Institution: University of Southampton		
Unit of Assessment: 10 Mathematical Sciences		
Title of case study: 10-02 Optimising baggage operations at London Heathrow Airport to achieve cost savings for the aviation industry		
Period when the underpinning research was undertaken: 2000 – 2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Chris N Potts	Professor of Operational Research	1986 – present
Period when the claimed impact occurred: January 2015 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Research at the University of Southampton's School of Mathematical Sciences into dynamic scheduling in the airport environment has been used to optimise operations in London Heathrow Airport's baggage handling system, as part of the airport's GBP16bn expansion programme. With its 80 million annual passengers (pre-COVID-19), inherent uncertainty in aircraft arrival and departure times, and costly, multi-stakeholder implications of baggage delay, Heathrow's baggage system posed a complex combinatorial optimisation problem.

Novel data-driven optimisation tools, developed by Professor Chris Potts through collaborations with Heathrow and leading consultancy firm Arup, resulted in a new approach for scheduling the delivery of luggage to baggage carousels (reclaims) and a 20% reduction in the rate of short-landed bags (bags not transported with the passenger to the destination airport).These significant improvements **increased convenience for passengers** and achieved **cumulative cost savings of GBP55m for the aviation industry**. This comprised **annual savings to the airline industry of GBP10m since October 2016** relating to short-landed baggage costs and a **reduction in capital expenditure of over GBP20m for Heathrow Airport Limited** by improved scheduling and thereby eliminating the need to invest in additional baggage carousels.

2. Underpinning research

Discrete optimisation has been a significant research area of the Operational Research (OR) group at the University of Southampton since the 1980s, with **scheduling** featuring prominently. An important sector where discrete optimisation is very useful is for planning airport operations. Specifically, airports require scheduling and other discrete optimisation problems to be solved in order to create cost-effective plans for baggage operations that provide passengers with an appropriate level of service. The OR group were therefore well placed to work with Arup and Heathrow Airport Limited on the optimisation of baggage operations.

Early research on scheduling mainly considered classical production scheduling problems having a single objective, with all problem data assumed to be deterministic and known in advance. However, **Professor Chris Potts** (School of Mathematical Sciences) introduced models, first published in 2001, that better capture some of the features that are present in practical scheduling applications. In one particular generalisation of classical scheduling, he extended the model beyond the production facility to include a larger part of the supply chain. For example, in [**3.1**, **3.2**] he proposed models and algorithms that combine decisions about production scheduling and the delivery of products to customers. In [**3.3**] he explored methods for addressing the trade-off between minimising waste when cutting materials to satisfy customer orders and reducing delays in the timely delivery of these orders to the customers.

More complex models require more sophisticated solution techniques. A widely-used approach for tackling these challenging problems is to use metaheuristics, often known as local search methods. These techniques typically provide near-optimal solutions while imposing limits on the computation time used. The key to the success of such methods is to navigate the solution space efficiently in the search for a high-quality solution.

Creating enhancements to models often transforms a single-objective problem into a problem with multiple objectives that are typically conflicting. Potts, in [**3.3**], adapted a single-objective metaheuristic solution approach to one that find solutions to problems with multiple objectives. This was achieved by setting primary and secondary objectives and periodically alternating between them throughout the search procedure performed by the metaheuristic.

The GBP5.3m EPSRC-funded LANCS Initiative (**G1**, 2008-14) had a research aim of building theory for application to practical OR problems. LANCS had Transportation and Logistics as a research cluster, with Potts having the role of co-leader. As a consequence of the collaborative opportunities offered through LANCS, the principles underpinning Potts' production scheduling studies [**3.1**, **3.2**] evolved into methodologies to improve the efficiency of transport and logistics systems. The problems addressed often have multiple objectives due to the different stakeholders. For example, maximising the convenience of passengers in a transport system often conflicts with minimising the operating costs of the transport provider. Furthermore, many problems are dynamic or on-line, implying that information about the future arrives over time so that decisions have to be made with incomplete knowledge.

In a project funded by EUROCONTROL, the European organisation for the safety of air navigation (**G2**, 2008-11), Potts led the design of various algorithms for more efficient scheduling of aircraft landings, without compromising safety. A key element of this problem is to increase runway utilisation by avoiding heavier aircraft landing immediately before lighter aircraft because safety constraints impose a longer separation time between landings in such cases due to the turbulence caused by wake vortices. This is an on-line problem because the appearance of aircraft onto an air traffic controller's radar screen is typically about 30 minutes before the landing time and landing times need to be fixed for aircraft arriving in the next 5-10 minutes. Potts designed a rolling horizon algorithm [**3.4**] in which the landing schedules are updated periodically to account for any new information about arriving aircraft. Multiple objectives included minimising: (a) the average and last landing time; (b) penalties for deviation from preferred landing times; and (c) extra fuel used for any delayed landing. This on-line problem with multiple objectives has similar characteristics to those arising in the planning of baggage operations for arriving aircraft; the passenger experience in the baggage hall in terms of crowding, and waiting time needs balancing against the efficient deployment of baggage handlers.

This body of research in large-scale combinatorial optimisation underpinned a partnership with Heathrow Airport Limited, beginning in 2012, to maximise the efficiency of the airport's baggage processing operations. Much of the methodology was already in place to address the challenges. In particular, Potts' research expertise in scheduling was used to design algorithms for determining the timing and routing of baggage to the airport arrivals hall, making use of available techniques in optimisation with multiple objectives [**3.3**] and also in algorithms for on-line problems [**3.4**].

3. References to the research

3.1 Hall, N. G., Lesaoana, M., & Potts C. N. (2001). Scheduling with fixed delivery dates. Operations Research, 49(1), 134-144. https://doi.org/10.1287/opre.49.1.134.11192

3.2 Hall, N. G., & Potts, C. N. (2003). Supply chain scheduling: Batching and delivery. Operations Research, 51(4), 566-584. https://doi.org/10.1287/opre.51.4.566.16106

3.3 Bennell, J. A., Lee, L. S., & Potts, C. N. (2013). A genetic algorithm for two-dimensional bin packing with due dates. International Journal of Production Economics, 145(2), 547-560. https://doi.org/10.1016/j.ijpe.2013.04.040

3.4 Bennell, J. A., Mesgarpour, M, & Potts, C. N. (2017): Dynamic scheduling of aircraft landings. European Journal of Operational Research, 258(1), 315-327. https://doi.org/10.1016/j.ejor.2016.08.015

Relevant Funding

G1 The LANCS (Lancaster, Nottingham, Cardiff and Southampton) Initiative in Foundational Operational Research: Building Theory for Practice, 2008-14. Funded by EPSRC (EP/F033982/1) under their Science & Innovation Awards scheme: GBP5,328,605.

G2 European Organisation for the Safety of Air Navigation (EUROCONTROL), Research Grant for Innovation Studies, 2008-11 (08-120920-C): EUR114,885.

4. Details of the impact

London Heathrow Airport served over 80 million passengers annually at its pre-COVID-19 peak [**5.1**] and handled an estimated 110 million pieces of baggage [**5.2**]. Baggage operations are vital for the smooth running of an airport and the resource allocation and scheduling methods required to determine their efficient operation are not available in standard business process software. The operations represent a significant cost to airport operators and airlines. Airport charges that cover the cost of these processes have become a more significant part of the overall ticket price in recent years and consequently efficiency improvements are important for all of the three key stakeholder groups: passengers, airlines and airport operators.

The three key stakeholder groups for the airport each have their own objectives for the baggage system. While the airport operator is focused on cost, passengers and airlines tend to be more concerned about the level of service that they receive, e.g. the time spent waiting for bags to arrive or the level of overcrowding in the airport arrivals hall. This makes the optimisation problems multi-objective. An airport also operates with a significant amount of uncertainty stemming from the stochastic nature of aircraft arrival and departure times.

Based on his research expertise in combinatorial optimisation, including work on runway scheduling, Potts began working with Heathrow Airport Limited on optimising its baggage operations in 2012 with the key outcomes of the collaboration occurring during the REF 2021 impact period [**5.3**]. The baggage handling system at an airport the size of Heathrow is complex and requires careful planning to be robust against uncertainties in flight arrival and departure times. Potts' work contributes in two ways. First, it ensures that advance planning is in place. Second, it allows the daily planning of operations to be adapted to flight delays and uncertainty about the arrival order of aircraft, which is dictated on the day by air traffic control. Accounting for uncertainty requires a data-driven approach in which operational plans are updated in real time using online optimisation algorithms that can find effective new solutions quickly. A specific example of this is the allocation of arriving flights to baggage carousels. Potts designed an algorithm for allocating baggage reclaims which incorporates multiple objectives, thereby helping to ensure that passenger waiting times for baggage are kept as low as possible, passenger crowding in the baggage hall is not excessive, and baggage handlers' time is used effectively.

According to the Director of Operational Planning at Heathrow Airport, "*The work stopped us from changing the operational approach to a fixed allocation plan (which was preferred by some of the handling teams) as it demonstrated this would have led to a deterioration in performance, and a worsening of passenger experience at Heathrow. The project showed us that allocation needed to be kept dynamic or we would need additional capacity to avoid congestion*" [**5.3**]**.** He continued: "*… the work carried out with the University of Southampton has allowed us to take a more scientific approach to managing the complex baggage handling system at Heathrow that is able to react quickly to disruptions in flight arrivals. This has been invaluable in improving our operational efficiency*." The benefits in terms of increased operational efficiency in an airport the size of Heathrow are substantial. The Director of Operational Planning concluded: "*As an indication of the value of this, increasing capacity efficiency to the extent of avoiding the requirement to add one additional reclaim has been estimated* ***to save over £20mill in Capex*** [GBP20,000,000 in capital expenditure]."

In 2016, Arup was part of a consortium awarded a GBP16bn contract to manage the expansion of Heathrow where a key component of the expansion plans involved a transformation of the baggage handling systems. Arup is an independent firm of designers, planners, engineers, architects, consultants and technical specialists, with annual revenues of GBP1.7bn. Due to his earlier work with Heathrow Airport Limited, Potts was approached by Arup to assist with some aspects of the transformation project, drawing on his expertise in multi-objective combinatorial optimisation [**3.3**] and on-line scheduling [**3.4**]. Specifically, he developed a data-driven performance tool that produced a better characterisation of the reasons for baggage being short-landed (bags not transported with the passenger to the destination airport). Not unexpectedly, results showed that delays to aircraft landings have adverse effects on baggage movement and thereby incur subsequent costs [**5.4**]. They also suggested a set of key performance indicators that distil the multiple data sources into just a handful of statistics that provide the best way of monitoring the behaviour of the baggage handling system [**5.4**]. Summing up the significance of the challenge that the development tool was designed to address, Arup's Airport Development Team Leader wrote: "*The cost of failure can be high. Within the industry, the overall costs incurred as a result of a bag not being delivered for the passenger to collect are estimated to be around £100 per bag … At Heathrow alone, we estimate that the cost arising from short-landed bags, before the opening of Terminal 5 in 2008, used to be around £60 million annually* [**5.4**]."

The resulting tool, based on the University of Southampton research, has significantly reduced the number of short-landed bags, which has translated into substantial cost savings for the airline industry. Arup confirms: "*Heathrow's short-landed rate has, since this particular piece of work was completed in October 2016, improved by around 20% -* ***saving airlines an estimated £10 million annually****,*" [**5.4**] amounting to a **cumulative saving of approximately GBP35,000,000** up to the start of the COVID-19 pandemic.

Describing its collaboration with Southampton as "*extremely fruitful*", Arup stated that the research results were of direct relevance to their own business and that of their clients [**5.4**]. Its Airport Development Team Leader said: "*It has proved the concept and value of integrating large, disparate data sets to produce information upon which action can be taken. At Arup we are actively pursuing ways in which this approach to baggage data can be productionised and used as a commercial service offering to other airports* [**5.4**]." This is further evidenced by Arup's use of their baggage handling project with Heathrow as a case study for its business development aims [**5.5**]; Arup is using the knowledge transfer from Southampton as a significant component of their consultancy offering for other airports in order to access a market that, it says, could represent several millions of pounds per year [**5.4**].

Potts' work also feeds into Heathrow's growth plans for developing Terminal 5, which are currently on hold owing to the COVID-19 pandemic. Heathrow's Director of Operational Planning said: "*We were also in the process of implementing the full findings of this work on a wider scale by including it in growth plans for Terminal 5, the largest terminal, when the pandemic began … and we are already looking at similar approaches to tackle the new issues created by the impacts of COVID-19 and hygiene measures such as social distancing.*" [**5.4**]

5. Sources to corroborate the impact

5.1 News release on the Heathrow Airport website: *Heathrow reaches 80 million in 2018*, January 11, 2019: https://www.heathrow.com/latest-news/heathrow-reaches-record-80-million-milestone-in-2018-as-airport-takes-big-steps-towards-expansion

5.2 Article on the Association of Project Management website to corroborate the 110-million bag figure: *Change programme: Award-winning Heathrow Terminal 3 baggage syste*m, February 1, 2017: https://www.apm.org.uk/news/change-programmes-terminal-velocity/

5.3 Testimonial by Director of Operational Planning, Heathrow Airport Limited.

5.4 Testimonial by Arup Airport Development Team Leader, Arup.

5.5 Arup online case study on the delivery of the baggage handling optimisation project with Heathrow Airport: https://www.arup.com/projects/heathrow-airport-digital