Understanding the Role of UFOs Within Space Exploitation

Camille Beyrouthy[1], Edmund K. Burke[1], J. Dario Landa-Silva[1], Barry McCollum[2,3], Paul McMullan[2,3], and Andrew J. Parkes[1]⋆

[1] School of Computer Science & IT, University of Nottingham,
Nottingham NG8 1BB, UK.
{ `cbb, ekb, jds, ajp` }`@cs.nott.ac.uk`
[2] Queen's University of Belfast, Belfast, BT7 1NN, UK
{ `b.mccollum, p.p.mcmullan` }`@qub.ac.uk`
[3] Realtime Solutions Ltd, 21 Stranmillis Road, Belfast, BT9 5AF
`b.mccollum@realtimesolutions-uk.com`

In this paper, we are concerned with understanding the efficient planning and management of teaching space, such as lecture rooms, within universities. There is a perception that such space is a rather scarce resource. However, some studies have revealed that in many institutions it is actually chronically under-used [3, 4]. Specifically, overall space-usage efficiency is measured by the "utilisation" (U), which is basically the percentage of available "seat-hours" that are exploited:

$$\text{Utilisation, } U = \frac{\text{used seat-hours}}{\text{total seat-hours available}} \tag{1}$$

It is also standard practice to measure the overall frequency, F,

$$\text{Frequency, } F = \frac{\text{used time-slots}}{\text{total time-slots}} \tag{2}$$

and the room occupancy, O,

$$\text{Occupancy, } O = \frac{\text{used seat-hours within occupied rooms}}{\text{total seat-hours available within occupied rooms}} \tag{3}$$

The three measures U, F and O are not independent. If all the rooms were the same size, then, directly from the definitions, we would have $U = F\text{O}$, and a similar relationship continues to hold when we have rooms of different sizes.

Surprisingly, in practice, rooms are often occupied only half the time ($F \approx 50\%$), and even when in use they are often only half full (O $\approx 50\%$), with the result that utilisations of 20-30% are not uncommon. The 'Higher Education Funding Council for England' (HEFCE) has reported low utilisations, and two of the authors have commercial experience of such low utilisations from their work with Realtime Solutions Ltd [3, 4].

Naturally, many institutions would like to improve this situation in order to reduce costs, improve services, or to permit teaching space to be converted to other uses. Also, for long-term capacity planning it is necessary to incorporate

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⋆ Contact Author (ajp). Authors listed alphabetically.

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excess capacity in order to compensate for the expected low utilisations. Naturally, this is expensive, and we want to be able to ensure that spare capacity is well-engineered. However, such better management is hampered because there does not appear to be a good understanding of why low utilisations happen in the first place. This motivates our two main goals:

1. to understand the factors leading to low utilisations.
2. to develop methods to choose excess capacity that is more cost-efficient: aiming to reduce the teaching space that needs to be provided, whilst not increasing the risk of it turning out to be inadequate

To model the domain, we start from a simple event allocation problem. The goal is to select events so as to maximise the utilisation yet permit an assignment of events to rooms that satisfies the following standard hard constraints:

1. the size of an event must not exceed the room capacity
2. the number of events allocated to a room must not exceed the number of time-slots, as events cannot share room time-slots.

In this model the utilisation can be optimised in polynomial time [2]. However, on using real data for rooms and courses (obtained from one building of a university in Sydney, Australia) it was clear that this model gave unrealistically high values of utilisation (around 80-95%). This suggested that a model based purely on space issues is inadequate for real-world universities.

Moreover, in reality, event allocation usually takes place within the context of many constraints on locations and timings of events. Accordingly, we also included within our model objectives that are intended to provide a simplified approximation/abstraction of real timetabling issues; in particular the use of a conflict matrix between events, and a location penalty for placing events in rooms that belong to different departments. Note that the inclusion of the conflict matrix means that the polynomial time methods can no longer be used, and instead we use local search together with simulated annealing.

On exploration of the resulting multi-objective trade-off surfaces, we find that the utilisation can be forced down to much more realistic levels, in the range of 20-40%. The results support the hypothesis that the location and timetable penalties have the potential to dramatically drive down utilisations, and are a reasonable candidate to explain low utilisations in the real world.

Now let us return again to the issue of planning future capacity. We take the point of view that a (tentative) set of courses effectively form a "request for a given number of seat hours", and hence correspond to a request for a given level of utilisation. In the absence of low utilisations, then we would be confident that as long as we request no more than 100% of the available seat-hours then we would be able to satisfy all of the request. However, this is no longer true when utilisation is expected to be lower than 100%. Hence, we set up the methodology to answer the following question

> "Under what conditions is a request for utilisation fully satisfiable?"

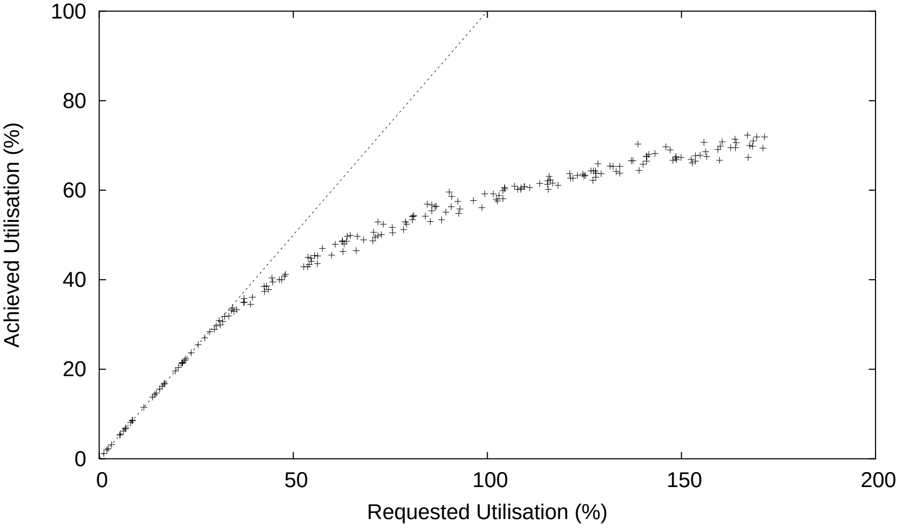

Fig. 1. An example of Requested Utilisation (U_R) vs. Achieved Utilisation (U_A). The line $U_R = U_A$ is given for reference purposes.

We studied this question by taking a wide variety of randomly-selected subsets of our real set of events, and for each subset finding the maximum achievable utilisation. A representative example is shown in figure 1 for the achieved utilisation plotted against the requested utilisation. From this and other experiments, we obtain the following results.

Firstly, the values of achieved utilisations for given corresponding requests, tend to be "grouped around the mean": The variation between points near to some requested value is small. This implies that properties of the system are statistically predictable.

Secondly, we see a threshold phenomenon on the utilisation U. There is a "critical value", U_C, for the requested utilisation, U_R, that demarcates a sharp division between regions in which the answer is "almost always yes" and those of "almost always no". (In the case of Figure 1 we have $U_C \approx 30\%$.) We then have two distinct regions:

SAFE: $U_R < U_C$. Requests for the seat-hours are almost always totally satisfied.

UNSAFE: $U_R > U_C$. Requests for the seat-hours are almost never totally satisfied. Even in the cases when there are sufficient seat-hours available, it turns out that the oversupply is very unlikely to be usable.

These results are typical of those in threshold phenomena; perhaps best-known within the context of random graphs [1]. For example, the chromatic number of random graphs is similarly predictable. The threshold behaviour has an important implication. When planning course offerings we cannot assume that we can simply count seat-hours, but must realise that we are unlikely to be able to rely upon using more than some predictable critical utilisation, and this will (almost) inevitably mean that some of the events will need to be dropped.

Our work suggests that progress in space management and planning will arise from an integrated approach. Firstly, combining purely space issues with restrictions representing an aggregated or abstracted version of key constraints such as timetabling or location. And secondly, also performing statistical studies to reveal underlying threshold phenomena.

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