Report to SICSA: Workshop on *modelling and optimisation of real-world transportation problems* was held at the University of Stirling, on 16 January 2015.

This event was hosted by Alexander Brownlee and Nadarajen Veerapen, postdoctoral researchers in the CHORDS group, Division of Computing Science and Mathematics, University of Stirling. We are grateful to SICSA for funding this event under the *Complex Systems Engineering* theme: this allowed us to cover catering and refreshments for attendees, and travel costs for the guest speaker.

The aim of this workshop was to bring together academics across SICSA to discuss current research in addressing real-world transportation problems, exploring future trends and possible collaborations. The workshop opened with an invited talk entitled *"Real-World Airport Operations Optimisation"*, by Geert de Maere, an Assistant Professor & Research Fellow in the ASAP Group, School of Computer Science, University of Nottingham. This set the agenda of the day: focussing on the difficulties surrounding real-world transportation problems and the importance of truly understanding a domain in order to find solutions efficiently.

This was followed by six talks by researchers from SICSA institutions, with a break for lunch halfway:

- Michael Rovatsos (Edinburgh): *Travelling collectives: The human side of transportation modelling*
- Alexander Brownlee (Stirling): *Airport Ground Movement: Real World Data Sets and Approaches to Handling Uncertainty*
- Daniël Reijsbergen, Jane Hillston and Stephen Gilmore (Edinburgh): *Formal analysis of Edinburgh buses using GPS data*
- Olivier Regnier-Coudert, John McCall, Charles Neau and Steven Anderson (RGU): *Evolutionary Algorithms for Dynamic Truck Scheduling: A case study*
- Pavlos Andreadis (Edinburgh): *Decision-theoretic ride-sharing optimisation with coarse user preferences*
- Simon Dobson, Saray Shai, Emanuele Strano and Marc Barthelemy (St Andrews): *Multiplex cities: interacting transport networks in metropolitan areas*

Over lunch there was a good series of discussions as the researchers mingled to discuss the morning's talks. There were also two posters presented:

- Alexander Brownlee (Stirling): *Addressing Taxi Time Uncertainty in Airport Ground Movement*
- Simon Martin: (Stirling): *A Multi-Agent Based Cooperative Approach to Scheduling and Routing*

Abstracts for the above are given overleaf. The day concluded with a final session of tea and coffee, followed by a period of informal discussion between the several researchers that remained.

The workshop was attended by 25 delegates: **Edinburgh Napier University:** Emma Hart, Kevin Sim, Neil Urquhart; **Robert Gordon University:** Olivier Regnier-Coudert; **Robert Gordon University, ARR Craib Ltd.:** Charles Neau; **University of Edinburgh:** Pavlos Andreadis, Daniël Reijsbergen, Michael Rovatsos; **University of Glasgow:** Dyaa Albakour, Ciaran McCreesh; **University of Mostagamen, Algeria (visiting Stirling):** Dalila Hamami; **University of Nottingham:** Geert De Maere; **University of St Andrews:** Simon Dobson; **University of Stirling:** Una Benlic, Andrea Bracciali, Alexander Brownlee, David Cairns, Michael Epitropakis, Angeliki Gretsista, Saemundur Haraldsson, Jingpeng Li, Simon Martin, Amjad Ullah, Nadarajen Veerapen

Several attendees remarked that it was a useful day. The majority of SICSA groups working with transportation problems were represented and were able to exchange ideas. The major outcome of the workshop is improved knowledge within the SICSA community of what the other groups in are tackling in transportation problems and feedback given to individual researchers on the work they presented. Furthermore, those attending were able to benefit from hearing our guest speaker: an introduction to airport operations research (a new application for most of those present); encouragement of a highly successful partnership with industry (Heathrow Airport); and useful insights into approaching a challenging real-world problem.

Appendix 1: talk abstracts

Michael Rovatsos (Edinburgh): Travelling collectives: The human side of transportation modelling In recent work, we have started to look at transportation planning for large-scale populations of travellers, especially through ridesharing. In this talk, we focus on the impact working with actual users has affected our research in interesting an unexpected ways. We start by presenting work on well-defined (but hard) combinatorial problems involved in planning joint rides for groups of self-interested travellers, and then look at the ways in which the reality of dealing with human users challenges some of our theoretical assumptions, while raising interesting new computational problems. These affect both the design of optimisation and travel recommendation algorithms, as the development of appropriate distributed systems platforms to deploy intelligent travel planning systems in the real world.

Alexander Brownlee (Stirling): Airport Ground Movement: Real World Data Sets and Approaches to Handling Uncertainty The airport ground movement problem involves allocating routes for aircraft to take as they proceed along taxiways between runways and gates (stands), and timings or orders for them to take them. The aim is to find a schedule that reduces delays, reduces the fuel burn associated with taxiing, and is resilient to last-minute changes. Innovation in this area is potentially limited by the difficulty in accessing real-world data sets. While some freely-available toy problems exist in the literature, none truly reflect the inherent complexity of operations at a real airport. This acts as a barrier to new researchers entering the field, who would have to develop working relationships with airport staff to obtain relevant data. This talk describes the collection of data from publicly available websites, approaches to cleaning and combining it for use in research, and describes some tools and benchmarks that have been made publicly available.

Daniël Reijsbergen, Jane Hillston and Stephen Gilmore (Edinburgh): Formal analysis of Edinburgh buses using GPS data We present recent work on the development of stochastic performance models of a public transportation network using real-world data. The data is provided to us by the Lothian Buses company, which operates an extensive bus network in Edinburgh. In particular, we use datasets of GPS measurements with about 30-40 seconds between subsequent observations. Some quantities of interest that can be analysed using this data are the times needed to complete specific route segments, and the 'headway', the distance (in terms of journey completion) between subsequent buses. Both can be modelled using established formalisms, namely Markov chains and time series respectively. We briefly discuss several applications, including a 'what-if' scenario involving the introduction of trams to the Edinburgh city centre, and the evaluation of the punctuality of frequent services in terms of criteria set by the Scottish government.

Olivier Regnier-Coudert, John McCall, Charles Neau and Steven Anderson (RGU): Evolutionary Algorithms for Dynamic Truck Scheduling: A case study With growing demand, growing resource and the diversification of services, the field of transportation is becoming increasingly challenging to manage by sole operators. ARR Craib Ltd, a leading haulage company in Scotland is faced with the issue of scheduling hundreds of jobs of different types and constraints, using a heterogeneous fleet of vehicles. Jobs are received dynamically requiring recommendation systems to cope well with a fast changing environment. Although constructive methods have shown that feasible solutions can be obtained, these are very likely to be sub-optimal. Consequently, the use of Evolutionary Algorithms is investigated, raising the issues of representation, algorithm design and fitness modelling. Preliminary results are presented which highlight the challenges faced by EAs.

Pavlos Andreadis (Edinburgh): Decision-theoretic ride-sharing optimisation with coarse user preferences Ridesharing is an emerging socio-technical application that has already seen early stage deployment in companies like Uber and Lyft. While these existing instances of ride-sharing are merely mobile-enabled matching services, they point the way towards adaptive and continually optimising systems. Systems that will provide efficient matching of users to rides while simultaneously optimising global system goals, such as congestion or operating costs. We begin our analysis by describing a version of the ride-share problem, as it arises in our EC FP7 project, SmartSociety. In our model, we aspire to go beyond traditional formulations of matching by taking users' utilities into account. Assigning rides such that individual user utilities and system goals are optimized requires explicitly addressing a trade-off. To the extent that real human users' preferences have certain forms of coarseness, this trade-off can actually be formulated in terms of a set of feasible solutions for the users. This set then acts as a constraint for optimisation of the system's other objectives while also providing alternatives in case of invalidated partial assignments. We formulate this problem in a novel ride-matching model, involving two phases - one that generates a set of optimal assignments and another which finds a system operating point that ensures minimal loss of user satisfaction.

Simon Dobson, Saray Shai, Emanuele Strano and Marc Barthelemy (St Andrews): Multiplex cities: interacting transport networks in metropolitan areas Cities typically have multiple transport networks: for example road, light rail, and underground rail. How do these networks interact in terms of commuters' journey times, the robustness of the network to delays and failures? How does investment that improves one transport modality affect these features? We develop a set of techniques for modelling metropolitan transport as layered multiplex networks. We demonstrate that our techniques scale to practical problems by exploring the transportation networks of New York and London, allowing us to determine computationally important urban planning metrics such as local outreach.

Appendix 2: poster abstracts

Alexander Brownlee (Stirling): Addressing Taxi Time Uncertainty in Airport Ground Movement Airport ground movement is the challenging problem of allocating routes to taxiing aircraft. However, existing work in this area considers taxi speeds to be completely predictable, which is rarely the case. Variations in speed can cause conflicts that introduce delays and decrease the airport's efficiency. This work extends an existing state of the art approach (the QPPTW algorithm) which finds the shortest path for a given aircraft given the routes which have already been allocated to other aircraft. An existing approach to handling the similar problem of flow shop scheduling with uncertain (fuzzy) processing times is adapted and integrated with QPPTW. Some preliminary results are presented exploring and contrasting the impact on final taxi-times and ground movement efficiency of adding fixed time padding and applying the fuzzy approach.

Simon Martin: (Stirling): A Multi-Agent Based Cooperative Approach to Scheduling and Routing This study proposes a general agent-based distributed framework where each agent implements a different metaheuristic / local search combination. Agents continually adapt themselves during the search using direct cooperation based on reinforcement learning and pattern matching. Good patterns making up improving moves are identified and shared by the agents. This system can be applied to a variety of different problems domains. In this work, we show its success in yielding three new best-known results for Capacitated Vehicle Routing benchmarks. Furthermore, we also apply it to Permutation Flow-shop Scheduling benchmarks where it finds results commensurate with the best-known values.