Institution: Birkbeck, University of London

Unit of Assessment: Computer Sciences and Information Systems

Title of case study: Enhancing Vehicle Deployment Strategies at the London Ambulance Service

Period when the underpinning research was undertaken: 2010-2018

Details of staff conducting the underpinning research from the submitting unit:

Period when the claimed impact occurred: March 2015 to date

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Birkbeck researchers Roussos, Poulton and Weston worked with the London Ambulance Service (LAS) to create software developed using a novel data-driven model, which predicts ambulance response times within the LAS area of responsibility with 80% greater accuracy than was previously possible. Specifically, the Birkbeck model was incorporated into two new software tools: (i) Geotracker, a visualization tool which gives ambulance shift leaders an overview of their capacity to respond to incidents within the mandated time; and (ii) the QUEST simulator that helps assess the impact of strategy changes on the performance of the service and in particular on incident response times. Geotracker and QUEST have enabled LAS to deploy its ambulances more effectively and, as a result, to save more Londoners' lives.

2. Underpinning research

The speed with which emergency medical services arrive following a life-threatening incident is a critical factor in patient survival rates and is, consequently, a key performance indicator against which ambulance services are assessed in the UK and internationally. Notably, the Handbook to the NHS Constitution mandates that all ambulance trusts must respond to Category 1 calls (that is, calls classified as life-threatening and needing immediate intervention and/or resuscitation) within 7 minutes on average and to 90% of these calls within 15 minutes. Research in urban analytics has been underway at Birkbeck's department of Computer Science and Information Systems since 2005, extending earlier work on data-driven algorithms for the analysis of consumer navigation patterns in retail [1]. Our contributions [2, 3, 5] include methods and techniques for the analysis of personal mobility patterns, for landmark identification and itinerary personalization, and for the exploration of the relationships between personal motivations and patterns of urban navigation.

In 2010, research student Marcus Poulton joined the department, bringing a detailed knowledge of the London Ambulance Service (LAS) information systems and a desire to apply modern data-driven techniques to improve the efficiency of emergency response. Marcus was attracted by the department's expertise in urban navigation analytics (as detailed above), and his arrival precipitated the development of a programme of research focussing specifically on the problem of improving the efficiency of ambulance emergency response. In particular, the Birkbeck team, led by Roussos, identified the analysis of mobility patterns as the key element in predicting ambulance travel times.

Between 2010 and 2013, Roussos and Poulton investigated methods for the identification of gaps within the LAS area of responsibility: that is, regions where under certain circumstances LAS ambulances would be unable to reach the location of an emergency incident within the mandated timeframe. This problem was addressed by developing algorithms incorporating route selection and arrival time prediction techniques that could be applied to estimate operational coverage reflecting the specifics of a particular configuration of ambulance resources [4]. These techniques were developed using a data-driven approach whereby historical incident and ambulance tracking data were employed to build dynamic predictive models. Moreover, the approach is adaptive to changing traffic conditions depending on the time of the week, and it facilitated the development of a new method for resource relocation that significantly improved area coverage [4].

Between 2014 and 2018, Roussos, Poulton and Weston extended the work presented in [4] to account for the interplay between strategy and tactics so as to improve the ability of LAS to cover its full area of responsibility more efficiently. Specifically, working on a road network graph representation that was modified to reflect the differences between emergency and regular vehicle traffic (a key innovation over previous predictive models based on patterns of civilian traffic), they developed a methodology for precisely matching low-frequency and often erroneous GPS coordinates emitted by ambulances to the road segments travelled. This approach permits reconstruction of complete ambulance tracks in detail and gives an accurate characterization of how long a particular road segment takes to traverse under specific traffic conditions at a particular time during the week. This novel methodology for improving the quality of the data employed to build their models provides one of the key ingredients for the development of methods that can be used to calculate significantly more precise estimates of future travel times for different types of ambulatory response vehicles.

Further, from this foundation Roussos, Poulton and Weston introduced the novel hybrid multi-dimensional model presented in [6], which can precisely predict the actual route taken by an ambulance travelling under blue lights and sirens, while minimizing the journey duration estimate error. This was accomplished by combining a method which correctly predicted routes selected by LAS's ambulance navigation system in current use, and the Birkbeck team's best-performing speed estimation method selected from several alternatives presented also in [6]. Assisted by Noulas of the New York University Data Science Institute, the Birkbeck team conducted experiments demonstrating that this model significantly outperforms alternative mobility models in its ability to predict the time taken by an ambulance to travel from its point of departure to its destination [6]. This finding also suggests that an operational navigation system for LAS tailored specifically to ambulance mobility and the traffic patterns of London would offer substantial operational improvements. The model described in [6] provides the computational basis underpinning the development of the two software systems developed with LAS, namely Geotracker and QUEST described in Section 4 below.

3. References to the research

1. Panos Kourouthanassis and George Roussos. 2003. 'Developing Consumer-Friendly Pervasive Retail Systems.' *IEEE Pervasive Computing* 2, 2 (April 2003), 32-39. http://dx.doi.org/10.1109/MPRV.2003.1203751
2. Dikaios Papadogkonas, George Roussos and Mark Levene, 2008, 'Analysis, Ranking and Prediction in Pervasive Computing Trails', *IET Intelligent Environments* (IE08), Seattle, 21-22 July.
3. Vassilis Kostakos, Eamonn O'Neill, Alan Penn, George Roussos, and Dikaios Papadongonas. 2010. 'Brief encounters: Sensing, modeling and visualizing urban mobility and copresence networks.' *ACM Trans. Comput.-Hum. Interact.* 17, 1, Article 2 (April 2010). http://dx.doi.org/10.1145/1721831.1721833
4. Marcus Poulton and George Roussos, 'Towards smarter metropolitan emergency response,' 2013 *IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, London, 2013, pp. 2576-2580. http://dx.doi.org/10.1109/PIMRC.2013.6666581
5. Theano Moussouri and George Roussos. 2015. 'Conducting Visitor Studies Using Smartphone-Based Location Sensing'. ACM *J. Comput. Cult. Herit*. 8, 3, Article 12 (March 2015). http://dx.doi.org/10.1145/2677083
6. Marcus Poulton, Anastasios Noulas, George Roussos and David Weston, 2018, 'Modelling Metropolitan-area Ambulance Mobility under Blue Light Conditions', IEEE Access http://dx.doi.org/10.1109/ACCESS.2018.2886852

4. Details of the impact

Birkbeck's novel hybrid model for metropolitan-scale ambulance route selection provides the computational basis of Geotracker and QUEST, two bespoke software tools used operationally on a daily basis by the London Ambulance Service. The improved accuracy in route planning and optimization offered by this software is especially critical for LAS as it is the busiest ambulance service nationally, having responsibility for an area with the highest population density in the UK. Capitalizing on the ability of the Birkbeck model to predict more precisely the time required for an ambulance to reach a particular incident, the software has helped improve the accuracy of service area coverage, the efficiency of resource deployment strategies, and the ease with which this information can be accessed and interpreted. This enables LAS staff to make informed and effective decisions more quickly, furthering the Service's lifesaving mission. Ambulance control room shift supervisors rely on the predictions of the software to make rapid decisions about how best to deploy their fleet. The Assistant Director of Information Management and Technology at the LAS states that "The work from Birkbeck has changed the way we map and deploy ambulances for the better, and that means helping to save lives. I can't think of a more important application of research than that." [B]

The two software tools developed in collaboration with Birkbeck have assisted LAS to achieve shorter response times, thus addressing a well-established clinical finding of critical importance for the survival of individuals involved in high-severity emergency incidents [F]. In the UK, ambulance services operating under the National Health Service treat approximately 30,000 Category 1 out-of-hospital cardiac arrest patients every year [G] with a survival rate of approximately 9% for those reaching hospital discharge [H]. Short ambulance response times are a key factor in attaining improved clinical outcomes because longer delays between collapse and the commencement of emergency life support result in significantly reduced survival rates [I]. After 10 minutes, very few patients survive [J]. Achieving this level of performance is particularly difficult in London: the LAS attends to over 3,000 emergency incidents every day, making it the busiest service in the country. It does so across a region with the highest population density in the United Kingdom: 8,770,000 people inhabiting an area of approximately 1,572 km^2. This population distribution is associated not only with a high number of medical emergencies but also with traffic congestion that presents particular challenges to rapid ambulance movement across the city.

Roussos, Poulton and Weston worked with LAS to address this problem, using historical incident and response performance data maintained by the Service. They employed a data-driven methodology to adaptively reconstruct ambulance mobility patterns across the city which they encapsulated in a hybrid model for route prediction [6]. This model also incorporates a bespoke road map of London derived from Ordnance Survey data and tailored specifically to emergency vehicle traffic travelling under blue lights and sirens. In particular, the map reflects the fact that ambulances can take routes that civilian vehicles cannot; for example, they can make right-hand turns where civilian traffic is forbidden from doing so. The model developed by Roussos, Poulton, Weston, and validated with the support of Noulas, allows accurate estimates for travel speeds over particular road segments at different times of the week and under different conditions. This approach results in 80% better accuracy in predicting the time taken by an ambulance crew to reach an emergency incident compared with alternative systems, for example the industry-leading Google Distance Matrix API [F].

Geotracker capitalizes on the performance gains enabled by the Birkbeck model to provide a comprehensive software application that allows LAS shift managers to track ambulances across the city and use available resources with considerably improved effectiveness. The software incorporates a visualization tool, also powered by the Birkbeck model, which provides control room staff with an intuitive "heatmap" of ambulance coverage across the LAS area of responsibility. Geotracker continuously calculates which locations can be reached by available ambulances within the time limit set by the NHS performance targets. The software responds to changing patterns of the overall demand on the service, generating notifications when increased demand is predicted to adversely impact LAS resources. It also enables staff to make fully-informed decisions about how best to deploy the approximately 300 LAS vehicles that are operational at any one time. This goal is achieved through interactive exploration of alternative tactics via a 'drag-and-drop' user interface feature, which assesses the effect of deploying a particular vehicle to a specific incident or standby point.

Geotracker is now routinely used in the control room at LAS. The Head of Quality Assurance at LAS explains that its use represents a milestone for the Service, which had attempted to introduce a dynamic emergency vehicle deployment system for some time but had found predecessors to Geotracker limited. The updated Geotracker which Marcus, George and David built has benefited the LAS by allowing the service to use resources more effectively and efficiently, basing decision-making on historical information as well as on an accurate real-time picture of its crews at work. This in turn benefits the patients served by enabling the LAS to respond more quickly to emergency calls. Such increased effectiveness also benefits the taxpayers whose money supports this publicly-funded service.

As well as increasing its efficiency today, the tool also enables the LAS to plan more effectively for the future. Having an accurate understanding of the time taken by our vehicles to cover specific routes allows the LAS to identify hotspots where crews can most usefully be stationed during key periods of demand. Geotracker also allows them to monitor the coverage of these hotspots, informing discussions around coverage and resourcing at the local station level (e.g. this information might be used to make a case for stationing more vehicles at a particular location). Indeed, [redacted] also reports that local managers have found the system so useful that access to the server has had to be rationed to cope with demand [A].

This forward-planning functionality combines with that of the QUEST routing engine, also powered by the hybrid model described in [6]. QUEST provides an accurate simulation of ambulance movement, which allows the LAS planning department to assess the likely impact of new NHS policies or response strategies on service delivery. The availability of an accurate simulator to predict the implications of strategic change enables LAS to anticipate and pre-empt problems that have direct implications for people's lives: 'LAS needs to make absolutely sure that the system works well all of the time' [C].

Moreover, QUEST provides an open application programming interface (API), which facilitates innovation by supporting further research in effective response strategies by others. In 2018, a group of researchers at King's College London visited LAS as part of the ESRC-funded project 'Improving Efficiency and Equity of Ambulance Services through Advanced Demand Modelling.' By using the QUEST API, they were able to investigate a family of novel incident response allocation strategies inspired by bio-memetic robotics, with preliminary experiments suggesting a potential reduction in response time of approximately 50% [E]. QUEST enabled this experimentation without the need for LAS to share historical data of incident occurrence and response, which incorporate sensitive personal information, and demonstrates how the work of Roussos, Poulton and Weston can also enable innovation by others by removing barriers related to open data sharing.

In 2019, London Higher, the membership body representing over 40 higher education institutions in London, selected the work undertaken by Roussos, Poulton and Weston with the LAS for their London Impact Catalogue. The catalogue exemplifies the distinct contributions London's universities make for, and to, the Capital with the Birkbeck work selected specifically as a demonstration of impact on health and analytics. This work was also presented at the event 'Impacting London – What London's Universities do for London' which took place at the House of Lords in December 2019.

In summary, by substantially improving the way ambulances are tracked and deployed, Birkbeck's novel model of metropolitan-scale route selection for ambulances and the resulting Geotracker and QUEST software, have enabled the LAS to enhance their vehicle deployment strategy and hence further their lifesaving mission. The computational tools developed in collaboration with Birkbeck achieve this through their tailored design to match the unique challenges of the Capital's characteristics, namely the nationally highest emergency call volume, highest population density and lowest traffic speed. The tools enable LAS staff in operational and management roles to make informed and effective decisions on a day-to-day basis more quickly, and thus to make the best use of fixed resources under high demand. By providing concrete evidence to inform discussions around coverage and resourcing and by facilitating further research, the work by Roussos, Poulton and Weston makes a significant contribution towards supporting LAS to deploy its ambulances more effectively and as a result, to save more Londoners' lives.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. Testimonial from [redacted], London Ambulance Service
B. 'Blue lights, ticking clocks', pp.26-27 in *BBK* Magazine issue 35 (2016)
C. KCL report on their work with LAS: Policy Institute at King's, *Data for Ambulance Dispatch: New and emerging forms of data to support the London Ambulance Service* (KCL: London, 2018). https://www.kcl.ac.uk/policy-institute/assets/data-for-ambulance-dispatch.pdf
D. Ordnance Survey case study on Geotracker tool: https://www.ordnancesurvey.co.uk/business-government/products/case-studies/ambulance-geotracker
E. E. Schneider, M. Poulton, A. Drake, L. Smith, G. Roussos, S. Parsons and E.I. Sklar (2020), 'The Application of Market-based Multi-Robot Task Allocation to Ambulance Dispatch', Arxiv pre-print
F. T. D. Valenzuela, D. J. Roe, S. Cretin, D. W. Spaite and M. P. Larsen, "Estimating effectiveness of cardiac arrest interventions: A logistic regression survival model", *Circulation,* vol. 96, pp. 3308-3313, Nov. 1997.
G. G. D. Perkins and S. J. Brace-McDonnell, "The UK out of hospital cardiac arrest outcome (OHCAO) project", *BMJ Open*, vol. 5, no. 10, pp. e008736, Oct. 2015.
H. M. R. Daya et al., "Out-of-hospital cardiac arrest survival improving over time: Results from the resuscitation outcomes consortium (ROC)", *Resuscitation,* vol. 91, pp. 108-115, Jun. 2015.
I. M. L. Weisfeldt and L. B. Becker, "Resuscitation after cardiac arrest: A 3-phase time-sensitive model", *JAMA*, vol. 288, no. 23, pp. 3035-3038, Dec. 2002.
J. R. Graham, M. A. McCoy and A. M. Schultz, *Emergency Medical Services Response to Cardiac Arrest*, Washington, DC, USA: National Academies Press, 2015.
K. ESRCC Project Improving Efficiency and Equity of Ambulance Services through Advanced Demand Modelling, https://gtr.ukri.org/projects?ref=studentship-2317339
L. London Higher, London Impact Initiative, 2019 https://www.londonhigher.ac.uk/wp-content/uploads/2019/12/London-Higher-London-Impact-Catalogue-Dec-2019.pdf