Institution: University College London		
Unit of Assessment: UoA 17, Business & Management Studies		
Title of case study: Using real-time analytics to improve passenger flows at London Heathrow Airport		
Period when the underpinning research was undertaken: 2007- 2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Bert De Reyck	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 01/08/2007 – present
Period when the claimed impact occurred: 2016 – present		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Passengers missing their connection at an airport can have a major impact on passenger satisfaction and airline delays. Accurate forecasts of the flow of passengers through an airport can help improve the experience of connecting passengers and support airline, airport, and air space punctuality. In collaboration with London Heathrow Airport, Professor Bert De Reyck led a team to develop and implement a real-time predictive system that predicts passengers' journey times through the airport, the expected number of late passengers for each outbound flight, and estimated passenger flows at the airport's immigration and security areas. The project was based on underpinning research developed by Professor De Reyck on applying machine learning to generate real-time quantile forecasts, in this case for transferring passengers' connection times, and on copula-based simulation methods to produce aggregate quantile forecasts, in this case for the number of passengers arriving at the immigration and security areas. The system was implemented at Heathrow Airport in 2017, and its real-time predictions are currently being used to improve resourcing levels at security and immigration, to inform airlines of delayed passengers, and to inform the airport of required departure time adjustments.

2. Underpinning research

The complexity of many operational decisions requires a systematic approach to decision making, which can sift through huge amounts of data, optimizing and trading off multiple (quantitative and qualitative) objectives, incorporating conflicting stakeholder opinions, while minimizing risks. Such decisions can benefit greatly from state-of-the-art decision support tools. Professor De Reyck's research on decision analytics is focused on developing such decision support systems, using decision analysis, optimization, and machine learning.

The research produced by Professor De Reyck that underpins this case study **([a], [b])** was the first to apply machine learning for building a predictive system that can generate real-time distributional forecasts, i.e., producing complete distributions and predicting quantiles, moving beyond point forecasts. In this case, such a prediction model, based on classification and regression trees (CART), was applied to predict the connection times of passengers transferring between flights at a hub airport. To predict the number of passengers arriving at airport immigration and security areas at each point in time, a model was developed based on Professor De Reyck's novel work on copula-based simulation methods to produce aggregate distributional forecasts in the presence of correlations between individual predictions **([a], [b])**. The research proposes a way to combining individual, but correlated, predictions, in this case the connection and travel times of individual passengers, into aggregate-level distributional and quantile forecasts, in this case a predicted distribution of the total number of passengers showing up at various points throughout the airport in specific time intervals. In particular, the aggregate-level forecasts are generated by simulating observations from the individual distributions predicted by the regression trees. To recalibrate the typically overconfident

forecasts, dependencies between individual predictions are incorporated into the simulation via a copula approach.

This case study is part of a larger collaborative research endeavour led by Professor De Reyck with Eurocontrol, the European air traffic management organisation, funded by the European Commission's *Framework Programme* and *Horizon 2020*. The collaboration goes back to 2007, when Professor De Reyck first worked with Eurocontrol to develop an integrated decision-making framework for reaching an agreement on the changes and technologies required to integrate Europe's air traffic management systems **([c] and [d])**. This research project was part of the European Commission's Single European Sky (SES) Initiative, which seeks to reform the fragmented European air traffic management with the aim of satisfying future needs of the European airspace, in terms of capacity, safety, efficiency and environmental impact (Eurocontrol 2010).

Between 2016 and 2017 Professor De Reyck again worked with Eurocontrol, this time to examine the opportunities offered by co-location of, and real-time data sharing by, various airport stakeholders in the newly developed Airport Operations Centres (APOCs) at major European airports. In particular, Professor De Reyck was asked to identify the key APOC processes that could be enhanced by data-driven predictions and advanced analytics, and to implement a case study at a key airport that demonstrates how shared data and advanced analytics can improve the airport's operations. The result was a system **([e])** to better estimate passenger connection times, based on Professor De Reyck's work on real-time quantile forecasting, which is currently being used to predict which passengers are likely to miss their connecting flights, and to predict passenger bottlenecks at various points throughout the airport. This is based on Professor De Reyck's work on copula-based simulation for producing aggregate quantile forecasts.

3. References to the research

[a] Guo X., De Reyck B., Grushka-Cockayne Y., Lichtendahl K., Karasev A., Garside T., Coss N., and Tasker F. "Machine Learning Techniques for Airport Passenger Flow Management." *INFORMS Annual Meeting*, Nashville, November 2016.

[b] Guo, X., Grushka-Cockayne, Y. and De Reyck, B. 2020. "Forecasting Airport Transfer Passenger Flow Using Real-Time Data and Machine Learning" *Manufacturing and Services Operations Managemen*t, in press, published online. https://dx.doi.org/10.2139/ssrn.3245609

[c] Grushka-Cockayne, Y., De Reyck, B. and Degraeve, Z. 2008. "An Integrated Decision-Making Approach for Improving European Air Traffic Management," *Management Science*, 54 (8), 1395–1409. https://doi.org/10.1287/mnsc.1080.0878

[d] Grushka-Cockayne, Y. and De Reyck, B. 2009. "Towards a Single European Sky" *INFORMS Journal on Applied Analytics*, 39 (5), 400–414. https://doi.org/10.1287/inte.1090.0436

[e] Guo, X., Grushka-Cockayne, Y. and De Reyck, B. 2020. "London Heathrow Airport Uses Real-Time Analytics for Improving Airport Operations" *INFORMS Journals on Applied Analytics*, *INFORMS Journal on Applied Analytics*, 50 (5), 325-339. https://doi.org/10.1287/inte.2020.1044

The underpinning research was undertaken by Bert De Reyck, Professor at the UCL School of Management, in collaboration with Yael Grushka-Cockayne, Professor at the Darden School of Business at the University of Virginia, and Xiaojia Guo, Assistant Professor at the Robert H. Smith School of Business at the University of Maryland. Professor De Reyck was the principal investigator.

The research was financially supported by the European Commission's *Horizon 2020* programme. Evidence of the quality of research is provided by publications in key peer-reviewed journals, awarded research funding, and award nominations.

4. Details of the impact

Prior to the COVID-19 global pandemic, Heathrow Airport was the busiest airport in Europe, carrying more than 80 million passengers each year to over 200 destinations worldwide. The airport community employs over 6,500 people and operates collaboratively with over 200 stakeholder organizations. Improving airport collaborative decision-making is at the heart of Heathrow's Airport Operations Centre (APOC), established in 2014. The APOC brings together all airport stakeholders in a single 'room', providing real-time access to shared data sources, with the intention to get an accurate overview of the status of all the airport's operations, enabling real-time communication and collaborative decision making on operational functions such as passenger flow, baggage flow, security, gate management, and crisis management.

Professor De Reyck began by reviewing the various APOC decision-making processes in order to identify potential candidates that would benefit from a decision support system based on real-time data and advanced analytics. He identified three such processes **([1])**: (1) baggage flow management; reducing the number of misconnecting bags, (2) aircraft stand allocation; reducing bottlenecks, and (3) passenger flow management; predicting passengers' whereabouts throughout their journey at Heathrow to improve passenger experience and airline departure punctuality. After presenting these options to Heathrow stakeholders, the third option was selected as the subject of a pilot study.

Passengers navigating an airport often encounter delays, especially at immigration and security. Once passengers have arrived at the airport, whether as a departing, arriving, or connecting passenger, airports have little knowledge of passengers' whereabouts in the airport. Improved passenger tracking in real-time would enable airports to better serve their passengers, stabilize and predict departure times for outbound flights, and improve planning of resourcing needs. For instance, missed connections are the third leading reason for filing a complaint with an airline (MacDonald 2016). Therefore, it is critical that the passengers' transfer journeys are optimized to ensure the airport can fulfil its mission to "give passengers the best airport service in the world" (Ferrovial 2016).

Heathrow's APOC consists of a variety of airport teams, with the common goal of ensuring "happy passengers, travelling on time, with their bags." (Heathrow 2017). Professor De Reyck and his team interviewed the key decision makers, including the passenger flow manager, the security flow manager and the aircraft flow manager, all of whom can influence the passenger journey, in order to identify their role in the handling of passenger flows, their objectives, decisions that they routinely make, and the information they have at hand to support their decisions. From the interviews, it became apparent that the stakeholders would all benefit from more timely and accurate predictions of passengers arriving at various points throughout the airport. Such a predictive system would: enable the resourcing of immigration desks and security areas in advance of passenger surges, and allow airlines to be warned in advance that some passengers were unlikely to catch their connection, so that either the passengers could be offloaded, expedited, or the plane's scheduled departure time modified. This information however, would need to be generated in real-time, and made available to operations managers in time for them to be able to adjust their original plans to any newly generated forecast. In order to accurately predict the passengers' journey throughout the airport, Professor De Reyck developed a real-time predictive system based on machine learning that predicts passengers' journey times through the airport, the expected number of late passengers for each outbound flight, and estimated passenger flows at the airport's immigration and security areas **([1])**.

The system developed by Prof. De Reyck enables predicting which passengers are likely to miss their flights, reducing the likelihood that departures will incur delays while waiting for delayed passengers. This can be done by offloading passengers in advance, by expediting passengers through the airport, or by modifying the departure times of aircraft in advance. By aggregating estimated passenger arrival time at various points throughout the airport, the system also improves the passenger experience at immigration and security desks, by enabling modifications to staffing levels in advance of expected surges in arrivals. Dynamic

resourcing of immigration and security areas reduces queuing and delays to passenger journeys, which in turn increase passenger satisfaction and reduce the chances of passengers missing their connection.

The system was first tested at Heathrow in a live trial on 19 July 2016, with outcomes highlighting improvements to airport punctuality due to increased confidence in passengers making tight connections **([1])** and a greater understanding of the driving forces between passenger transfer connection times by managers. Prof De Reyck and his team then delivered a report and the final system for Heathrow and Eurocontrol in November 2016 **([1])**, accompanied by presentations to Heathrow's senior management team and Eurocontrol. In the months after, the system was tested for stability, prior to being fully implemented in 2017. Accuracy tests over July and August 2017 showed that the accuracy of the model outperformed Heathrow's existing methods, which relied on using historical averages to predict future passenger movements **([e])**.

The predictions generated by the system are currently used to assist managers at the APOC in making real-time decisions, including: (1) identifying passengers who are likely to be late for their connection flight and contacting ground staff to provide support to these passengers; (2) communicating with airlines to inform them of likely delayed passengers, and to help them adjust their departure times; (3) adjusting resourcing in real time at the immigration and security areas based on expected passenger flow numbers in 15-minute intervals. A recently completed back-testing study ([b]) revealed that the system offers a reduction in cost between 12% and 54% at immigration and security areas compared to Heathrow's legacy system **([e])**. In addition to providing accurate forecasts, the system also helps the APOC mangers understand the key factors that influence passengers' connection times (, including the time of day, type and capacity of aircraft, load factor, travel class, inbound and outbound flight region, and punctuality of the flight).

The Head of Airport Research at Eurocontrol writes **([2])** that this "ground breaking" study has "*become a reference*", and "*is used by a number of major European airports [including Paris CDG] with a first deployment since 2017 in London Heathrow's Airport Operations Centre*". He adds that the study "demonstrates how decision making can be better informed by the flow of data and the use of predictive algorithms, and brings state-of-the-art thinking in machine learning, applied to a problem of crucial importance to airports around the world into the airport operations domain".

The Head of Integrated Planning at Heathrow Airport, writes that, "*this study has demonstrated how the latest analytical techniques, using real-time data, can be used to improve the experience of connecting passengers, and to support aircraft punctuality. We are now looking at how we deploy this approach into live operations and to apply similar techniques to other airport processes*" **([3])**.

Plans are underway to deploy this broader solution across Europe as part of the European Commission's Pilot Common Project **([3])**, and for this purpose, Prof. De Reyck and his team presented their work at several European workshops organised by Eurocontrol **([4],[5])**, attended by airport operators from across Europe.

The impact of the research was recognized with the 2018 INFORMS *Aviation Applications Section Best Presentation Award* **([6])**, awarded at the INFORMS Annual Meeting in Phoenix (2018). The research was also selected as a finalist for the *2019 MSOM Practice-Based Research Competition* **([7])** and for the *2019 Daniel H. Prize for Excellence in Operations Research* **([8])**, which both recognize high-impact applications of management science and operations research in practice.

5. Sources to corroborate the impact

[1] De Reyck, B., Guo X., Grushka-Cockayne, Y., Lichtendahl, K., Karasev, A., Garside, T., Cross, N., Tasker, F. "APOC business process reengineering big data study", Eurocontrol Technical Report, 21 November 2016, https://www.eurocontrol.int/publications/apoc-business-process-reengineering-big-data-study

[2] Testimonial from Director of Airport Research, Eurocontrol.

[3] https://www.sesarju.eu/newsroom/all-news/heathrow-tests-machine-learning-algorithms-improve-passenger-flight-connections. Includes quote from Head of Integrated Planning and Performance, Airport Operations, Heathrow Airport

[4] Garside T., De Reyck B. and Guo X. “Big Data in Airport Operations.” Agency Research Team Workshop on Airport Capacity, Madrid, 2016.

[5] Garside T., De Reyck B. and Guo X. “Big Data in Airport Operations.” Airport Operations Team Workshop, Brussels, 2016.

[6] Link to INFORMS *Aviation Applications Section Best Presentation Award*:

https://connect.informs.org/aas/awards/presentation-competition

[7] Link to *MSOM Practice-Based Research Award competition*:

https://connect.informs.org/communities/community-home/digestviewer/viewthread?MessageKey=6e2bda02-0449-4ccc-a11c-9c20eee6fa27&CommunityKey=1d5653fa-85c8-46b3-8176-869b140e5e3c&tab=digestviewer

[8] Link to Daniel H. Wagner Prize for Operations Research Excellence:

https://www.informs.org/Resource-Center/Video-Library/Wagner-Competition-Videos/2019-Wagner-Competition-Videos/2019-Wagner-Prize-Finalist-London-Heathrow-Airport-Uses-Real-Time-Analytics