Examination Timetabling in British Universities - A Survey

Edmund BURKE, Dave ELLIMAN, Peter FORD and Rupert WEARE

R.Weare@Cs.Nott.AC.UK
Department of Computer Science
University of Nottingham
Nottingham, UK.

ABSTRACT

This paper describes the results of a questionnaire on examination timetabling sent to the registrars of ninety five British Universities. The survey asked questions in three specific categories. Firstly, universities were asked about the nature of their examination timetabling problem: how many people, rooms, periods are involved and what difficulties are associated with the problem? Secondly, we asked about how the problem is solved currently, whether a manual or automated system is used. Lastly, we asked what qualities are required in a good timetable. We conclude by making some comments, based on the survey replies, as to what sort of criteria a general automated timetabling system must meet.

1. Introduction

There has been much literature on the subject of timetabling over a wide variety of subtly, and not so subtly, different problems. A great variety of algorithms have been proposed, employing heuristics and search methodologies, producing complete timetables or just helping the process along. One of the great questions for timetabling is whether it is unifiable, that is to say, can we find an algorithm or method, sufficiently general, that it will produce good timetables for all problems and for all constraints? The alternative, of course, is to continue developing isolated specialised algorithms each time the timetabling problem appears.

This survey is of the University Examination Scheduling Problem. Its main aim was to discover how the requirements of each university differ and whether these differences are sufficiently small that a unified system may be produced? Specifically, the survey aimed to answer the following questions. How widespread is computer aided timetabling? Is a general timetabling package required at all? What functionality must such a package have? How big and complex is the timetabling problem and how does this vary between universities? What properties must an acceptable timetable possess before an institution will use it?

Fifty six out of ninety five universities (59%) replied to the survey of which 40 (71%) were former polytechnics. All universities, except one, returned a full questionnaire, two, unfortunately, being too late to be included in the results. Manchester Metropolitan University, one of the largest in the country, returned separate questionnaires for each faculty. These were incorporated, by the authors, into a single reply as seemed appropriate for each question.

Very few similar surveys have been carried out, none deal with examination timetabling as such. Comm and Mathaisel[1] surveyed 1494 U.S. college registrars to find out whether a computerised timetabling system existed. If not, whether one was needed and what characteristics it should possess. The study concluded that there was a large market for such a system and that, despite a high degree of automated assistance, most registrars were unhappy with their current systems.

Dowsland[2] and Junginger[3] both consider the school timetabling problem but provide alternative views on the usefulness of automated systems. Junginger states that "Even though the timetables produced required modification, the schools were content with the results. The time saved was remarkable, up to 75%." Dowsland, on the other hand, concludes that "It is very difficult to judge the present success of the mainframe packages for timetabling, but the very limited use to which they are put suggests that most consider the advantages to be limited." Clearly, no system designer may take for granted the idea that their product will be welcomed with open arms.

Pendlebury[4] surveyed British polytechnics with respect to course timetabling. Of the twelve from thirty that replied, seven utilised computer scheduling of which four were on a small scale and the others using the Amended SATS system as developed at Leceister Polytechnic. It is interesting to note that Pendlebury finds that most courses run are primarily class-based i.e. are largely independent of each other, and that, in most of the institutions surveyed, individual departments are responsible for producing their own timetable. Finally, Miles[5] and Schmidt and Strohlein[6] give useful bibliographies of early developments in computer-aided timetabling.

In this paper we only consider examination scheduling. Course scheduling is another subtly different problem again. We may hope to unify the processes of course and examination timetabling in which case, the bringing to together of all variations on the examination timetabling problem is a good first step.

2. The Timetabling Problem

Timetabling, the act of scheduling exams to periods, has long been known to be equivalent, and therefore as hard as, the general graph colouring problem. Graph colouring being one of a family of known computationally difficult problems. Often, we may make assumptions about the nature of the problem which may allow us to find a solution more efficiently. However, when trying to build a general system, we are obviously limited in that our assumptions must be the lowest common denominator of all possible scenarios.

One implicit assumption that has often been made is that of independence between separate academic units. The University of Huddersfield schedules by asking its individual schools to come up with a timetable for their own exams. A central merging facility is then used to ensure that all relevant constraints are satisfied. In many cases, as at Nottingham University, this is still how the normal course timetable is produced, although some departments have developed their own course scheduling software.

Several of the universities surveyed indicated that students may take all of their courses outside the department with which they are registered (where such a concept was appropriate). Most quoted figures over fifty percent as the maximum allowed and only very few that quoted a figure said under fifty percent. Obviously independence should not be generally assumed, although there may well be a difference between the maximum allowed and the actual figure. At Nottingham, for example, the average probability of an exam conflicting with one not in the same department is 0.023 whereas the probablitiy of two exams conflicting in the same department is 0.281, a considerable difference, despite the degree scheme being modular for over two years. In Scottish Universities, students are assigned to faculties which encompass a whole range of different departments so these two figures may be closer and therefore, the problem more difficult.

2.1. Exams and Students

The size of a timetabling problem is essentially related to the number of events that are required to be scheduled, in this case exams. Clearly the size of the problem ranges considerably between universities, from small problems with around one hundred exams up to around two and a half thousand exams. This variation in size will obviously affect the time required to solve the problem. A small problem with just one hundred exams may almost be able to solved optimally whereas at the other end of the scale, heuristics or other ways of cutting down the search space must be used for a solution to be found in reasonable time.

It might be expected that the number of exams and number of students would be correlated. While there is a certain pattern, it is clear that there are also many special cases where the ratios are considerably different giving new complexions to the problem. The number of exams given, and therefore marked, by each member of staff may be calculated by extrapolating from the average ratio of full time equivalent staff to students in Britain (about 1:15) and is about one and a half exams per session. There may, of course, be many examination sessions per academic year. Whether it is more convenient for one member of staff's exams to be scheduled together or apart is unclear although if together they would need to be in the same hall according to normal rules.
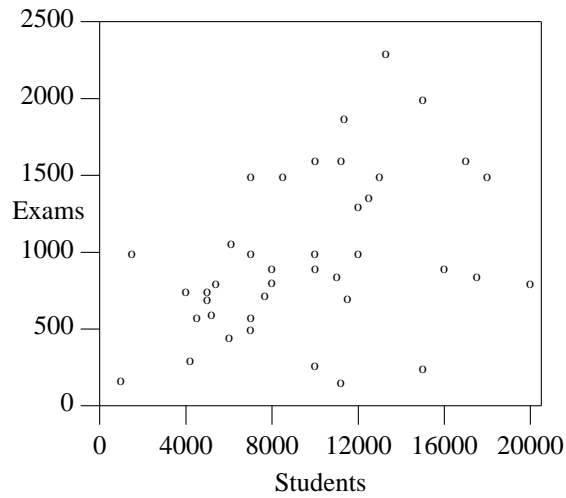
Figure 1: Exams and students

Figure 2 gives some extra insight into the nature of the timetabling problem. It might be argued that on the left hand chart, the higher the number of exams, the more conflicting the problem and that, on the right hand chart, the higher number of student, the greater the problems of room assignment. These arguments have some value although there are many other factors to take into account. For example, no reference is made here to the inter-dependance of courses or to the amount of room available (see section 2.4) which may affect the difficulty of the problem as least as much.
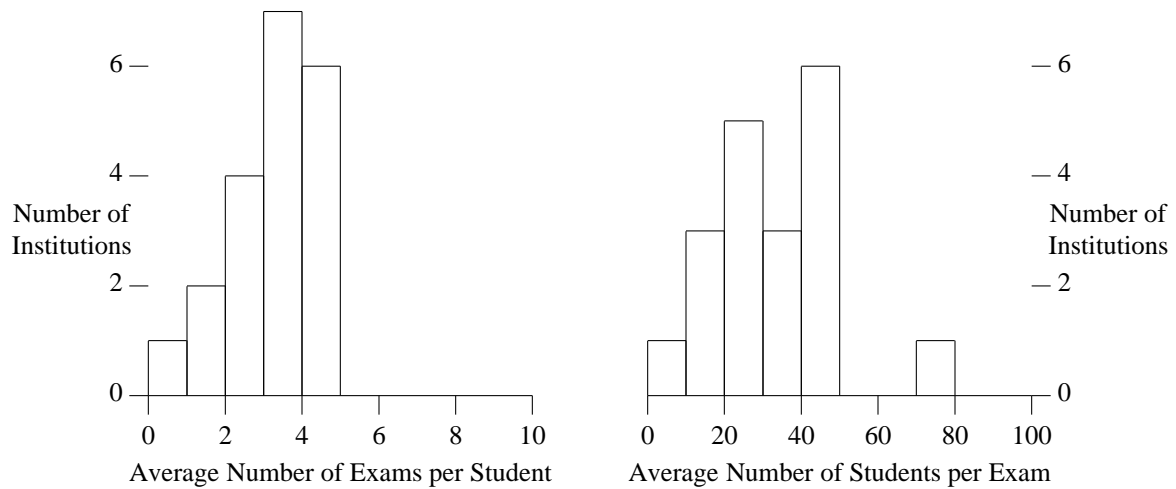

Figure 2: Exams per Student and Students per Exam

2.2. Exams and Departments

The average number of exams set by a particular department varies considerably between universities. The ratio, despite its variability, may still be seen as an indicator of the nature of the timetable conflict graph for the reasons given earlier.

Figure 3 takes the academic unit which occurs most often within the institution. This we shall refer to as a department although it may be a faculty, school, department or a combination of these.
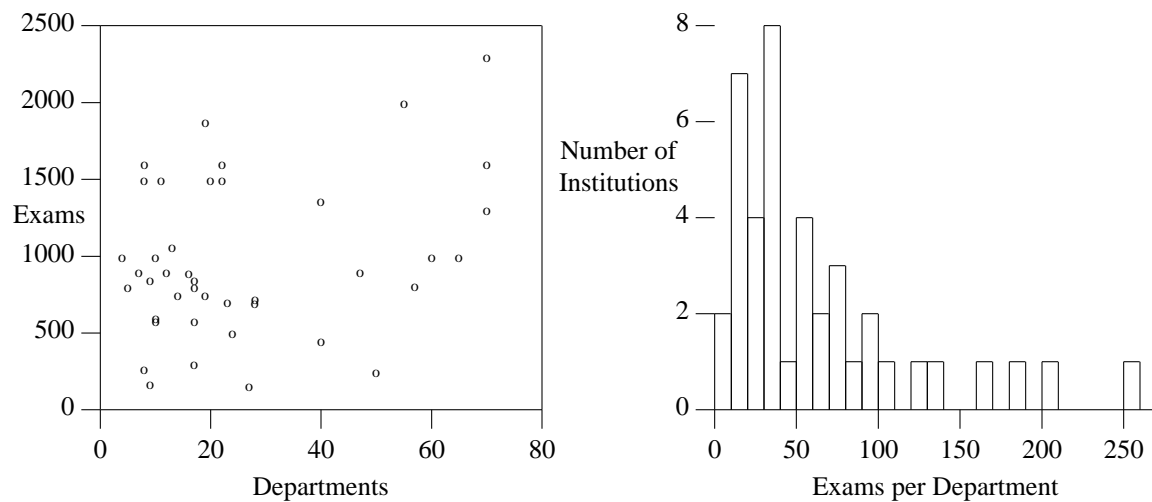
Figure 3: Exams and departments

2.3. Exams and Periods

One of the assumptions of the survey, which may be seen as unrealistic with the advantage of hindsight, was that the exam timetable is periods based. That is to say, there are distinct timeslots in which exams take place and, generally, exams start only at the beginning of that time period. Most universities do use this system, however, there are some alternatives which may be worth considering given the pressure on resources most universities describe (see next section).

Salford University does not use the concept of periods at all. Exams may be scheduled at any time between 9.30am-12.30pm and 1.30pm - 6pm. Although potentially making the timetabling process considerably more difficult, it does allow rooms to be used a greater proportion of the time, especially where they is a large variation in exam lengths. Spread constraints must then be reformatted in terms of real time rather than a number of periods, for example, two hours may be required as a gap between two exams rather than one period.

Brighton University actually uses periods but is flexible about how many that are used on a particular day. This may be a reasonable compromise between the two ideas but relies partly on the assumption that exams of similar length may be scheduled at the same time as otherwise, the longest exams must be spread throughout the periods. Experience suggests that exam lengths are more likely to be uniform within a department than between them and therefore, those of similar length having a greater than average probability of conflicting.
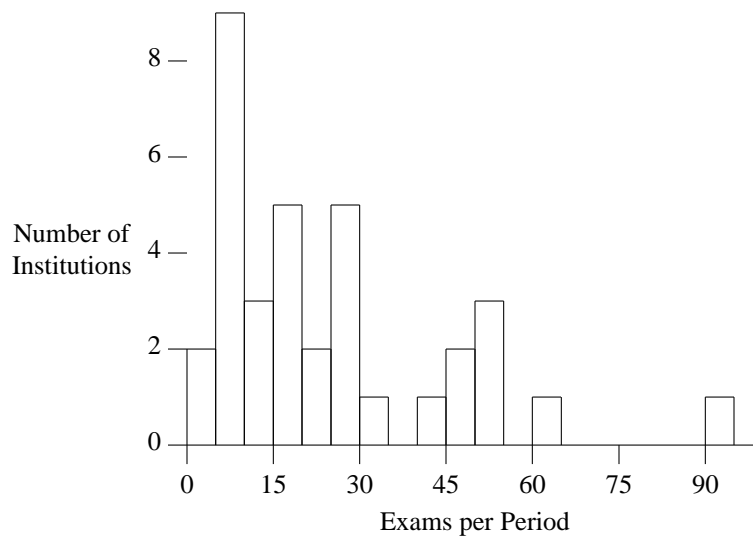
Figure 4: Exams and periods

2.4. Exams and Rooms

Seventy three per cent of those universities that replied stated that accommodating exams is a major problem. This stems from two major problems. The first problem is the lack of halls available, many large lecture theatres being unsuitable for exams or possibly still being used for teaching. The second is the problem of splitting exams between more than one room. In many cases (86%), the size of an exam alone is enough to cause a split which may be into five, or more, different rooms.

Several universities overcome the problem of insufficient accommodation by hiring external halls. This solves the problem to a certain extent but, since the halls are also used for other functions, their availability is variable. These halls may also not necessarily be close to the university thus causing problems similar to that of split campuses where students must be allowed extra commuting time.

Splitting exams between rooms does not in itself seem to be a particular problem, though this may be because of the more important pressure on resources. Different universities vary greatly in terms of the number of halls they have available. Clearly, a timetabling problem where three close together large halls are used is going to be markedly different to one with a large number of small halls spread across several sites. A number of universities have a very large number of exam rooms (in the order of sixty to seventy) and are not included in figure 5 for practical reasons.
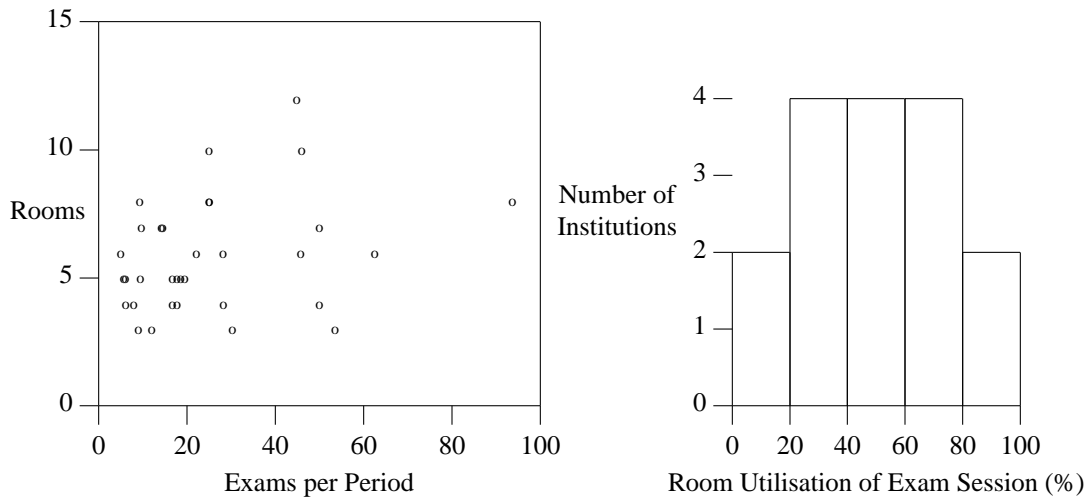
Figure 5: Exams and rooms

Figure 5 (right) shows that the problem of assigning exams to rooms can vary in difficultly from almost being trivial to being of the upmost importance. Clearly, the greater the required utilisation, the more an algorithm must concentrate on efficiently placing exams into rooms.

2.5. Exam Lengths

In a fixed-length period-based timetable, the length of the individual periods is governed by the length of the longest exam. Where there are many shorter exams, periods of different lengths may be used which restrict the exams that may be scheduled then. Thirty two percent of universities said that there are some periods in which not all exams may be scheduled because of the exam length.
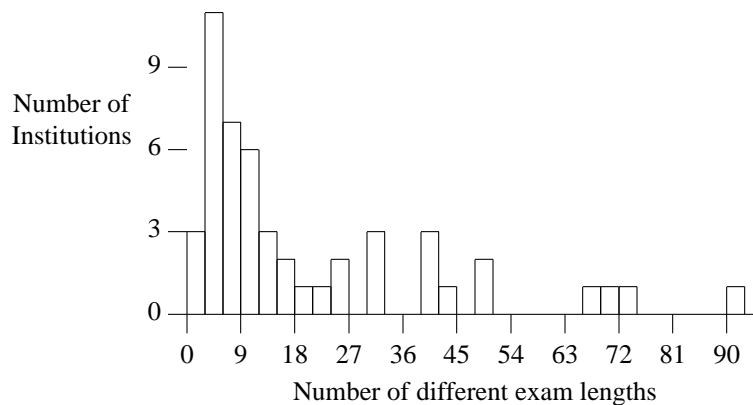
Figure 6: Exam lengths

2.6. Scheduling Invigilators

Although this was not a major themes of the survey, it was asked whether scheduling invigilators was a problem. Twenty nine percent of those universities that schedule invigilators centrally say this is a major problem. In some cases, professional invigilators are used, whereas in others, a specific department or member of staff is specified. In this latter case, it is generally required that the burden is spread evenly between staff and departments while at each exam, a member of the relevant department is present.

3. The Timetabling Process

The Timetabling Process encompasses every action that is required to create a final complete, correct timetable from the initial data input. This includes receiving, validating and formatting data, sending out draft versions and then making alterations and then producing the final timetable. These are perhaps of less interest to us though than the actual point when exams and rooms are assigned which is considered the computationally hard stage although it may not be the most difficult part of the process, that depends on what resources are available. This section of the survey asks what computer based resources are used for timetabling, how much time is available to produce the timetable and why might timetables change from year to year as well as between draft and final versions.

3.1. Computer Usage

Fifty eight percent of those universities that responded use a computer at some stage in the timetabling process. Of these, eleven (21%) have a facility to perform scheduling, although these may, in some cases, still require a certain amount of manual input and previous knowledge of the particular timetabling problem. Two of the eleven scheduling systems are commercial with the rest having been developed in house. Four other universities stated that they are either currently developing their own or customising a commercial package.

Given the size of the timetables involved it is surprising that so many do not use any form of automation at all. This may, in some cases, be because the timetable does not change significantly from year to year. However, of those universities that do not schedule by computer, the split between those that use last year's timetable and those that construct a complete new timetable each year is exactly even. It is interesting to note, however, that in every case, those that do not use the previous year's or a computer take at least four weeks to produce a timetable (see figure 8). Where a scheduling system is used, virtually all (10/11) take no account of the previous year's timetable.

Two alternative timetabling approaches were given by those without scheduling aid. The first approach (Huddersfield)* is to take draft examination timetables as produced by each schools or department and then merge them centrally into a final timetable. This uses the assumption of independence between departments and is possibly a very good way of timetabling while the assumption holds. Many universities are however now heading towards modular schemes which make such an assumption very tenuous. The second approach is to *tweak* the teaching timetable. Since a working timetable using similar data is already in operation, why not use it to produce the examination timetable? To quote Coventry, who are incidently developing a new system, "This, of course, doesn't work, since some lectures are repeated in different slots, or have more students in large lecture theatres than we can accommodate simultaneously in flat exam rooms." Obviously this approach depends on the nature of the associated course timetable.

3.2. Causes of Change from Year to Year

For a timetable to be usable year after year it must be sufficiently robust so that whatever changes occur in the input data, only a small alteration is necessary for the timetable. Whether it is possible to use the previous year's timetable depends on how robust the timetable is and also how much the exam data changes from year to year. Leeds University, who have an automated system, report that they have timetable is, for them, the best option. Some other universities say that rather than completely rescheduling, part of the old timetable is reused, while part is reconstructed. Timetables will obviously exhibit similarities from year to year since their driving factor, the combination of courses on offer to the students, will remain the same in many, if not, most cases.

Figure 7 gives four possible reasons for changes in the timetable and the number of universities that consider them major causes of change.

New Exams	75%
Student Numbers	67%
Student Preferences	54%
Policy	21%

Figure 7: Causes of change from year to year

Other causes given were: joint papers, modularisation/semesterisation, accommodation, departments' preferences and exams only being set in alternative years.

3.3. The Length of the Timetabling Process

The time it takes to produce a timetable may, in practice, often be measured in months and the actual scheduling may take much of this. Figure 8 (left) clearly shows that automated timetabling packages can reduce the time required to produce a timetable although this is not by any means guaranteed. This time may then be used to allow more extensive consultation, ease the pressure to rush the rest of the process or allow the timetables to be printed earlier. Figure 8 (centre and right) shows that although the time required by automated systems is less, the expected time to completion is also less.
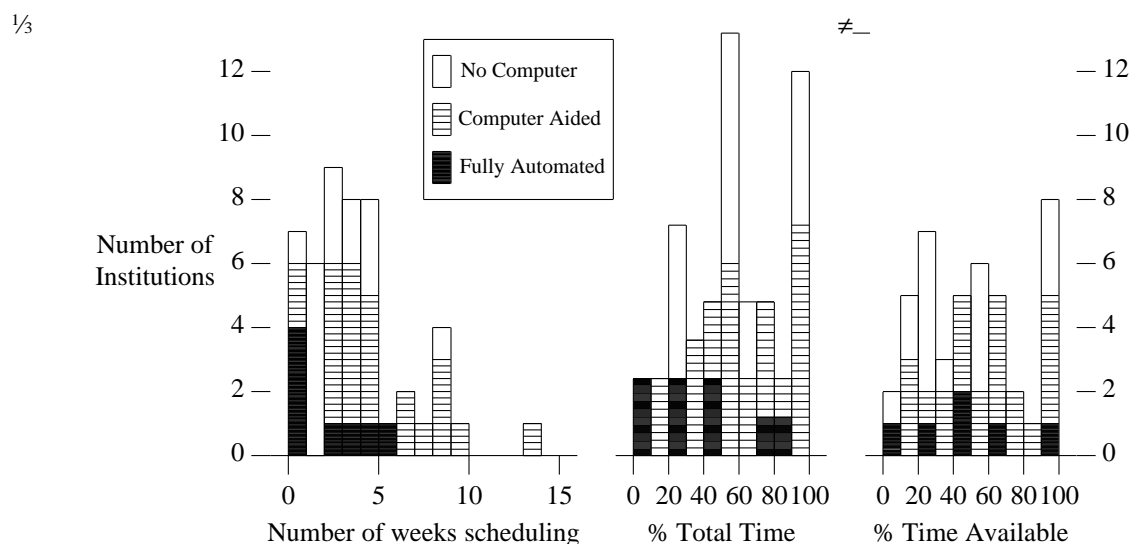

Figure 8: Time required for scheduling

Generally, a draft timetable is first produced which, after consultation with departments, is turned into a final timetable. This may or may not include room or invigilator allocations which would be added after the draft version has been accepted. Some institutions quoted figures up to 75% of the timetable being altered between draft and final versions. Reasons for these alterations were given as follows along with the number of universities that consider then major reasons for amending the timetable.

Late Data	79%
Incorrect Data	65%
Poor Quality Timetable	17%

Figure 9: Causes of change to the draft timetable

Incorrect data generally means that the students have filled in their registration form incorrectly or changed courses after the data was collected. The assessment of poor quality usually comes from Departments who notice that, for example, their students may have too many exams together at the beginning of the Examination Session or too short a gap between exams scheduled at different sites.

4. The Timetabling Solution

There are a vast number of possible constraints on the timetable produced, over and above those soley due to resources. These relate directly to the quality of the timetable in terms of its usability and requirements on those who are subject to it. The survey asked about thirteen of the more common requirements, ranking each in terms of its usage, its importance and how many exams if effects. Space was also provided for universities to add their own constraints where an extra seventeen constraints were given. The survey assumed that the constraint that no student should be timetabled in more than one place at once although, in some situations the authors have heard of, the breaking of this constraint is tolerated for a small number of students.

Figure 10 gives the survey results for each of the thirteen constraints, these being ordered by the number of universities that use them. The x axis gives the importance of the constraint (rated 1-10) and the y axis, the number of exams if effects. **x** marks the modal value of those that replied, where the constraint was used, and its surrounding box defines a sixty-six percent confidence interval.
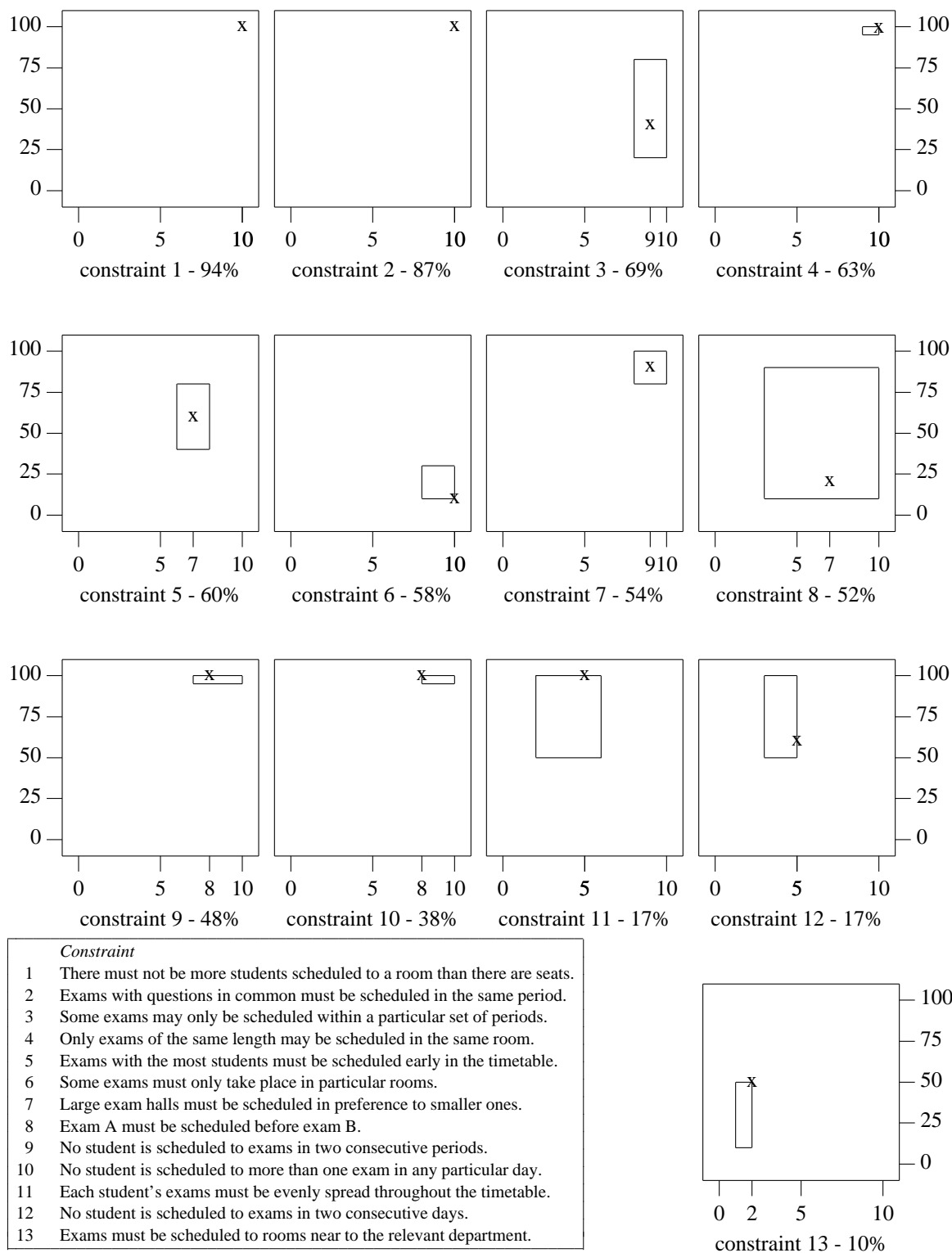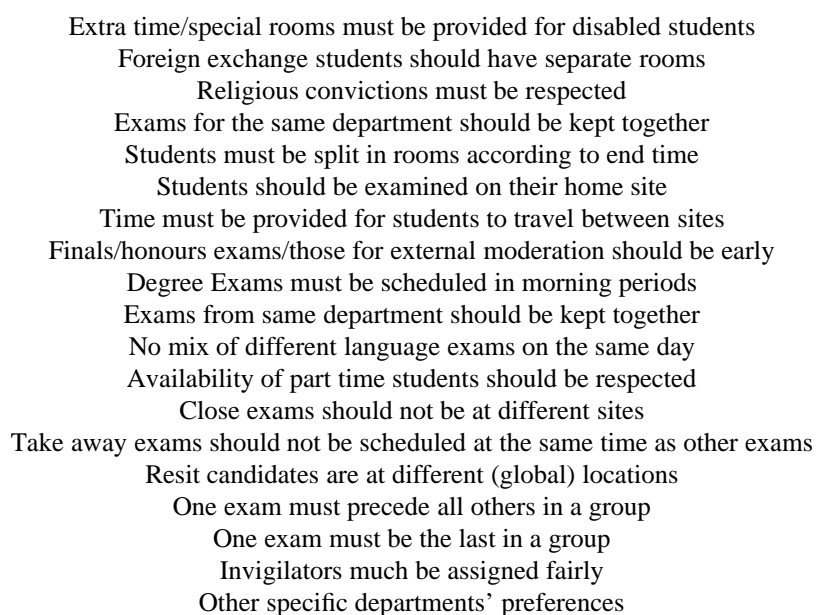
Figure 10: Timetabling constraints

	Constraint
1	There must not be more students scheduled to a room than there are seats.
2	Exams with questions in common must be scheduled in the same period.
3	Some exams may only be scheduled within a particular set of periods.
4	Only exams of the same length may be scheduled in the same room.
5	Exams with the most students must be scheduled early in the timetable.
6	Some exams must only take place in particular rooms.
7	Large exam halls must be scheduled in preference to smaller ones.
8	Exam A must be scheduled before exam B.
9	No student is scheduled to exams in two consecutive periods.
10	No student is scheduled to more than one exam in any particular day.
11	Each student's exams must be evenly spread throughout the timetable.
12	No student is scheduled to exams in two consecutive days.
13	Exams must be scheduled to rooms near to the relevant department.

The following extra constraints were also given in no particular order.

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Extra time/special rooms must be provided for disabled students
Foreign exchange students should have separate rooms
Religious convictions must be respected
Exams for the same department should be kept together
Students must be split in rooms according to end time
Students should be examined on their home site
Time must be provided for students to travel between sites
Finals/honours exams/those for external moderation should be early
Degree Exams must be scheduled in morning periods
Exams from same department should be kept together
No mix of different language exams on the same day
Availability of part time students should be respected
Close exams should not be at different sites
Take away exams should not be scheduled at the same time as other exams
Resit candidates are at different (global) locations
One exam must precede all others in a group
One exam must be the last in a group
Invigilators much be assigned fairly
Other specific departments' preferences
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Figure 11: More timetabling constraints

This demonstrates the wide variety of different factors that any general system would have to cope with. Many of these constraints will conflict either directly or indirectly. For many universities, due to the difficultly of the problem many are ignored altogether. The university that gave the constraint that no student should have exams in two different languages on the same day, went on to say that they were unable to enforce this.

5. Conclusion

"There are so many variations within the timetabling schedule
- we could write a book really!"

It is clear that examination timetabling problems can vary greatly both between and within institutions (some have up to seven examination sessions per year spread across several sites). Certain themes have, however, occurred in the survey which lead us to the following comments on the nature of any future generalised examination timetabling system.

- The system must produce good quality timetables

Obviously, any new package, to be accepted must outperform the method currently used to produce timetables within an institution. This means that it must produce good draft timetables and then be able to alter the master timetable with minimal disruption to other exams to produce a generally accepted final timetable. It must then be able to take account of a wide variety of complex constraints and be sufficiently flexible to cope with special circumstances which fall outside the scope of the normal timetable.

- The users will not be computer experts

Although the users may be reasonably relied upon to have experience of the particular timetabling problem and other local knowledge, it is clear from the survey that many do not use any form of automation in the timetabling process. Where computers have been involved, it is often the case that only the results are seen by the examinations' officer and that the actually computing is done by the University's main computing center.

A requirement may therefore be placed on the system that it must be intuitive and easy to use, possibly using current practice as a model for development. The interface should also then provide at least as much

functionality as previous systems, for example, giving clash lists or equivalent guides as to where exams may be moved. The examination department from one university said that they could "see the disadvantages in a fully automated system of examination timetabling. ... There is (dare it be said), also a case for working through the initial stages of timetabling with a chart and a pencil! This allows instant overview of the progress of timetabling in the whole of the examination session rather than reliance on a system of queries and scrolling almost inevitable on a computer screen."

- The system should be complete

Timetabling is concerned with whole process from collecting registration to outputting results. Just to isolate the scheduling part may be interesting from a research point of view but cannot provide useful general systems. Requirements for a general timetabling package, as given in survey replies, are given below.

Schedule exams to periods or times
Allocate rooms for exams
Validate data
Assign invigilators
Print timetables for students, staff and departments
Print set up/set down requirements including stationary
Print desk cards, attendance lists and labels
Produce room layouts
Interact with other scheduling systems on semi-independent sites
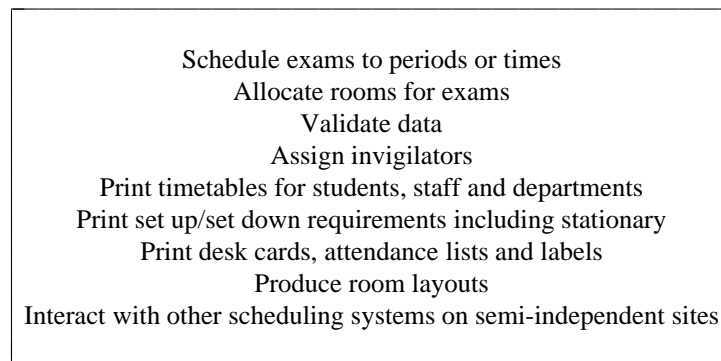

Figure 12: Requirements for a complete general timetabling system

It must also be able to cope with other exam related events which fall outside the normal examination session, for example, take-away exams and language orals.

- The timetabling system should be compatible with present software

Many British universities have spent large amounts of time and money investing in computerised administration systems. The timetabling software must be able to download data from current systems and produce output in a form that these systems may accept.

- Real timetabling test data is required

Since timetabling problems vary so much, it is unrealistic to fully test a system without a range of real timetabling problem data. Even randomly generated data sets, while still useful in testing individual aspects of systems, may not provide the richness and complexity associated with real problems.

It seems appropriate to finish by passing on a comment by one university timetabler who has tried automating the timetabling process before.

"Having tried to do in the past what you are proposing now, I hope you have the time and resources to match your enthusiasm. Do not underestimate the complexity of the problem! Good luck anyway."

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Appendix - Universities that replied.

University of Aberdeen, Aston University, University of Birmingham, Bournemouth University, University of Bradford, University of Brighton, University of Bristol, University of Buckingham, University of Cambridge, University of Central Lancashire, City University, Coventry University, De Montfort University, University of Derby, University of Dundee, University of East Anglia, University of East London, University of Edinburgh, University of Essex, University of Exeter, Glasgow Caledonian University, University of Greenwich, Heriot-Watt University, University of Hertfordshire, University of Huddersfield, University of Keele, University of Lancaster, University of Leeds, University of Liverpool, Liverpool John Moores University, Loughborough University, University of Manchester, University of Manchester Institute of Science and Technology, Manchester Metropolitan University, Napier University, University of Nottingham, University of Oxford, Oxford Brookes University, University of Plymouth, University of Reading, University of St Andrews, University of Salford, Sheffield Hallam University, University of Southampton, Staffordshire University, University of Sunderland, University of Surrey, University of Teesside, Thames Valley University, University of Ulster, University College of North Wales, University College of Swansea, Saint David's University College, University of Warwick, University of Wolverhampton, University of York.