



Keynotes and Extended Abstracts

Edited by
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University of Exeter

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Peter Chalk Centre
University of Exeter



THE OR SOCIETY

YOR18

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Keynote Papers
and
Extended Abstracts

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University of Exeter, UK

Foreword

On behalf of the entire organising committee I am delighted to welcome you to the biennial conference of The OR Society, YoungOR18, held at University of Exeter, which was selected as “University of the Year” by Sunday Times.

Held during 9-11 April 2013, YoungOR presents a rich and exciting programme for both practitioners and academics with experience of up to ten years in Operational Research. The conference brings together the future generation of operational researchers to provide an excellent forum whilst sharing and updating the knowledge of the field in a collaborative and supportive way. Moreover, scheduled tutorial and training sessions in the programme give the opportunity of engaging with various challenging issues in your field of interest while widening your network.

Like the previous ones, a number of interesting keynote papers from both academics and practitioners have been received for this conference. In addition to the keynote papers, the submissions of extended abstracts were also accepted to be included in this book. The papers presented here cover a wide range of opportunities for learning from some of the best and brightest in their fields. We hope that you enjoy them.

In the *Infrastructure* stream, Andy Chow presents a framework for linear modelling and optimisation of road transport infrastructure. This framework contributes to the assessment, modelling, and management of infrastructure. Particularly, it provides useful insights on managing traffic flow with a specific example of motorway networks.

Franklin Fomeni, Konstantinos Kaparis, and Adam Letchford review the first level relaxation with alternative methods for mixed 0-1 programmes for *Optimisation* stream. They also propose a method of generating cutting planes that can be applied to any pure or mixed 0-1 programmewith a linear or quadratic objective.

In the *Supply Chain* stream, Vicky Forman presents a case study which shows the importance of embedding operational research techniques in any part of a well-known UK based retailer’s (Marks & Spencer) supply chain. This study analyses the critical role of OR in the company’s transformation process of supply chain structure to cope with increased complexity while delivering a reduction in inventory.

The *Strategy & Sustainability* stream comprises an interesting work by Miles Weaver and Andrea Bonfiglioli that provides an overview of the key contributions that have addressed issues in strategy and sustainability. They explore the OR Society contributions to sustainability against the OR/MS literature. It is asserted that OR contributions are predominantly focus on the theme of environmental management dimension but not social impact of sustainability.

Another interesting work, which surveys the importance of operational research, is carried out by Pavel Albores, Oscar Rodriguez, and Priyanka Roy in *Disaster Management* stream. They present an overview of the importance of OR in disaster management while providing some critics from previous contributions in the field, the most common OR tools to cope with

logistics issues in an emergency, and further research directions for new research opportunities are also waiting for the attention of the readers.

Paul Kailiponi and Duncan Shaw have also presented their keynote for *Disaster Management* stream on an interesting topic, evacuation decision making. A modular system of influence diagrams is presented for strategic decision-making processes along with an example of utilising this system to analyse evacuation policies on different aspects.

In the *DEA* stream, Jamal Ouenniche briefly reviews the basic concepts of DEA, and proposes an orientation-free super-efficiency DEA framework for assessing the relative performance of competing forecasting models for crude oil prices volatility

In the *Soft Methods* stream, Ashley Carreras analyses some significant developments within a few soft OR approaches, collectively known as Problem Structuring Methods (PSMs), by discussing the usage and effects of soft methods in practice.

In the *Health* stream, Hazel Squires, James Chilcott, Ronald Akehurst, and Jennifer Burr propose a conceptual modelling framework to help decision makers make appropriate policy decisions to improve the quality and communication of Public Health economic models.

Michael O'Connell and John James present how data scientists and other business users can be organised into a productive unit to cope with the differing requirements of data analysis, in *Analytics* stream.

The key similarities and variations between simulation models and general software development methodologies are discussed by Steven Jones, in the *Simulation* stream. The crucial points that simulation model developers can learn from other areas are emphasised as well.

Another exciting study in *Disaster Management* stream is presented by Priyanka Roy, Oscar Rodríguez-Espíndola, Pavel Albores-Barajas, and Christopher Brewster this year. They address the gap between the authorities and academics within this field and emphasise the importance of an effective logistical management process to deal with disaster within developing countries. A multi-method approach, which carries some advantages such as simpler models, increased interaction with authorities, easier tools, and more geographical systems, is proposed in the study.

We sincerely appreciate all keynote speakers and authors whose valuable contributions were helpful in making the conference a great success.

Ibrahim Kucukkoc

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KEYNOTE

Modelling and Management of Road Transport Infrastructure - A Linear Programming Approach

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Abstract

This paper presents a linear modelling and optimization framework for road transport infrastructure. The framework is developed based upon a macroscopic model of traffic flow. This underlying model of traffic is piecewise linear with which optimization of the network operations can be formulated as a linear programming and hence can be solved by established solution algorithm for the global optimal solution. The concept is illustrated through a specific example of motorway networks. The global optimal solution obtained from the linear programming may not be readily implementable in practice. However, it provides useful insights and guidance on how we should manage traffic flow. The work presented herein contributes to the assessment, modelling and management of transport infrastructure.

Keywords: Transportation; Traffic flow model; Congestion; Active traffic management; Linear programming (LP)

1. Introduction

The ever-increasing demand for travel raises various problems and issues including congestion, energy, environmental impact, safety and security. The UK Eddington study (Eddington, 2006) states that the monetary cost due to road congestion will reach £22 billion (at 2002 prices) per annum for all road users by 2025, in which 13% of road traffic will be subject to stop-start travel conditions. In a report published in 2009, UK Department for Transport (DfT) also suggests that congestion across the English road network as a whole will increase from 2003 levels by 27% by 2025, and 54% by 2035 (HM Treasury, 2012). Continuous construction of new roads will not be a sustainable solution due to the increasingly tight fiscal, physical and environmental constraints. Consequently, governments, businesses, and research teams around the world want to explore alternative ways to effectively utilize and manage existing road infrastructure. A sustainable solution for mitigating congestion calls for effective management of existing infrastructure through appropriate planning and control measures. Such an infrastructure system will have to be active so that it can sense prevailing conditions, and derive and implement appropriate actions without the need for additional physical capacity. Following Hegyi (2004), objectives of traffic management include: (i) maximizing efficiency (e.g. minimize the total time spent in travel); (ii) maximizing safety; (iii) maximizing travel reliability; (iv) minimizing fuel consumption; and (v) minimizing emission.

The paper presents the modelling framework for analysing and optimizing the operational performance of transport infrastructure. This paper will illustrate the concept through a specific example of motorway networks. Infrastructure management is a continuous process of (i) obtaining and processing the traffic data; (ii) performance analysis; (iii) deriving the most promising control plans; and (iv) predicting the traffic state in the near future. Figure 1 shows the overall structure, where we have

1. the on-site sensors monitor the infrastructure and collect traffic data;
2. the central computer uses the traffic model to evaluate the transport network performance and produce short-term predictions. The computer also has an optimization algorithm to derive optimal control strategies accordingly;
3. the control devices implement the control strategies to the field.

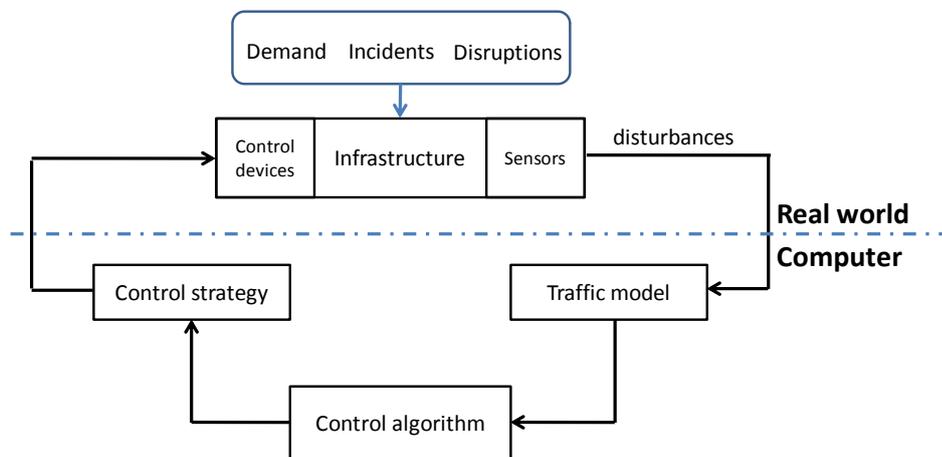


Figure 1 Architecture of transport management system

The core part of the system will be the embedded traffic model which is responsible for processing feeding data, deriving control plans, and generating state predictions. Traffic models are mathematical representation that describes, estimates, and hence controls the behaviour of traffic flow. The importance of traffic model for active transport management is highlighted by Kotsialos and Papageorgiou (2001). Traffic models can be broadly categorized into micro- and macroscopic models. Microscopic models simulate the behaviour of each vehicle and their laws are drawn from cognitive studies, artificial intelligence, and measurements with the use of in-vehicle devices. Although microscopic models capture fine details of the real-world, they are demanding in terms of computation and calibration which hinders models of this kind from large-scale and real time applications. For real time applications, the traffic model has to be efficient and reliable: it has to be parsimonious and easy to calibrate and operate; it has to be founded on sound theory of traffic flow. (Kurzhanskiy and Varaiya, 2010).

Macroscopic models represent traffic dynamics in terms of aggregated quantities: volume, density and mean speed of traffic. In general, the required macroscopic data can be readily obtained from standard surveillance infrastructure such as loop detectors, cameras, and other kinds of fixed sensors. Moreover, macroscopic models are much more efficient than their microscopic counterparts in terms of computation and calibration. This makes macroscopic models feasible candidates for large-scale applications in real world. Consequently, the modelling and optimization framework presented in this paper is developed based upon macroscopic models.

This paper is organized as follows: Section 2 introduces the traffic model that we use to capture the traffic flow characteristics on the infrastructure networks. Section 3 summarizes various indicators that we use to assess the performance of transport infrastructure operations. Section 4 presents different control strategies that we use to manage traffic flow. We also present the formation of the optimal design of control strategies as a linear programming based upon the assumed traffic model. Finally, Section 5 provides some concluding remarks.

2. Modelling of traffic flow

This section introduces the model of traffic dynamics that we adopt and the associated numerical scheme.

2.1. Lighthill-Whitham-Richards' kinematic wave model of traffic flow

Lighthill and Whitham (1955), and later Richards (1956), propose a macroscopic dynamic model of traffic which is known as the kinematic wave model or LWR model. The model considers three variables $f(x,t)$, $\rho(x,t)$ and $v(x,t)$ which respectively represent the average flow [dimension: veh/time], density [dimension: veh/space] and speed [dimension: space/time] at location x along a road section at time t . The speed $v(x,t)$ is considered to be related to the corresponding flow and density values as

$$v(x,t) = \frac{f(x,t)}{\rho(x,t)}, \quad (1)$$

for all x and t . The evolution of flow and density is governed by the conservation law:

$$\frac{\partial \rho(x,t)}{\partial t} + \frac{\partial f(x,t)}{\partial x} = r(x,t) - s(x,t), \quad (2)$$

where $r(x,t)$ and $s(x,t)$ are respectively the exogenous inflow (e.g. on-ramps) and outflow (e.g. off-ramps) at (x, t) .

Finally, $f(x,t)$ and $\rho(x,t)$ are related by a predefined flow-density function which is known as the *fundamental diagram* of traffic flow where:

$$f(x,t) = \Phi[\rho(x,t)] \quad (3)$$

for all x and t .

The flow-density function Φ , which is commonly known as the fundamental diagram (see some examples in Figure 2), is assumed to be concave and is defined for $\rho \in [0, \bar{\rho}]$, where $\bar{\rho}$ is called the jam density which is the maximum density of traffic that can be achieved at the corresponding location x . Moreover, a critical density ρ^* is defined at which a maximum value of flow is obtained, in which Φ is increasing for all $\rho < \rho^*$ and Φ is decreasing for $\rho > \rho^*$. Heydecker and Addison (2011) and Carey and Bowers (2012) present a comprehensive review of different fundamental diagrams Φ for traffic flow modelling.

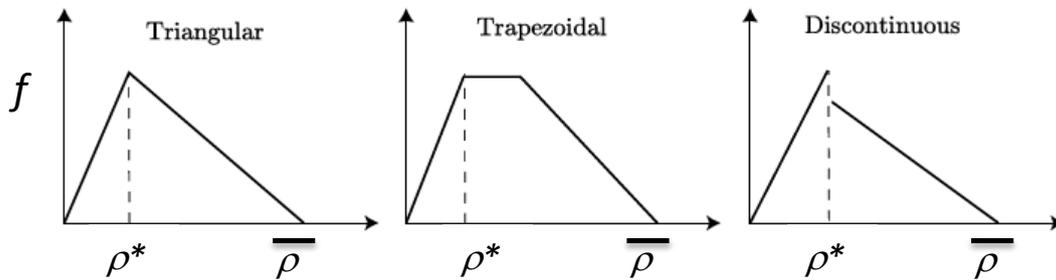


Figure 2 Different specifications of fundamental diagrams Φ

2.2. Numerical implementation – cell transmission model

A number of numerical schemes have been proposed for solving the LWR model, where the cell transmission model remains one of the widely adopted solution framework in both research and industrial communities. The cell transmission model (CTM) is a finite difference approximation of LWR model proposed by Daganzo (1994). Under the cell transmission formulation, the road section is discretized into a collection of sub-sections or ‘cells’ as shown in the figure below.

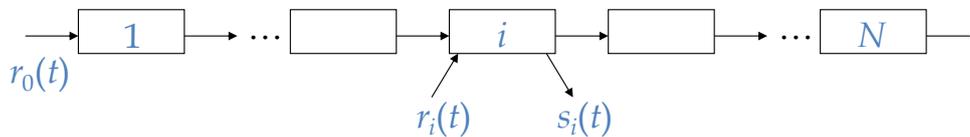


Figure 3 Discretization of a road section

The cells are numbered from the upstream 0 to the downstream N . Each cell i can further be associated with an external incoming flow $r_i(t)$ (e.g. an on-ramp) and an external outgoing flow $s_i(t)$ (e.g. an off-ramp) at each simulation time step t .

In the cell transmission formulation, traffic dynamics are characterised by flow and density in each cell at each time. The evolution of traffic flow and density is governed by the principles of flow conservation and propagation.

Define $f_i(t)$ be the traffic outflow from cell i during time step t , and hence $f_{i-1}(t)$ (outflow from upstream cell $i - 1$) will be the inflow to cell i during the same time t . The density in cell i at the following time step $t+1$ can then be updated by the conservation equation:

$$\rho_i(t+1) = \rho_i(t) + \frac{\Delta t}{\Delta x_i} [f_{i-1}(t) - f_i(t) + r_i(t) - s_i(t)], \quad (4)$$

where Δt and Δx_i are respectively the lengths of simulation time step and the cell i . It is noted that Equation (4) indeed is a discretized version of Equation (2). The time step size Δt is set such that $v\Delta t \leq \min_i \Delta x_i$, and $\min_i \Delta x_i$ refers to the shortest cell length along the section, v is largest value of free-flow speed along the stretch. The above condition is known as the Courant-Friedrichs-Lewy (CFL) condition which is used to ensure the numerical stability by constraining the traffic not travel further than the length of the cell in one simulation time step.

Given the cell density, the cell transmission rule models the outflow from cell i within time step t by a piecewise linear fundamental diagram as

$$f_i(t) = \min \{v_i \rho_i(t), Q_i, w_{i+1} [\bar{\rho}_{i+1} - \rho_{i+1}(t)]\}, \quad (5)$$

where Q_i is the maximum flow (or capacity flow) that can enter cell i . Equation (5) can be regarded as a piecewise linear approximation of Equation (3). When there is no congestion, the traffic stream moves from one cell to the next at free flow speed, v_i . The notation w_{i+1} is the backward shockwave speed specified by the fundamental diagram at the downstream cell $i + 1$, and $\bar{\rho}_{i+1}$ is the jam density at cell $i + 1$. The quantity $[\bar{\rho}_{i+1} - \rho_{i+1}(t)]$ specifies the available space for incoming traffic at the downstream cell $i + 1$ during time t . The above formulation covers both congested and uncongested regimes.

2.3. Calibration of cell transmission model

The fundamental diagrams in the cell transmission model will have to be calibrated before the model can represent the real world traffic dynamics. As an illustration, Figure 4 shows a scatter plot of flow against density data from a typical detector on motorway. The scatter plot shows a bivariate relationship between flow and density as discussed in previous section. For each of these useable detector stations (i.e. detector containing valid data), calibration of the corresponding fundamental diagram can be carried out in three stages: determination of free-flow speed v , determination of capacity Q , and determination of congestion shockwave speed w . Given the flow-density data, these parameters can be determined by a least-square method

where Figure 4 shows an example. Critical and jam densities can be derived accordingly after obtaining the above three parameters.

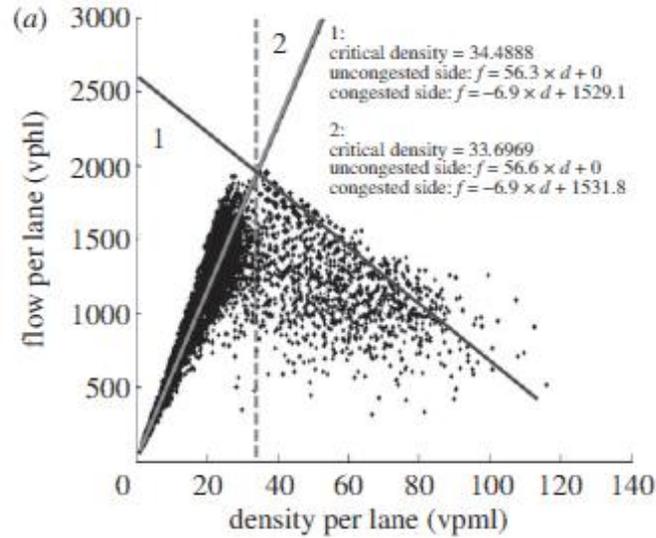


Figure 4. Calibration of fundamental diagram

In addition to the fundamental diagrams, we also need to define the boundary conditions (i.e. the demand profiles and off-ramp split ratios at each node) to complete the formulation of the dynamic model. On-ramp and off-ramp flow data on UK motorways are available from MIDAS (Motorway Incident Detection and Automatic Signalling) data set which can be used to construct the on-ramp demands and off-ramp split ratios. In cases where the ramp data are missing, one can adopt some imputation algorithm (see for example: Muralidharan and Horowitz, 2009) to fill in the missing ramp data.

3. Performance measures

Before proceeding to optimization, we need to formulate a set of indicators of performance for assessing the infrastructure operations. The indicators should provide quick, meaningful, and reliable quantitative assessment of the performance benefits that can be gained from various control plans. Some performance indicators that can be derived from measured data and simulator are listed as follows:

- a) **Traffic speed** (at location x and time t) – speed, which is just like journey time, is one of the most important indicators of mobility. According to the fundamental definition of the traffic flow quantities, speed can be taken as the flow divided by associated density at (x, t) , which is

$$v_i(t) = \frac{f_i(t)}{\rho_i(t)} \quad (6)$$

- b) **Vehicle-Distance-Travelled (VDT)** – is the measure of the throughput of the link during the current time step:

$$VDT_i(t) = f_i(t)\Delta x_i\Delta t \quad (7)$$

- c) **Vehicle-Hour-Travelled (VHT)** – reflects the time that the vehicles spend in the link:

$$VHT_i(t) = \rho_i(t)\Delta x_i\Delta t \quad (8)$$

- d) **Delay (D)** –

$$D_i(t) = VHT_i(t) - \frac{VDT_i(t)}{v_f} \quad (9)$$

where v_f is a predefined free flow speed threshold.

It is noted that all the performance indicators can be computed at run time of the simulation model. Knowing these performance indicators one can evaluate the overall performance of different control plans.

4. Control and optimization

Consider motorway operations, there are three main control strategies: ramp metering, variable speed control, and dynamic hard shoulder. They are introduced briefly as follows.

Ramp metering (see Figure 5) aims at improving the traffic flow on motorway by regulating the inflow from the on-ramps to the mainstream. Ramp metering can be either fixed time or traffic-responsive. Traffic responsive meters are based on real-time measurements from detectors or other kinds of sensors installed in the motorway network. Ramp metering can further be classified into local or coordinated.

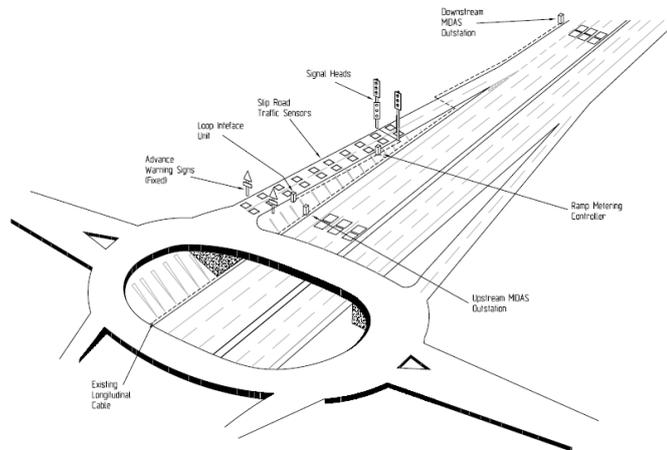


Figure 5 UK installation of ramp metering system (Source: Highways Agency, 2007)

Variable speed control scheme aims to adjust to speed limit according to traffic conditions on the road. The objective is to improve mobility through managing the formation of congestion and smoothing traffic flow, as well as safety through reducing the variance in speed.

Dynamic hard shoulder - on a conventional motorway, the hard shoulder must not be driven on except in an emergency or breakdown. In areas where a “Dynamic hard shoulder” scheme is in force, motorists may use the hard shoulder as a running lane when indicated.

The control strategies can be implemented in a local and ‘ad-hoc’ manner in which we can make use of measurements from the vicinity of the controllers. Some prominent examples of local strategies include ALINEA strategy (Papageorgiou et al., 1991) and its variations. The ALINEA strategy and its variations are feedback control schemes targeting a set-point (typically the critical value) for the downstream occupancy.

The weakness of the control strategies mentioned above is that they are local and feedback (i.e. they operate based upon observations in the past). An effective control system should be network-wide and predictive. The need for a predictive global control system leads to the development of a centralized optimization algorithm.

The optimization algorithm uses a traffic model of the infrastructure network and predict the response of the system to the control actions. It consists of the following components:

1. the objective function;
2. the traffic model with calibrated parameters;
3. origin-destination pairs for the motorway network;
4. the definition and constraint set on the control variables.

It is known that the traffic dynamics in cell transmission model (the outflow function, (5)) can be reformulated as the following linear program (Lo, 1999, Ziliaskopoulos, 2000, Gomez and Horowitz, 2006):

$$\begin{aligned} &\text{Maximize} && f_i(t) \\ &\text{Subject to} && f_i(t) \leq v_i \rho_i(t) \end{aligned} \tag{10}$$

$$f_i(t) \leq Q_i \tag{11}$$

$$f_i(t) \leq w_{i+1} [\bar{\rho}_{i+1} - \rho_{i+1}(t)] \tag{12}$$

for all cell i and time t .

This enables the optimization problem based upon cell transmission model to be formulated as a linear programming (LP) and to be solved sequentially in time and space by established algorithm (e.g. SIMPLEX algorithm) for the global optimal solution.

Given the network configuration (with calibrated parameters: v_i , Q_i , w_i , and $\bar{\rho}_i$) and demands, we can formulate a optimization problem that aims to seek an optimal flow pattern that minimizes the total network delay as follows:

$$\min \sum_i \sum_t D_i(t) = \sum_i \sum_t \left[VHT_i(t) - \frac{VDT_i(t)}{v_f} \right] \quad (13)$$

subject to

conservation equation (4)

outflow equations (10), (11), and (12)

constraints on control variables (e.g. maximum queue lengths, minimum speed limits, etc)

The global optimal solution obtained from the programming may not be readily implementable in practice, say, one may not be able to limit the access from every single ramp or the speed at every single section along the motorway. However, it provides useful insights and guidance on how we should manage traffic flow. The LP formulation has been used to solve for optimal signal timing strategies in urban networks (Lo, 1999) and ramp metering strategies in freeway networks (Gomez, 2004).

The control plans can be implemented and tested on the macroscopic model through manipulating the model parameters. For example, ramp metering can be implemented by adjusting the ramp inflow rate (r_i) of the associated on-ramps, variable speed limit by adjusting the free-flow speed (v_i) of the associated sections or cells, hard shoulder running can be captured by adjusting the capacity value (Q_i) of the associated sections.

5. Conclusion

This paper presents a linear modelling and optimisation framework for transport infrastructure management where we illustrate through a specific example of motorway networks. The framework is developed by using Daganzo's (1994) macroscopic cell transmission model, which is shown to be a plausible and reliable representation of real traffic through extensive theoretical and empirical studies. With the piecewise linear structure of the cell transmission model, the corresponding optimization of network operations can be formulated as a linear programming which can be solved by established algorithms for the global optimal solution. The optimal solution may not be readily implementable in practice, while it provides

important insights to how we should manage traffic flow. For motorway management, the optimal solution can be used as guidelines for deriving ramp metering, variable speed limit, and dynamic hard shoulder running strategies for maximizing efficiency, reliability, and safety of motorway operations. The optimizer can also be implemented into a dynamic optimization framework, say optimal control and dynamic programming, for real-time operations. The work presented herein contributes to the assessment, modelling and management of transport infrastructure.

Acknowledgement

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KEYNOTE

Strong First-Level RLT Relaxations of Mixed 0-1 Programs

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Abstract

The *Reformulation-Linearization Technique* (RLT), due to Sherali and Adams, is used to construct hierarchies of linear programming relaxations of various optimisation problems. We review the *first-level* (RLT) relaxation, along with alternative relaxations for *mixed 0-1 programs*. We also describe a method for generating cutting planes in the space of the first-level RLT relaxation, based on optimally weakening valid inequalities for the second-level. The resulting cutting planes can be applied to any pure or mixed 0-1 program with a linear or quadratic objective function, and any mixture of linear, quadratic and convex constraint functions.

Keywords: Reformulation-linearization technique, Cutting planes, 0-1 quadratic programming, Quadratic knapsack problem, Quadratic assignment problem.

1. Introduction

Numerous methods for tackling 'hard' optimization problems, rely on solving some *relaxation* of the original problem. By relaxing the 'hard' conditions of the given formulation, one yields a bound and other useful information for the true optimal solution. This information can be exploited within an algorithmic framework to guide the search of the solution space. The most prominent example is probably the *linear programming (LP) relaxation* for *integer linear programs*, obtained by relaxing the integrality condition.

The *Reformulation-Linearization Technique* (RLT), developed by Adams, Sherali and co-authors, is a general framework for constructing strong linear programming relaxations of various optimisation problems. It was first developed in Sherali and Adams (1990), in the context of 0-1 Linear Programs (0-1 LPs). Then, in Sherali and Adams (1994), it was extended to the *mixed* case, i.e., the case in which some variables are continuous rather than binary. Since then, it has been further extended, to cover a wide range of integer programming and global optimisation problems (see, see, e.g., Sherali (2007); Sherali and Adams (1998)).

Actually, RLT enables one to construct an entire *hierarchy* of LP relaxations. If the original problem has n variables, then the first relaxation in the hierarchy, the so-called *first-level*

relaxation, has an additional $\binom{n}{2}$ variables. The relaxation above it, the *second-level* relaxation, has a further $\binom{n}{3}$ variables, and so on. This hierarchy has some interesting theoretical properties, but, for many problems of practical interest, one can hope to solve only the first-level relaxation, since the higher-level relaxations have too many variables. In fact, even solving the first-level relaxation can be a challenge.

First-level RLT relaxations can be derived for many different kinds of problems; specifically, any mixed 0-1 program in which the objective function is either linear or quadratic, and each constraint is either linear, quadratic or convex. In this paper, we present a procedure for generating valid linear inequalities that strengthen these relaxations. The inequalities are derived by taking valid linear inequalities for the *second-level* relaxation (which can be easily derived in a number of ways), and then weakening them to make them valid for the first-level relaxation. Interestingly, a single valid second-level inequality can be the source for an exponentially-large number of first-level inequalities.

The paper is organised as follows. In Section 2, we review the relevant literature. In Section 3, we present the valid inequalities and discuss the associated separation algorithms, for the special case in which all of the original constraints are linear. Some concluding remarks are presented in Section 4.

2. Literature review

2.1. The original version of RLT

The RLT was first introduced in Sherali and Adams (1990), in the context of 0-1 LPs. Suppose we have a 0-1 LP of the form:

$$\min c^T x \tag{1}$$

$$s.t. Ax \leq b \tag{2}$$

$$x \in \{0,1\}^n, \tag{3}$$

where $c \in Q^n$, $A \in Q^{m \times n}$ and $b \in Q^m$. The *continuous relaxation* of the 0-1 LP is the problem obtained by replacing the constraints (3) with the weaker constraints $x \in [0,1]^n$.

Let $N = \{1, \dots, n\}$. For all pairs $\{i, j\} \subset N$, let y_{ij} be a new binary variable, representing the product $x_i x_j$. We now construct new linear inequalities involving the x and y variables, in the following way:

- Each linear inequality in the system (2), say $\alpha^T x \leq \beta$, is multiplied by each variable

in turn, to obtain n quadratic inequalities of the form $(\alpha^T x)x_s \leq \beta x_s$. Replacing quadratic terms of the form $x_i x_s$ with y_{is} , and using the identity $x_s^2 = x_s$, we obtain n new linear inequalities of the form:

$$\sum_{i \in N \setminus \{s\}} \alpha_i y_{is} \leq (\beta - \alpha_s) x_s. \quad (4)$$

- Each linear inequality is also multiplied by the *complement* of each variable, to obtain n quadratic inequalities of the form $(\alpha^T x)(1 - x_s) \leq \beta(1 - x_s)$. This yields n new linear inequalities of the form:

$$\sum_{i \in N \setminus \{s\}} \alpha_i (x_i - y_{is}) \leq \beta - \beta x_s. \quad (5)$$

- Finally, we multiply pairs of bounds of the form $x_i \geq 0$ or $1 - x_i \geq 0$, to obtain $y_{ij} \geq 0$, $y_{ij} - x_j \geq 0$ and $y_{ij} - x_i - x_j + 1 \geq 0$ for all pairs i, j .

Sherali and Adams showed that this new LP relaxation of the problem is stronger than the LP relaxation of the original problem. Of course, this is at the expense of introducing $\binom{n}{2}$ new variables and $O(n(m+n))$ new constraints.

It is known (see, e.g., Balas et al. (1993); Laurent (2003); Lovasz and Schrijver (1991)) that the projection of the above extended LP formulation into the space of the original x variables satisfies all *simple disjunctive cuts*. A simple disjunctive cut is a valid linear inequality for the original 0-1 LP that is implied by the original constraints (2), the bounds $x \in [0, 1]^n$, and a single *disjunction* of the form $(x_i = 0) \vee (x_i = 1)$, for some $i \in N$. Simple disjunctive cuts were introduced by Balas (1979).

Sherali and Adams went on to construct an entire hierarchy of relaxations, by defining variables that correspond to products of 3 variables, products of 4 variables, and so on. The continuous relaxation gets stronger as one moves up the levels of the hierarchy, but the number of variables and constraints increases dramatically. For the sake of brevity, we do not go into details. In any case, in practice, it is often the first level that is of most use. See Sherali and Lee (1996) for an application of the first-level RLT to the set partitioning problem, and Hunting et al. (2001) for an application to the so-called *edge-weighted clique* problem.

2.2. Extensions of RLT to more general problems

The RLT was extended to *mixed* 0-1 LPs in Sherali and Adams (1994). The procedure is similar, but with three small differences. The first is that one must first scale all continuous variables so that they are bounded between zero and one. The second is that one defines the

variables y_{ij} only when at least one of the variables x_i and x_j is binary. The third is that one multiplies the original linear inequalities and bounds only by binary variables and their complements.

Adams and Sherali (1986) applied the first-level RLT to 0-1 *quadratic* programs. The idea is simply that any quadratic term $x_i x_j$ in the objective function is replaced with the corresponding term y_{ij} . This RLT variant has been applied, for example, to the *quadratic assignment* problem Adams and Johnson (1994), the *quadratic semi-assignment* problem Saito et al. (2009), the *quadratic three-dimensional assignment* problem Hahn et al. (2008), the *quadratic knapsack* problem Billionnet and Calmels (1996) and the *linear arrangement* problem Amaral (2009).

The RLT has been extended to many other problems in integer programming and global optimisation. See, e.g., Sherali (2007); Sherali and Adams (1998) for details. Also see Laurent (2003) for a comparison between the Sherali-Adams procedure and other related procedures.

One other extension of particular relevance to us, due to Lovasz and Schrijver (1991), is the following: suppose that, instead of being given a linear inequality system $Ax \leq b$, one is simply given the condition that x must belong to some convex set $C \subset [0,1]^n$. One can define inequalities of the form (4) and (5) in this more general setting, by choosing any pair (α, β) such that the inequality $\alpha^T x \leq \beta$ is valid for C . Lovasz and Schrijver showed that, if an efficient separation algorithm exists for C , then an efficient separation algorithm exists also for the inequalities that can be derived in this way.

2.3. Further relaxations

Relaxations alternative to the first level RLT have been proposed in the literature. In this subsection, we briefly outline some of them.

2.3.1. Polyhedral theory

Given a nonempty and compact set described by a finite set of *linear inequalities*, the *convex hull* of its integer points is a *polytope* characterized by a finite set of linear inequalities. Unfortunately, for most practical cases computing the full polyhedral description of the convex hull is a hard 'problem'. Still, *partial descriptions* can be rather useful since they can reduce significantly the number of points that should be enumerated.

A milestone idea was introduced by Fortet in his seminal paper (1959). He outlined a way to linearize any pure 0-1 quadratic problem with n binaries by adding $O(n^2)$ binaries and constraints. Linearisation methods with $O(n)$ additional variables and constraints were proposed later on by Glover (1975) and more recently by others (Chaovalitwongse et al. (2004); Adams and Forester (2005); Sherali and Smith (2007)).

By studying the *convex hull* of feasible solutions for the linearised formulation, one can discover families of *valid inequalities*. Such inequalities can be used to derive strong relaxations of quadratic programs.

Padberg in his seminal work (1989) defined the *Boolean Quadric Polytope*

$$BQP_n := \text{conv} \left\{ (x, y) \in \{0,1\}^{n+\binom{n}{2}} : y_{ij} = x_i x_j, (\{i, j\} \subset N) \right\}. \quad (6)$$

Furthermore, he characterized many valid and facet-defining inequalities like the *triangle inequalities*.

$$-x_k - y_{ij} + y_{ik} + y_{jk} \leq 0 \quad (\forall i, j, k \in N) \quad (7)$$

$$x_i + x_j + x_k - y_{ij} - y_{ik} - y_{jk} \leq 1 \quad (\forall i, j, k \in N) \quad (8)$$

Many other inequalities for the BQP_n have been discovered thereafter. The excellent book of Deza and Laurent (1997) surveys most of them.

Polytopes related to special cases of quadratic programs have also been studied. We mention for instance the *quadratic assignment polytope* Junger and Kaibel (2001), the *quadratic semi-assignment polytope* Saito et al. (2009), and the *quadratic knapsack polytope* Helmberg et al. (2002).

2.3.2. Semidefinite relaxations

Over the past two decades, *semidefinite programming (SDP)* has been extensively used to model mixed 0-1 quadratic programs. The so-called SDP relaxation constitutes the core part of many successful exact schemes (e.g., Fujie and Kojima (1997); Helmberg et al. (2002); Lemarechal and Oustry (2001); Lovasz and Schrijver (1991); Poljak and Wolkowicz (1995); Ramana (1993); Shor (1987); Buchheim and Wiegele (2013)). The main idea is described below.

Given a vector of decision variables $x \in R^n$, let X be the $n \times n$ symmetric matrix in which $X_{ii} = x_i$ for all i and $X_{ij} = x_i x_j$ for all $i \neq j$. Note that a quadratic function on x is linear on X , and $X = xx^T$. The matrix X is real, symmetric and positive semidefinite (psd) for any $x \in R^n$. The SDP relaxation is obtained by replacing the *non-convex* constraint $X = xx^T$ with the condition that X is psd. Furthermore, one can also define the *augmented matrix*

$$\hat{X} = \begin{pmatrix} 1 \\ x \end{pmatrix} \begin{pmatrix} 1 \\ x \end{pmatrix}^T = \begin{pmatrix} 1 & x^T \\ x & X \end{pmatrix}. \quad (9)$$

which is also a psd matrix. SDP relaxations for quadratic programs are based on this principle.

It is worth pointing out that the first-level RLT relaxation can be strengthened by using the ideas described in Subsections (2.3.1) and (2.3.2). Moreover, one can add the constraint that the augmented matrix \hat{X} must be psd Lovasz and Schrijver (1991). As Anstreicher (2009) showed the quality of the resulting bounds is substantially improved, but the extra computational cost is rather excessive. Similarly, valid inequalities for the Boolean quadric polytope can be used to strengthen the first level RLT relaxation.

As well as multiplying linear inequalities by individual variables or their complements, one can also multiply pairs of linear inequalities together (Lovasz and Schrijver (1991)). Specifically, given two inequalities of the form $\alpha^T x \leq \beta$ and $\gamma^T x \leq \delta$, one sees that $(\beta - \alpha^T x)(\delta - \gamma^T x) \geq 0$, which yields the valid inequality

$$\alpha^T X \gamma - \beta \gamma^T x - \delta \alpha^T x + \beta \delta \geq 0. \quad (10)$$

3. New cutting planes for the linear case

In this section, we show how to generate cutting planes for first-level RLT relaxations of mixed 0-1 *linear* programs. Note that, for such problems, we need to define the variable y_{ij} only when at least one of x_i and x_j are binary.

Throughout this section, N , A , b , n and m are defined as in Subsection 2.1. We also let $B \subseteq N$ denote the index set of the binary variables. (Note that the number of binary variables is then $\binom{|B|}{2} + |B|(n - |B|)$.) We also let Q denote the convex hull of pairs (x, y) that satisfy the constraints:

$$\begin{aligned} Ax &\leq b \\ x_i &\in \{0, 1\} (i \in B) \\ x_i &\in [0, 1] (i \in N \setminus B) \\ y_{ij} &= x_i x_j (\{i, j\} \subset N, \{i, j\} \cap B \neq \emptyset). \end{aligned}$$

Also, for any $S \subset N$ and any $\alpha \in Q^n$, we will let $\alpha(S)$ denote $\sum_{i \in S} \alpha_i$, S^+ denote $\{i \in S : \alpha_i > 0\}$ and S^- denote $\{i \in S : \alpha_i < 0\}$.

3.1. The main concept

Our method is based on the following idea. First, we construct a 'cubic' valid inequality, by which we mean a non-linear inequality that involves products of up to *three* x variables, but no y variables. Then, we weaken the cubic inequality, in order to make it valid for Q .

So, to begin with, let us consider possible ways of generating cubic inequalities. In our view, the most obvious are the following:

1. We can take three binary variables, say x_i , x_j and x_k , and form the following four cubic inequalities:

$$x_i x_j x_k \geq 0 \quad (11)$$

$$x_i x_j (1 - x_k) \geq 0 \quad (12)$$

$$x_i (1 - x_j) (1 - x_k) \geq 0 \quad (13)$$

$$(1 - x_i) (1 - x_j) (1 - x_k) \geq 0. \quad (14)$$

2. We can take a single linear inequality from the system $Ax \leq b$, say $\alpha^T x \leq \beta$, and two binary variables, say x_s and x_t , and form the following three cubic inequalities:

$$(\beta - \alpha^T x) x_s x_t \geq 0 \quad (15)$$

$$(\beta - \alpha^T x) x_s (1 - x_t) \geq 0 \quad (16)$$

$$(\beta - \alpha^T x) (1 - x_s) (1 - x_t) \geq 0. \quad (17)$$

3. We can take two linear inequalities from the system $Ax \leq b$, say $\alpha^1 \cdot x \leq \beta^1$ and $\alpha^2 \cdot x \leq \beta^2$, and a single binary variable, say x_s , and form the following two cubic inequalities:

$$(\beta^1 - \alpha^1 \cdot x) (\beta^2 - \alpha^2 \cdot x) x_s \geq 0 \quad (18)$$

$$(\beta^1 - \alpha^1 \cdot x) (\beta^2 - \alpha^2 \cdot x) (1 - x_s) \geq 0. \quad (19)$$

4. We can take three linear inequalities from the system $Ax \leq b$, say $\alpha^i \cdot x \leq \beta^i$ for $i = 1, 2, 3$, and form the following single cubic inequality:

$$(\beta^1 - \alpha^1 \cdot x) (\beta^2 - \alpha^2 \cdot x) (\beta^3 - \alpha^3 \cdot x) \geq 0. \quad (20)$$

Some more complex ways of generating cubic inequalities are described in Formeni et al. (2013). For now, however, let us consider how we can weaken a cubic inequality in order to make it valid for Q . Since quadratic terms of the form $x_i x_j$ can be replaced with y_{ij} , and linear and constant terms can be left unchanged, the only real issue is how to deal with cubic terms, of the form $x_i x_j x_k$. The following lemma addresses this issue:

Lemma 1 Let x_i , x_j and x_k be three variables, all constrained to lie in the interval $[0,1]$. Let $y_{ij} = x_i x_j$, and similarly for y_{ik} and y_{jk} . Then we have the following lower bounds on $x_i x_j x_k$:

$$x_i x_j x_k \geq \max \left\{ 0, y_{ij} + y_{ik} - x_i, y_{ij} + y_{jk} - x_j, y_{ik} + y_{jk} - x_k \right\}, \quad (21)$$

and the following upper bounds:

$$x_i x_j x_k \leq \min \left\{ y_{ij}, y_{ik}, y_{jk}, 1 - x_i - x_j - x_k + y_{ij} + y_{ik} + y_{jk} \right\}. \quad (22)$$

Proof. The inequality $x_i x_j x_k \geq 0$ is trivial. The inequality $x_i x_j x_k \geq y_{ij} + y_{ik} - x_i$ comes from the fact that $x_i(1-x_j)(1-x_k)$ must be non-negative. The inequalities $x_i x_j x_k \geq y_{ij} + y_{jk} - x_j$ and $x_i x_j x_k \geq y_{ik} + y_{jk} - x_k$ are proved similarly. The inequality $x_i x_j x_k \leq y_{ij}$ comes from the fact that $x_i x_j(1-x_k)$ must be non-negative. The inequalities $x_i x_j x_k \leq y_{ik}$ and $x_i x_j x_k \leq y_{jk}$ are proved similarly. Finally, the inequality

$$x_i x_j x_k \leq 1 - x_i - x_j - x_k + y_{ij} + y_{ik} + y_{jk}$$

comes from the fact that $(1-x_i)(1-x_j)(1-x_k)$ must be non-negative. \square

One can check that, if the cubic inequalities (11)--(14) are weakened using Lemma 1, then one obtains only either trivial inequalities of the form $y_{ij} \geq 0$, $x_i - y_{ij} \geq 0$ or $y_{ij} - x_i - x_j + 1 \geq 0$ (all of which are already present in the first-level RLT relaxation), or triangle inequalities of the form (7), (8). If however one weakens the remaining cubic inequalities (15)-(20), one obtains new and non-trivial cutting planes for Q . This is explained in the next subsection.

3.2. Example: (s, t) -inequalities

Now we consider what happens when cubic inequalities of the form (15)-(17) are weakened. It turns out that it gives rise to three huge (exponentially-large) families of valid inequalities for Q .

The following theorem characterise the inequalities that can be derived by weakening the cubic inequality 15):

Theorem 1 For any pair $\{s, t\} \subset B$, let S, T and W be disjoint subsets of $N \setminus \{s, t\}$, let R denote $N \setminus (\{s, t\} \cup S \cup T \cup W)$, and let $\alpha^T x \leq \beta$ be one of the inequalities in the system $Ax \leq b$. Then the following ' (s, t) ' inequalities are valid for Q :

$$\begin{aligned} & \sum_{i \in S \cup W} \alpha_i y_{is} + \sum_{i \in T \cup W} \alpha_i y_{it} - \sum_{i \in W} \alpha_i x_i \leq -\alpha(W^-) + \alpha(S^+ \cup W^-) x_s \\ & + \alpha(T^+ \cup W^-) x_t + (\beta - \alpha(\{s, t\} \cup S^+ \cup T^+ \cup W^- \cup R^-)) y_{st}. \end{aligned} \quad (23)$$

Proof. Since x_s and x_t are binary, we have $x_s x_t = x_s^2 x_t = x_s x_t^2 = y_{st}$, and the cubic inequality (15) can be re-written as:

$$\sum_{i \in N \setminus \{s, t\}} \alpha_i x_i x_s x_t \leq (\beta - \alpha_s - \alpha_t) y_{st}.$$

Now, from Lemma 1, we can weaken this inequality, by replacing $x_i x_s x_t$ with

- $y_{is} + y_{st} - x_s$ when $i \in S^+$,
- $y_{it} + y_{st} - x_t$ when $i \in T^+$,
- $y_{is} + y_{it} - x_i$ when $i \in W^+$,
- 0 when $i \in R^+$,
- y_{is} when $i \in S^-$,
- y_{it} when $i \in T^-$,
- $1 - x_i - x_s - x_t + y_{is} + y_{it} + y_{st}$ when $i \in W^-$,
- y_{st} when $i \in R^-$.

Doing this and re-arranging yields the inequality (23). □

Note that, there are an exponentially-large number of ways of selecting S , T and W for a given pair (s, t) and a given linear constraint $\alpha^T x \leq \beta$.

In Formeni et al. (2013) we show that one can apply Lemma 1 to the cubic inequalities (16) and (17), to derive respectively the form of *mixed* and *reverse* (s, t) inequalities.

For the sake of brevity, we do not give details on the valid inequalities for Q that can be obtained by weakening the other cubic inequalities listed in Subsection 3.1. One can check, however, that the resulting inequalities are also exponential in number.

3.3. Separation

Since the inequalities produced by our procedure are exponential in number, we need separation algorithms. For a given family of inequalities, the separation algorithm takes a fractional point (x^*, y^*) as input, and outputs a violated inequality in that family, if one exists.

It turns out that, for all families of inequalities that can be generated using our procedure, the separation problem can be solved easily in polynomial time. To see this, note first that the cubic inequalities (11)-(20) are polynomial in number. Then, for each one, we can obtain a most-violated cutting plane (if any exists) as follows. Consider each cubic term $x_i x_j x_k$ in turn. If it has a positive coefficient on the left-hand side of the cubic inequality, then replace it with the term on the right-hand side of (22) that has the smallest value at (x^*, y^*) . If it has a negative left-hand side coefficient, replace it with the term on the right-hand side of (21) that has the largest value at (x^*, y^*) .

As an illustration, the following theorem applies this general separation scheme to the (s, t) inequalities presented in the previous subsection. The complete proof of the theorem is given in Formeni et al. (2013).

Theorem 2 *The separation problem for the (s, t) inequalities (23) can be solved exactly in $O(mn |B|^2)$ time.*

One can solve the separation problems for the mixed (s, t) inequalities and reverse (s, t) inequalities, in $O(mn |B|^2)$ time, in a similar way. Moreover, using the same strategy, one can show the following results:

Proposition 1 *The separation problem for the inequalities that can be derived by weakening the cubic inequalities (18) and (19) can be solved exactly in $O(m^2 n^2 |B|)$ time.*

Proposition 2 *The separation problem for the inequalities that can be derived by weakening the cubic inequalities (20) can be solved exactly in $O(m^3 n^3)$ time.*

We omit the (simple but tedious) proofs for brevity. Note that the running times given in these last two propositions are rather excessive, unless m is small.

In Formeni et al. (2013) we use a simple disjunctive argument to strengthen the (s, t) inequalities. Furthermore, we show that the separation problem for the *strong* (s, t) inequalities can be solved exactly in $O(m^2 n^2 |B|)$ time.

4. Concluding remarks

The RLT constitutes a general framework for constructing strong relaxations of various optimizations problems. Practically, it is the first level that is applied in most real cases due to the excessive size of higher level formulations.

We showed that one can introduce in the first level RLT relaxation some of the strength of the second level without the burden of the extra variables implied by the latter. Moreover, We introduced three exponentially-large families of valid inequalities that can strengthen the first-level RLT relaxation and can be separated in polynomial time.

Possible topics for future research could include (i) a search for more general families of valid inequalities that could be used to further strengthen the relaxations, (ii) the derivation of analogous valid inequalities for higher levels of the RLT hierarchy, and (iii) the incorporation of our valid inequalities and separation algorithms into branch-and-cut algorithms for specific problems, such as the quadratic assignment, quadratic knapsack and edge-weighted b-clique problems.

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KEYNOTE

Case Study: OR in the Marks & Spencer Supply Chain

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Abstract

Marks & Spencer is a UK-based retailer which over the last 20 years has become an increasingly international multichannel retailer. To facilitate these changes and growth a world class supply chain is needed. The current General Merchandise (non-food) supply chain was set up in the 1980s and is in need of development by way of a new strategic network. This development is currently underway with the building of a new E-commerce and national distribution centre. The design and implementation of the new network needed a large amount of data and for it to be analysed correctly. This is where OR has been used, in the form of simulation, simple and not-so-simple analytics and mixed integer linear programming, among others. A summary of the tools used, the benefits realised and challenges faced during this process so far and going forward will be described.

Keywords: Supply chain; Logistics; Retail; Simulation; Warehousing

1. Background

Marks & Spencer is a UK-based retailer of food, clothing and homeware. The business was established in 1884 as a ‘penny bazaar’ in Leeds and now has over 1,000 stores in 43 countries with total global revenue of £9.9bn (Marks and Spencer, 2012).

The current supply chain supporting the General Merchandise (non-food) part of the business was originally set up in the 1980s. Since that time, the business has seen substantial changes, including globalisation of sourcing and stores, proliferation of store formats and product range and the growing importance of multi-channel.

The “legacy” supply chain is characterised by a network of 110 distribution points in the UK, with most products being handled at least twice prior to dispatch to stores and customers. Home delivery was an add-on to the store replenishment network, with slow delivery and poor availability.

The development of the new supply chain began in 2008, based on the principles of being faster, leaner and more agile. The integration of multi-channel into the store supply chain is critical to drive fast response to customer demand and improved inventory utilisation. The new supply chain will ultimately reduce the number of sites to less than 10.

The General Merchandise supply chain delivers around 500m single items per year to stores and customers from a catalogue of around 350,000 unique products (SKUs), handled either in cartons or on hangers.

2. Data and analytics

To facilitate the transition from 110 distribution centres to less than 10, a large amount of core business data was required, but initially there was no common source of all of this data. In order to create this repository, a number of data extraction routines were created with data being fed on a frequent (mostly daily/weekly) basis from a number of operational systems into the 'LDM' database. This database contains an accurate picture of all product movements, including store and E-commerce sales and stock, product movements and inventory. The database is now around 7TB in size, with new feeds being added when gaps are identified and data becomes more readily available.

The data from LDM is used in a number of different ways to feed into the various projects including amongst other things the design of the new network. In most cases, data is channelled from LDM into Excel where it is merged with other data inputs and then processed further. A range of OR tools alongside traditional data analysis have been used including simulation, linear programming and transport scheduling.

3. Legacy network

Using the data in LDM for projects in the legacy network is just as important as designing the new network. One key part of running an efficient warehouse is managing stock levels, clearing end of life stock and maintaining appropriate levels of stock for active lines, freeing up capacity for new lines. From the data held on warehouse stock and despatches and store sales, SKUs can be classified as to what stage in the product lifecycle they are: new, active, ending and dormant. Dormant stock (defined as a SKU that has not been received or despatched from the warehouses for a defined period of time) is identified and flagged for transfer out of the warehouse to "outlet" stores to free up space for new lines. Additionally any excess stock in the current E-commerce warehouse is identified, defined as anything over the required number of weeks' stock cover plus a buffer to ensure that any transfers would not have an adverse effect of availability. The stock levels and despatches at other DCs were analysed to see where best to move any excess stock to, with the aim of increasing availability and thus sales.

A second piece of analysis looking at the current legacy network is a bespoke Cost-to-Serve tool which models the margin generated by SKU and by location. The model provides insight into the reasons why certain parts of the operations yield higher margin than others. Linked to this model is the inventory model (another bespoke tool), developed to interact directly with the LDM server. It simulates different rules impacting flow of product and determines the required inventory at each node in the supply chain at SKU level. This has been used to validate the design of the new strategic network in sizing the warehouse based on how much

stock and how many SKUs it is expected to need to hold. Other analytical tools have been developed from the LDM data to look at parts of the legacy network with the aim of further optimisation, including transport scheduling and modelling the storage and throughput capacity of the sites.

4. Castle Donington

The first part of the new strategic network is Castle Donington EDC NDC, a national distribution centre and E-commerce distribution centre for general merchandise. At 875kft² in area and 82ft high, it can hold 3,507 double decker buses or 11 Wembley football pitches. The warehouse will hold both hanging and boxed products despatching to around 600 stores and the homes of E-commerce customers. This solution is highly automated to drive efficiency - for example, a hanging product that is required by stores will be manually unloaded from the vehicle and will then not go through another manual process until it is loaded onto the vehicle to the store.

Design of the site began in 2009 and transition will start from April 2013. Throughout this time, a variety of tools have been used for its design and implementation. Before designing the site a mixed integer linear programme was used to determine the optimum network configuration including the number of sites and their locations.

Design is not solely about the building of the optimum site for the end state but must also include the ability to operate as efficiently as possible during the transition phase. To model this a supply route optimisation tool was used. Castle Donington needs to start up with a sub-optimal product load for a short period of time. In order to limit the impact of this sub-optimal routing, a mixed integer model was created to maximise the potential of the site within the physical constraints of the materials handling equipment and building.

4.1. Simulation

One of the key tools in the design and implementation of Castle Donington are five discrete event simulation models, which simulate the main flows through the site (both automated and manual) from goods in through to goods out. The five models are:

1. Boxed goods in and pallet high bay
2. Bulk carton store (BCS) and box picking
3. Hanging high bay storage and picking
4. E-commerce packing and despatch
5. Store despatch

The simulations have been developed with Saker Solutions in Flexsim.

The models were initially set up to simulate a full day during the Christmas peak in 2015, but have the functionality to run for longer and for the input data to be refreshed with the latest information. Due to differing levels of detail in each of the models they take between 30 seconds and five hours to run a simulation of a full day.

Each model was built with differing levels of detail based on the purpose of the model, the hanging model is the least detailed with no SKU information and only high level flows each hour through the system to enable testing for bottlenecks. At the other end of the scale the BCS and box pick model contains information about 50k SKUs and 300k orderlines (unique customer SKU combination), with the capacity for more. Real and simulated orders are used with SKU level detail and the routing logic is a replica of the actual warehouse control system (WCS) logic, which controls the launch of orders for picking and triggers replenishment of SKUs from the BCS to the pick system. This creates a large number of calculations for every order and orderline; checking whether the order is available to launch, that the stock is available at the pick station, that there is capacity at the pick station for another order and if the order needs SKUs from different pick stations, resulting in the run time of around 5 hours with the current dataset.

These models have been used from design through to implementation and will continue to be used after Castle Donington goes live for continuous improvement. To get a full picture of the site, all the models need to join together meaning the outputs from one are the inputs for the next. This is all done in Microsoft Excel to be as user-friendly as possible. Creating one model of the entire warehouse would have been unfeasible due to the number of objects, the complexity of the logic and the processing capabilities that would be required to run a model of this size. There are also times when experimentation is only needed on a section of the site, for example the E-commerce packing operation, without changing processes or inputs in the rest of the site. Having to run the simulation of the whole site would add unnecessary complication and time. Despite this, building five separate models that must all link together posed challenges of its own. Because of the differing levels of detail in each of the models, some of the inputs or outputs were not available directly from the models, so these had to be simulated separately with user-defined delays and process times. For the inputs and outputs that could come directly from the models, methods of importing and exporting the data have been built in to make the process as automated as possible. This is another time consuming process in the running of the simulations - importing the data to the E-commerce packing model and updating formulas takes around 40 minutes, the same as the run time.

4.1.1. Design

The design of the automation is a crucial phase of the project; most of the main processes within the warehouse will be carried out by the automation with minimal manual input. The simulation models were built during the design phase and initially used for verification and validation. The automation suppliers also built their own simulation models as a proof of concept for the design. Using both sets of models we were able to easily identify any potential issues and their solutions with equipment, layout or logical controls during the design stage,

rather than after the physical installation when the cost of implementing any changes or contingency plans increases significantly and there is a risk of disappointing customers.

One area in which the simulation identified a potential issue was in the palletising/depalletising of boxed products. The stations are multifunctional, being able to palletise and depalletise. This is an innovative way of working with new control logic having to be defined. The simulation identified that the original logic resulted in significant idle time for the operator while waiting for the empty or full pallet to be lifted or lowered into place. A full cycle to lift and lower a pallet to and from the station takes around a minute - as such, any reduction in this time will contribute to higher productivity of the operator and higher throughput for the same equipment. The cycle time is fixed by the physical constraints but new logic was proposed by the automation suppliers which limited the number of lifts that needed to be performed. This was tested using both their simulation and the Flexsim simulation and both showed that the amount of idle time was significantly reduced and therefore the throughput was increased, so the logic in the WCS was changed before going live. Without the simulation this issue may not have been spotted until either much closer to going live or potentially after when it may have impacted the smooth running of the operation and been more costly to rectify.

There are also disadvantages of building the simulation during the design phase, in that it takes more iterations to reach the final accurate version of the model. This is due to the actual system logic continually changing as improvements are identified. This proved a challenge as much of the logic is very detailed so any changes to be made were non-trivial. With both activities going on in parallel, communication between the two teams was also important as issues that the simulation identified cannot be rectified unless the design team are told. Conversely, new logic cannot be tested in the simulation unless they are notified of the changes.

4.1.2. Implementation

As the project has progressed from design phase to the physical build to testing, going live is becoming closer and closer and the team involved has grown to now include the design team, testing team and operations team. Every new starter needs an introduction to how Castle Donington will operate and the different flows of product through the site. During design and the initial phases of installation it was very hard to get a sense of how the site would work and the 2D plans are very detailed and difficult to follow. One of the main reasons for choosing Flexsim as the simulation software was its graphics options, with 3D visuals as standard. This 3D representation was very useful for painting a clear picture of the flows around the site that was starting to look like a web of conveyors. A video was created of the all simulation models and put together for a full fly through of the site, making it accessible for the whole team.

The Excel interfaces of all the models for inputs and outputs also help with the communication of results and capabilities of the simulation, as the results are easily and quickly available at the end of the run and can be shared with the wider team without having

to consider software or knowledge of simulation. The ability to easily communicate the power and flexibility of the simulations is important to get buy-in from other areas of the business when giving recommendations based on the results, but also to give other teams ideas of how they can use the simulations to assess any plans they have that Castle Donington plays a part in.

4.1.3. *Post go live*

Product will begin to transition into Castle Donington from April 2013; however because of the nature of simulation, many “what-if” scenarios of going live and thereafter have already been run. This gives the operations team much more time to create contingency plans based on reliable information about the impacts of certain changes and events.

A key area in which several simulations have been run is in the packing of E-commerce orders. The design for Castle Donington was started in 2009, and since then E-commerce businesses across the world have changed vastly, with rapid growth in the traditional channels and increasingly via new channels such as smartphones and tablets. This is also changing the profile of orders; with shorter order lead times and more delivery options. These and other impacts of the changing face of E-commerce poses the site with additional challenges beyond those in 2009. Flexibility in the original design has been tested using the simulations to see the impact of these changes and also the best way to utilise the flexibility. E-commerce is such an important part of the operation to get right as there is the potential to disappoint a lot of customers. It is not only developments outside our control but internal changes too; these changes have also been assessed using the simulations. This work has been completed already but there is the flexibility in the simulations to run many different scenarios in the future when there are more changes and also once the operation of the site is fully understood.

Other scenarios have been run such as the best way to balance the inbound operation across the day. This is done so as not to impact the replenishment of the pick stations because the storage cranes are over-utilised with putaway of inbound product. What-if scenarios include the impact of out-of-order cranes, shortages of manual labour or if a vehicle arrives containing only cartons that can't be stored in the BCS. The options are endless and will be utilised more once the site is fully functional and the operation is fully understood, enabling the operations team to create contingency plans based on reliable information before anything has gone wrong and customers have been impacted.

As with all large capital investment projects they can only be designed to the best of your knowledge of the future at that moment in time, as such flexibility and space for expansion has been built into the design. The simulations can be used to analyse when it is best to install some or all of this extra equipment and assess the benefit of doing so. This once again provides valuable reliable information for decision making before large amounts of time and capital are invested.

5. Conclusion

The M&S supply chain program has already delivered substantial savings and is on track to deliver more over the next few years. This has been delivered against a background of increased complexity as multi-channel requirements grow exponentially. The new supply chain is also delivering a reduction in inventory and increase in availability.

The Operational Research element in this change has been critical; it would not have been possible to work through the required analysis or get the required levels of buy-in from the wider business without the data, information and conclusions that have been generated.

References

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KEYNOTE

Embedding Sustainability into Strategy: Assessing the OR Society Contribution

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Abstract

This paper sets out an overview of the key contributions that have addressed issues in strategy and sustainability particularly from an *OR Society* perspective. The paper provides clarity on emerging perspectives to define sustainability in terms of the economic and social/environmental/governance (SEG) challenge. *OR Society* contributions to sustainability are reviewed against the *OR/MS* literature in general and operations and supply chain research. *OR* contributions are found to predominately focus on the use and application of modelling in environmental management issues and not the social dimension of sustainability. This review identifies that this is not necessarily the case in *OR Society* titles (i.e. equal mix between environmental and social) but contributions are minimal. A turning point is emerging, post-financial crisis with more prominence attended to the governance dimension. Although papers in *OR Society* titles have a slight lag compared with *OR/MS* in general, and supply and operations management literature. It is argued that the *OR Society* can play a significant role in addressing the sustainability challenge. Further work should focus on a more extensive literature review and a survey of *OR Society* members on the utility and applicability of *OR* to address the sustainability challenge.

Keywords: Sustainability; Governance; Strategy; Corporate responsibility; *OR* research and practice

1. Introduction

The field of sustainability has aroused much interest and grown in great importance over recent years. It is an expansive, multi-faceted and heavily debated concept (Wilkinson *et al.*, 2001) predominately since Meadows *et al.*, (1972) first discussed the "*Limits to Growth*". At the heart of this debate is an explicit connection and widespread recognition of a changing relationship between companies and communities as noted in the UN Global Compact (2011). This change has been bought in part due to unprecedented levels of economic growth in the majority of countries, spearheaded by the industrial revolution from the 1760's onwards. In the last decade alone we have seen vast technological change, market consolidations and new markets emerging, shift to a service-based knowledge economy, innovations that fundamentally change the rules of the game and all shaped and based to an extent on global economic activity. For instance, the early 90's saw great pressures of globalisation, to outsource non-core activities and utilise the lowest forms of production, predominantly

overseas in China and India (See Friedman, 2005). In more recent years we have experienced a period of austerity and extensive government spending cuts, which has resulted in high levels of unemployment, particularly amongst young people and social inequality that undermine the type of society we aspire to achieve. These changes present many challenges for practicing managers to act and evaluate their responsibilities towards the pressures on both people and planet. What the last decade particularly has shown is that the freedom to act is not a license to abuse (Cannon, 2011). This challenge has not changed and is no greater as noted by Barack Obama (43rd President of the United States) in his first inaugural speech:

“For even as we celebrate tonight, we know the challenges that tomorrow will bring are the greatest of our lifetime - two wars, a planet in peril, the worst financial crisis in a century”. – Barack Obama Victory Speech (2008)

The challenge for business was most notably made by Friedman (1962) whom suggested that the *‘social responsibility of businessmen is to make maximum profits for their shareholders’*. This he argued should be within the law and rules for society, if so leaders and organisations are acting responsibly. Additionally, he noted that any expenditure on social/environmental activities will, in his view, reduce profits and, therefore, managers who *‘indulge’* in such practices will be neglecting their duty to maximise profits for shareholders. On this matter, Friedman is not short of his critics, particularly leaders who demonstrate ethical and moral leadership. This includes Henry Ford (1863-1947) who once said *“business that makes nothing but money is a poor kind of business”* and Richard Branson who has more recently commented that *“with extreme wealth comes extreme responsibility”* (See Coughlan, 2006).

The responsibility for business is becoming much clearer, as public perception change and leaders take to the task made more prominent by issues such as the rise in CO₂ emissions and population growth (i.e. UK Government Climate Change Act in 2008). These issues lead business and society to question how our lives can be sustainable in the future and for our children’s children. These include great CSR and corporate governance failures (e.g. BP Deepwater Horizon Oil Spill in 2010); Horsemeat labelled as beef scandal in UK supermarkets and supply chains (See Lichfield *et al.*, 10/02/2013) and crises in the financial system (i.e. RBS and Lloyds TSB took government bail-out and ownership, See BBC News, 13/10/2008). These failures have undermined consumer confidence in business and on the part of civil society and give rise to the environmental, social and governance challenges that question the predominantly capitalist socio-economic system.

Laszlo and Zhexembayeva (2011) argue that *‘embedding sustainability’* is the *‘next big competitive advantage for business’*. Taking just the environmental dimension, a survey of managerial perceptions by Ghobadian *et al.*, (1995) found that developing a response to environmental issues were a source of business opportunity and could lead to a competitive advantage. This could be explained in part by considering that *‘cost’* can be minimised by addressing environmental issues (e.g. eliminating waste) and taking environmental action is explicitly linked to the concept of *‘quality’*. Interesting, Ghobadian *et al.*, (1995) note that the operations function present the greatest focus to minimise environmental impact. While these

considerations are steadily being realised by managers, the social dimension has received much less attention (Glavic and Lukman, 2007). As Weaver and Nunes (2007) note that the response from political and business leaders has not developed fully yet, but the journey has begun, although slower than is needed to reach the final destination. The two are important and inherently linked as Ghobadian *et al.*, (2005) also found that both market and non-market forces are important in shaping environmental strategies (e.g. customers, regulatory agencies).

2. Corporate responsibility to sustainability

The term sustainability has embraced many terms and has evolved significantly over the past decade alone. Little surprise due to the focus of research on the environmental dimension that sustainability definitions are skewed towards addressing 'green' issues. Glavic and Lukman (2007) note that these terms have included: *cleaner production, pollution prevention, pollution control, and minimisation of resource usage, eco-design* and others. New terms emerge as many literature reviews and theory/concept development papers are published and special issues presented in different journals. For instance, the *International Journal of Manufacturing and Technology Management* (in 2015) will focus a special issue on '*manufacturing and supply chain sustainability: relationships and governance*' and *Harvard Business School* will hold a conference on '*Sustainability and the Corporation: Big Ideas*' in November 2013.

Since the industrial revolution, the sustainability agenda has been dominated by individual and corporate philanthropy to demonstrate good corporate citizenship. This is formed on what Carroll (1991) terms the three philanthropic responsibilities: *ethical, legal and economical*. Carroll recognises that to '*be profitable*' is the foundation block that the other responsibilities rest. The power of the machine over man, raised major issues on responsibility and ethics that bore attention to the relationship between business, society and the natural environment. The ethical responsibilities were noted by Mill (1848) in his *Principles of Political Economy* when he welcomed the wealth produced by industrialisation but saw the dangers in the processes that created that wealth and the changing relationship between workers and their products. Cannon (2011) lists other key contributors that have questioned ethics since industrialisation: such as writers and philosophers, *Charles Dickens, Henry David Thoreau*; religious leaders, *Pope Leo XIII*; politicians, *Theodore Roosevelt* and by the 1950s corporate leaders, *Frank Abrams* (see Abrams, 1951) and *Howard Bowen* (see Bowen, 1953).

In 2006, Dahlsrud reviewed 37 definitions on CSR demonstrating the different cultural and economic influences on the definition. Common in the definitions is not only Carroll (1991) view as discussed but also the obligation of corporations to constituent organisations other than shareholders (i.e. customers, suppliers, employees and related community groups) that is present in what is termed '*stakeholder theory*'. These wider responsibilities are captured in Waddock (2009) definition of corporate social performance that emphasises the relationship with numerous stakeholders as well as the natural environment. The UN Global Compact (2011) also makes explicit that these relationships are partnerships and require openness

between business, governments, civil society, labour and the United Nations. In this broader view, there are two compelling reasons for businesses to have a moral duty to take into account a wider range of stakeholder interests. First, the responsibility to make good social and environmental 'harms' created by their business operations. Secondly, to acknowledge the 'contributions' made by these stakeholders to their successful business operations.

Elkington (1998) encapsulates this wider view of business responsibility by proposing the 'triple bottom line' (TBL) approach. This postulates that those businesses have a set of goals which extends beyond merely responding to shareholder expectations. In the TBL framework Elkington argues that businesses can still, legitimately, aim at adding economic (shareholder) value, but should acknowledge that such benefits may potentially be, at least partially, offset by negative social and environmental (stakeholder) costs. Therefore, businesses should have an extended goal set in which the issues of social and environmental value must be addressed. The concept of CSR implies that companies voluntarily integrate social and environmental concerns in their operations, and actively interact with stakeholders. This is framed around 'sustainable development' which is defined by the Brundtland Commission report for the United Nations (1987):

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

The focus involves business consideration of the interests of society, striking the right balance between economic, environmental and social concerns. Corporate responsibility is interested in the direct and indirect actions of a business on various stakeholders that may include customers, suppliers, employees, communities and the environment, as well as their shareholders. Wartrick and Cochran (1985) note that there are different responsive strategies to corporate responsiveness: *reactionary*, *defensive*, *accommodating* and *pro-activity*. Arguably, it is the pro-activity category that organisations need to fulfil in order to address the economic SEG challenge by going beyond minimum requirements of stakeholders and acting in accordance with CSR principles which transcend the law. This is certainly the case if we are to meet Laszlo and Zhexembayeva (2011) aspiration for sustainability to be the 'next big competitive advantage'. However, in this paper the authors note that this implies for the 'few'. Hence, pro-activity to meet the challenge should be stretched to become the 'next big de facto standard' or in strategic management terms a 'threshold capability'. Whereby the standard is raised, but a seismic shift may be required before this may be a possible route.

Taking Friedman (1962) argument, to create stakeholder value would, inevitably, destroy shareholder value. This is at odds with the concept of CSR which is built on the premise that positive engagement with stakeholders will enhance shareholder value. Thus, business no longer has to make a choice between 'profits versus ethics'. In a supply chain context this includes creating mutually beneficial stable and long-term relationships. This includes all issues involving the inputs to a business, in terms of resource consumption and the outputs, pollutant emissions (Sanders, 2012). For instance, the environmental dimension will include the use of fossil fuels for power generation and the resultant carbon emissions (Mangan *et al.*,

2012). On the other hand, the social dimension would include a concern for employee's welfare and social issues, whether to use existing staff or to outsource non-core activities. Also, a 'local' concern on the wider community and civil society to reduce conflict, satisfy expectations and forge purposeful and meaningful relationships with suppliers (that supply the inputs) and honest treatment of customers (at the demand side). In addition to addressing these two dimensions there is a need for new governance models and frameworks to navigate and offer a point of reference for partnerships and relationships to be built external to the organisation stretching out to capture and nurture stakeholder involvement in sustainable development. It is these relationships that concern an emerging need to develop potential new corporate governance models that could navigate and lead an organisation in the future in partnership with the value created with and by stakeholders.

The sustainability agenda will be shaped over the next decade or so further. Particularly, as a 'local' connection becomes increasingly more important. This will bring about different thinking, unleashed through new political activism and ideology, the role religion plays, the nature of a market led system and businesses identifying sources of business opportunity in its business and with stakeholders (i.e. suppliers) to drive value.

3. Assessing OR Society response to the sustainability challenge

This paper addresses the question: *What responses have been made in Operational Research Society journals on the sustainability challenge?* Additionally, draws some comparisons with systems/operational research in general and with research in supply and operations management journals. This paper does not claim to present a systematic literature review of all systems/OR contributions but notes that this would be a useful avenue for further research. The boundary of the literature review is OR Society journals as this paper forms a keynote discussion at the *Operational Research Society YOR18 conference* in April 2013. The protocols for identifying, selecting and reviewing the literature relevant to the question follows that used by Ashby *et al.*, (2012) reviewing the sustainability literature in supply chain and sustainability literature. Ashby *et al.*, (2012) systematic literature review built on earlier work and contributions by Seuring and Muller (2008) and Burgess *et al.*, (2006); these studies are used for comparing the OR Society response to sustainability (i.e. the ESG dimensions).

3.1 Search criteria

The search focuses on sustainability in relation to the ESG dimensions within the six OR Society publications, listed in table 1 with the associated ABS ranking (2010). The Palgrave research database was used for this study as all OR Society publications are listed in both abstract and full text form and the list was consolidated when a publication was listed more than once. The economic dimension is omitted in accordance with Ashby *et al.*, (2012) review that noted that this is outside the scope of the review as it can be argued that the economic dimension is inherent in all discussions on sustainability. The governance dimension was not noted in Dempsey *et al.*, (2009) conceptual framework on sustainability but is added to this

study due to the growing importance of moral and ethical decision making by stakeholders in a sustainability agenda for a given organisation. Publications from 1983 onwards have been reviewed as this was the year that the World Commission on Environment and Development (WCED) was established by the United Nations. It was after this date that the environmental and social dimensions were more formally recognised (Ashby *et al.*, 2012).

Table 1 No of papers per journal title using search terms

| Journal Title | ABS ranking (2010) | No. of papers | |
|---|--------------------|---------------|----------------------|
| | | All terms | Supply chain related |
| European Journal of Information Systems | 3 | 0 | 0 |
| Health Systems | (launched in 2012) | 0 | 0 |
| Journal of Simulation | - | 0 | 0 |
| Journal of the Operational Research Society | 3 | 26 | 15 |
| Knowledge Management Research & Practice | 1 | 1 | 1 |
| OR Insight | 1 | 2 | 0 |
| Total | N/A | 29 | 16 |

Table 1 includes a search criteria that focuses on ‘supply chain related’ contributions can be compared with Ashby *et al.*, (2012) review of supply and operations journals. Interestingly, Ashby *et al.*, (2012) did not include the *Journal of the Operational Research Society* but did include the *European Journal of Operations Research* (EJOR - has a similar ABS rank). The *European Journal of Information Systems* which also has an ABS rank of 3 was omitted, which in part understandable due to Ashby *et al.*, (2012) focus on journals with an operations focus. The other publications would not have been included in Ashby *et al.*, (2012) review due to the low ranking of the publication. For comparison purposes, Ashby *et al.*, (2012) identified only 2 publications in EJOR while a similar search in JORS would have identified 26 in general and 15 specifically on SCM related terms. Figure 1 shows the number of reviewed papers per year. There has consistently been one paper, which is fair in comparison to Ashby *et al.*, (2012) identification of two until the year 2000 (with a greater population). Ashby *et al.*, (2012) noted a substantial change in growth from 2001 onwards; OR society contributions lagged behind when notable contributions increased from 2005 onwards (except in 2003, note only two papers). Both studies showed a dramatic change in 2009 to date, post-global financial crisis.

The number of papers identified in this review is insufficient to draw useful comparisons but demonstrates how sustainability is an emerging subject. As in Ashby *et al.*, (2012) review to identify the broadest range of papers a full text search was used in the six OR Society titles using the search terms noted in table 2. For comparison purposes, the same terms were reviewed in the *International Abstracts in Operations Research* which consists of 68,000

abstracts of the world's OR/MS literature. This shows that there is an existing body of knowledge in sustainability that requires further examination to identify trends and areas of opportunity for further theory development. However, the review does point out that OR/MS research is sufficiently lacking in the area of corporate social responsibility and social sustainability.

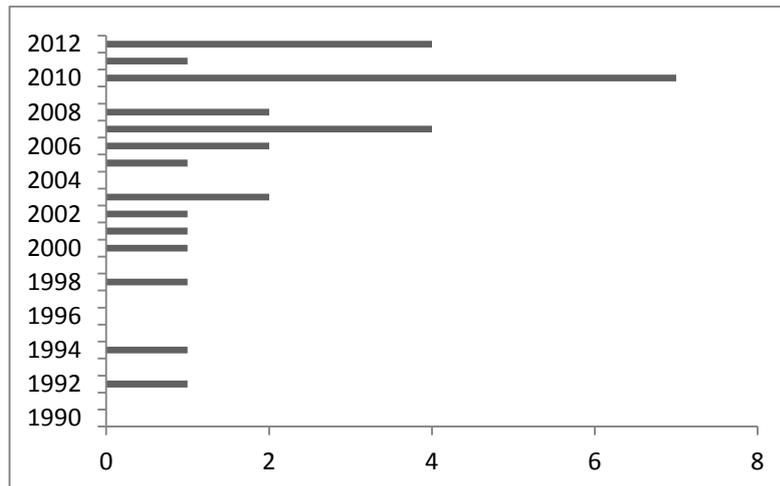


Figure 1 Number of OR Society reviewed papers per year (all search terms)

Table 2 Search terms

| Boundary | Search terms | No of papers in operations and supply journals noted in Ashby <i>et al.</i> , (2012) | No of papers in IAOR | No of papers in OR Society specific journals |
|-----------------------|--|--|----------------------|--|
| Organisational | Sustainability | 16 | 60 | 8 |
| | sustainable development* | | 33 | 4 |
| | Corporate social responsibility | 8 | 2 | 0 |
| | Social sustainability | 7 | 4 | 0 |
| | Life cycle analysis (LCA) | 3 | 8 | 1 |
| Supply | Green supply chains | 35 | 15 | 1 |
| | Sustainable supply chain management (SSCM) | 14 | 1 | 0 |
| | Closed loop supply chains | 7 | 23 | 1 |
| | Integrated supply chain | 1 | 10 | 0 |

* The term sustainable development was searched with sustainability by Ashby *et al.*, (2012). For the purposes of this review the terms are split to ensure that no papers are omitted from the search.

3.2 Sustainability dimensions

Table 3 lists the fifteen papers that were consolidated from the previous identification of OR Society titles using the search terms noted in table 2. It shows that to date, there is an equal

amount of research that has focused on the environmental and social dimensions. This is at odds with Ashby *et al.*, (2012) study of operations and supply chain management literature and earlier reviews of OR literature by White and Gregory (2007). Both suggest that research has focused more one sided on the environmental dimension as opposed to addressing the social sustainability challenge. White and Gregory (2007) had specifically noted that OR responses to sustainability had concentrated on the relationship between environmental management and product supply chain and rarely focus on the social dimension. At present the OR Society community is equal, although as White and Gregory (2007) point out, it can still be argued today that OR has yet to be fully utilised in the area of sustainability/sustainable development. The governance dimension is emerging, particularly post financial crisis and would also be useful to research each dimension further across the OR/MS literature in each geographic location.

Table 3 Occurrences in the OR Society literature on the economic, environmental, social and governance dimensions

| N° Paper | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | TOTAL |
|------------|------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|-------|
| Dimensions | Environmental / green | . | . | . | | | . | . | | | . | . | . | . | . | . | 11 |
| | Social | . | . | | | . | | . | . | . | . | | | . | . | . | 11 |
| | Economic | | . | . | | . | . | | | | . | | . | | | . | 8 |
| | Governance | | | | | | . | | | . | . | | . | | | . | 5 |

Bell (1998) argued that operational researchers had been slow to define and claim a strategic role for OR. This may help to explain the lack of research into sustainability issues as it can be argued to be of a strategic nature (but this should not be seen exclusively). Bell (1998) points out that the community should discuss OR as a strategic asset and that OR in 1998 had an exciting future to provide a vision. More recently, Lane (2010) argues that OR/MS retains the ability to do high stake work and capable of high level interventions. Both Bell (1998) and Lane (2010) did not cite the sustainability challenge posted in this paper, which here is argued as one of the greatest of a lifetime. Just as Bell noted that ‘*strategic OR*’ is not an oxymoron, the same can be suggested for ‘*sustainability and OR*’ and can be used to evaluate sustainability as a source of business opportunity and thus to underpin competitive advantage.

4. Discussion on OR Society contributions to sustainability

Midgley and Reynolds (2004) suggested an agenda for systems/OR research in the context of sustainable development. The authors make one substantive claim that for every paper on sustainability and management that is explicit about using OR methods there are at least five making claims to methodological innovation that are using the same or similar methods without reference to OR. This highlights the need to compare Ashby *et al.*, (2012) study of one domain, operations and supply chain and to identify the full extent of coverage with OR. This also highlights that OR-related research is presented in non-OR journals on the topic on sustainability and this requires attention of OR journal editors.

Special issues could be found calling for papers on the use of OR for the public interest (i.e. societal issues, in *Operations Research*, 2010), environment and sustainable development (in *Operational Research - An International Journal*, 2009) and the better management for sustainability (in *European Journal of Operational Research*, 2009). Interestingly, there is a call for papers for March 2013 in as special issue of *Computers and Operation Research* on 'Advances in Operations Research for Sustainable Supply Chain Management'. In this call it is noted that the majority of research is based on empirical or case studies, with a dearth of papers that take a rigorous modelling approach to produce general analytical results (Kannon and Cheng, 14/02/2013). No special issues relating to sustainability can be identified in OR Society titles although *Knowledge Management Research & Practice* will include a special issue in 2013 on 'Sustainable Quality: Knowledge and Information Management'. Therefore, the trend identified in the study of a lack of OR/MS research in the sustainability area is bucking. Although, contributions in OR Society titles are lagging there are some signs that this is to change.

White *et al.*, (2009) make the point that the label 'OR' appears to have a low profile in the discourse about appropriate methodologies and methods in sustainability citing the studies by Bloemhof-Ruwaard *et al.*, (1995) and Daniel *et al.*, (1997). Midgley and Reynolds (2004) suggests an agenda for systems/operational research and sustainable development. They argue that OR have considerable scope to address sustainability issues and cite the three essential characteristics of operational research. This includes OR has a *systems orientation*, being of an *interdisciplinary nature* and being explicitly *purposeful*. A systems orientation is important as it concerns a critique of the boundary, which is key when concerning the governance dimension of sustainability. Important questions include 'who owns controls or even governs a supply chain'? 'How are relationships forged and managed'? These questions have yet to be explicitly addressed by the community but in each of the studies the boundaries of a model are described (i.e. reviewed papers 3, 5, 8, 12, 15). This requires holistic thinking, dealing with complexity and uncertainty regarding the unpredictability of natural and social phenomena. The purpose of studies show a range of disciplines covered, most notably tourism and supply chains, sustainable development, sustainable communities and ethical investment. In terms of OR tools and techniques, many have been applied and adapted including the balanced scorecard approach, benchmarking, robustness analysis, life-cycle analysis as well as general modelling and simulation tools.

It would be useful to extend this initial review to extensively survey OR/MS literature on the OR tools and techniques used for sustainability issues but more over to understand there utility to address the challenges posed in this paper. As noted in Midgley and Reynolds (2004) addressing sustainable issues will lead to raising the profile of OR in the future. Where OR may play a substantive role is in assessing sustainability responses that achieve a cost advantage (e.g. modelling, simulation, optimisation) and in corporate decision-making on addressing environmental, social and governance issues (i.e. multi-criteria decision making).

No evidence was found on conceptual modelling of sustainability issues but this is one tool that could help determine boundaries, understand complexity and improvements that can be made (See Weaver, 2010). Systems thinking, such as soft systems methodology deal with problems that are generally ill-defined, explores connectivity between relationships and action-orientated around improvements (See Checkland and Scholes, 1999). Conceptual modelling for sustainability issues may be an interesting starting point as it is a crucial and necessary step before modelling and/or simulation (Robinson, 2004; Weaver, 2010) and is also incorporated into soft systems thinking. Midgley and Reynolds (2004) note that sustainability are generally so complex that they resist quantification and OR promote technical answers to what are ethical or moral questions. The authors suggest this should not be the case as noted by Checkland and Scholes (1999, pg. A11), OR can be used to observe the perceived real-world as a system so that one can be engineered ('hard') and/or organised and explored as a learning system ('soft'). In terms of quantitative methods, Midgley and Reynolds (2004) also note quantitative methods should not replace debate about values. However, once these values are defined OR tools and techniques are purposeful when evaluating the impact of dynamic behaviour on performance and power relationships (i.e. governance issues).

5. Conclusions and implications for the OR community

The range and extent of contributions in both this initial study and Ashby *et al.*, (2012) is limited considering the importance placed on sustainability in practice. This is even more concerning since OR tools and techniques are well placed to address a whole of host of sustainability issues on each of the dimensions sustainability (i.e. *economic, environmental, social* and *governance*). Contributions can be found in OR Society titles demonstrating an equal split between environmental and social dimensions. This is at odd with OR literature in general and does not fit the pattern identified by Ashby *et al.*, (2012) in terms operations and supply chain research contributions (i.e. focus on environmental issues). It is clear that there was a slight increase in contributions across the board, post-global financial crisis and the prominence of the governance dimensions taking shape. Additionally, numerous special issues have been presented since 2010 in OR/MS journals and the number of forthcoming special issues is promising. It is noted that a special issue in OR Society titles has yet to emerge but may play an influential role in focusing thought-leadership and utility and applicability of OR to sustainability issues.

OR research has considerable advantages to deal with strategic issues and grand challenges. Lane (2010) ends his paper discussing high leverage interventions by quoting Archimedes who he suggests offers some lessons for OR/MS today. Lane (2010) notes how Archimedes showed great boldness when faced with a grave challenge to demonstrate what OR/MS is capable of today.

"There is no limit, just give me somewhere to stand, and I shall move the earth"

Drachmann, 1958, p. 281.

For the sustainability agenda, the earth does not need to be moved, but we need a seismic shift to address many of the challenges that face both people and planet today. The OR Society has made a contribution on both social and environmental dimensions and to a lesser extent the governance challenges to date. However, great challenges, bring about great responsibilities to step up and use OR tools and methods for today current problems that will impact upon generations to come. There is a need to extend this initial survey to identify the extent of OR research on sustainability in different geographic locations. To identify emerging themes and trends that can be addressed by OR approaches in the future. This includes the area of modelling/simulation and problem-structuring techniques. Underlining these methods is the need to conceptually model a system, identifies the boundary and capture complexity in terms of the connectedness between links and relationships and to deal with uncertainty. This paper concludes that a stream at YOR18 is a start, an extensive literature review and survey of OR Society members on the applicability and utility of OR approaches would be helpful. This should form a call for action to be addressed in the future by the OR community.

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KEYNOTE

Operational Research: Key for Successful Disaster Management

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Abstract

Disasters are an unpredictable phenomenon and they can happen anywhere at any time, something reflected on several unfortunate chapters of history related to the experiences of several countries. The uncertainty around disasters and recent events (e.g. Japan tsunami (2011), Hurricane Katrina (2005), Pakistan Floods (2010) are increasing awareness about the importance of comprehensive disaster management. The goal now is not only to mitigate disasters, but to be prepared to cope with these phenomena, looking to protect vulnerable people and to provide them with survival items and improve community recovery, establishing concepts such as vulnerability, risk, service levels, among others, as crucial elements to aid the decision making. Thus, the complexity of comprehensive disaster management calls for suitable techniques that can provide tailored solutions to achieve the goals aforementioned, and that is the role of operational research.

The flexibility and wide range of techniques comprised by operational research can provide useful solutions for disaster management supported by the advances on emergency logistics, relying on close cooperation between authorities and researchers. The field of emergency logistics is still young, but the contributions of operational research are substantial and the opportunities for improvement are wide-ranging.

The purpose of this paper is to present an overview of the importance of operational research within disaster management, mentioning previous contributions from several authors on the field, the most common tools of operational research applied to emergency logistics and opportunities for new research that can improve emergency operations performed currently worldwide.

Keywords: Modelling, Disaster management, Emergency response, Operational research

1. Introduction

According to (UNISDR, 2012), from 1992 to 2012 4.4 billion were affected by disasters with almost 2 trillion USD in damages and 1.3 million people killed worldwide. The economic losses caused by disasters are increasing every year, and an example is given by the unprecedented amount on economic losses registered last year. "In 2011, total economic losses to society (both insured and uninsured) due to disasters reached an estimated USD 350 billion, compared to USD 226 billion in 2010" (Swiss-Re, 2011).

Moreover, “the trends in the number and impact of disasters and the massive scale of recent global relief efforts have brought growing attention to the need for effective and efficient disaster response operations” (B. Balcik & Beamon, 2008).

Therefore, the complexity of disaster management combined with the impact of several recent disasters highlight the need to introduce tools to improve decision-making looking to use efficiently the resources at hand, and operational research can provide a set of powerful tools to accomplish that.

Authorities globally are trying to improve operations for disaster management, aiming to provide a proper assistance to affected communities. But disaster management goes beyond the response to any disaster, starting with long-term planning and considering also the support for the affected people to get back to their normal lives. The importance of the field relies on the fact that there are lives on the line every step of the way (both, rescuers and rescuees) and every decision impacts a large number of affected people.

A disaster is a “serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its own resources” (UNISDR, 2009). In many jurisdictions, a confirmation of a disaster constitutes an official request for, or promises to, provide support. In the beginning of this discussion another two terms are specified with disaster: natural disaster and manmade disaster. According to UNISDR (2004), a disaster "takes place when the following three conditions occur at the same time:

- When people live in hazardous places like, for example, close to an active volcano, on unstable slopes where landslides are likely to happen, or close to rivers which could flood.
- When a hazardous phenomenon occurs, be it natural or human-made.
- When the phenomenon also causes a lot of damage, especially where no preventive measures have been taken".

Disasters are commonly classified depending on its origin (natural or man-made) and its quickness (sudden onset and slow onset). Figure 1 illustrates examples of disasters at each of the categories. It is important to notice that depending on the characteristics of each disaster it is the nature of the appropriate response operations to try to cope with the disaster.

Therefore to cope up with high impact disasters mankind needs an active and well-organized disaster management process. The objective of disaster management is:

- Total prevention of disaster;
- Effective rescue and treatment of disaster affected population;
- Mitigating the severeness of disaster and control the whole situation;

- Causality identification, classification and provide the necessary relief items to the affected people.

| | Natural | Man-made |
|--------------|--------------------------------------|--|
| Sudden-onset | Earthquake Hurricane Tornadoes | Terrorist Attack Coup d'Etat Chemical leak |
| Slow-onset | Famine Drought Poverty | Political Crisis Refugee Crisis |

Figure 1 Types of disaster (Van Wassenhove (2006))

2. Operational research: techniques for better performance

According to Altay and Green (2006), the most common operational research techniques used in disaster management are:

- Mathematical Programming
- Probability and Statistics
- Simulation
- Decision Theory and Multi-Attribute Utility Theory
- Queuing Theory
- Fuzzy Sets
- Stochastic Programming
- Experts Systems and Artificial Intelligence
- Systems Dynamics
- Constraint Programming
- Soft OR

The first two categories account for more than half of the papers reviewed by the author and the first four cover over 73% of the research contributions. Thus, there will be only a brief mention of the first four.

2.1. *Mathematical programming*

Mathematical programming is the most used technique for emergency logistics Caunhye, Nie, & Pokharel, (2012), Balci and Beamon (2008), Kongsomsaksakul, Chen, and Yang (2005), Duran, Gutierrez, and Keskinocak (2011) and Lin, Batta, Rogerson, Blatt, and Flanigan

(2011), among others are examples where the authors used mathematical programming and constraints programming for disaster management. Also, Sheu (2007b) and Tzeng, Cheng, and Huang (2007) used fuzzy optimization for the distribution of relief during disaster operation.

2.2. Probability and statistics

Probability and statistics are a very flexible tool to calculate the probability of occurrence (Tao, Tao, & Jiang, 2012) and to analyze scenarios (Dudin & Nishimura, 1999) within emergency management.

2.3. Simulation

It is the technique of building a (computer) model of a real or proposed system so that the behaviour of the system under specific conditions may be studied. Its application in disaster management have several examples (e.g. Albores & Shaw, 2008; Banomyong & Sopadang, 2010; Lee, Ghosh, & Ettl, 2009; Nagarajan, Shaw, & Albores, 2012) and specially tools based on agent-based systems (Fiedrich & Burghardt, 2007; Hawe, Coates, Wilson, & Crouch, 2012),

2.4. Decision theory and multi-attribute utility theory

Decision theory provides a rational framework for choosing between alternative courses of action when the consequences resulting from this choice are imperfectly known. Two streams of thought serve as the foundations: utility theory and the inductive use of probability theory (North, 1968). "Decision theory concentrates on identifying the "best" decision option, where the notion of "best" is allowed to have a number of different meanings, of which the most common is that which maximises the expected utility of the decision maker. Decision theory provides a powerful tool with which to analyse scenarios in which an agent must make decisions in an unpredictable environment" (Parsons & Wooldridge, 2002), although recently there is a calling for improvements on decision analysis to cope with several challenges identified (Cox, 2012).

3. The role of operational research in disaster management

Winston (1994) defines operational research as a scientific approach for decision making, which pursues to define the best way of design and operation of a system, usually under conditions requiring the allocation of scarce resources.

In disaster management there are several trends of research related to social sciences, specifically focused on sociological impacts after disaster, organisational design and communication problems. But the other main stream of research is aiming to provide an effective disaster management process, focusing on operation techniques and tools to fulfil the needs of decision-makers by combining operational research with disaster management.

It is important to notice that “prospective research on optimal disaster management has often been characterized as ‘difficult, if not impossible’, providing challenges to the establishment of evidence based guidelines for disaster planning. Systems approach, however, offers numerous optimization tools that can be applied to the investigation of a wide range of disaster management problems” (Simonović, 2010)

Within disaster management there are several important activities to perform to minimize the risk of occurrence and the impact of disaster, along with the provision of adequate care for vulnerable communities. The activities are carried out on different points of time, depending on the needs at hand. That is the reason Drabek and Hoetmer (1991) provided four phases for comprehensive emergency management, which “overlap in practice but have specific individual goals” (Drabek & Hoetmer, 1991). The phases are:

- *Mitigation*. Comprises the activities performed to avoid or reduce the disaster occurrence risk.
- *Preparedness*. Includes individual or collective efforts to lessen the impact of disasters, and it has a close relation with planning.
- *Response*. Takes place in the moments before, during and after the disaster strikes and it considers activities aiming to rescue, avoid property damage, satisfy the immediate needs for survival goods of the affected people, among others.
- *Recovery*. It is integrated by the efforts oriented to return to the normal conditions of the community.

The phases actually create a cycle repeating itself to relieve the impact of disaster, as it can be seen on Figure 2.

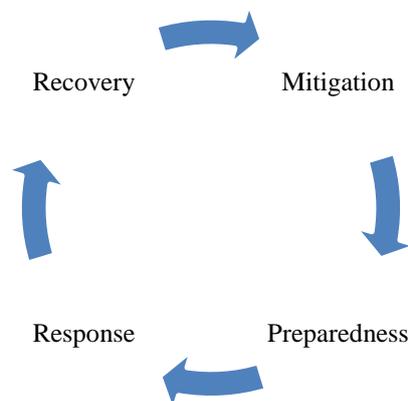


Figure 2 Disaster phases

Altay and Green III (2006) provided a framework of the application of operational research to disaster management, and they identified that most of the articles developed up to that point were related to mitigation, followed by response and preparedness, with just a few articles focusing on recovery. The importance of operational research in this context lies on the fact that it has a very broad set of tools to improve disaster management across different stages,

reason why operational research is widely used in emergency logistics and disaster management.

At every phase the circumstances are different and obviously the needs and the decisions to make are also different. Thus, it will be useful to analyze the role of operational research at each stage to understand the relevance of the use of these techniques.

3.1. Mitigation

Mitigation is very commonly address by governmental authorities using cutting-edge engineering techniques to build dams, dykes, protective walls, among others (Lopez-Pelaez & Pigeon, 2011; Uddin & Ang, 2009; Yi, Furen, & Zhenming, 2012); forecasting (Davidson, Zhao, & Kumar, 2003; Hsieh, 2004) and risk assessment (Coles & Pericchi, 2003; Lian & Yen, 2003; Matisziw & Murray, 2009).

3.2. Preparedness

To improve planning and prevention, there are several applications of operational research techniques in the field. The most common activities are location of emergency facilities (B. Balcik & Beamon, 2008; Basar, Catay, & Unluyurt, 2011; Chowdhury, Watkins, Rahman, & Karim, 1998; Dekle, Lavieri, Martin, Emir-Farinas, & Francis, 2005; R. Huang, Kim, & Menezes, 2010; X.-R. Huang & Xie, 2009; Jia, Ordóñez, & Dessouky, 2007; Ng, Park, & Waller, 2010; Sherali, Carter, & Hobeika, 1991) and pre-positioning (Campbell & Jones, 2011; M.-S. Chang, Tseng, & Chen, 2007; Cross, 2009; Rawls & Turnquist, 2010, 2011, 2012; Salmeron & Apte, 2010).

3.3. Response

This phase is highly aided by operational research for distribution (Burcu Balcik, Beamon, & Smilowitz, 2008; Berkoune, Renaud, Rekik, & Ruiz, 2012; Özdamar & Demir, 2012; Özdamar, Ekinici, & Küçükyazici, 2004; Sheu, 2007b, 2010; Suzuki, 2012; Wang & Dai, 2010; Widener & Horner, 2011), evacuation (Alçada-Almeida, Tralhão, Santos, & Coutinho-Rodrigues, 2009; Apivotanagul, Davidson, & Nozick, 2012; Kongsomsaksakul et al., 2005; Kulshrestha, Wu, Lou, & Yin, 2011; Li, Zhang, Liu, & Tan, 2011; Park, van de Lindt, Gupta, & Cox, 2012; Saadatseresht, Mansourian, & Taleai, 2009; Sbayti & Mahmassani, 2006; Scheer, Varela, & Eftychidis, 2012; Sherali et al., 1991; R. Song, He, & Zhang, 2009; Ye, Wang, Huang, Xu, & Chen, 2012) and inventory planning (Beamon & Kotleba, 2006; Davis, Samanlioglu, Qu, & Root, 2013; Ozbay, Kaan, Erman, & Eren, 2007; Ozguven & Ozbay, 2011).

3.4. Recovery

Although it is the less studied phase, there are some papers related to allocate displaced people (Nikolopoulos & Tzanetis, 2003), infrastructure assessment (S. Chang & Nojima,

2001; Cret, Yamazaki, Nagata, & Katayama, 1993; B. Song, Hao, Murakami, & Sadohara, 1996) and reconstruction (Kim & Dshalalow, 2002).

4. Conclusion and future research

This article focused on the disaster management domain and basically how operational research techniques can be able to increase the efficiency of decision making process during the critical situation of disasters. It looked at previous literature related to the use of operational research in disaster management (See Altay & Green III, 2006; Caunhye et al., 2012; Kovács & Spens, 2007) and identified new trends of research and the fact that more contributions are needed for better decision-making in disaster management.

Moreover, the techniques presented are very flexible and can be used along with IT technologies and soft methods to provide more comprehensive solutions, creating systems with the advantages of different methods whilst reducing the constraint of a single perspective.

Although there have been an increasingly number of papers regarding disaster management recently, the number of topics to address is still very large and there is a need to come up with new approaches to some topics. There are several areas that ought to be further investigated and problems to be tackled using operational research, such as coordination, needs assessment, humanitarian supply chain, emergency logistic operations, among others.

Overall there are great advances on the field, but more research is necessary to really improve disaster management and the first key is to close the gap between practitioners and researchers. Authorities have the insights and the experience, meanwhile researchers have the tools and the expertise, and therefore a mutual arrangement could contribute to develop more feasible and reliable systems for disaster management.

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KEYNOTE

Inter-Model Influence Diagram Analysis Using Modular Elicitation Methods for Evacuation Decision-Making

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Abstract

Graphical modelling of decisions has been a common tool used in a wide range of analysis methodologies including decision theory and systems thinking. While these models can be effective in assessing a single decision context/situation, little emphasis has been placed on simultaneous analysis of these decision representations for models that represent similar decision problems. This paper will present a modular system of influence diagrams for strategic decision-making for similar decision problems. An example of this modular ID system will be shown by utilizing strategic-level influence diagrams to analyse evacuation policies across a flood, nuclear and terrorist attack scenarios. The analytical process of the modular influence diagrams also allows for an analysis of multiple objectives that exist for evacuation decisions. These results show how communications strategies and public interaction provide a wider breadth of influence on identified evacuation objectives across the three disaster scenarios. The analysis also identifies uncertain factors that affect a wide range of different emergency scenarios and makes transparent strategic decision-making. The process can be generalized to organizations with identifiable strategic values where either scenarios or lower-level decisions must be made using a subset of overarching objectives.

Keywords: Scenarios, Decision analysis, Multiple criteria analysis, Knowledge-based systems

1. Introduction

Graphical models have been widely used as a way to analyse decision processes within a wide range of fields including mind maps in systems dynamics (Senge & Sterman, 1992), rich pictures in soft systems methods (Checkland, 2001) and influence diagrams (IDs) in decision theory (Pearl, 2005). In these cases the modelling of these decision processes are used to assist elicitation of problem structures, specify explicit causal relationships and build strategy for the decision context (Mingers & White, 2010). This paper will explore the extent to which IDs elicited from different contexts can be analysed to identify common probabilistic elements. This will be done by outlining a single objective-based modular elicitation of IDs which can be combined into a multi-objective IDs. An inter-model analysis based on these modular single-objective IDs will then be completed to identify common uncertainties between different scenarios and common probabilistic strings of uncertainties across all scenarios and objectives.

The modular elicitation of IDs combined with inter-model analysis attempts to combine elements of both decision theory and systems dynamics. This can be beneficial both as a way of sharing important domain knowledge across disparate organisations and provide insight into uncertainties that have the widest breadth of influence over a single decision context. By basing the decision model elicitation on IDs, it is possible to assess causal relationships between uncertainties in order to quantitatively specify probability functions (*pfs*) (Clemen & Reilly, 2001). IDs also allow for multi-objective problems by specifying separate objective-based *pfs* for each identified joint and conditional relationship (French & Rios Insua, 2000; Raiffa & Schlaiffer, 2000). An example of this process will be given for emergency evacuation decision-making in cases of catastrophic disaster. This is based on the Evacuation Responsiveness by Government Organisations (ERGO) Project which includes the identification of overarching criterion for evacuation decision-making across various catastrophic disaster scenarios (Shaw et al., 2011).

Section 2 of this paper will discuss current methods of decision structuring within systems dynamics and decision theory. In particular we will discuss the objectivity of these different decision structures when using them to disseminate information between different groups or individuals. Section 3 will discuss the process of modular ID analysis including the elicitation of individual objective modules and their combination into complete IDs. Section 4 will describe results of the case study of modular ID analysis using catastrophic evacuation decision-making for different emergency scenarios. This section will also discuss the common elements in evacuation decision-making that were identified when comparing the different emergency scenarios. Common modular elements include spatial/temporal aspects of the risk, population characteristics and building characteristics. Common probabilistic stings identified across all evacuation scenarios include communication continuity and evacuee casualty rates. An evaluation of the modular analysis process and possible expansion to other fields will be given in Section 5. This analysis is appropriate for problems where an overarching objective structure is available for a related set of narrative scenarios.

2. Graphical model use and analysis

As a part of operational research, graphical models hold an important position as both a method to disseminate and structure decision problems (Huff, 1990). Influence diagrams, however seem to have taken a very different arc within operational research as a framework for quantitative specification (Quigley, 2009). This section will describe causal map techniques in order to show the strengths of inter-model analysis within systems dynamics along with the advantages of multi-objective modelling and quantitative specification found in influence diagrams.

2.1. Systems thinking problem structuring

Causal maps fit into a much larger body of literature concerning the use of graphical representations of decision processes. Besides causal maps some other common graphical tools to support decision-making are mindmaps (Buzan, 2005; Buzan & Buzan, 1994),

cognitive maps (Eden & Ackermann, 1998) and rich pictures (Checkland, 2001). Causal maps differ from the aforementioned models in an epistemological sense as they are focused on the description of cause-and-effect relationships between uncertain factors. Goodier (2010) describes causal maps as frameworks around which “coherent and coordinated behaviours and actions are critical”.

Another development within the systems dynamics literature is the comparison of causal maps developed by separate organisations. This can be useful in identifying common elements either within different interpretations of a single problem elicited from multiple individuals or as a method to compare like-scenarios. Markoczy & Goldberg (1995) describe a method that focuses on identifying the difference between separate causal models by assessing the nodes and arcs to create a distance ratio. Two primary conclusions were drawn by the authors in regards to the comparison of these models. First, that an effective analysis between causal maps is only possible where a systematic elicitation process is used for all member maps. A second important finding deals with the elimination of subjective aspects of the causal maps which can result in biased results especially for the identification of clustered portions of the causal maps.

Causal mapping are commonly used to foster learning and support cause-effect relationships for complex systems. Comparison between these models can be difficult due to the multiple meanings that can be attached to each node in the graphical structure and possible variation due to elicitation methods (Burt, 2011). An explicit, consistent facilitation process was mentioned by Markoczy as vital to effective comparisons between causal maps. Additional quantitative processes can be completed to both identify difference between different causal maps as well as both sequences and clusters of concepts that are common between the maps.

2.2. Influence diagrams

Developed by Howard & Matheson (2005) an influence diagram is a graphical representation of a single decision context. In order to limit confusion any instance of influence diagrams within this work will refer to those described by Howard & Matheson. When these graphics are used in conjunction with elicitation methods it can be a powerful tool to verify and communicate key issues between decision-makers (DMs). IDs can also be used as a way to verify that all relevant factors of the decision have been included (requisite modelling) (French & Rios Insua, 2000). This verification of client-analyst understanding is vital to increase buy-in of the results of the decision model (Carrigan, Cardner, Conner, & Maule, 2004). The structure of an ID can also be used to develop a quantitative model of the decision.

An ID utilizes shapes (called nodes) and arcs (connecting lines) to represent conditional and joint relationships between factors in the analysis. Figure 1 is an ID of the basic evacuation decision.

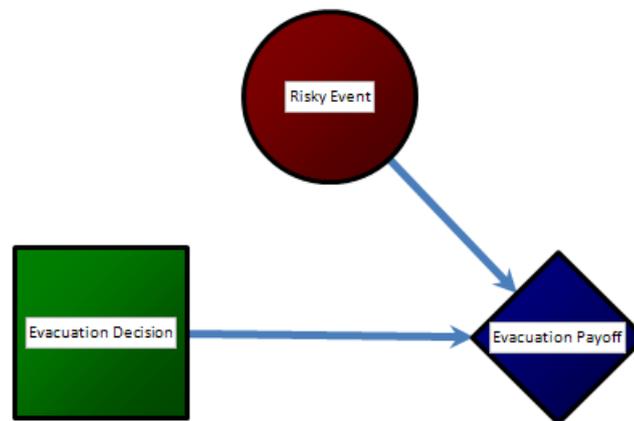


Figure 1 Influence diagram example

The decision is represented by the rectangle and leads to the outcome which is shown as a diamond. Outcomes, however, are not solely influenced by the decision taken by emergency managers. The outcome is also influenced by an uncertain factor which in this case is the possibility of a risky event occurring. The uncertainty, in this case a probability function (pf) representing the risk/hazard event is represented by the oval. The arcs indicate that the outcome is influenced both by the decision of the emergency manager as well as the uncertain risk. The specification of an ID is much more specific than causal maps which allows for a wide range of concepts or actors to be represented with a node. While this does limit the overall flexibility of the ID it increases the interpretability of the graphical representation of decisions. With effective decision context definitions this provides a strict elicitation method that will allow for improved consistency for IDs developed from disparate experts.

An important concept within the ID is that each node represents both a conceptual and probabilistic representation of the underlying phenomenon. At a qualitative level each node may represent an uncertain concept which can then be quantified into either a discrete or continuous pf . An ID simplifies a decision problem by making explicit probabilistic dependence/independence. This is done through the use of arcs to connect the different nodes representing influence between concepts.

Scenario building using IDs has been forwarded as a way to overcome the inability of a DM to describe uncertainty with enough detail to create complete pf s (Schoemaker, 1995). Once the basic structure of the decision context has been specified within the ID, a set of key uncertainties are given point estimates to represent a range of possible outcomes. This process is repeated in order to create a set of scenarios based on the single decision context usually representing either extreme outcomes or highly likely outcomes (Goodier, Austin, Soetanto, & Dainty, 2010). Fischhoff *et al.* (Fischhoff, de Bruin, Guvenc, Caruso, & Brilliant, 2006) provides an example of this process in the development of emergency strategies in cases of an avian flu epidemic. This process first begins with *narrative scenarios* (Harris, 2005) which are used within the emergency management community to describe possible disaster situations. These *narrative scenarios* can be shared with domain experts to

create a framework of uncertainty around which a set of compatible scenarios can be identified. Similar process to develop *narrative scenarios* have been developed for emergency management (Aven & Renn, 2009), energy policy (Kowalski, Stagl, Madlener, & Omann, 2009), and environmental issues (Lempert, Groves, Popper, & Bankes, 2006).

A modular criterion-based approach to elicitation will provide the additional structure that will allow for inter-model analysis not currently present within IDs. Because the inter-model analysis is based on an ID it can also be used to represent the mixture of probabilistic dependencies between identified factors. Both of these factors are important and represent important contributions to both decision theory and emergency management. It also represents a novel combination of system dynamics methods with decision theory that is appropriate for problems that have a similar objective structure that is influenced by varied sets of uncertainties. Within emergency management it will provide insight into common probabilistic factors that affect evacuation outcomes and underlying strategies to improve those outcomes.

3. Methodology

The process of objective-based ID modules will be developed in this section including the elicitation, combination and comparison process for different *narrative scenarios* of evacuation decision-making. The ERGO project will also be described in order to illustrate and define the specific emergency scenarios chosen to analyse evacuation operations. Because modular elicitation process is focused on cross-model comparison an explicit process for problem structuring will be used in the elicitation of the underlying ID. The entire elicitation process is outlined in Table 1.

Table 1 Modular Influence Diagram process

| |
|---|
| 1. Specify an overarching decision context |
| 2. Identify multiple objectives for that decision context |
| 3. Define a set of <i>narrative scenarios</i> to analyse |
| 4. Specify a set of objectives for each narrative scenario |
| 5. Complete modular Influence Diagrams for each objective within each <i>narrative scenario</i> |
| 6. Combine objective ID modules for each scenario |
| 7. Node-based analysis |
| 8. Identification of common module clusters |

Overarching decision context refers to a single decision that must be made under a set of unique *narrative scenarios*. In this case an evacuation decision is an overarching decision that an emergency manager faces given a wide range of possible risks/threats. Multiple objectives for complex decision problems are a common occurrence in emergency management (Bertsch, Geldermann, Rentz, & Raskob, 2006). Once the context and objectives have been identified a set of *narrative scenarios* will be chosen. A *narrative*

scenario refers to a descriptive situation that fits the overarching context and is comprised of both a objective-based structure representing multiple, conflicting objectives and unique set of uncertainties that influence outcomes of the scenario for each identified objective. The elicitation of explicit IDs for each objective within the *narrative scenario* is then completed. These modular criterion-based IDs are then combined to create full multi-objective IDs that are then used to analyse common structural elements between the *narrative scenarios*.

3.1. Evacuation Responsiveness by Government Organisations (ERGO)

Evacuation operations in advance of catastrophic disaster are of great concern for emergency management organisations around the world. One important goal of the ERGO project was the identification of a set of overarching objectives for evacuation operations across of participating nations. Kailiponi (2009) explains the process through which semi-structured interviews and facilitated group sessions were used to identify and compile overall objectives for evacuation operations across a wide range of catastrophic emergency scenarios. Table 2 shows the identified evacuation objectives along with possible attribute measurement scales for each.

Table 2 Overarching evacuation objective list

| Objective | Attribute |
|---|---|
| 1. Minimise health and safety threat | |
| Minimise loss of life | # of Casualties |
| Minimise injuries | # of Serious injuries |
| Minimise individuals subject to radiation | # of individuals irradiated |
| 2. Minimise economic disruption | |
| Minimise business disruption | Monetary loss |
| Minimise personal disruption | Monetary loss |
| 3. Minimise public disorder | # of individuals that exhibit panicked behaviour |
| 4. Minimise cost to emergency organisations | Monetary loss |
| 5. Minimise public disregard for future evacuation orders | # of individuals that fail to regard future evacuation orders |
| 6. Maximise public confidence in officials | Public approval strategy |
| 7. Maximise integrity of possible criminal investigations | Time delay of investigation due to evacuation |

The ERGO project was also vital in identifying an initial set of disaster scenarios. Evacuation scenarios to further develop were chosen based on the number of participating countries who expressed concern over that specific scenario. While there was variation within countries as to their experience with those actual events, there was a great deal of expertise for each of the

identified high-concern scenarios among the ERGO participating countries. While these situations represent scenarios of high concern for almost all ERGO countries, it also allowed the analyst to focus on DMs who have the greatest amount of practical experience in preparing for evacuation actions in advance of these events. These individuals were then contacted to further develop the specification of IDs for those catastrophic events.

3.2. Elicitation of modular influence diagrams

For any given scenario j a set of objectives i must be identified that represents the primary goals that a DM should consider when making the decision chosen from an overarching set of objectives (Table 2). For each scenario the decision is then structured in such a way that a separate ID is developed for each pair of objective/scenario. Arcs are used to specify independence, joint and conditional relationships between each node. This creates the modular basis for influence diagrams that will then be used to complete inter-model analysis between scenarios. This process conceptually simplifies the elicitation process by allowing a DM to focus on a single objective and the identification of uncertain factors that may have an influence on that objective. A single module is a set of nodes n_{ij} that represents the factors that influence outcomes for that identified objective. Because the process of node identification and ID specification is repeated for each identified objective it is possible to have multiple instances of a single node n_{ij} between scenarios.

3.3. Inter-model analysis of MIDs

Inter-model analysis of different *narrative* scenarios can be completed once each set of objective-based modular IDs have been elicited and combined. This is accomplished at the node level by counting instances of each node for each objective across all scenarios. This initial count represents the number of times a single chance node influences an objective across all scenarios. These simple counts represent the breadth of influence that a single chance node has across all scenarios and objectives. The purpose of the inter-model analysis is not based on an understanding of the quantitative elicitation of multi-objective functions but is instead based on the count of common elements between objectives and scenarios for a single decision context.

In cases where the underlying set of objectives is similar between the different *narrative scenarios* a large amount of overlap in multi-objective structures are possible. Because of this it is possible to identify clusters of causal relationships. A cluster in this sense is a common string of probabilistic uncertainties that are present for objective-based ID modules across different *narrative scenarios*. This would indicate a combination of both nodes representing the underlying *pf* as well as the arc structure that represents the relationship between the various elements within in ID module. While it is not possible to assume that the probabilistic modelling of the cluster is common between different *narrative scenarios*, the multi-objective ID created when combining modular IDs can provide some insight as to possible differences between modelled scenarios. Probabilistic clusters within IDs can be easily seen due to the objective-based modular elicitation of influence diagrams. When these

modular IDs are elicited in succession across *narrative scenarios* clusters will occur as the underlying objectives included between those scenarios become more homogenous.

The methodology of modular objective-based elicitation of IDs allows for a type of inter-model analysis that is more common within system dynamics methodology. The use of ID elicitation using an objective-based structure also simplifies the elicitation for multi-objective problems and allows for greater prescriptive control to verify that the elicitation is done in a manner that is consistent across different organisations. The modular elicitation structure also makes explicit the underlying probabilistic structure of uncertainties for multi-objective IDs. Given the ability to create consistent decision models, an effective inter-model analysis is then possible. Both a node-based and cluster identification process will be used to identify common elements within evacuation decision-making. The findings will represent both a form of knowledge sharing between subject experts but also a form of all-hazard analysis to guide policy decisions across all possible catastrophic scenarios that may lead to evacuation operations.

4. Findings

Initial findings indicate that there is a large amount of overlap in the objectives that emergency managers consider when faced with flood, nuclear dispersion and terror events. This combination of scenario and objectives led to the creation of 11 separate modular objective-based IDs. These findings also indicate that a similar set of objectives were considered when assessing the evacuation decision. This would indicate that the decision-making process is not sensitive to some of the underlying conditions that may cause the evacuation. This facilitated the creation of the modular IDs as similar objective structures that naturally lead into similar probabilistic specification of uncertainty even across different emergency scenarios. Objective-based modular IDs were then assessed from a primary decision-maker for each respective emergency scenario. An example of a MID is given in Figure 2 representing the *panic and disorder* objective for *terror attacks*.

The asterisks within Figure 2 represent nodes that have a unique *pf* for each predecessor. This notation was used within the figure to simplify the ID. Following the elicitation of ID modules for all objectives within each narrative scenario and combination of those modules into a multi-objective ID, a node-based analysis can be completed to find the breadth of influence that any given elicited uncertainty affects evacuation outcomes. Table 3 provides the results of the node-based analysis. Each node is listed along with the number of instances in which it can be found within different objective modules and within each scenario. A general qualitative category was also connected to each node based on the underlying content elicited from the appropriate emergency manager.

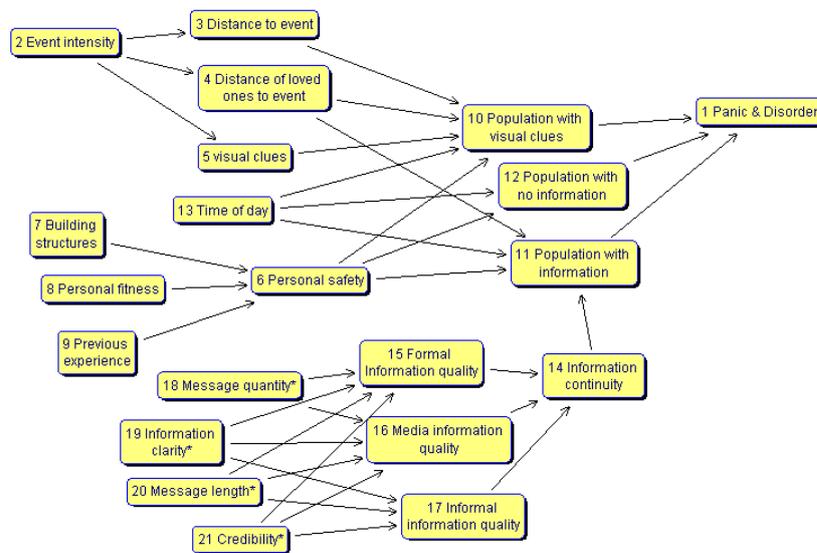


Figure 2 Example of modular objective-based ID

The qualitative categories are useful in broadly grouping the uncertainties according to common topics across the evacuation decision context and also represent common nodes within a string across the different modules.

Risk factor refers to uncertainties related to the primary threat/hazard that may cause the evacuation decision. Risk factors between the different evacuation scenarios are unique and as such they do not exhibit influence across the range of scenarios. The exception to this is the way that weather conditions affect evacuee casualty rates. Population information holds a prominent position between all scenarios. An interesting set of findings in regards to the population at-risk in catastrophic disaster situations are the characteristics of the population that are important to emergency managers in evacuation situations. The inter-model analysis shows that general age and health-based characteristics of the population are important in regards to the associated casualty rates, ability to evacuate from the at-risk area ability to receive official communications from emergency managers. Building factors also had a wide-breadth of influence over evacuation objectives. These factors affect both the associated casualty rates for both evacuees in some scenarios and non-evacuees in all of the scenarios. Building strength was also found to have an effect on the possible panicked behaviour exhibited by individuals in at-risk zones. Conceptually this refers to the idea that appropriate building characteristics can mitigate the effect of a risk/hazard on the public.

Communication factors were found to have a very wide breadth of influence across all evacuation scenarios. These factors represent a mixture of the formal/informal communications to the public that ultimately influence evacuation compliance rates and panic/disorder outcomes across all scenarios. These factors also make explicit aspects of communication messages (i.e. length, repetition, credibility and clarity) that lead to information continuity that ultimately affects evacuation compliance rates. This same group

of factors also influences the amount of panic and disorder of individuals within the area. Simply because an identical string of factors is present within across different modules does not mean that the underlying *pfs* are also similar. Indeed quantitative analysis that would follow these structural findings would focus of eliciting the effect that these communication factors influence either panic/disorder among the public for each scenario or evacuation compliance and that effect on final causality/injury outcomes.

Table 3 Inter-model node analysis

| Node name | Total count | Scenario | Objective | Category |
|----------------------------------|-------------|----------|-----------|----------------|
| Population | 6 | 3 | 2 | Population |
| information received | 6 | 3 | 2 | Population |
| age | 6 | 3 | 2 | Population |
| disability | 6 | 3 | 2 | Population |
| transition | 6 | 3 | 2 | Population |
| Time of day | 6 | 3 | 2 | Temporal |
| Evacuation compliance rate | 3 | 3 | 1 | Behaviour |
| River height forecast | 1 | 1 | 1 | Risk |
| Rainfall forecast | 3 | 3 | 1 | Risk |
| Ground saturation | 1 | 1 | 1 | Risk |
| Dyke effectiveness | 1 | 1 | 1 | Risk |
| Pumping efficiency | 1 | 1 | 1 | Risk |
| Temporary defence effectiveness | 1 | 1 | 1 | Risk |
| Building structure | 6 | 3 | 2 | Infrastructure |
| Casualty rate | 3 | 3 | 1 | Health |
| Evacuee casualty rate | 3 | 3 | 1 | Health |
| Personal fitness | 5 | 3 | 2 | Population |
| # of previous events | 3 | 3 | 1 | Population |
| Gov't interaction with media | 3 | 3 | 1 | Communication |
| Gov't interaction with public | 6 | 3 | 2 | Communication |
| Media report (positive/negative) | 2 | 2 | 1 | Communication |
| Business type | 3 | 3 | 1 | Communication |
| Previous event outcomes | 2 | 2 | 1 | Behaviour |
| Economic losses | 3 | 3 | 1 | Spatial |
| Area to evacuate | 6 | 3 | 2 | Spatial |
| Initial event intensity | 1 | 1 | 1 | Risk |
| Distance to event | 3 | 3 | 1 | Spatial |
| Distance of loved ones to event | 3 | 3 | 1 | Spatial |
| Visual clues | 3 | 3 | 1 | Risk |
| Proximity to event | 6 | 3 | 2 | Risk |
| Secondary threat probability | 1 | 1 | 1 | Risk |
| Road conditions | 3 | 3 | 1 | Infrastructure |
| Radiological type | 1 | 1 | 1 | Risk |
| Release quantity | 1 | 1 | 1 | Risk |
| Atmospheric dispersion | 1 | 1 | 1 | Risk |

Finally temporal and spatial factors concerning the evacuation scenario have a wide breadth of influence across ID modules. These factors include such uncertainties such as the time of day in which the emergency occurs and area that needs to be evacuated. These factors are also dispersed across the different modules and are usually antecedents to population information. In the case of evacuation decisions for catastrophic disasters the MID node analysis found that general temporal and spatial uncertainties for each scenario, building structure characteristics and communication factors had the widest breadth of influence across objectives for the analysed *narrative scenarios*.

4.1. Common probabilistic clusters

Consistent strings of uncertainties have also been identified for evacuation decisions. These repeating strings are identical joint/conditional relationships between objective modules for multiple *narrative scenarios*. This would indicate either that the string remains similar across different evacuation objectives between scenarios or that a single string of nodes is identical for a single objective across all elicited scenarios. The most consistent string across objectives and evacuation scenarios deals with the interaction between government officials and communications networks to minimise panic and disorder and increase the level of evacuation compliance. A second cluster identified between modular objective-based IDs deals with evacuee casualty rates and the interaction between weather and road conditions that can lead to possible fatalities during evacuation operations, which influences the health/injury objective across the evacuation scenarios. Figure 3 & 4 provide the probabilistic structure between uncertainties in both common clusters for evacuee casualty rates and information continuity respectively.

The explicit descriptive form given in the ID can then be used as a framework for the quantification of this concept. While Figures 3 & 4 illustrate the common uncertainties between all scenarios it does not include some of the scenario-specific differences between these strings. In the case of evacuee casualty rates the structure shown in Figure 3 is identical within flood and terror attacks. Evacuee casualty rates for nuclear dispersion events are also influenced by the type and intensity of radioactive material in atmosphere within the evacuation zone. The information continuity cluster represents a string of uncertain factors that affect both panic/disorder and health/safety objectives for all evacuation scenarios. As such within evacuation decision-making it is has the widest breadth of influence across objectives.

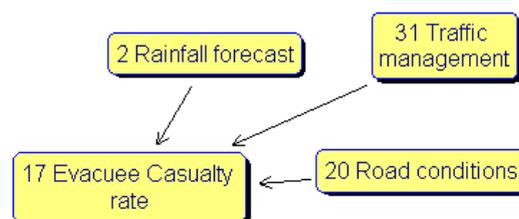


Figure 3 Evacuee casualty rate cluster

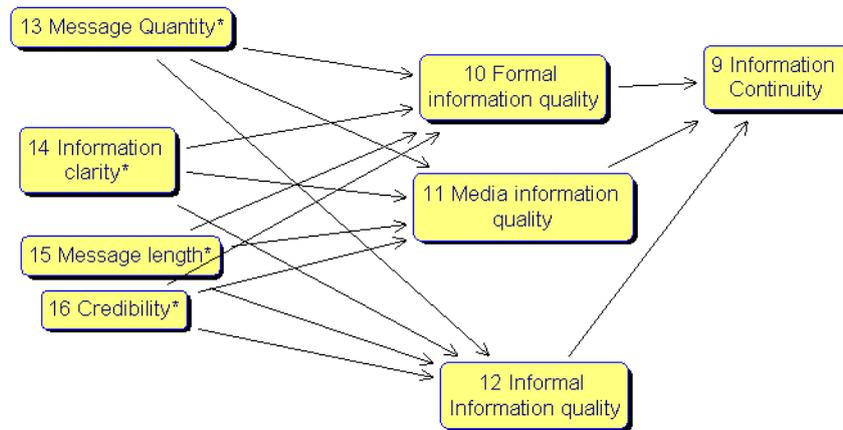


Figure 4 Information continuity cluster

Information continuity is different from evacuation casualty rates in that the underlying *pf*s between evacuation scenarios are unique. Additionally there is a high level of complexity even within the cluster identified between the different objective-based modules. Emergency managers can use this information to guide their communication development and dissemination to the public within at-risk areas. In the case of communication development, coordination with media outlets and specific aspects of the evacuation order influence compliance. Message length, repetition and credibility (all of which are specific aspects of communications made with the public and media outlets) were found to widely influence outcomes related to the public compliance with evacuation orders as well as panic/disorder exhibited by the public. The development of specific *pf*s for this cluster is more complex as effective measurement of these concepts can be difficult. Despite this, the identification of the communication provides insight into a set of communication strategies that may have a much wider breadth of influence over the appropriate evacuation decision objectives.

5. Discussion & Conclusion

The process of creating modular influence diagrams can have many advantages in the modelling of complex decision problems. A modular assessment of a specific decision context improves the clarity of probabilistic relationships between identified uncertainties for multi-objective problems. It also simplifies the elicitation process for experts who, instead of developing complete multi-objective models, need only create sections of the same model based on the objectives they feel are appropriate for the decision context. The development of different *narrative scenarios* for a single decision context also allows for a structure to perform inter-model analysis as well as the ability to increase knowledge sharing in cases where experience concerning a single scenario is external to the existing managers. The ID structure in this way is appropriate for decision problems where little information is available and the scenario based expertise that is required for planning is widely dispersed.

In the case of evacuation decision-making common elements were identified across the three different scenarios proposed by ERGO participating experts. Between the three different

evacuation scenarios spatial/temporal, population characteristics and building characteristics were all found to be concepts that influence all scenarios as well as multiple objectives within those scenarios. This can be used by emergency officials to guide data gathering in preparation of catastrophic disaster events as well as during evacuation operations to make acute emergency decisions. The identification of evacuee casualty and communications clusters is also important to guide policies that affect evacuation planning for multiple hazards.

This modular process to ID elicitation has the potential to support a wide range of decision problems where different *narrative* scenarios share a similar objective structure. By splitting the elicitation into single objective ID modules the decision structure is made explicit for each objective, something that is not made explicit in an ID that attempts to show the multi-objective decision context. Inter-model analysis in this case also provides emergency managers in this example with some insight into the evacuation decision without the need to elicit the complete set of joint and conditional relationships to finalise a quantitative decision model. These findings represent both a strong addition to decision theory methodology using a combination of inter-model analysis taken from system dynamics and soft systems methodology with the explicit decision structuring possible through the use of influence diagrams.

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Performance Evaluation of Forecasting Models: At Last, Problem Solved!

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Abstract

The current methodology for assessing the relative performance of competing forecasting models is unidimensional in nature in that models are compared to each other using a single criterion at a time, which typically leads to different rankings for different criteria thus resulting in conflicting results or conclusions regarding the performance of competing models. Xu and Ouenniche (2011, 2012a, 2012b) addressed this methodological issue by proposing several data envelopment analysis and multi-criteria decision making analysis frameworks for determining a single ranking that takes account of several criteria. In this paper, we overcome some issues with the previously proposed DEA-based methodologies by proposing an orientation-free super-efficiency DEA framework; namely, a slacks-based super-efficiency DEA framework. For illustration purposes, we assess the performance of competing models for forecasting the volatility of crude oil prices.

Keywords: Forecasting crude oil prices' volatility; Performance evaluation; Slacks-based measure (SBM); Data envelopment analysis (DEA); Super efficiency

1. Introduction

Xu and Ouenniche (2011, 2012a, 2012b) highlighted a common issue faced by the forecasting community; namely, the fact that the current methodology for assessing the relative performance of competing forecasting models is unidimensional in nature; that is, models are compared to each other using a single criterion at a time. To be more specific, although most forecasting studies use several criteria to assess the performance of competing forecasting models, the assessment exercise of these models typically consists of ranking them based on a specific measure of a specific criterion, which could lead to as many different rankings as performance measures a study would include (e.g., Sadorsky, 2005; 2006; Coppola, 2008; Agnolucci, 2009; Murat and Tokat, 2009). As a consequence, conflicting results about the performance of specific forecasting models are often reported in that some models perform better than others with respect to a specific criterion, but worse with respect to other criteria; thus, leading to a situation where one cannot make an informed decision as to which model performs best overall when taking all criteria into account. In order to overcome this methodological issue, Xu and Ouenniche (2011) proposed a multidimensional framework for assessing the relative performance of competing forecasting models of the level of a continuous variable (i.e., oil price); namely, context-dependent data envelopment analysis (CDEA), which is based on the CDEA model of Seiford and Zhu (2003). In 2012, they

proposed an alternative framework based on multicriteria decision analysis methods (Xu and Ouenniche, 2012a). On the other hand, Xu and Ouenniche (2012b) proposed a super-efficiency DEA framework for assessing the relative performance of competing forecasting models of the volatility of a continuous variable (i.e., oil price), which is based on the super efficiency model of Andersen and Peterson (1993). In sum, these multicriteria frameworks allow one to obtain a single ranking that takes account of several performance criteria. In another research paper (Ouenniche, Xu and Tone, 2013), we propose an alternative framework to the one proposed by Xu and Ouenniche (2012b) which overcomes the following issues. First, under the variable returns-to-scale (VRS) assumption, input-oriented super-efficiency scores can be different from output-oriented super-efficiency scores, which would lead to different rankings. Second, in many applications such as ours, the choice of an orientation in DEA is rather superfluous. Third, radial super-efficiency DEA models may be infeasible for some efficient decision making units; therefore, ties would persist in the rankings. Fourth, radial super-efficiency DEA only takes account of technical efficiency. In sum, we propose an orientation-free super-efficiency DEA framework; namely, a slacks-based super-efficiency DEA framework for assessing the relative performance of competing volatility forecasting models.

The remainder of this paper is organized as follows. First, we describe the application context of the proposed multidimensional framework for assessing the relative performance of competing forecasting models; that is, crude oil prices' volatility. Second, we briefly review the basic concepts of DEA and propose an improved DEA framework to evaluate the relative performance of competing forecasting models for crude oil prices volatility. Third, we present and discuss our empirical results. Finally, we summarize our conclusions.

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Productive Dialogue is the Answer, Now What is the Question?

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Abstract

In recent years several researchers have assessed the state of development of the soft OR field and identified challenges and opportunities for moving the field forward (e.g. Ackermann, 2012; Franco & Montibeller, 2010; Howick & Ackermann, 2011; Paucar-Caceres, 2010; Rosenhead, 2006). These recent reviews of the field signal a significant departure from the early efforts by the soft OR pioneers to get their methods understood and accepted as legitimate fields of enquiry within the OR community and across the wider academic community of which they are a part. Indeed, long forgotten are the heated debates between the OR ‘hardies’ and OR ‘softies’ that appeared in the Viewpoints section of the Journal of the Operational Research Society back in the 1980s. Today soft OR is as a legitimate part of mainstream OR (Mingers & Rosenhead, 2004), at least on this side of the Atlantic (Mingers, 2011), and thus current debates among soft OR scholars are more about the best ways for practitioners to learn and apply soft OR skills (e.g. Ackermann, 2011; Carreras & Kaur, 2011). These are important discussions that I suspect will continue for the foreseeable future. From a practitioner’s perspective being part of the debate is important, but it can also serve as a distraction. This paper will concern itself with particular developments within a few soft OR approaches, collectively known as Problem Structuring Methods (PSMs), and show how these recent developments advances our understanding of how these methods are used in practice (e.g. workshops), and with what effects. This can help OR analysts to gain a better appreciation of the potential of PSMs to support their work, and how to ‘sell’ PSMs to their clients.

1. Framework of analysis & method

Currently a number of soft OR scholars are examining the structures of group conversations and how they pertain to the progression of interventions where PSMs are applied (e.g. Franco & Rouwette, 2011; Papadopoulos & Franco, 2012; Tavella, 2012). This work has highlighted concepts that I contend serve a useful function in understanding why PSMs can offer successful approaches for organizational change and importantly, from a consultants perspective, why clients agree to an intervention where the consultant proposes the use of PSMs. The concept that will serve as the lens through which we view the empirical cases I will be discussing is that of a “productive dialogue” (Tsoukas, 2009). I will begin by discussing the relevance of this term, the way in which it is understood in the context of PSM application, and the reasons why I think it is central to understanding not only what goes on in a PSM intervention, but also where and when a PSM has been chosen by clients as a technique that they see of value. It also has the added bonus of putting into focus the manner in which facilitators provide feedback to each other after an intervention and adjust their technique for future interventions.

Tsoukas (2009) provides a concise illustration of the series of interactions that might be construed as the foundation of productive dialogue. Productive dialogue enables individuals to take ‘distance from’ their usual or ‘customary and unreflective’ ways of acting as a practitioner, that is, they achieve ‘self-distanciation’. This in turn is dependent upon a ‘relational’ engagement between those engaged in a conversation. Relational engagement encourages proactive behaviour in terms of taking responsibility for one’s own tasks and the tasks that one will jointly engage in with others. It may also act as means by which one is able to improve one’s own understanding of one’s own current activities and from a consultant, or researcher’s perspective, develop a deeper understanding of, or new insights about, the techniques and methods that they use in their respective practice.

This concept of productive dialogue has been extended and incorporated within micro level explanations of PSM interventions (Franco, 2006, 2012). Where, for example, an understanding of how the visual models that are an integral part of PSMs affect knowledge development within a group, can assist the facilitator in explaining the progress that is made at various stages of a PSM intervention. This can also be extended to an understanding of models as boundary objects that enable the development (within a group) of: A shared language (*transfer*), shared meanings (*translation*) and common interests (*transformation*). These in turn help in the creation of new knowledge and overcome of some of the syntactic, semantic and pragmatic barriers often encountered in group decision making. Productive dialogue is also a fruitful way of interpreting the structures of conversations and public statements that can lead to the agreement of collective actions (Carreras, 2012).

2. Discussion and conclusions

Whilst research at the micro level has been mainly in the realm of causal mapping workshops, relational engagement is a key feature in the application of all of the PSM interventions in which I have been involved including: Soft Systems Methods, Strategic Options Development an Analysis, Strategic Choice Analysis, Decision Conferencing and Robustness Analysis. I do not have direct experience of utilizing Drama Theory nor Viable Systems Models. Based upon a reflection of more than 30 separate interventions I will argue that attention to the nature of the dialogue between all of the actors involved in the intervention (Client, Facilitator, participants and other stakeholders) will add significantly to the value of the intervention.

One further aspect that will be discussed is the development of the agreement between client and consultant. As is the case with all consultancy one is aware that the process of consultancy begins the moment that one meets the client, prior to any agreement about working together, memorandum of understanding or contract is signed. The consultant and potential client engage in a dialogue from the moment they meet, and it is my experience that attention to the common patterns of dialogue that one encounters is important in moving the potential client to actual client. This in itself should not be viewed as some sort of insincere attempt to ingratiate oneself to the client and persuade them to employ a process that is not to their overall benefit. Being sensitive to the nature of the dialogue between client and

practitioner, being aware of the way in which a relational engagement serves the interests of both parties is something that I believe improves the chances of each recognizing that a working together will be of mutual benefit.

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Health Economic Modelling: A Conceptual Modelling Framework for Public Health Economic Models

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Abstract

Health economic evaluation attempts to provide a rational and coherent framework to help decision makers choose which health interventions to fund by comparing the differences in costs and outcomes between alternative options (Drummond M.F., 2005). Within England and Wales, health economic modelling is employed to inform national guidance issued by the National Institute for Health and Clinical Excellence (NICE). Approaches for health economic modelling were originally developed to compare the cost-effectiveness of clinical interventions. Since 2005 NICE have also assessed the cost-effectiveness of Public Health interventions such as minimum pricing for alcohol (National Institute for Health and Clinical Excellence, 2013). Public Health systems tend to be dynamically complex and require consideration of a broader range of determinants of health than clinical interventions, including understanding human behaviour and estimating impacts upon non-health costs and outcomes (Claxton K et al., 2007; Shiell et al., 2008). In 2010, qualitative research by Chilcott *et al.* found that there were no formal methods for developing the structure of health economic models which were systematic or transparent (Chilcott J. et al., 2010). Since 2010 such methods have been developed for the assessment of clinical interventions (Kaltenthaler E. et al., 2011; Roberts M. et al., 2012); however the structural development of Public Health economic models continues to be based upon ad hoc non-transparent methods which are highly dependent upon the modeller. This presentation will briefly review methods for assessing the cost-effectiveness of healthcare interventions within the UK and describe a conceptual modelling framework for developing Public Health economic models.

Models typically developed within health economic evaluation include decision trees, cohort Markov models and patient-level simulation (Briggs A. et al., 2006). Outcomes are generally presented in terms of the incremental cost per quality-adjusted life year (QALY) gained. Due to the difficulty of optimisation within the entire healthcare system, simple decision rules have been developed to choose between alternative options (Drummond M.F., 2005). Each of these will be briefly described within the presentation.

The conceptual modelling framework for Public Health economic evaluation was informed by two literature reviews, qualitative research with modellers and an application of a draft version of the framework within a pilot study. The first literature review aimed to describe the key challenges in Public Health economic modelling and the second reviewed existing conceptual modelling frameworks within the broader literature. They were undertaken using a systematic, iterative search method. The qualitative research aimed to understand the

experiences of modellers with developing model structures and their views about the barriers and benefits of using a conceptual modelling framework. This involved; (i) following the development of a Public Health economic model including observing key meetings and

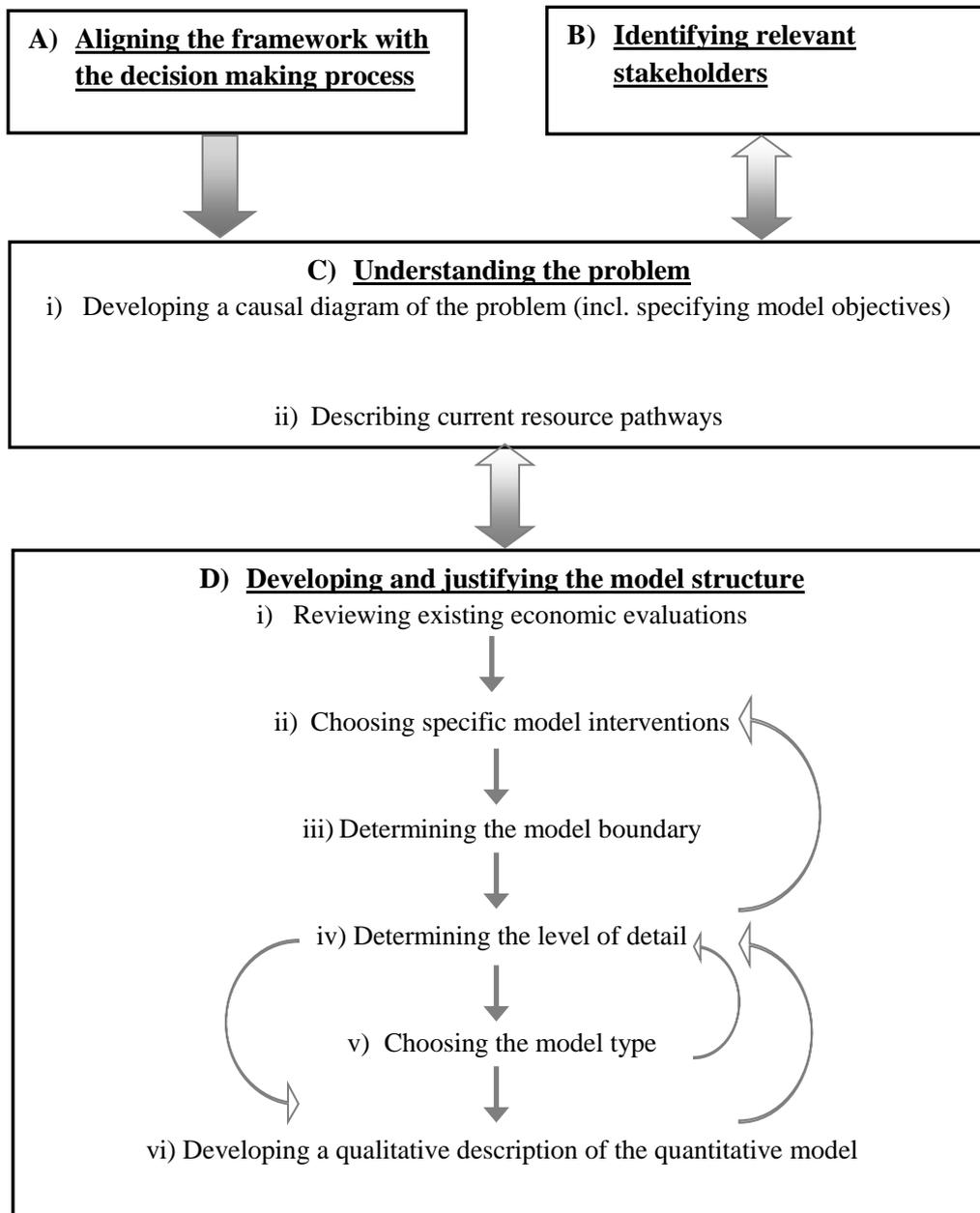


Figure 1 Overview of a conceptual modelling framework for Public Health economic modelling

undertaking in-depth interviews with the modellers involved; (ii) systematically analysing my own notes from a previous Public Health economic project; and (iii) holding a focus group meeting with Public Health modellers. A draft version of the conceptual modelling

framework was piloted within a project assessing the cost-effectiveness of interventions for diabetes screening and prevention in order to develop it further.

Three key principles for the conceptual modelling framework were identified; (1) that a systems approach to Public Health modelling is most appropriate (i.e. the system should be understood as a whole taking into account feedback loops and unintended consequences); (2) that communication with stakeholders and members of the team throughout model development is important; and (3) that specifying the modelling objectives and developing a thorough documented understanding of the problem is valuable prior to developing and justifying the model structure.

An overview of the conceptual modelling framework is shown in Figure 1. Methods for undertaking each of the stages shown within Figure 1 are described within the conceptual modelling framework and non-prescriptive suggestions around the processes modellers might follow are proposed. These will be described within the presentation.

This conceptual modelling framework should help to improve the scope, quality and communication of Public Health economic models in order to help decision makers make appropriate policy decisions.

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Data Science 2.0 – Guided and In-line Analytics

Why being a Data Scientist is Sexy in the era of Big Data

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Abstract

This paper looks at how data scientists are of increasing importance in the era of Big Data and how they and other business users can be organized into a productive unit that address the differing requirements of data analysis across a business, drawing particularly on our experiences in financial services organizations. This is described by the author as “Data Science 2.0”. Further, the author looks at a best-practice approach to data analytics and a common pitfall that may expose organizations to substantive risk.

Keywords: Big Data, Data scientist, Predictive analytics

1. Introduction

In virtually all profit-making industries, IT initiatives and business projects are justified by improving productivity, reducing risk and/or growing revenues. Excluding the latter, we could extend these criteria to the non-for-profit sector as well. The various functional areas of these organizations rely on “big data” analytics – trading and managing portfolios, creating value across customer/ citizen relationships, detecting and preventing fraud and managing risk across the organization.

2. Data scientists and vertical markets

Data Science is the practice of deriving insights from data to solve business problems. The current market wave is tied to the new world of big data, and *Data Scientist* is now touted as the sexiest job of the 21st century in the Harvard Business Review (Davenport and Patil, 2012). McKinsey has noted a 50-60% supply-demand gap for data scientists, with a shortage of more than 150,000 data scientists and 1.5 million managers with big data analytics understanding over the next 5 years (McKinsey, 2011).

The value of data science is undeniable, with core applications driving a wide array of governmental, business and customer intelligence programs including:

- acquiring and growing customers (cross-sell / up-sell)
- attrition modelling (with intervention!)
- trigger-based marketing (including mobile and location based offers)
- sales lift analysis (test and learn)
- dynamic segmentation (treating different segments differently!)

- pricing analytics (including loyalty and lifetime value)
- sentiment and attribution analysis (staff performance and advertising/campaign effectiveness)
- fraud and risk analytics (operational execution and enterprise analysis)

In addition, specialized data science programs drive industry vertical solutions, with industry-specific data sources that are expanding and evolving e.g. to incorporate social networks and real-time data. In the Financial Services market, this plays out across all of the core functional areas including:

- capital markets (trading, portfolio)
- retail (market and customer insight)
- risk management (enterprise, credit and counterparty, market)
- fraud and compliance (AML, credit card, trading)

While for the oil and gas sector we would see a very different set, such as:

- production optimization (and calculation of ultimate reserves in fields)
- maintenance of the integrity of key assets (such as rigs and pipelines)
- optimizing the location and operation of drilling operations (including geospatial, geological and geochemical data)

While there would be a cross-over in the area of energy trading, on the whole these two industries require the mastering of very different data sets and statistical techniques. It is evident that “vertical” is a key driver of differentiation here, and this can be extended equally well to virtually all commercial and non-commercial activities.

3. A common pitfall

With the current excitement around big data and data science there are some solutions getting attention that are dangerous e.g. promoting isolated, end-user, database analyses with all the attendant problems such as chasing noise, throwing out data that don't match pre-conceptions, confusing leading and lagging indicators, interpreting correlations as causation e.g. as described by Silver (2012). Some new companies are even making bold claims that they invented visual analytics, that data scientists will be dead in 18 months; or that we don't need data scientists, just easier access to big data. This type of thinking introduces substantive risk – not only of heading in entirely the wrong direction, but with significant negative ramifications, like bringing down businesses, operations or financial systems! The end-user community can be readily enabled with self-service analytics (as outlined below), but there needs to be inbuilt guidance, and a framework of end-user data discovery, collaboration and enterprise readiness that promotes rigorous and real analysis on the business!

4. From Data Science 1.0 to Data Science 2.0

I outlined the basic Data Science 1.0 process in a 2012 Forbes article, “What is a Data Scientist” (Woods, 2012), and in notes to the European Banking Forum (O'Connell, 2012a) and WSTA communities (O'Connell, 2012b). With recent technology innovations (TIBCO, 2012; The Forrester Wave, 2013), we have now jumped beyond this to what I believe to be a new **Data Science 2.0** state. The expanded workflow in this new state includes:

- identifying the high-value business problems and developing value theses with demonstrable ROI
- assembling the appropriate data mashups to address the problems
- ordering the data aggregations and filters – in-database and in-memory
- exploring the data (EDA) – visually and interactively
- constructing and validating the features that inform the problem – leading and lagging indicators
- *deploying the feature sets and exploratory data analyses as self-service, guided, collaborative analyses* across all relevant functional areas in the enterprise – with elastic architectures to efficiently meet demand
- building and evaluating models that describe and/or predict the measured response
- *deploying the champion model in the real-time event system* driving the business solution across the customer and market space
- building and evaluating new features, dashboards and challenger models for *evolution of the guided analyses and in-line event analysis systems*

This workflow is illustrated in Figure 1 for a typical business insight use case in financial services.

In the Financial Services market, our businesses are evolving rapidly and we are working hard to be nimble and intelligent with our information solutions. This combination of interactive, visual, descriptive and predictive analytics; with self-service guided and collaborative workflows for the masses, and in-line deployment in real-time event systems, is the future. This is Data Science 2.0.

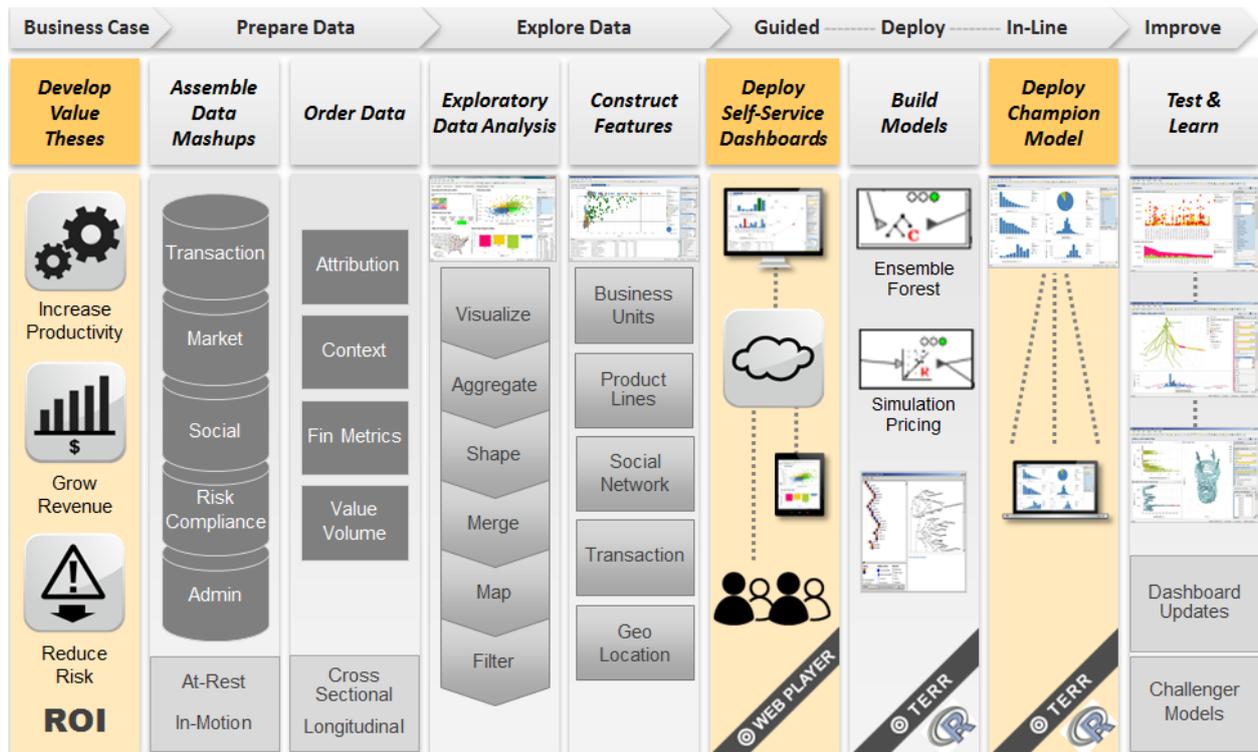


Figure 1 Data Science 2.0 workflow for a typical business insight use case in financial services.

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What can Simulation Model Developers Learn from Software Developers?

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Abstract

Simulation model development practices and methodologies vary widely but many share similarities with general software development. This paper discusses the key similarities and differences between simulation model and general software development methodologies, focussing on what simulation model developers can learn from other areas. The advantages and disadvantages of re-use of these methods are discussed. Examples are given of the steps in each process as applied to simulation models.

Computerised discrete-event simulation has been around nearly as long as computers and software have existed. In some ways computerised simulation model development is a subset of general software development. Software development has in total, across the world, more investment and more resources than simulation specifically and so has developed more practice guidelines and methodologies. Simulationists can leverage these techniques where they apply, and yet many do not. If these cross-over techniques are used to generate more efficient simulation projects of a higher quality then they can vastly improve the positive impact of simulation.

So what techniques from software development could improve our simulation projects? Here are some examples of techniques from the world of software development that we will explore with the use of a simulation project example:

- **Development lifecycle methodologies**

Development lifecycles such as the V-model, the Waterfall model, the spiral model, Agile and XP (eXtreme programming), object oriented

- **Coding practices**

Best practice coding from using an agreed naming convention, code commenting rules, exploring the goal of each section of code and using checked and unchecked assertions

- **Verification and Validation methods**

Code metrics such as code coverage during testing, black box testing, decision table and all-pairs testing,

- **Industry standards**

Process modelling standards such BPMN (Business Process Modelling Notation), and simulation standards such as BPSim

- **Supporting disciplines**

Configuration management (including software to keep control of files), documentation, Project management, User interface design

New OR Perspectives for Disaster Management in Developing Countries

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Abstract

Recently, natural disasters have become a common phenomenon affecting several countries world-wide. But developing countries are the most affected by natural disasters due to the amount of vulnerable people and the scarcity of resources to protect them. To identify the logistical challenges faced by authorities in developing countries, the authors performed an analysis of the Thailand flood (2011), Haiti earthquake (2010), Chile earthquake (2010), Pakistan flood (2010) and Mexico flood (2007). After analysing reports from the 5 large-scale disasters, the authors highlighted the main logistical issues presented, showing that the advances in research are probably not providing suitable mechanisms for developing countries.

There is a gap between authorities and academics within this field, and the authors believe that a multi-method approach can draw interest from the authorities to the developments on the area. The idea is to combine two or more tools sequentially to provide less complex tools with more comprehensive potential, taking advantage of the features of the different methods. Therefore, this paper will stress the importance of an effective logistical management process to cope with disaster within developing countries, along with a multi-method approach for the development of decision support systems to improve disaster management within developing countries.

Keywords: Preparedness; Response; Developing countries; Disaster management

1. Introduction

Management of disasters is crucial to protect and provide as quickly and efficiently as possible for the people affected by any kind of disaster. Experiences over time enhance the efforts to improve the activities currently performed because "over the last thirty years, mankind has been facing disasters on an unprecedented scale: an annual average of over ¼ million people worldwide have been affected by natural disasters, with an absolute magnitude ranging between 68 million, and more than 620 million inhabitants" (Gheorghe SĂ, 2011).

2. Emergency logistics

The relevance of disaster management forces to continuous improvement of all the operations performed by either governmental or non-governmental authorities. Emergency logistics is a very useful stream of research to accomplish that because of its high relationship with

operational research (Caunhye et al., 2012). Emergency logistics is defined as "a process of planning, managing and controlling the efficient flows of relief, information, and services from the points of origin to the points of destination to meet the urgent needs of the affected people under emergency conditions" (Sheu, 2007a). Before, during and after a disaster (slow or rapid onset disaster) the necessity is to secure and move the require materials (food, water, medicine, shelter etc.) from one point to the other point in the most efficient and effective way.

3. Disaster phases

Due to the complexity of emergency management, Drabek and Hoetmer (1991) provided four phases for comprehensive emergency management which "overlap in practice but have specific individual goals" (Drabek and Hoetmer, 1991). The phases are:

- **Mitigation.** Activities performed to avoid or reduce the disaster occurrence risk.
- **Preparedness.** Efforts to lessen the impact of disasters
- **Response.** Activities aiming to rescue, avoid property damage, satisfy the immediate needs for survival goods of the affected people, among others.
- **Recovery.** Efforts oriented to return to the normal conditions of the community.

The phases actually create a cycle repeating itself to relieve the impact of disaster, as it can be seen on Figure 1.

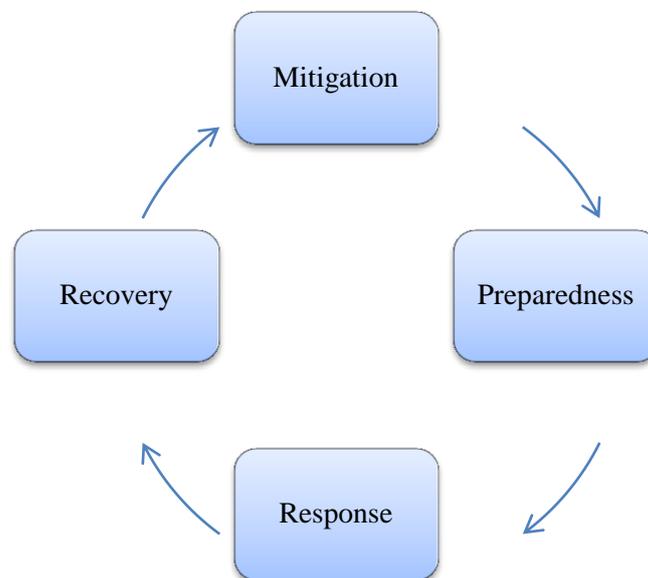


Figure 1 Disaster phases

During disaster the most challenging effort is to rescue the affected people, take them to safe places and provide them with resources. Therefore designing an emergency plan, conducting training to the volunteers, on-going evacuation of vulnerable population, shelter planning,

organisational exercise, pre-positioning of relief materials, relief delivery, setup of a temporary distribution centre, among others, are essential activities to cope with large-scale disasters. Preparedness and response are the phases where the above activities are pursued. These phases engage with unpredictability, quickness of events, short decision and action times, unavailability of resources, uncertainty about the situation and high pressure.

Also it is important to notice that every emergency is unique and hence preparedness and response plans need to be customised according to the situation/emergency. Different kind of emergency operations need different preparedness and response plans.

Therefore it is essential to use operational research techniques for a well organised decision support system which helps the decision makers to act quickly and efficiently during the preparedness and response.

4. Disaster management in developing countries: 5 cases

The role of emergency logistics is to try to help people affected by disasters by providing the decision makers with tools suitable to improve operations, and this trend of research has been increasing in recent years as a result of several disasters occurred worldwide, whether on developed or in developing countries. Although the difference lies on the amount of resources available and the quantity of vulnerable people, thus sometimes two disasters with similar characteristics occurring on a developing and a developed country can have significantly different death tolls, with higher impact on the developing country (Julca, 2012).

“The social and economic cost of natural disasters due to climate is in a process of continuous expansion throughout the world. The trend is largely attributable to increasing vulnerability in less developed countries, especially in the poor nations, where the population remains, in most cases, more vulnerable to extreme climate events that occur later, after the people experienced a first severe disaster” (Gheorghe SĂ, 2011).

Therefore, for the present paper there will be an analysis of 5 recent large scale disasters in developing countries and the common issues between them. The cases reviewed were the Thailand flood (2011), Haiti earthquake (2010), Chile earthquake (2010), Pakistan flood (2010) and Mexico flood (2007). These cases were selected using EMDAT (<http://www.emdat.be>) and the selection criteria included recent events (less than 10 years) in developing countries (non-first world countries) with high impact on the population (more than 1,000,000 people affected).

Table1 shows the characteristics of every disaster and the last column shows some briefs examples of the logistical issues found reading different reports. Looking at the disasters altogether, problems such as shortages on food, inadequate places used as shelters, issues with relief distribution and lack of pre-defined distribution facilities are constantly mentioned. The fact that some of the problems happened in different disasters on different locations is a calling to try to come up with ways to tackle those problems.

Table 1 Logistical issues presented on five recent disasters

| Country | Year | Disaster | People affected (million) | Examples of logistical issues found |
|-----------------|------|------------|---------------------------|--|
| <i>Thailand</i> | 2011 | Flood | 13.6 | Lack of communication and lack of sanitation |
| <i>Haiti</i> | 2010 | Earthquake | 2.3 | Lack of coordination, lack of allocating land and weak of accountability of clusters. |
| <i>Chile</i> | 2010 | Earthquake | 2 | Lack of pre-defined distribution facilities, shortages of medical items and delays on relief delivery |
| <i>Pakistan</i> | 2010 | Flood | 20 | Lack of infrastructures, shortages of food, ignorance of minority during relief distribution, lack of security of food items |
| <i>Mexico</i> | 2007 | Flood | 1.6 | Unsafe shelters, food shortages, inconsistent relief delivery |

5. Multi methods: an approach towards comprehensive disaster management

There are several operational research techniques which are used in humanitarian to improve the solutions on this field. According to Altay and Green III (2006) mathematical programming, probability and statistics, simulation, stochastic programming, fuzzy set theory, decision theory, queuing theory, system dynamics, constraints programming are the dominant operational research techniques which have been used in the domain of disaster management. Also, there are several articles using qualitative techniques and geographic information system (GIS) to improve disaster management with interesting results. Balcik and Beamon (2008), Duran et al. (2011), Kongsomsaksakul et al. (2005), Lin et al. (2011) are some examples where the authors used mathematical programming and constraints for facility location, distribution, and logistics for the disaster relief operation. Also, Sheu (2007a), Tzeng et al. (2007) used fuzzy optimization for the distribution of relief during disaster operation.

It is important to notice that although optimization is the most common tool used in emergency logistics (Caunhye et al., 2012), recently the combination of different methods to addressed disaster management has increased considerably (See Alçada-Almeida et al., 2009, Chang et al., 2007, Turğut et al., 2011). The limitations of optimization models along with the need for comprehensive disaster management are drawing the attention towards the use of different tools for the same system. For this part, firstly we will explain the most common methods used for disaster management and the new trends of research.

The idea of multi-methods refers to the use of two or more methods sequentially to benefit from the advantages of each method, looking to provide a comprehensive tool to improve operations in disaster management due to the complexity inherent of disasters.

For this approach, there are several possible combinations and the potential is outstanding because of the versatility of the tools embedded in operational research. Within disaster management, the use of GIS with optimization models has been explored successfully (Alçada-Almeida et al., 2009, Chang et al., 2007), taking advantage of the geographical potential of the GIS and the decision-making capacity of optimization. Also the use of Fuzzy Theory with AHP has been used before in the literature (Turgut et al., 2012), delivering a very interesting tool for facility location in disasters.

From the perspective of the authors, although there are some examples in the literature, a multi-methods approach can be advantageous to provide solutions applicable for the problems in the real world, considering more than only one perspective in the analysis. This is particularly crucial for developing countries, because even though there are great articles in the literature, a lot of them are too complex because of the difficulties to capture all the features of any disaster on one tool.

Therefore, the idea is that multi-methods can provide a useful solution for developing countries because models can be less complex if there is a supplement provided by other tool.

6. Conclusions and future research

Within this paper the importance of research on emergency logistics for developing countries was highlighted, noticing the unfortunate number of events in these kinds of countries worldwide and also considering the poor operations performed in five independent events worldwide. The main logistical issues found are mentioned to provide a framework to understand that even though a lot of papers in the literature do not distinguish between developed and developing countries; there are differences that should be addressed to develop new systems.

There are common logistical issues presented on the cases studied, showing that the current state of research regarding emergency logistics is not working effectively for developing countries. Thus, the gap between the activities performed by authorities and the researchers has to be addressed to be able to provide suitable tools for developing countries.

The multi-methods approach introduced by this paper has been used before, but there is an opportunity to analyse this approach more deeply to come up with better tools. Advantages such as simpler models, more interaction with authorities, the combination of expertise on the field with decision-making tools, tools easier to understand and use, more graphical systems, among others, are only the beginning, and also some reasons to go further in this trend of research.

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