Investigation of Timetabling in Tertiary Institutions in Southern Africa

THIRUTHLALL NEPAL AND STUART MELVILLE
Department of Computer Studies
ML Sultan Technikon, PO Box 1334, Durban
e-mail : nepal@wpo.mlsultan.ac.za, stuart@wpo.mlsultan.ac.za
Facsimile : 031-3085355

Abstract: This paper deals with approaches to the timetabling problem, focussing on tertiary institutions in Southern Africa. A questionairre which dealt with, inter alia, student population, number of class groups, methods used for timetabling and local constraints was distributed to tertiary institutions in Southern Africa. The response rate was over 80%. Analysis of the responses yielded a number of interesting results, chief amongst these being that there is little consensus on any one method, and that the timetabling process is not fully automated in any institution. The analysis further indicated that a great deal of time and effort is involved in the process, up to 200 person-hours in some institutions. This paper details previous work in the field and outlines results from the questionairre. Future research will be directed towards either finding a more efficient approach to the problem or determining which of the current methods is in fact most effective.

Keywords: Timetabling, scheduling.

Computing Review Category: F2.2, H4.1

1. Introduction

1.1 Overview of the Timetabling Problem

A number of works [1,2,3] credit C Gotlieb's 1962 paper, *'The Construction of Class-Teacher Timetables'*, presented at the 1962 IFIP Congress, as being the base point for research into the timetable problem. This is not necessarily so as earlier publications do exist, for example CE Lewis's book *'The School Timetable'* [4], or JF Blakesley's 1959 paper on scheduling at Purdue University [5]. Regardless of the true origin of the timetable problem it is clear that since the 1960's it has been an area for a great deal of research [4,6,3,7,2,8,9,10,11,12,13,14,15,1,16,17,18,19 - references chronologically ordered] and has achieved such recognition that the basic ('naive') problem appears in at least one undergraduate text, Bondy and Murty's *'Graph Theory with Applications'* ' [15].

D de Werra [10] identifies two major problems within the timetabling field: the class-teacher problem and the course scheduling problem. The former, the class-teacher problem, concerns allocating teachers to classes (and vice versa) given a set number of periods required for each teacher/class group and a limited number of total available periods (a more formal description is given below). The latter, the course-scheduling problem, is where students may select from a wide choice of offerings. After their selections are made a timetable which minimises clashes must be constructed. This paper shall concentrate on the class-teacher problem.

1.2 Formal Statement of the Class-Teacher Problem

Given c classes and t teachers, and a need for each class c_i to meet with teacher t_j (classes and teachers indexed from 1 to c and 1 to t respectively) for a certain number x of time units (periods) in a p-period schedule (indexed p_k with k running from 1, the first period of the schedule, to p), how to assign teachers to classes in particular periods so that all necessary periods involving class c_i and teacher t_j are held (for $i = 1$ to c and $j = 1$ to t) without either:

(a)Any t_j being assigned to two different classes at the same time.
(b)Any c_i being assigned to two different teachers at the same time.

1.3 Real-World Constraints

The above problem is greatly complicated by a number of other constraints encountered in practical situations, the more important of these are detailed below.

1.3.1The Rooms Problem

Most institutions do not have an unlimited supply of venues, and so these resources and their use must be considered in practical solutions. In addition certain specialist rooms (laboratories, etcetera) may have to be treated as special cases where a particular class and teacher (eg. Chemistry, Computer Studies) may require a specific room. There are reports of attempts to solve the problem with these constraints [1,12,14] using hypergraphs. It seems however that the more general rooms problem (which seems to be a feature of many tertiary institutions) that of having a wide range of venue sizes to match with another range of class sizes has not been seriously addressed. (Note that this problem typically does not arise in the school situation, where all class sizes and most venue capacities remain more or less fixed.)

1.3.2 Preallocations

Here class c_i is obliged to meet teacher t_j at some fixed time p_k. This could arise, for example, when it is desired that students meet a part-time lecturer from industry in some set period of each day. (Note : these are also referred to as 'preassignments' in the literature).

1.3.3 Unavailabilities.

These occur when a particular class or particular teacher is not available for a particular period or periods (for example, third-year students at a technikon might be guaranteed certain afternoons free for experiential training). This is closely allied to the preallocation problem and a number of writers [1,5,10] have shown that in fact the unavailability problem can in fact be converted into a preallocation problem by merely creating dummy classes/teachers for these periods. For example, Purdue University built in a 'course' called 'residence hall waiter service' to cater for those students that would be unavailable during certain periods as they were employed as waiters during those times [5].

1.3.4 Minimising versus equitation.

There are two possible goals beyond merely creating a feasible timetable, which may be desirable to an institution. The question of minimising involves attempting to minimise some resource (eg. number of rooms used for institutions where venues have a certain cost - such as rental - or alternately minimising the total number of periods needed). In equitation the requirement is for some form of 'even spread' - say that class c_i needs to meet teacher t_j for 5 periods of Economics classes in a week. To generate a timetable which puts all five periods on Monday (in the pathological case, on five **consecutive** periods on Monday) would not be acceptable to most institutions. Similarly such equitation is often desired across days, so that the load of staff and students is more or less the same on each day of the week rather than having very heavy ('clustered') days intermingled with very light ('sparse') days. While we use a week as a scheduling period here, and will continue to do so for ease of understanding, it should be noted that there is no imperative that this be the scheduling period, a day or a fortnight or any other scheduling timespan will admit similar problems and be amenable to similar solutions - Lewis [4] in fact presents cogent arguments for a fortnight-based schedule in preference to a week-based one.

1.3.5 Preferences.

Unlike unavailabilities, where there is a rule involved (lecturer X will **not** be able to give classes in 4th period on Tuesdays), preferences relate to 'nice-to-haves'. Such preferences can arise from personal reasons such as the lecturer who wishes to be free to attend to children at particular times, or on didactic grounds, such as preferences regarding which subjects should follow others in a timetable. Certainly preferences are not vital considerations in creating **feasible** timetables, but approaches which do take account of these will lead to greater user satisfaction.

1.3.6 Miscellaneous constraints.

A number of other considerations may be important, largely functions of the particular institution involved. Both Lewis [4] and Punter [7] stress that there is a vast number of requirements specific to institutions and courses and that generalised solutions must of necessity be adapted to individual circumstances. One particularly common constraint here is the need for double (and occasionally triple) periods in a particular subject (often those involving laboratory work). 'Team teaching' (more than one lecturer to a class) and class-splitting (into, say, small tutorial groups) in particular add a great deal of complexity to the problem.

1.4 Difficulty of the Problem

Konig's important result, reported by de Werra [10], that there is a necessary and sufficient condition for the basic problem, i.e. the-class-teacher problem and the-course-scheduling problem, to be solved seems at first encouraging. The result is that there is a timetable in p periods iff no teacher or class is involved in more than p periods. However, quite apart from the fact that the basic problem is of little practical relevance, a further complication is that the knowledge that there is a feasible solution in no way guarantees that such a solution can be found.

Indeed Even [3] asserts that in general the basic timetable problem with preassignments/unavailabilities is *'a rather naive model since it ignores several factors which definitely play a role in practise'* and is NP-complete. Thus we can expect even the best algorithm to take exponential time to arrive at a solution (given that P = NP remains unresolved). Day's observation on preassignments [1] is also relevant here *'in general the problem associated with preassignments becomes one of finding the least number of colours to properly edge-colour where certain edges are precoloured. Unfortunately, this is a well-known unsolved problem.'* If teachers and classes are free at all times (no preallocations/unavailabilities) then the problem admits a solution by the edge-colouring of simple graphs [1,10], however as soon as the rooms problem is considered hypergraphs are needed [1], and the problem is once again NP-complete.

All this mitigates against the development of useful computer programs which arrive at 'perfect' solutions (or even feasible ones) by purely deterministic mechanisms/algorithms, and the comment that *'in a certain sense an amount of heuristics may be found in every known timetable system'* [1] seems to be well-justified. Although a number of programs have been developed to address the problem [2,6,7,19,21] they are all either limited in scope or unable to guarantee solutions even where such solutions may well exist.

2. Prior Approaches to Solving the Problem

Day [1] and de Werra [10] give overviews of various approaches that have been employed to tackle the problem. These include :

- graph theoretical approaches
- operational research approaches
- branch and bound tree searches
- relational approaches
- Boolean matrix iterational approaches.

Space considerations preclude detailed discussion of the methods used, for a synopsis of approaches by Carlson and Nemhauser [20], Aust[2], Lazak[6], Punter[7], and various graph-theoretical approaches see [21]. What is important is that the considerable research effort in the field has generated approaches which are all in some way heuristic, relying on iteration or 'good-guess' approaches to provide (hopefully) workable solutions. More importantly, all the approaches which do not rely on the large-scale involvement of a human expert are without exception only capable of handling very limited problems not common in the real-world situation. This by no means makes such approaches practically useless, a human might well be able to use these approaches to solve sub-problems while constructing a timetable or schedule. It does, however, imply that a higher-level heuristic approach (such as an expert system) might be usefully employed to handle timetables. This is borne out by the results of the questionairre (detailed in the following section) which indicate that there is still a great deal of manual timetabling at tertiary institutions with one or more 'boffins' being entrusted with the task and using previous experience and heuristics as the base of timetable construction.

3 Questionairre and Results

3.1 Questionairre Logistics

3.1.2 Questionairre Design

The questionnaire is based on information obtained from the literature survey, and on information gleaned in discussions with Mike Mullany, Department of Computer Science, University of Natal, Pietermaritzburg. It was designed to elicit information in seven broad areas, viz., responsibility, staffing and groups, lecture periods, constraints, method used, effectiveness, and a comments area. The questionnaire comprised 17 questions impacting on the study. The questions were phrased to elicit, inter alia, "yes/no" responses as well as quantitative and qualitative questions. Even numbers of alternate responses were given to stop people returning neutral answers and force expression of views to be either negative or positive.

3.1.1 Questionairre Procedure

The questionnaire was sent to the chief timetable co-ordinators of all technikons and universities in Southern Africa, as well as to two Colleges of Education and one Technical College. In cases where no chief timetable co-ordinator existed, requests were made to circulate copies to the faculty or departmental co-ordinators. A total of 46 questionnaire were sent. Respondents were given 6 weeks for the remission of the questionnaire.

3.1.3 Response

Fifty (50) responses were received - this might seem impossible in light of the fact that only 46 were dispatched, but in a number of cases respondents were kind enough to make copies of the questionnaire and distribute them to various persons involved in timetabling at their institutions (eg. person in charge of each Faculty timetable, and so on). Responses were received by 16 of the 20 residential universities within South Africa (80% return) as well as by two other Southern African universities (Namibia and Zimbabwe). Thirteen of the sixteen residential technikons responded for a return-rate of a fraction over 81%. The extremely favourable return rate can probably be attributed to both the questionnaire design (quick, relevant questions, and not too many of them) as well as to the obvious interest many institutions had in the study.

3.2 Analysis of Responses

Twenty-four respondents prepared timetables for 200 to 999 students, nine for 1000 to 3000 students, and nineteen for students populations of over 3000. The timetables had to cater for less than ten lecturers in 3 cases, eleven to nineteen lecturers in eight cases, 20 to 50 lecturers in thirteen cases, and over 50 lecturers in 23 cases. Nineteen respondents reported that departments were not restricted regarding the number of lectures given per subject, while 33 reported that they had to stick to a set number of periods per subject.

Reported constraints in terms of venues (lecture and specialist) are depicted in Figures 1 and 2 below. It is clear that both resources are a major problem/scarce resource for the majority of respondents. A number of respondents also indicated that the lack of sufficient large venues was a major problem.

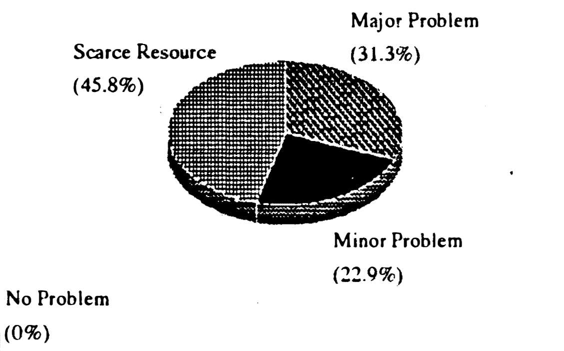

Figure 1 - Lecture Venues as Constraints

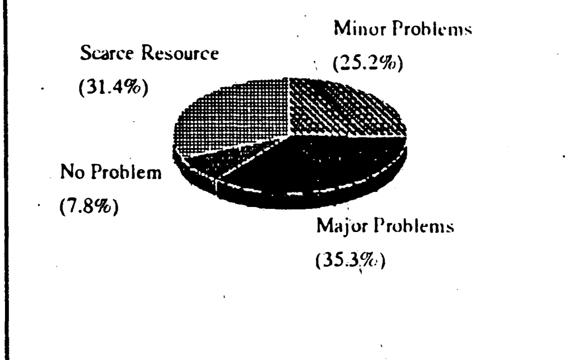

Figure 2 Specialist Venues as Constraints

Figure 3 below depicts the types of method used by the various respondents. It is interesting to observe that over two-thirds of the respondents indicate that timetabling is a completely manual exercise at their institutions. One respondent indicated that the process was completely automated, however further investigation has revealed that this was a misunderstanding as the 'timetable automation' referred to was in fact the ITS student registration system.

Figure 4 below depicts the number of person-hours spent timetabling per year. In a majority of cases this is a full working week (40 hours) or more, while a significant number of institutions (over 11%) expend more than 100 hours and in the case of almost 6% of the respondents, over 200 hours. Clearly a tremendous amount of effort is being put in countrywide on timetable construction.

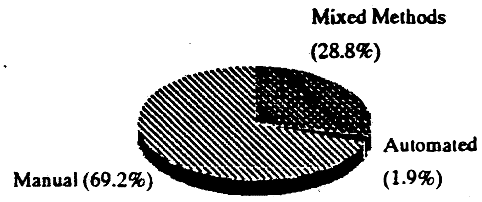

Figure 3 Type of Timetabling Method

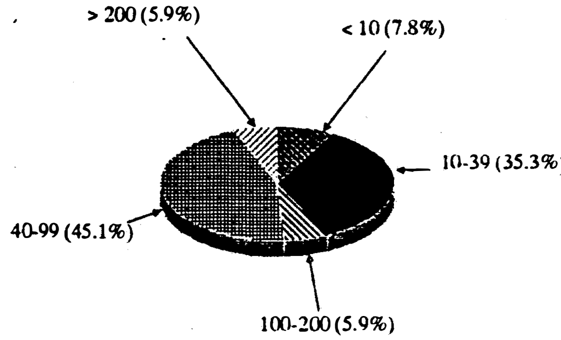

Figure 4 Person-hours Spent Timetabling

Figure 5 shows the ease with which changes can be made to timetables once established. The fact that 73% of the responses indicated that this was either fairly or very difficult is interesting. Figure 6 shows the respondents' general level of satisfaction with their system. While less than 6% considered their system completely satisfactory, a majority were generally satisfied. This makes an interesting contrast to the results on person-hours depicted in Figure 4 and those on ease of change in Figure 5.

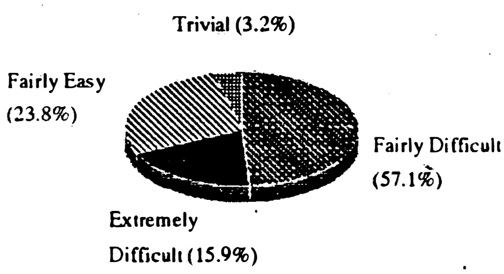

Figure 5 Ease of Changes to Timetable

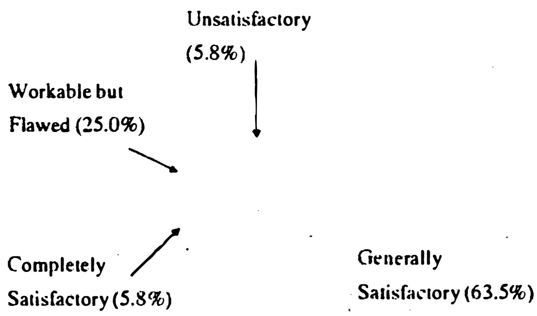

Figure 6 Degree of Satisfaction with System

3.3 South African Approaches

In many institutions the master timetable is itself constructed by hand. In most cases the timetabling is decentralised to faculties or to those levels at which the timetabling problems are largely independent of one another. Undergraduate lectures are generally timetabled at the level of the faculty. Tutorials and post graduate teaching at the departmental level. Service classes, provided by one faculty for other faculties, require co-ordination and are in general timetabled first so that the remainder of the problems can be dealt with independently of one another. In some cases, changes from year to year tend to be minor, and the previous year's timetable is taken as a starting point. In other cases, the previous year's timetable is ignored and a new one is constructed taking into account changes and new requirements.

Different approaches are used to allocate the actual periods and venues for the different groups. The most common method is making use of a grid depicting the days in the week and periods in each day. A different set is used for the lecturers, venues, and the groups (other similar approaches make use of magnetic boards and cards, different colour cards, planning boards). The timetable panel then allocates subjects to specific periods to particular venues. They normally start with the service subjects first, special laboratory periods, then consecutive double and triple periods and practicals scheduled mainly in the afternoons. The others are scheduled on a trial and error basis. Tutorials are scheduled mainly on a departmental basis at the end.

Some institutions make use of the "block system". Subjects are grouped into six or seven blocks (blocks A...F/G). The lectures for subjects in a particular block (say block A subjects) are scheduled at the same times in different venues, i.e. the subjects are already timetabled into specific periods, and maybe into specific venues on different days of the week. Students are therefore compelled to choose courses according to the timetable. No two subjects can be chosen from the same block because the lectures are conducted at the same time. In some cases, the group size is also fixed e.g., the maximum number of students for Labour Law I is fixed at 100. The department cannot register more than 100 students. If it intends to increase its registration then permission must be sought from the Senate. The effect of the block system is to break a single timetabling problem over a week (normally) of lectures into multiple timetabling problems (one per block), each over a shorter timespan (the number of periods in the week allocated to the block). Thus the system is not a solution per se, but an attempt to simplify the problem. Two specific disadvantages of this system were identified by respondents - firstly it clearly limits freedom of choice for students; and secondly it ensures underutilisation of resources unless all subjects have exactly the same number of contact periods (which, respondents indicate, is not always didactically desirable).

3.4 Constraints

The major constraint is the lack of adequate availability of large lecture venues and adequate availability of specialist laboratories. There is therefore a need to split large groups that can be lectured to as a single unit. If there are 600 students in Financial Accounting I and the capacity of the largest lecture venue is 200, then the class is split into 3 groups of 200 which means that the same lecture has to be conducted 3 times, maybe by the same lecturer or by different lecturers. This also has an impact on the staffing. A particular lecture may have to be given fifteen times instead of five (if five periods were initially allocated a particular subject). Pretoria Univerity's comment that, by a senate decision, no class should be larger than 250, is interesting in this regard.

4 Conclusion

Since the 1960's, timetabling has been an area for a great deal of research. Since then several attempts have been made to find a solution to the timetable problem. In 1985, De Werra [10] identified two major problem area in time tabling, viz., the class-teacher-problem and the course scheduling problem. The main problem highlighted were: preallocations/preassignments, the room's problem, unavailabilities, and preferences.

There are a number of possible approaches to the timetabling problem. All these approaches are in some way heuristic, relying on iteration or 'good-guess' approaches to provide workable solutions. The approaches which do not rely on the large-scale involvement of a human expert are without exception only capable of handling very limited problems not common in the real-world situation. It therefore seems that a higher-level heuristic approach might be usefully employed to handle timetables.

Questionnaires were designed and sent to timetable co-ordinators of the different tertiary institutions. A total of 46 questionnaires were despatched. There was a return rate of over 80% in the case of Universities and Technikons. 36 institutions indicated that the timetable was constructed manually, 15 used a mixed approach using either the trial and error method or the so called "blocking system". In the mixed approach the allocation of venues were mainly done by the computer. The major problems highlighted in the literature survey was once again highlighted in this investigative study, e.g., the problems of preallocations/preassignments, the room's problem, unavailabilities, and catering for preferences are still prevalent today.

5 Future Work

Domain experts have been identified in this study, and some potentially useful rules of thumb (eg. schedule scarcest resources first, schedule contiguous periods from largest to smallest, users must give input as to the relative importance of equitation and preferences) have already been determined. These experts will be interviewed, and their method to timetabling examined in order to understand their approach to timetabling so that rules can be defined clearly. Knowledge gained from the questionairre results, the domain experts and the literature study will form a knowledge base.

Eventually it is hoped that an expert system can be developed which provides heuristic solutions to the inherently heuristic problems of timetabling. If this is not feasible, then at the very least this work will be able to identify which of the many and varied current methods in use in Southern Africa is the most effective

- the results of the questionairre show clearly that at least the majority of institutions are doing more work than they need to be.

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