Institution: Queen's University Belfast

Unit of Assessment: 11 – Computer Science and Informatics

Title of case study: The commercial impact of scheduling and optimisation on university space planning and utilisation

1. Summary of the impact (indicative maximum 100 words)

A QUB spin-out company, EventMAP, led by Queen's University Belfast researchers, has commercialised joint research in resource planning and optimisation by QUB and University of Nottingham to build a global capability in resource planning and management. The specific impact of the QUB team's activities in research and commercialisation include:
(i) Saving real estate construction costs through simulation and optimisation at the planning stage. In one recently completed commercial project for Victoria University, Australia (2009-2011), the use of EventMAP's tools and involvement enabled the University to avoid new construction costs estimated by Victoria University at £70m.
(ii) In another international construction project in Abu Dhabi, UAE, the property developer estimates that EventMAP's involvement saved an estimated £4.6M in reduced real estate construction costs.
(iii) Similarly, EventMAP enabled Imperial College London to achieve savings of around £600k in its South East Quadrant redevelopment project within the impact period.
(iv) EventMAP has solved major planning and timetabling problems for around 15 leading UK and international educational institutions. Among them are three of the Russell Group's top five universities, and Paris-Sorbonne University.
(v) Since 2008 the company's headcount has grown from 2 part time employees to 8 full time and 5 part time employees, and turnover has doubled each successive year.

2. Underpinning research (indicative maximum 500 words)

For over a decade, researchers in Computer Science at Queen's University Belfast have been a key part of a collaborative research programme in optimisation and scheduling, with researchers at the University of Nottingham. The lead QUB researchers, Dr Barry McCollum and Dr Paul McMullan, have both been in academic posts at QUB for over 10 years. Dr McCollum was previously employed in timetabling and scheduling at University of Nottingham in 1995-97, and this was the starting point for the ensuing long-standing collaboration.

As part of the collaborative research programme, the specific research contributions of the QUB team include the following two examples:

(i) The development of novel meta-heuristics which are sufficiently generic to achieve performance across a range of different datasets and application areas [1]. Recent research has led to the development of adaptable heuristics, which make the finding and adapting of optimal parameter settings more automatic, and makes the software more generic. Such 'Hyperheuristic Approaches' have been shown to be extremely versatile and robust [2]. Algorithms developed by the QUB team, specifically a hybridisation of the extended Great Deluge Improvement metaheuristic with an adaptive construction heuristic, are part of the commercial software. The techniques have been applied by the QUB researchers, under consultancy arrangements, to a number of diverse commercial application areas, including building resource planning, aircraft fuel management, advertisement scheduling, manufacturing scheduling, staff rostering, parallel processing and campanology.

(ii) The modelling of resource management problems
Detailed modelling of a commercial project and its constraints is essential to commercial success. The QUB team's research, published in leading journals, has presented novel problem modelling techniques and evaluated them using international benchmark standards and real world implementations [3, 6]. They have shown that there is a clear relationship between how the problem is modelled and the structure of the application algorithm.

The team at QUB led the development of new industrially relevant benchmark standards

during their leadership of the 2nd International Timetabling Competition (http://www.cs.qub.ac.uk/itc2007). The team has also led a number of key international initiatives. Dr McCollum is permanent co-Chair of the PATAT series of conferences, and organised the very successful conference in Belfast in 2010. Dr McMullan gave an invited plenary talk at the PATAT 2012 conference in Norway. Dr McCollum is permanent co-Chair of the MISTA series of conferences (http://www.mistaconference.org/2011/). This is recognition of the team's standing and setting of the research agenda in the field of algorithmic development and real world problem modelling.

3. References to the research (indicative maximum of six references)

[1] Bai R, Burke EK, Kendall G, Li J and McCollum B, "A Hybrid Evolutionary Approach to the Nurse Rostering Problem", IEEE Transactions on Evolutionary Computation 14(4): 580-590, 2010.
This paper illustrates the use of the team's novel Hybrid evolutionary approach. Journal ISI impact factor: 4.371. 20 Google Scholar citations.

[2] Qu R, Burke EK and McCollum B, "Adaptive Automated Construction of Hybrid Heuristics for Exam Timetabling and Graph Colouring Problems", European Journal of Operational Research, 198(2): 392-404, 2009.
This paper moved the area of hybrid heuristics forward by adding the novel capability of *adaptable* hybrid heuristics. 48 Google Scholar citations.

[3] McCollum B, Schaerf A, Paechter B, McMullan P, Lewis R, Parkes A, Di Gaspero L, Qu R, Burke EK, "Setting The Research Agenda in Automated Timetabling: The Second International Timetabling Competition", INFORMS Journal on Computing, Vol 22, No 1, 2010, pp 120-130.
This paper establishes new models of complex real world problems, and underpinned the 2007 International Timetabling Competition which attracted major international interest. The paper is ranked among the top 1% cited papers in Computer Science (ISI's Essential Science Indicators). 111 Google Scholar citations.

[4] Qu R, Burke EK, McCollum B, Merlot LGT & Lee SY, "A Survey of Search Methodologies and Automated System Development for Examination Timetabling", Journal of Scheduling, Volume 12(1), pp 55–89, 2009.
This presents a major review of heuristic search based approaches, and includes novel research contributions by the team. 139 Google Scholar citations.

[5] Beyrouthy C, Burke EK, Landa-Silva D, McCollum B, McMullan P, Parkes AJ, "Towards improving the utilisation of university teaching space", Journal of the Operational Research Society (JORS), Vol 60, pp 130-143. 2009.
This work presents an in-depth investigation into the factors that contribute to low utilisation of teaching space in universities, and provides evidence that timetabling and location requirements are key contributors to low space utilization in practice. This research was funded by EPSRC and Real Time Solutions Ltd. 17 Google Scholar citations.

[6] McCollum B, McMullan P, Parkes AJ, Burke EK, Qu R, "A new model for automated examination timetabling", Annals of Operational Research, Vol 194, pp 291-315. 2012.
This work produced a formal model of examination timetabling that incorporates many features found in real-world problems. 15 Google Scholar citations.

Grants: As well as participating as part of the research team in the EPSRC-funded research at Nottingham (GR/T26115/01, 2005-2009; and EP/D061571/1, 2006-2011), the commercialisation of the research was supported by two grants under InvestNI's Growth Acceleration Programme: for £41K (January 2012) and for 27K (April 2013)

4. Details of the impact (indicative maximum 750 words)

The QUB team's lead researchers McCollum and McMullan have led the commercialisation process to exploit the fundamental collaborative research. In 2003, they established EventMAP

(www.eventmapsolutions.com) – a spinout company based in Belfast whose backers included QUBIS Ltd (Queen's University's holding company) and the University of Nottingham.

Initially EventMAP sold a timetabling product based on the collaborative research undertaken by QUB and the University of Nottingham. The company then developed a more adventurous approach to impact based on involvement in construction projects *at the planning stage*. This required EventMAP to develop its next generation of products based on the latest joint research between QUB and Nottingham. This new strategy has enabled EventMAP to have much greater impact on commercial construction projects in the education sector, by reducing the amount of new real estate which needs to be constructed. This is made possible by simulation and optimisation of real estate at the planning stage, using EventMAP's sophisticated modelling and timetabling tools.

Details of the five areas highlighted in the 'Summary of the impact' section above are now given.

(i) In 2009, the University of Victoria, Australia, was beginning a major planning project to meet the expansion needs for the next decade. The Manager, Space Management at Victoria University at the time (now at Deakin University) expressed their problem as follows:

> "*Victoria University is a large multi sector (Higher Education and Vocational Education) University based in the west of Melbourne. The University has 11 campuses with a total gross floor area of over 300,000 m^2. The University was faced with significant challenges in planning for new space and in optimising the use of existing facilities. Traditional planning and management approaches to facilities had resulted in an oversupply of poor quality, inappropriate rooms that were poorly utilised. The University was actively pursuing significant student growth, but lacked the financial resources of other Universities to aggressively expand facilities*."

EventMAP Ltd were engaged by Victoria University to undertake an analysis of existing teaching space use, both through an analysis of timetable data and from data collected from physical audits of space. EventMAP staff were on site for two weeks over the course of the project. Using their software tools, EventMAP delivered a customised, portal-based interactive report with power to run simulations. The Manager has recorded the impact of EventMAP's involvement:

> *"These reports provided the starting point for measuring capacity to accommodate growth. Modelling on timetable scenarios gave the University confidence that significant growth could be achieved within existing physical resources through to the end of the current decade without the recourse to construct new teaching spaces. This analysis provided by EventMAP enabled the University to avoid new construction costs, estimated at $120m* [~£70m] *over the forecast period."*

(ii) In a similar international project starting in 2010, the Higher Colleges of Technology (HCT), United Arab Emirates, received approximately £100M funding from the Abu Dhabi government to construct a new campus for its Abu Dhabi Men's College. This figure was based on a business case submitted by the HCT and the challenge was to ensure that the total construction area fell within it. The commercial property development arm of the Abu Dhabi Government, Mubadala Development Corporation, used the EventMAP software in partnership with EventMAP as a planning tool to determine the full schedule of accommodation for the campus development.

Applying the software to determine key space drivers, the project was able to reduce the total required floor area by 25,000 m^2, ensuring that the parameters of the business case could be met. Validation through the construction of a valid timetable proved to both the Abu Dhabi Government and to HCT that the reduced total floor area was adequate and appropriate for their requirements. The commercial developers, Mubadala Infrastructure, have estimated that the usage of the Optime software and associated engagement with EventMAP helped reduce the resource requirement, leading to savings of £4.6m. (Because of regional commercial sensitivities, it has not been possible to obtain written confirmation of this financial aspect of the impact, though the second source below can corroborate the details.)

(iii) At Imperial College London, a similar use of EventMAP's tools and expertise led to further impact through involvement in ICL's South East Quadrant project. Imperial College sits on some of the most expensive real estate within the UK. Prior to the engagement with EventMAP, projected

short-term capital build costs were estimated at more than £20m. As the need to maximise space utilisation was therefore paramount, Imperial College engaged with EventMAP. Work took place between April 2008 and September 2012. Using EventMAP's Optime and AutoMAP tools, the QUB team, through EventMAP, conducted a thorough space assessment. Recommendations informed the College's capital build strategic planning. This included the internal remodelling of space within the South East Quadrant. One outcome, as expressed by Imperial, was:

"*EventMAP's expertise and software tools for planning and scheduling enabled Imperial College to generate capital savings estimated at £600K*."

EventMAP also delivered a distributed Enterprise Resource Planning (ERP) system for Imperial College, which maximised the use of institutional space while improving the education environment for students and staff. The Timetabling Project Manager at the time has said that the system:

"*has allowed Imperial College to deliver much improved flexible timetables while maximising the use of space… the time taken to construct departmental timetables was halved. The overall implementation process has represented significant cost savings*. "

(iv) As EventMAP's reputation has built up, the company has won a number of significant contracts during the assessment period in resource management and timetabling with around 15 leading UK and international educational institutions. These include three from the Russell Group's top five universities. EventMAP has also extended its reach overseas. Since 2008 it has won contracts with leading overseas universities; in addition to the above examples in Australia and Abu Dhabi, these include Deakin University, Melbourne, the University of Sydney, Helsinki University and Paris-Sorbonne University. After the success of the major international projects above, EventMAP received financial assistance from Invest Northern Ireland (£41k in January 2012 and £21K in April 2013) to accelerate the company's entry into key export markets.

(v) At the start of the assessment period (2008), the company had just two part time employees. Since then, it has grown to 8 FT and 5 PT employees and doubled turnover in each successive year to £410k. In this period it has developed and launched four separate products covering resource modelling and exam and event scheduling, all underpinned by its powerful Optime scheduling engine which incorporates algorithms developed by the QUB team as part of the underpinning research. Specifically, these include a hybridisation of the extended Great Deluge Improvement metaheuristic with an adaptive construction heuristic. The algorithms were also implemented within EventMAP's bespoke AutoMAP management methodology which accurately models sustainable change within an institution.

EventMAP's tools uniquely link intuitive problem modelling of resource requirements and constraints with a range of underlying techniques capable of producing practical and holistic solutions. Competitors, by contrast, are unable to translate the resource needs into a usable model which is intuitive and interactive. In addition, because competitor solutions use 'greedy' optimisation algorithms that work sequentially through a problem, resultant solutions are often incomplete and therefore unworkable. This has given EventMAP an important competitive advantage, and has helped in delivering commercial impact.

5. Sources to corroborate the impact (indicative maximum of 10 references)

To corroborate the impact of EventMAP on the Victoria University project, the contact is now at :
Manager, Space Management Systems
Facilities Services Division, Deakin University

For corroboration of the impact of EventMAP on the Abu Dhabi Men's College project:
Senior Business Development Manager
Mubadala Infrastructure

To corroborate the impact of EventMAP on the Imperial College South East Quadrant project
Space Management and Timetabling Project Manager
Imperial College London