Preface

Not until the recent attacks on transport systems has transport security become a focus of public concern and academic research. Various aspects of transport security have already been analysed under different agendas. Some research was focused on the potential risk to the environment resulting from transport, in particular from the transport of hazardous or dangerous goods, while other research considered critical elements of transport networks or supply chains as vital lifelines in the case of natural disasters. Recently, new threats stimulated interest in transport security as a stand-alone issue, placing it at the forefront of political and academic agendas. A NATO Advanced Research Workshop held at Imperial College London in January 2009 brought together those with expertise in the above-mentioned fields in order to verify the current state of knowledge in the field and identify promising areas for future work. The workshop concentrated on maritime and intermodal transport, risk management and long-term strategic planning, rather than on the details of monitoring or detection techniques. This collection of papers emanates largely from that workshop.

While transport systems are widely recognized as terrorist targets, complete protection of these systems is economically and practically infeasible. The workshop looked at analytical methods to identify critical points in the transport infrastructure and the prioritization of defensive and mitigating measures given the limited resources available. Deficiencies in methods for conducting such an assessment were identified and the need for cost-effective mitigation measures was emphasized. The difficulty in identifying the benefits of "avoided attacks", or more generally in finding adequate levels of response to threats that would balance security benefits against the investments costs, were discussed. In principle, the workshop came to the view that there is an urgent need for simplified organizational structures and rationalized procedures to decrease the cost of security.

The workshop recognized the presence of trade-offs between security and civil liberties, and agreed that there is a need for a multi-disciplinary approach to security, in particular the incorporation of behavioural science in current analysis, which is based largely on a systems approach and the mathematical techniques of operations research. The confidentiality issues involved in obtaining and using the data in research were raised, leading to the application of methods designed to deal with data scarcity, such as Bayesian analysis.

The transportation of hazardous materials has been recognized as a topic in which security issues closely intertwine with environmental ones. Particular hazardous materials have risks associated with their transportation, arising from the location of sources and destinations or the timing of deliveries. In many cases, congestion increases the hazard and exposure of not only inhabitants but also of other travellers in the network. Although the environmental exposure can be reduced by the appropriate routing of hazardous materials and the timing of the deliveries, implementation may be hindered by various legislative restrictions, such as limited access by heavy goods vehicles to certain areas or roads. With

respect to risk mitigation, optimization methods applicable in rail and airport transport were presented, showing that it is beneficial to segregate non-hazmat and hazmat loads, and move larger shipments at the same time. Speakers presented case studies of hazmat transport in the Ukraine, Mexico and Albania.

Another theme emanating from the workshop was climate change and increasing oil scarcity, as well as the dependency of transport on the fossil fuels in general. Examples from Armenia and Romania showed that specific geographical, historical and legislative issues increase the reliance of goods supply on vehicle transport. Life Cycle Analysis was presented as a comprehensive framework for assessing the sustainability of transport. Other workshop conclusions were:

- Application of advanced analytical methods for the assessment of the robustness or vulnerabilities of transport systems is constrained by the communication of the results to the wider public.
- Dependency on conventional or single energy sources should be reduced in order to prevent political and economic conflicts. Security of energy supply chains was considered a burning problem.

Key fields for further research identified by the workshop were:

1. Connecting security with social and other sciences to create a wider framework for cost-benefit assessment of security measures;
2. Security of energy supply chains;
3. Modelling of low-probability high-consequence events;
4. Risk assessment and mitigation methods in multi-modal and maritime transport; and
5. Behaviour of individuals and organisations in the face of information deficiency arising in an emergency.

How the workshop came to these conclusions is evidenced by the papers contained in this book. The paper by Tsamboulas, on terrorism and the threat to multi-modal transport, provides a comprehensive overview of current work and related gaps in threat, vulnerability, and criticality assessments regarding a potential terrorist attack of multi-modal passenger and freight transport systems. The paper concludes by posing three important questions for the research community: How can we measure and model risk since security is a state that is only shown in its absence? How can analysts generate comparative data across sectors and countries – are stations, bridges, borders, airports and seaports comparable? How can the conclusions of cognate disciplines like sociology, psychology, political science and anthropology be integrated?

The paper by Bersani et al., on the risk averse routing of hazmats, proposes spreading the risk in both space and time. The time dimension is particularly significant where vulnerability is time-dependent. The models presented allow delays to be added to schedules where this may reduce maximum exposure to loss. Two objectives are considered, the sum of maximum losses in each time period and the maximum loss overall. A small numerical example is used to illustrate the trade-off between the two objectives and to compare the results with a model

(referred to as Bell's model) without schedule delay. The results highlight the potential importance of departure time choice.

The paper by Garbolino, on the transposition of the "defence in depth" model from the nuclear industry to the transport of hazmats, sets out the 5-level model used in the nuclear industry. This covers prevention of dangerous "abnormal situations" (level 1), the control and correction of abnormal operation (level 2), the mitigation of minor accidents (level 3), the prevention of accident progression (level 4), and the management of major crises (level 5). Following a discussion of biophysical and social vulnerability, the 5-level model is transposed to the transport of hazmats. The concepts of "barriers" and "lines of defence" make a useful contribution to the development of a defence in depth strategy for hazmat transportation.

The paper by Schmoecker, on decision-making under uncertainty in the context of the routing hazardous materials, begins by considering various formulations of "games against nature" (situations where incident probabilities are independent of path choices). He then notes that, in the case of one or more malevolent agents, incident probabilities are related to path choice. This leads to the well known strategy of assigning shipments randomly to a set of paths so as to minimize the maximum exposure to loss by attack. There are, however, circumstances where the probability of an incident is known a priori to correlate positively (or possibly also negatively) to link usage – he describes some of these – in which case the minmax exposure to loss strategy is wasteful. When this correlation is known a non-linear optimization problem can be formulated and solved, in his paper by a version of the Frank-Wolfe algorithm.

The paper by Lozano et al., on urban hazmat line haul, distribution and mode change with particular reference to Mexico City, highlights the problems of transporting hazmats in the rapidly growing conurbations of the developing world. Three case studies relating to Mexico City are presented. The first case study, the line haul of chlorine along designated routes, shows the differing implications of day-time and night-time spills. The second case study, the routine distribution of petrol within the urban area, shows there is often little to be gained in terms of reduced population exposure from deviating from the shortest tours. The third case study, a spill arising while unloading a container of hazmat from a ship, illustrates the kind of delays that may occur in managing the incident and the consequences when a fire arises.

The paper by Dadkar et al., on the routing of hazmats under the threat of terrorist attack, starts with a thorough review of game theory applications in transport. They then set up a simple non-cooperative, two-player, non-zero sum game between a shipper/carrier (or dispatcher) and a terrorist, which despite its simplicity is difficult to solve. A heuristic method was validated against an exact method. A case study confirms the result, shown earlier by Bell in the more tractable context of non-cooperative, two-player, zero-sum games, that as the probability of an attack rises the shipper/carrier should select increasingly conservative routes, leading to a decline in the utility to the shipper/carrier but also limiting the exposure to damages caused by an attack. This behavior is of particular importance because historically when considering routing decisions for hazardous material shipments, the emphasis

has been on the identification of the single "best" route to use repetitively. This game shows the weakness in that strategy and that it is dominated when the probability of an attack is significant.

The paper by Quafmolla, on the safe transport of radioactive materials and waste, reviews the international regulations that apply to radioactive hazmats of different kinds and danger. There is a focus on the Albanian situation, although not much radioactive material is transported there.

The paper by Boulmakoul et al., on "telegeomonitoring", is set in the context of GPS positioning, cellular communication and databases holding geographical, hazmat, moving object, risk, traffic and other data. It describes a fuzzy routing algorithm that captures the concept of risk. The paper illustrates how advances in computer science, in particular the accommodation of an innovative moving objects database in an object oriented model, combine with positioning and cellular communication to achieve useful advances in the safe transport of hazmats.

The paper by Garrido, on identifying potential routes for transporting hazmats under the threat of hijacking, sets up another form of attacker-defender model. Initially, by assuming known but small accident probabilities, a linear fractional programming problem is set out to find the set of routes that minimize the expected consequences of an accident. Equity constraints are added, leading to the generation of multiple paths. The problem is then made considerably more complicated, firstly by adding distance as a proxy for operating cost, and secondly by adding a hijacker who selects a node to stage the hijacking from among those contained in the dispatcher path set and a route to another destination, the terrorist target. While both the dispatcher and the hijacker are sensitive to distance, albeit to different destinations, the dispatcher seeks to minimize the expected impact of his trips while the hijacker seeks to maximize the impact of his trip. A Stackelberg game between the dispatcher and the putative hijacker is then discussed, along with the optimal deployment of resources to maximize the probability of hijacker capture.

The paper by Murray-Tuite sets out a systematic approach to the assessment of terrorist threat by considering "who, why, what, when, where, and how", stressing the importance of expert opinion and level of belief given a paucity of data. She then presents a Bayesian analysis of transportation risk so that, as and when incidents arise, levels of belief can be updated. When considering the effect of intelligence, the probability of the intelligence being correct or false must be assessed. The conditional probability of receiving correct intelligence given a scenario must be greater than the total probability of receiving intelligence, whether correct or false, irrespective of the scenario, in order for the posterior probability of correct scenario selection to be higher than the prior probability. Thus, high contributions of false intelligence to the total probability of receiving intelligence can actually decrease the probability of correct scenario selection.

The paper by Bichou, on a risk- and cost-based assessment of ports and maritime transport, begins by setting out the regulations governing container transport. The conventional approach to the analysis of hazards in ports and maritime transport is then described. The paper next conducts an economic evaluation of security

measures and concludes by estimating the impact of security measures on container terminal efficiency using Data Envelopment Analysis (DEA).

The paper by Nie et al., on a game theoretic approach to air marshal scheduling, looks at the deployment of a scarce resource, air marshals in this case, to flights given the classification of flights by security risk. The problem is treated as an attacker-defender game between the Transport Security Administration (TSA), which deploys marshals to minimise "expected terrorist threat exposure", and the terrorist, who decides which risk class to attack (he only attacks once) so as to maximise the exposure of the TSA and minimise his probability of capture. Imperfect information is assumed, in particular that the terrorist only knows the proportion of flights covered by an air marshal in each risk class. This is formulated as a bi-level programming problem, where the upper level problem allocates air marshals to flights, leading to the class-specific allocation probabilities governing the attack probabilities, which in turn influence the marshal allocation. This corresponds to a Stackelberg game of incomplete information with the TSA leading and the putative terrorist following. A potential solution method is described and a small numerical example illustrates the model.

The paper by Zavitsas and Bell looks at the global energy supply chain, with particular reference petroleum and petroleum products, and describes on-going work on establishing network vulnerability. The supply chain is given a network representation corresponding to the locations of oil wells, refineries, pipelines and maritime connections. As a consequence of the ability to reroute vessels, critical straits or canals can often (but not always) be avoided at the cost of detours which, depending on how lengthy the detours are, effectively reduce the capacity of the fleet. A linear program is formulated to calculate the minimum fleet size required to meet a given demand. In this way, the consequences of a range of scenarios can be evaluated.

Finally, the paper by Al-Alawi on the direct and indirect impacts of climate change on transport systems, nicely complements the preceding papers. The paper starts with a concise explanation of the mechanisms of climate change. There is then an analysis of the direct impact of climate change on transport – ranging from rail buckling to reduced aircraft efficiency due to less dense air. This is then complemented with an analysis of the indirect impacts – economic, environmental, demographic and political. While the paper draws no conclusions, it does paint a complex picture of the impacts, not all negative.

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