Institution: University of Oxford

Unit of Assessment: 11 Computer Science and Informatics

Title of case study: Improving Workforce Efficiency in Hospitals via Infrastructure-Free Indoor Localisation

Period when the underpinning research was undertaken: 2012 – 2015

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:
Niki Trigoni	Professor of Computer Science	May 2007 – present
Andrew Markham	Associate Professor of Computer Science	Aug 2008 – present
Hongkai Wen	Research Associate	Nov 2013 – Nov 2016

Period when the claimed impact occurred: 28 October 2015 – 31 December 2020

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

1. Summary of the impact

Location tracking is notoriously difficult inside buildings, where GPS does not work. To address this challenge, Trigoni's research group has developed a frictionless infrastructure-free indoor positioning solution based on smartphones, which avoids the significant cost and effort required to deploy existing solutions. Their award-winning map matching and pedestrian dead reckoning algorithms are licensed to Navenio, a University spinout founded by Trigoni in 2015. Since then, Navenio, which employs over 65 people, has applied the technology in multiple NHS trusts to build a workforce tracking and tasking solution for porters and other hospital staff. The new positioning technology and the enhanced analytics that it makes possible have helped NHS hospitals to reduce costs, use resources more efficiently, and improve compliance outcomes. These efficiencies have further resulted in changes in management practice, with the technology enabling a data-led approach to resource and workflow management; improved experience and outcomes for user groups within the hospital, such as porters and nurses; and improved patient experience and outcomes, as waiting times are reduced and staff time is freed for patient care.

2. Underpinning research

The state of the art in the indoor positioning systems market consists of solutions based on bespoke hardware infrastructure, such as Bluetooth, UWB, magnetic, or acoustic beacons. These require extensive beacon infrastructures placed throughout the target building, resulting in slow (4–6 months) and costly implementation. Existing solutions based on Wi-Fi access points – i.e., already-existing infrastructure in the building – require labour-intensive surveys, which can take 1–2 months for large multi-building hospital sites, and require frequent updates through repeat survey efforts every few months. To address this challenge and achieve a solution that avoids infrastructure and survey costs, Trigoni's group has worked on three novel technologies:

Robust Pedestrian Dead Reckoning. Work in [**R1**] focussed on robustly tracking the relative motion of a smartphone no matter how the user holds the phone while walking (on swinging hand, texting, making a phone call, in shirt pocket, or trouser pocket). This work was based on two key insights: a novel classification scheme for device attachment, and an algorithm for correcting drift of acceleration and gyroscope data and robustly estimating device orientation.

Lightweight Map Matching. In order to further refine the trajectories generated by the pedestrian dead reckoning algorithm, it is possible to exploit knowledge of the internal layout of the building (i.e. floorplans). Whereas previous approaches used Bayesian filters based on directed graphical models (e.g. Kalman filters and particle filters), Trigoni's group proposed a novel approach based on conditional random fields (undirected graphical models) [**R2**, **R3**]. The new map matching algorithm makes it possible efficiently and robustly to capture spatio-temporal correlations in the noise of sensor data and to increase the tracking accuracy, while remaining lightweight enough in terms of processing time to run locally on smartphones without compromising performance or battery life.

Indoor Positioning with Lifelong Learning. The third research contribution, in [**R4**], is the idea of exploiting the interaction between the pedestrian dead reckoning and map matching algorithms to improve the tracking accuracy of users in a building over time. In other words, the more the localisation app is used, the more accurate it becomes. Parameters are fine-tuned

automatically to fit the particular walking style of the user, the specific noise profile of the sensors of the particular smartphone device, and the layout of the building.

3. References to the research

[**R1**] Z. Xiao, H. Wen, A. Markham, N. Trigoni: Robust pedestrian dead reckoning (R−PDR) for arbitrary mobile device placement. 5th Int. Conf. on Indoor Positioning and Indoor Navigation (IPIN'14), 2014: https://doi.org/10.1109/IPIN.2014.7275483.

[**R2**] Z. Xiao, H. Wen, A. Markham, N. Trigoni: Lightweight map matching for indoor localization using conditional random fields. Int. Conf. on Information Processing in Sensor Networks (IPSN'14), 2014: https://doi.org/10.1109/IPSN.2014.6846747. *Best paper award*.

[**R3**] Z. Xiao, H. Wen, A. Markham, N. Trigoni: Indoor tracking using undirected graphical models. IEEE Tr. on Mobile Computing, 2015: https://doi.org/10.1109/TMC.2015.2398431.

[**R4**] Z. Xiao, H. Wen, A. Markham, N. Trigoni: Robust Indoor Positioning with Lifelong Learning. IEEE J. on Selected Areas in Comms, 2015: https://doi.org/10.1109/JSAC.2015.2430514. *Submitted to REF 2021*.

4. Details of the impact

Route to impact. The research contributions were protected through two patent applications: one on map matching and lifelong learning [**R2**–**R4**] has been granted in the US and Australia and is under consideration in Europe and China; one on pedestrian dead reckoning [**R1**] is under consideration in the US, Europe, China, and Australia [**E1**]. These patent applications were licensed to Navenio Ltd in December 2015. The algorithms have since been further refined by Navenio's engineers under the guidance of Trigoni [**E2**], making them robust enough to be deployed in complex multi-building hospital sites.

In 2018, Navenio received GBP427,714 in funding from the GBP17,000,000 Digital Health Catalyst competition run by UKRI, to develop their tracking technology – "an Uber for porters" that enables hospital staff to be in the right place at the right time [**E3**]. Navenio has developed two location-based services that use the novel indoor positioning technology developed by Trigoni's research group in [**R1**–**R4**]: 1) an intelligent workforce solution (IWS) for porters and other hospital staff; and 2) a cleaning compliance solution for hospitals.

Economic impact of Navenio. Navenio initially deployed their technology into two Manchester hospitals in 2018, and in the 2017–2018 financial year reported income of GBP175,782 and provided employment to 24 people. In 2018–2019 the company reported income of GBP489,326 and employed 58 people. In May 2020, Navenio raised GBP8,850,000 in a Series A funding round led by QBN Capital [**E2**]. As of December 2020, Navenio employed 67 staff (headcount: 67; FTEs: 65.2) and 3 consultants, with contracted annual recurring revenue of approximately GBP700,000 [**E4**]. The company has deployed its IWS portering technology to 9 UK NHS hospitals across 7 NHS trusts: Tameside and Glossop Integrated Care; Manchester University; North Tees & Hartlepool; Buckinghamshire Healthcare; East Kent Hospitals; Epsom & St Helier; and Royal Cornwall. Over 400 portering staff and over 700 task requesters in these hospitals are using the technology daily **[text removed for publication]** [**E4**].

At the 2020 annual Women in IT Awards, Trigoni was named CTO of the Year, recognising not only the impact of Navenio's technology services in healthcare to date, as documented below, but also Trigoni's important impact on diversity through her leadership role in a sector where female representation still stands at only 19% [**E5**].

Impacts on organisational efficiency in the NHS. Navenio uses intelligence about a hospital, its workflows, and the tasks it needs to perform in order to determine the optimal way of completing portering or cleaning tasks, and provides real-time tasking and tracking to streamline staff workflows. As evidenced below, the technology allows hospitals to identify and address non-optimised staff workflows, rota management, and resource utilisation. This leads to greater task completion at higher speed, reduced loss of ward staff time, and reduced spend on agency and helpdesk staff. The technology also enables the provision of data on employee activity, task completion, and adherence to the Service-Level Agreements (SLAs) with which hospital trusts are required to comply. These operational insights, provided via an analytics dashboard, allow

trusts to make evidence-based improvements in resource use and allocation, and to avoid fines for non-compliance with SLAs.

Workflow efficiency and cost savings. A major inefficiency currently experienced in NHS hospitals is the significant amount of nurses' time spent on portering tasks, due to difficulties in finding and tasking porters. Ward staff allocate tasks to porters via a helpdesk, with tasking affected by uncertain availability, and often reliant on individuals' site or staff knowledge. High call volumes can lead to delays and even service failure, and nurses' time is frequently spent chasing porters or completing portering tasks themselves. This reduces the time nurses spend on core patient care tasks, while hospitals recruit costly agency staff to make up for the shortfall.

Navenio's IWS has allowed hospital management to correct such inefficiencies and identify others, leading to substantial cost savings. The deployment of the technology across three hospitals in the East Kent trust, for example, led between November 2019 and September 2020 to a 15% reduction in portering calls to the helpdesk **[text removed for publication]** [**E6**.1]. Since its deployment at Tameside and Glossop in December 2017, the technology has removed the need for a helpdesk altogether, releasing capacity of 40 hours per week [**E7**.2]. Service delivery for portering has improved dramatically: Tameside and Glossop have recorded a 94% increase in portering tasks completed, while task response times and task completion times are 40% and 12% quicker respectively [**E7**]. At the East Kent trust, 18% more tasks are handled, despite reducing helpdesk calls; speed of task assignment has increased by 39%; task response times are 29% faster; 26% more tasks are completed; and 10% fewer tasks are cancelled. As a result, it is estimated that East Kent Trust hospitals have saved "up to 200 hours per week" of ward staff time previously spent "carrying out porter duties or chasing porters", with this time now freed for patient care [**E6**.2, **E6**.1]. Tameside and Glossop have also recorded 175 hours per week of released ward capacity, "as a function of reducing the need for ward staff to carry out portering tasks" [**E7**].

These gains are achieved through the technology's intelligent workflow optimisation, not by placing additional pressure on personnel: portering staff now walk fewer miles (per hour per resource), and "positive feedback has been received from all users", including porters [**E6**.1, **E8**]. At Tameside and Glossop, the Logistics Manager reports that "ward staff are able to book tasks quickly, and then be kept up to date on task progress – allowing them to plan their days better, in turn freeing up more of their time for patient care", while "porters find the solution easy to use – it allows them to focus on the most important tasks and ensures daily tasks are handled with the minimum amount of effort" [**E7**].

Evidence-based resource allocation. The detailed analytics enabled by Navenio's location-tracking technology have informed changes in resource alignment at NHS hospital trusts. At East Kent, the data "informs decision making and has allowed the Facilities Management team to review their staffing demand and understand where improvements need to be made. This allows for optimisation of staff productivity and allows managers to put forward a business case for an increased number of porters if needed" [**E6**.1]. The Facilities Manager states: "we have found the data from Navenio to be invaluable, it has allowed us to see a true reflection of what is actually going on 'on the floor'. Previously our data was just a data dump … but now we get to see where the operational focus should be" [**E6**.1]. Fine-grained resource demand analysis, "with the changing hospital flows, down to 15-minute intervals", has allowed departments across the hospital "to change their way of working to avoid unnecessary delays", and "overflow one team to another team when there is unexpected capacity or an increase in a specific service demand, i.e. COVID-19" [**E6**.1].

Insights based on location tracking can also highlight significant problems that were previously invisible. At one hospital, Navenio showed that a much higher volume of blood samples was being collected than at comparably sized sites **[text removed for publication]** [**E6**.1].

Data-enabled management. The actionable insights provided by the Navenio technology have resulted in changing management practices at hospital trusts, where Navenio data has been incorporated into regular decision-making processes. The East Kent trust uses Navenio's insights to give "all managers a complete overview of what has happened and where workflow can be improved", and "monthly review calls are carried out to help managers understand and

interpret the data so it can be used to improve processes and be disseminated for presentation to the board" [**E6**.1]. The Facilities Manager reports that "Navenio and our teams have…spent time building up our portfolio of data to feed into the SLT and Board papers to ensure that they see the highlights and trends they need to inform decision making" [**E6**.1].

Other trusts similarly report wider benefits flowing from data-enabled decision-making. At Tameside and Glossop, "management now have access to highly usable information, providing fascinating insights on operational practices and compliance levels, and that helps us address inefficiencies across the organisation as a whole" [**E7**]. In April 2019, the Care Quality Commission drew special attention in a Use of Resources report to these 'Outstanding Practices' for improving care at NHS Tameside: "the trust was able to demonstrate a clear theme of using technology and innovation to improve productivity throughout the trust through examples such as… Navenio – a portering app which monitors all portering activity in real time, with a live dashboard to inform team leaders of any demands on the service. The app has allowed the trust to review activity and response, has removed the need for clinical staff to pick up portering duties due to unavailability, has resulted in a reduction in the time spend logging calls and a reduction in overtime by increasing shift efficiency" [**E9**]. The impact of Navenio's technology across the breadth of hospital operations is recognised by new clients, who are investing in order to become "truly data-led organisation[s]" [Managing Director, NTH Solutions (facilities management for North Tees and Hartlepool Hospitals NHS Foundation Trust): **E10**].

Impacts on cleaning standards and compliance outcomes. The Navenio system configuration takes into account hospital compliance requirements, and analytics are generated that allow hospital management to monitor and improve compliance outcomes. These insights can mitigate significant financial risks for hospital trusts, whose SLAs include provisions for substantial financial penalties correlated with performance targets. Hospitals have reported measurable improvements in compliance outcomes due to the use of Navenio: in August 2019, for example, Queen Elizabeth The Queen Mother Hospital achieved task handling compliance levels for portering tasks of 100% for emergency moves, 97.3% for urgent moves, and 96.2% for routine tasks. Overall, facilities management for the three East Kent hospitals recorded a 12% increase in task compliance in the 10 months following November 2019 [**E6**.1]. Tameside recorded SLA compliance of 95% using Navenio [**E7**]. At **[text removed for publication]**, potential fines were identified by feeding Navenio's data insights into the hospital's PAYMECH compliance system. The hospital was then able to avoid penalties by adapting staffing capacity in response.

In 2020, Navenio won GBP441,616 in UK government funding to develop their applications to support the NHS in dealing with COVID-19 [**E12**]. This accelerated the development and launch of Navenio's cleaning compliance solution, which has already been purchased by 5 hospital customers [**E4**]. The tracking and tasking solution improves workflow and resource efficiency to achieve greater task completion and better cleaning standards and compliance. The technology can also be used directly to identify sources of hospital-acquired infections by determining which staff and assets have been in contact with infected patients.

Impacts on staff and patient experience and healthcare delivery. The efficiencies enabled by Navenio's IWS have benefitted staff user groups across NHS hospitals, with concomitant benefits for healthcare delivery. As part of the deployment process, Navenio gathers requirements from all relevant staff and departments, such that staff feel they are fully "able to input our needs into the system" [Radiology Lead, Epsom & St Helier: **E8**], and provides training to all users of the technology. Necessary adaptations are made, e.g. for partially sighted users. For portering and cleaning teams, adoption can mean a wholesale shift to a digital working culture. The technology has been embraced because it has shortened journey times, eliminated unnecessary journeys, and made it easier for porters and cleaners to manage their workload (for example, a porter stated: "it knows what stage of the task you are on…it will make things so much easier") [see staff feedback in **E6**.1, **E8**].

The experience of clinical staff, and in turn the quality of patient care, has improved as a direct result. At Tameside "ward staff are able to book tasks quickly, and then be kept up to date on task progress…freeing up more of their time for patient care" [**E7**]. At Epsom & St Helier, "we now have visibility of when porters have accepted tasks, an estimate of when they will arrive and

their progress. It has really improved the situation for staff and patients alike" [**E8**]. Patients experience these benefits in the form of faster response times (at the East Kent trust "response time to patients has been 29% faster, reducing from an average of 14 minutes to 9.9 minutes"), and more time for clinical staff to care for patients, "as they are spending less time doing porter tasks or chasing completion of porter tasks" [**E6**.1]. This translates both into better patient care – for example, faster turnaround times for X-rays – and improved patient safety, as in the blood sample case described above. An April 2019 CQC inspection report noted that NHS Tameside had been rated 'Good' for medical care service responsiveness in part because "technology had been used to improve productivity and understand service demand and capacity" [**E11**].

5. Sources to corroborate the impact

[**E1**] International patents filed Sep. 2015: WO/2016/042296A2; WO/2016/042296A3.
[**E2**] Navenio Ltd full accounts (2017–19) at CH, incl. records of Trigoni's consultancy.
[**E3**] Digital Health Catalyst competition grant and gov.uk press release, September 2018.
[**E4**] Letter from Head of Operations, Navenio Ltd, confirming information about the company and contracted services.
[**E5**] Women in IT Awards 2020 winners: http://archive.vn/S7GWq.
[**E6**] (1) Health Service Journal Awards 2020 entry document and (2) approved customer case study from Associate Director of Commercial Solutions, 2gether Solutions (facilities management for East Kent Trust).
[**E7**] (1) Testimonial and (2) approved customer case study from Logistics Manager, Tameside and Glossop Integrated Care NHS Foundation Trust.
[**E8**] Approved customer case study from Radiology Superintendent, Epsom & St Helier University Hospitals.
[**E9**] Care Quality Commission Use of Resources Report (July 2019), at pp. 5, 9, 11: https://www.cqc.org.uk/sites/default/files/Tameside_and_Glossop_Integrated_Care_NHS_Foundation_Trust_Use_of_Resources_published_04_July_2019.pdf.
[**E10**] Approved customer case study from Managing Director, NTH Solutions.
[**E11**] Care Quality Commission Inspection Report (July 2019), at pp. 6, 28, 40: https://www.cqc.org.uk/location/RMP01/reports
[**E12**] Innovate UK COVID-19 response funding for Navenio, Jun. to Aug. 2020: https://gtr.ukri.org/projects?ref=60094 and https://gtr.ukri.org/projects?ref=77726.