Institution: University of Portsmouth

Unit of Assessment: 10 Mathematical Sciences

Title of case study: The use of goal programming to optimise resource allocation in hospitals in the UK and China.

1. Summary of the impact

Managers of hospital units are required to allocate medical resources in accordance with, sometimes conflicting, objectives and performance targets and against continual variations in patient flow, staff and bed availability. The Logistics and Operational Research Group (LORG) at the University of Portsmouth has developed novel models, based on a combination of discrete event simulation, multi-phase queuing theory, and goal programming, that have improved the understanding of ward logistics by hospital managers in the UK and China, enabling them to make changes that have improved the efficiency of bed allocation, patient flow and allocation of medical resources and improved outcomes for patients.

2. Underpinning research

The underpinning research was conducted by members of the Logistics and Operational Research Group (LORG), which has grown from the former Logistics and Management Mathematics Group, Department of Mathematics, University of Portsmouth, under the leadership of Professor Dylan Jones (1997-present; Principal Lecturer at the time of the research). Key academic co-investigators included: Dr Patrick Beullens, Principal Lecturer, 2004-2010) and Professor M Tamiz, (Professor of Operational Research, 1991-2008).

Goal programming is one of the most widely known and used techniques within the field of Multi-Criteria Decision Making (MCDM) with decision makers appreciating its relative simplicity and ease of use. Members of the LORG in the Department of Mathematics at the University of Portsmouth have been involved in advancing the theory and application of goal programming since 1993, with their first publication on the topic of modelling non-linear preference functions (R1) appearing in 1995. Goal programming methodology was further developed by LORG members as a tool that can effectively model a variety of utility functions of decision makers, including the combination of balance and optimisation (R2), and was combined with other Operational Research modelling techniques, such as discrete-event simulation and queuing theory (R3), to provide a powerful and flexible modelling paradigm to capture and optimise the flow of entities through a system with multiple, conflicting criteria by which the effectiveness of a solution could be measured.

Members of the LORG have been advancing the use of goal programming as part of a mixed modelling methodology applied to healthcare resource optimisation, a topic which exhibits multiple criteria and a stochastic flow of patients in a complex and resource-constrained decision-making environment. A set of integer goal programming models was developed and used to predict resource levels in short-stay critical-care hospital units considering the conflicting objectives of minimising patient delay and achieving target levels for doctor, nurse, and bed numbers (R4). This work was further expanded to develop a novel mixed modelling methodology in which discrete event simulation and goal programming are combined (R5). The discrete-event simulation model is used to capture flow through a complex hospital unit, and the goal programming model to optimise resource levels whilst minimising delays for the different resource types. A different goal-programming methodology, suitable for non-critical care hospitals, was also developed. This used a combination of multi-phase queuing theory to model the arrivals of patients at a hospital and integer goal programming with piecewise linearization to allow for the generation of Pareto-optimal solutions against the conflicting criteria of probability of patient admission and generation of sufficient revenue (R6).

3. References to the research

The three references marked (*), R4, R5, and R6, best represent the quality of the research.

R1: Jones, DF, Tamiz, M. (1995). Expanding the flexibility of goal programming via preference modelling techniques, Omega, 23, 41-48. DOI: 10.1016/0305-0483(94)00056-G

R2: Tamiz, M, Jones, DF and Romero, C. (1998). Goal programming for decision making: An overview of the current state-of-the-art, European Journal of Operational Research, 111, 569-581. DOI: 10.1016/S0377-2217(97)00317-2

R3: Jones, Dylan and Tamiz, M. (2010) Practical goal programming. International Series in Operations Research and Management Science, 141 (141). Springer, New York. ISBN 9781441957702 http://www.springer.com/business+%26+management/operations+research/book/978-1-4419-5770-2

R4(*): J P Oddoye, M A Yaghoobi, M Tamiz, D F Jones and P Schmidt (2007) A multi-objective model to determine efficient resource levels in a medical assessment unit, *Journal of the Operational Research Society,* 58, 1563-1573. DOI: 10.1057/palgrave.jors.2602315

R5(*): Oddoye JP, Tamiz M, Jones DF, Schmidt P (2009), Combining Simulation and Goal Programming for Healthcare Planning in a Medical Assessment Unit, European Journal of Operational Research, 193, 250-261. DOI: 10.1016/j.ejor.2007.10.029 Ref2 output: 10-DJ-001

R6(*): Li X, Beullens P, Jones DF, and Tamiz M (2009) An integrated queuing and multi-objective bed allocation model with application to a hospital in China, Journal of the Operational Research Society, 59, 1-9.
DOI: 10.1057/palgrave.jors.2602565 Ref2 output: 10-DJ-003

R1, R2, R4, R5, and R6 are papers in highly-ranked and well-respected Operational Research journals: the journal Omega is ranked 3rd highest in SJR rankings for Operations Research and Management Science and has a 2012 5-year Impact Factor of 3.474. The European Journal of Operational Research is ranked 9th in SJR and has a 2012 5-year Impact Factor of 2.524.

Finally, the Journal of the Operational Research Society is ranked 23rd in SJR – within the SJR top quartile – has a 2012 5-year Impact Factor of 1.282, and is the premium publication of the UK OR Society. R5 and R6 are included in the research outputs of this submission. In addition, Jones has been invited as key speaker on this work at conferences, including the workshop of the Decision Analysis Special Interest Group (DASIG) of the Operational Research Society (UK, 2011) and as a plenary speaker at the international CMAC-Sudeste Conference on Applied and Computational Mathematics (Brazil, 2013).

4. Details of the impact

Details of two projects undertaken by LORG members for hospitals in the UK and China, each serving a catchment area of several hundred thousand potential patients, but with different objectives and modes of operations, will be given.

The first project involves the Queen Alexandra Hospital which is part of Portsmouth Hospitals Trust and provides acute care provision for the region of Portsmouth and South East Hampshire. The initial work involved helping the clinicians of the Medical Assessment Unit (a buffer department strategically placed between the Accident and Emergency Department and the rest of the hospital) understand the nature of the patient flow and resource capacity restrictions they faced. The project began when the University of Portsmouth was approached by the Queen Alexandra Hospital as the Medical Assessment Unit (MAU) was a new concept in UK patient flow management at that time.

Their MAU had undergone a rapid expansion from 8 to 58 beds and this had led to many questions regarding resource levels, optimal patient-flow pathways, and lengths of stay, that were non-trivial in nature and required the techniques developed by LORG members to answer. This was achieved by a series of over ten face-to-face meetings during which goal programming and simulation models were built and refined as the preferences and goals of the practitioners were elicited. In order to gain the depth of data required to build an accurate simulation model, a member of LORG spent a period of three weeks collecting data and liaising with medical staff at the MAU. The impact was due to the results of the models built and the knowledge gained by the MAU managers, particularly Dr Paul Schmidt who was responsible for the resource management of the MAU, which were used to inform the policy and practice of the medical assessment unit with respect to bed allocation policy, patient flow management, and resource allocation. The impact of this project has taken place in the period since the conclusion of the project in 2008 and has specifically resulted in:

- An understanding of the optimal levels of nurses and doctors which has assisted in the setting of appropriate resource levels in the MAU based on the knowledge gained during the formulation and solution of the model.
- A quantification of the amount of time that nurses spend on patient centred and non-patient centred tasks (shown by the project to be 50% on each) which has led to better policies for nurse workload allocation. Some non-patient centred tasks have hence been reduced and eliminated whilst others have been mitigated against.
- A successful application to the South Central Health Authority for a £160,000 grant allowing QA hospital to undertake a larger project simulating their entire emergency pathways. The MAU project has thus acted as a catalyst to allow the hospital management to engage with and utilise the power of mixed modelling simulation techniques.

The second case study involves the Zichan hospital, based in Zichan, China, a state run but profit making non-emergency care hospital serving the population of the Zichan region which approached the University of Portsmouth as they had a set of beds split between their hospital departments that were allocated in an arbitrary rather than a systematic manner. The hospital was looking to optimise their bed allocation against the two criteria of overall profit and probability of direct patient admittance. The hospital manager was also concerned that the preferences of all the department managers were fairly represented and modelled.

The preferences of the hospital and departmental managers where thus elicited through the analytical hierarchy process (AHP) technique, and multi-phase queuing theory was used to capture analytically the flow of patients requiring different treatments to the hospital. A LORG member visited the hospital in order to collect primary data to supplement the existing data. A set of goal programming models was then developed, in correspondence with the general manager of the hospital in order to validate and verify the models built and their results. The models recommended a different bed allocation between departments that improved both the probability of direct patient admission and the overall profits of the hospital. The impact occurred in the period from the conclusion of the study in 2008 until the present and has consisted in enhanced knowledge of the dynamics of the allocation of beds in the hospital. This has allowed for more efficient policies with respect to bed allocation at the hospital to be implemented which re-distributed the beds by allocating more to departments shown in the study to have overly high utilisation rates. This has led to the following improvements against the set objectives of the study:

- An improvement of the percentage of directly admitted patients in the period 2008-2013.
- The doubling of overall profits in the period 2008-2013.
- An efficient bed policy for the new expanded 450 bed (previously 280 bed) hospital to be implemented upon and since its opening in 2010. This policy used the logic of the LORG model as its base.

5. Sources to corroborate the impact

1) Factual Statement from the Medical Director, Trust Headquarters, Queen Alexandra Hospital, Portsmouth Hospitals NHS trust. This confirms details of the study undertaken and the benefits gained by the Queen Alexandra Hospital.

2) Factual Statement from CEO, Zichan Hospital, Zichan, China. This confirms details of improvements in the percentage of directly admitted patients, doubling of hospital profits and a new bed policy with efficiency improvements.

3) Conference Presentation Slides, IMA Quantitative Methods in Healthcare conference, London, 2008. These give details of the healthcare projects undertaken in both hospitals.

4) Poster presented at INFORMS conference, San Diego, USA, 2009. This give details of the healthcare projects undertaken in both hospitals.

5) Workshop presentation slides, presented at DASIG workshop, Portsmouth, UK. This give details of the healthcare projects undertaken in both hospitals.