking program and of the questions can force the candidate to reach a decision about the inclusion or exclusion of every alternative and greatly reduces any benefit of guessing. Pre-assigned weighting of the marks for different questions can take account of both variations in difficulty or importance, and computed weighting according to correlation or other calculations can give emphasis to those questions with large discriminating power.

Knowledge of correlations between the marks of individual questions and totals directs attention to suspect or superb questions and thence to question setters themselves.

Programs with these facilities have been used on internal examinations in the Schools of Physics and Medicine at Newcastle, and on a variety of national medical examinations, first on the Ferranti Pegasus in 1962 and since 1963 on the English Electric KDF9, when some examinations have consisted of 60 questions with up to 10 alternatives for 600 candidates. Larger sets can, of course, be processed.

Until recently answer papers were key-punched and verified; one examination has just used the English Electric Lector mark sensing reader for successful paper tape preparation and this equipment will be used increasingly in the future.

Examples of questions in medicine and reports on experience with the programs are given in the reference below.

Yours faithfully,

MARGARET BERRY
E. S. PAGE

Computing Laboratory,
Claremont Tower,
Newcastle upon Tyne, 1.
26 February 1968

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