Australasian Transport Research Forum 2018 Proceedings
30 October – 1 November, Darwin, Australia
Publication website: http://www.atrf.info

New technology changing how we achieve Service Realisation

Katelyn Bywaters[1], Michelle Zeibots[1], Nathan Kirchner[1]

[1] Institute for Sustainable Futures, University of Technology, Sydney, Australia

Email for correspondence: katelyn.bywaters@uts.edu.au

Abstract

New developments in robotic sensor and other digital information technologies have begun to exert an influence on the transport sector that potentially rivals the profound change to human societies brought about by mass transit, and later private motor vehicle technologies. Amidst this potential for change is a revival in systems thinking, or design thinking, and an interest in 'innovation', multi-disciplinary and even transdisciplinary research. But how is this brought together in practice? What do researchers from different disciplinary backgrounds actually do when they invent a new transport technology?

This paper documents some of the methods that have been used to guide the transition from broad concepts that reimagine key aspects of transport service delivery to the specific technical capabilities of new technologies currently under development within the rail transport sector. Specifically, this paper documents the methods used to create a new passenger behaviour monitoring technology called DwellTrack developed at UTS in collaboration with Downer Rail. DwellTrack, now the subject of a global patent, falls within a new class of rail operating system known as Responsive Passenger Information (RPI) Systems designed to facilitate self-organising approaches to the management of passenger congestion on heavy rail networks.

Through a retrospective review of DwellTrack's development, key methods for achieving what researchers call 'service realisation' — the point at which broad ideas and objectives are realised as specific technologies — is documented. These methods fall within the gambit of what are defined within the literature as behaviour to meaning mapping (BTMM) methods. In this application however, these methods are used to align human behaviour and operating system features with the robotic system architecture that underscores RPI system technology. Traditionally, BTMM methods are used to test whether or not users might interpret and use elements in the built environment in ways that were intended by designers. What both applications have in common is the need to translate purposes and meanings from one group of people to another.

From an academic perspective, the different aspects of human behaviours and features of transport operating systems sit within different disciplines. This paper also highlights the value of formalising the way BTMM methods are used to cross disciplinary boundaries and in the process fast track technology innovations. By efficiently achieving service realisation it significantly reduces the time taken to push a set of broad ideas through to productisation. This demystifies the innovation process for researchers and potentially offers transport service operators with less confusing ways of participating in the development of new technologies

that can be applied to day-to-day operations of increasingly congested railway and public transport networks.

1.0 Introduction

Since 2011, researchers at the University of Technology Sydney (UTS) have been working in collaboration with key industry partners Downer Rail, Queensland Rail and Sydney Trains to develop new technologies that form part of a new class of rail operating system called Responsive Passenger Information (RPI) Systems.

RPI Systems were originally conceived as a way of overcoming chronic passenger congestion at rail stations that can cause extended dwell-times for train services, which in turn pushes service delivery into 'degraded mode', thereby reducing the number of viable train paths on a network and its carrying capacity during peak periods.

leading to new rail operating system that introduces two-way information exchanges to enable better decision making by customers and service providers, and thereby expedite the self-organisation of users throughout the transport system easing passenger congestion. While some of the innovative technologies developed within the RPI System program – including DwellTrack – are nearing the end of the commercialisation process, others are yet to begin their design, testing and development phases.

In order to progress, new RPI System technology must first achieve service realisation (SR) – the point where early concepts and ideas transition into a clearly defined action or form of information that will enhance the transport service offering to customers. However, as a result of the human-centric system perspective, new data collection techniques, and new types of data, achieving service realisation within the RPI System research program has become more difficult.

With the aim of achieving a consistent approach to service realisation, a retrospective study on the development of DwellTrack – a sensor technology that monitors the dwelling behaviour of passengers around train doors – has been undertaken. Findings identify key activities that allowed designers and engineers to effectively cross disciplinary boundaries and align the behaviours observed in day-to-day rail operations with the capabilities of the emerging robotics technologies. These findings provide a step-by-step process for achieving service realisation in RPI system projects. This has been coined the behaviour to meaning mapping process (BTMM)

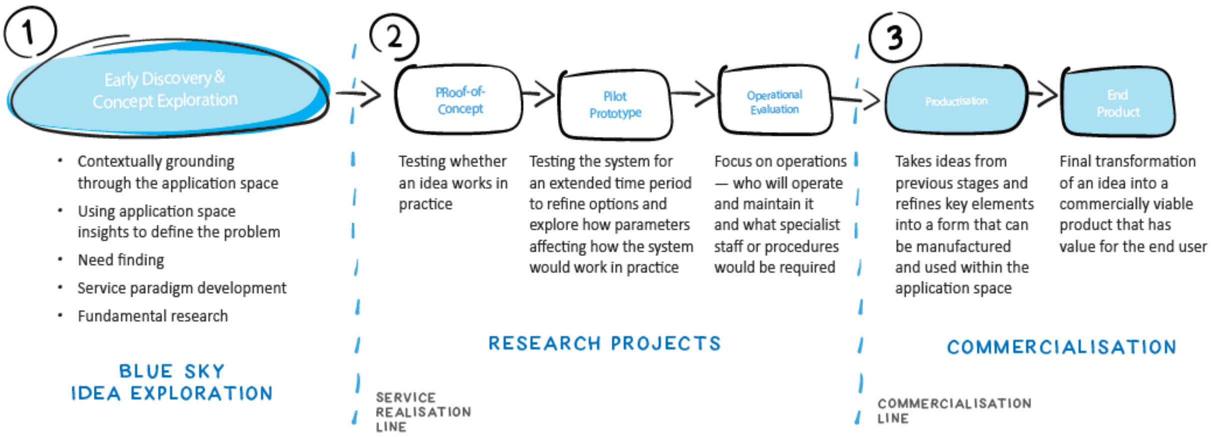
Previously, traditional behaviour mapping and modelling focus on the human participant and the meaning connections inferred from observed human behaviour and travel decisions (Hannes et al. 2012). However, in the context of RPI system research, this technique is extended to map the connections between other system actors which in the case of DwellTrack include operating procedures and rail infrastructure.

The structure of this paper is as follows. Section 2 will define the role of service realisation in the UTS research and innovation model. Section 3 will provide a brief overview of the RPI system research program, its purpose, significance and introduce key concepts and definitions. It will also discuss the challenges faced by the RPI system as a result of new technology and data. Section 4 includes a retrospective study of DwellTrack developments and describes key BTMM techniques and outputs. Section 5 summarises the key findings and proposes a streamlined BTMM process to achieve service realisation for the new RPI system technologies proposed.

2.0 What is Service Realisation and what is its significance?

In the development of any new technology, engineers and designers move through a series of key stages of the design process. While countless iterations of this process exist, all reflect the three essential phases of design – 1) need finding and idea generation 2) concept design and prototyping and 3) productisation and evaluation (Lawson 2005). Each of these three phases are evident in the *UTS Innovation Model* shown in Figure 1. This model has been used to guide development of RPI system technologies at UTS. By following this process, research teams acknowledge that a new piece of technology passes from a set of very broad, speculative ideas that might appear vague or ill-formed, through a point of service realisation where clarity is achieved and a more specific function identified.

Figure 1. The UTS Innovation Model



In the UTS innovation model, service realisation refers to the point at which early ideas and concepts transition into a clearly defined research project. Traditionally this is also known as product realisation. For a product to achieve realisation it could, for example, require a set of objectives, specifications, or descriptive drawings to be produced. Once achieved, these outputs are passed on to designers and engineers that make this concept a reality through testing and commercialisation. However, the advancements in technology used in day-to-day operations of the heavy rail network have had a significant impact on how engineers achieve the point of service realisation especially with the introduction of artificial intelligence and robotics. In the case of the RPI system research program a higher level of articulation is required to achieve service realisation and set foundations for the next phase of research and development.

3.0 Why Service Realisation is more difficult to achieve in the RPI System Project

3.1 Background to the RPI System projects

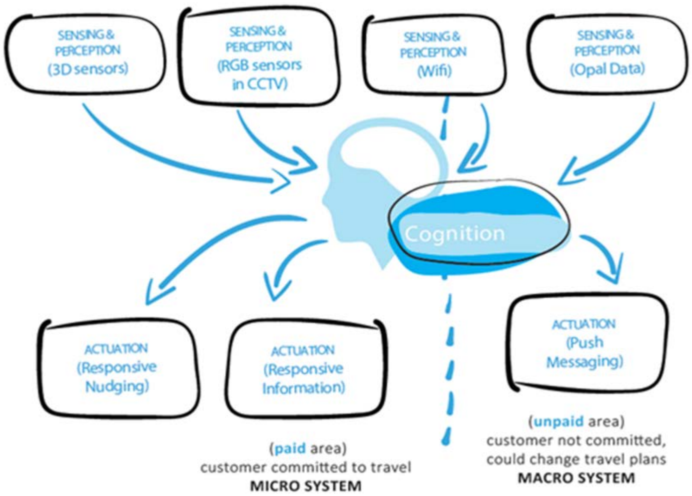
In recent years, transport service providers (TSP's) have become increasingly aware of the implications passenger congestion has on dwell-time and the direct impact it has on operations and on-time running of the transport network (D'Acierno et al. 2017; Kelley et al. 2016; Puong

2000; Seriani, Fujiyama & Holloway 2017; Wiggenraad 2001). Dwell time, in the context of a public transport network is the time taken from wheel stop, to wheel start of the (Karekla & Tyler 2012). Dwell time can be expressed as a combination of two processes (Collart et al. 2015). Firstly, operating processes that included the act of arriving and departing, and the door opening or closing while stopped. The second comprises of passenger behaviours around dwell events. These behaviours include, standing and waiting positions, or ingress and egress patterns (Collart et al. 2015). It also includes the interactions or collisions between passengers (Seriani, Fujiyama & Holloway 2017)

Previous works to develop a complex dwell-time diagnostic tool (CDD) (Collart et al. 2015) and devices to influence passenger egress (Colborne-veel, Kirchner & Alempijevic 2015; Kirchner et al. 2015) have been undertaken to aid operators in managing passenger congestion and minimise dwell times. A critical part of this development process has been collaboration with industry — Downer Rail (Australia's primary domestic rail manufacturer and maintainer), Queensland Rail (the heavy rail service provider in Brisbane) and Sydney Trains (the heavy rail service provider in Sydney). Downer is now about to go to market with a new rail technology called Dwell Track after four years of collaborative technical development with researchers from UTS and on-site testing support from Queensland Rail and Sydney Trains.

In turn, this work set the foundations for a research program to develop a Responsive Passenger Information System. This RPI system comprises several individual technology pieces that when placed in a robotic system architecture can provide *tools* or *technology sets* that support and enhance the user-experience and operations of the heavy rail network.

Figure 2. The RPI System architecture



The RPI System architecture shown in Figure 2 has three core robotic components which allows the system to detect, measure, predict and respond to real-time passenger congestion. *Sensing and Perception* components form the eyes of the system that gather a multitude of data from ticketing through to individual passenger movements. While sensing & perception tasks function in parallel, sensors capture an image of the world and perception algorithms translate it into a form allowing other system components to function. A centralised *cognition* program learns from the data and creates a plan of action in response to the congestion.

Actuation refers to the part of the system that enacts this plan and act as the information touch point between the system, its operators and users. There are a raft of actuation strategies that are possible for the RPI system all of which focus on various forms of information delivery to users and operators. For example, users could be sent a push notification to their mobile phones informing them of the network conditions. New actuation strategies such as responsive nudging includes delivery of discrete directional cues to increase the synchronicity of passenger flows in stations. This technology is currently facing similar challenges in achieving service realisation but is not discussed in depth within this paper.

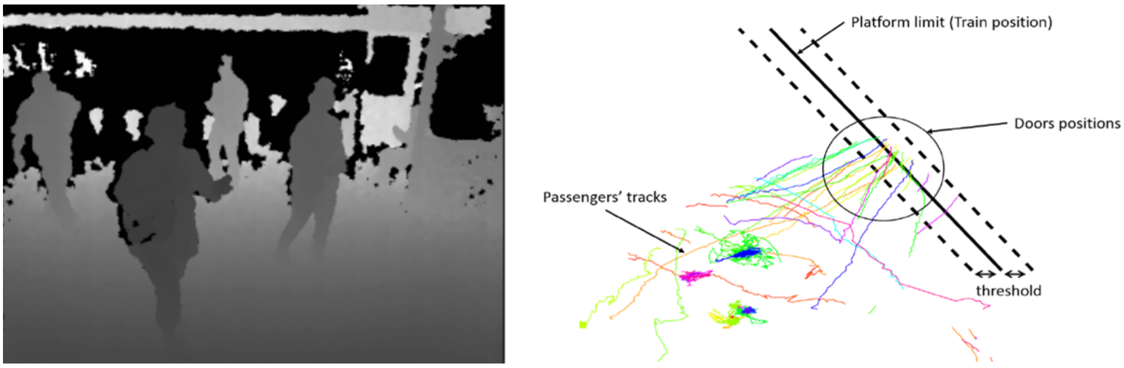
Traditionally, once these strategies have been proposed there would be a smooth transition between concept and research project i.e. achieving service realisation. However, the capabilities of individual sensing and actuation technologies proposed for use in some actuation strategies has presented challenges in progressing to the development and testing phases of the RPI system technology.

3.2 New technology creating new types of data

Within the RPI system project, 3D infrared sensors are the primary technology used for data collection on passenger movements in micro transport environments[1] and supplemented with a combination of other sensing technologies including closed circuit television (CCTV), Wi-Fi, and ticketing data.

On their own, the 3D sensors have the ability to sense, detect and track the movements of individual passengers using what is called a head-to-shoulder signature (HSS) (Collart et al. 2015; Kirchner, Alempijevic & Virgona 2012). While unique to each passenger the HSS doesn't rely on facial recognition thereby overcoming privacy concerns — a point of contention for conventional CCTV sensing (Patil et al. 2016).This innovative approach provides a unique insight into passenger walking behaviours and an unprecedented level of accuracy of real-time passenger movements. By itself this data can be used to generate visualisations of the scene as shown in Figure 3a) or could be used to show individual passenger tracks for a given scenario. Figure 3b) shows passenger tracks around a set of train doors during a period of dwell.

Figure 3a. Data visualisation and 3b. Passenger tracks from 3D Infrared Sensors

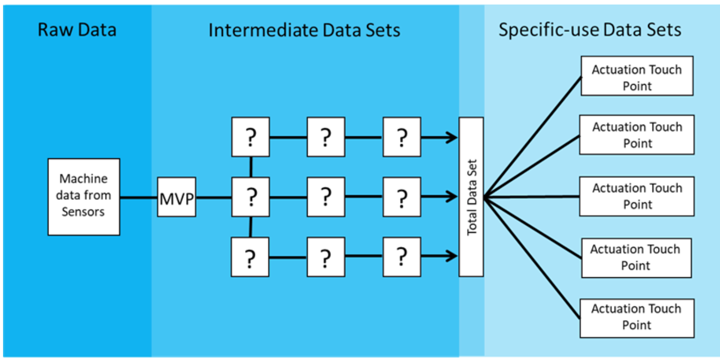


Once the data has been captured, perception algorithms are applied transforming the raw machine data into meaningful outputs that can used by the RPI System, the network operators, or its customers. During the process of manipulation a spectrum of data outputs are created which span from the raw machine data through to very specific actuation touch points. The data outputs that fall along the spectrum have been coined the Intermediate Data Sets (IDS). This process is shown in figure 4. While the IDS are not used as the final they can be utilised

[1] Micro transport environments include platforms, stairs, escalators and both paid and unpaid station concourses

by the RPI systems cognitive functions to form a complete data set. The minimum viable product (MVP) is the rawest form of data that can be used by a transport service provider to enhance their operations and performance.

Figure 4. Spectrum of data outputs



Resulting from the use of 3D infrared sensors as the primary form of data collection supporting actuation in the micro transport environment, service realisation must extend beyond the descriptive conceptualisation in order to effectively meet the diverse needs of stakeholders involved in the next phase development. In the case of the RPI technology development, service realisation must acts as a stepping stone to transfer the collaborative ideas of industry experts and operators into a language that allows robotics engineers and designers to:

- Identify the specific-use actuation touchpoint and corresponding data output
- Establish what Intermediate data sets and thus perception algorithms are need to translate and transform the raw data
- Determine what raw machine data can, and needs, to be captured

Currently work is being undertaken to achieve service realisation for the proposed RPI actuation strategies however, with the diversity and multitude of information outputs propose, achieving service realisation has become cumbersome and inconsistent.

3.3 A shift to human-centric perspectives

In addition to the added complexity of technology, there has been a significant shift in how idea and concept exploration is undertaken in the early stages of the *UTS Innovation Model*. This is due to the existing disconnect between the needs, perceptions and values of rail operators and their users. As a result the idea exploration phases is undertaken to enable the realignment of stakeholders interests through a series of collaborative reframing exercises. Using a technique called ‘Frame Innovation’ stakeholders are able to redefine the problem in accessible terms (Dorst, 2015). This process not only allows divergent and convergent thinking to occur simultaneously, but encourages stakeholders to consider problem solutions from alternative perspectives – i.e. the customer.

What results from these exercises are a series of design concepts that meet the objectives of stakeholders but are incompatible with the capabilities, terminology and knowledge of robotic technologies. For service realisation to be achieved in these scenarios, the outcomes of idea generation must be presented or transformed in such a way that robotics engineers can extract the required knowledge effectively and efficiently.

Bridging this disconnect in knowledge and language is not an insignificant task especially given the novel operating and user-centric approaches employed by the RPI system research program. More critically, the time taken to achieve service realisation directly impacts the speed a proposed concept undergoes prototyping, testing and commercialisation. With the increasingly high levels of congestion seen on heavy rail networks RPI system researchers must optimise the time taken to develop and productise a piece of concept technology and begin to assist operators in managing the chronic levels of passenger congestion experienced. In light of this, a retrospective study on the development process for the complex dwell-time diagnostic tool has been undertaken to identify key activities or methods for achieving service realisation in the hope a formal process can streamline service realisation for the current actuation strategies proposed.

4.0 Service Realisation in the development of Dwell Track

In order to achieve service realisation, a number of tools and methods emerged in the course of Dwell Track's development. Section 4 of this paper has been divided into project background followed by a description of each of the key steps and corresponding outputs in approximate sequential order.

4.1 Background of Dwell Track

The Dwell Track project began in 2014, motivated by the increasing variability in dwell times as a result of passenger congestion in rail stations. Around this time, TSP's were also becoming increasingly aware of the consequences of dwell-time 'blow outs' that have potential to cause a cascade of delays throughout the network depending on the configuration of hard rail infrastructure or operating logistics. This potential alone is key motivation for the development of a dwell-time diagnostic tool that can accurately detect and measure dwell time events.

Over the duration of the project researchers at UTS and Downer Rail collaborated with both QR and ST to develop the complex dwell-time diagnostic (CDD) tool that would later become commercialised as DwellTrack. Similar to the RPI actuation strategies, the 3D sensors again formed the primary sensing component of the CDD. In order for robotics engineers to design the senors and program the algorithms required, engineers began by identifying by identifying key objectives and outputs desired by QR.

4.2 Identifying use-spaces

The early stages of the Dwell Track's development followed an iterative action research methodology. The first cycle was dedicated to documenting the operator needs of QR. Within this need finding stage three broad use-spaces —areas of operational responsibility – were identified.

- Service Planning: focus on service offering at a macro level (network level) e.g. timetabling, stopping patterns, fleet management
- Operations Planning: focus on operating procedure at a micro level e.g. whole of station box objectives, goals, KPI's
- Day-to-day Operations: focus on operating procedure at specific locations within the micro environment e.g. actions at a specific barriers, train carriage or door

These use-spaces were determined to be the real-world application spaces in which information outputs could be utilised. Once the specific use-space – or outputs – had been identified, engineers and designers were tasked with marrying up the rail operator objectives with the proposed capabilities of the 3D sensors to identify what data collection and analysis the technology could achieve.

4.3 Operations/Machine-Language Translation Table (OMLTT)

The OMLTT is a tool that allows designers and engineers to identify key information about QR operating procedures, as well as fundamental passenger behaviours at a specific location in the station. The information about the operating procedures is then translated to determine what the tool can do, and how it can intervene or supplement existing operations. The resulting translation is a form of state machine – a model of computation – that is used to guide the programming of perception algorithms that process data from the robotic sensors. In practice, this process allowed the CDD to be configured to produce an output that satisfies a specific-use output.

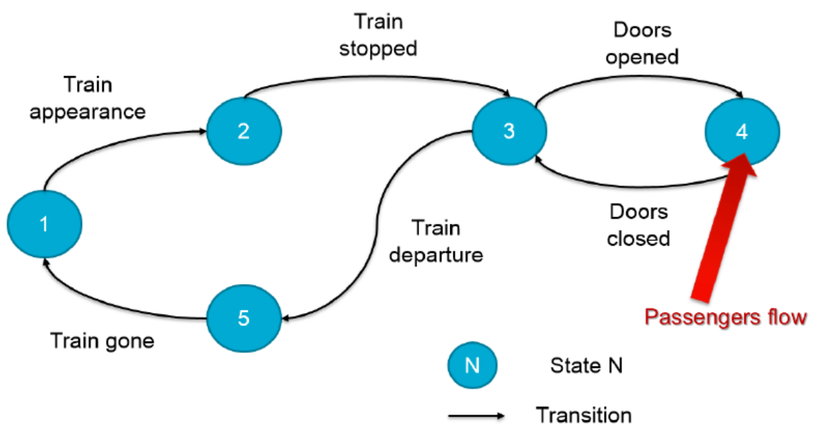
Logistically the OMLTT for Dwell Track is a spreadsheet that consists of two parts:

- Train Operations: Documentation of the QR operating procedures, including variations, to manage dwell times around the door of a train carriage. This includes a detailed expansion of the current dwell time process as defined by QR
- Sate Machine: Translation of the operating procedures into a language that robotics engineers can use to develop perception algorithms that generate meaningful data in a form that operators can use

The key outputs from the OMLTT Process include a;

- Dwell-time structure: the sequence of events that occur during a dwell from wheel stop to wheel start. This includes both operations and passenger behaviours
- Formal state machine diagram

Figure 5. State machine diagram with state descriptions (Collart et al. 2015)



The states: "train is gone, system is waiting for a train to arrive" (1), "train detected, waiting for it to stop" (2), "train is stopped with the doors closed, waiting for the doors to open or the train to leave the station" (3), "train is stopped with doors opened, waiting for the doors to close" (4), "train is leaving the station" (5); and the transitions (outputs of the events detections): "train appearance", "train stopped", "doors opened", "doors closed", "train departure", "train gone". The passenger flow occurs in state 4 but the passengers' behaviours before the doors

From this process researchers were also able to determine some potential intermediate data sets. These preliminary data sets were identified as potentially useful to operators. For example, the rate of passengers alighting from a carriage could be calculated from the difference in time stamp between dwell events 5 and 7. These preliminary IDS's here provided to QR for feedback to determine a preferential hierarchy for future development.

While the OMLTT method emerged as part of the technology development cycle, the method was revisited many times throughout the entirety of DwellTrack's development. As a result there were several iterations of this process to ensure all system requirements were considered to produce a comprehensive guide for the robotics development team.

4.4 Nomenclature and Passenger States

Accompanying the previous outputs, designers and engineers also produced a common nomenclature and a spatial structure for all actors involved in the dwell time sequence. While traditional behaviour mapping almost exclusively focuses on the human participant, this output however, advocates that the behaviour of other actors is critical in designing technology that relies on static, dynamic and responsive interactions.

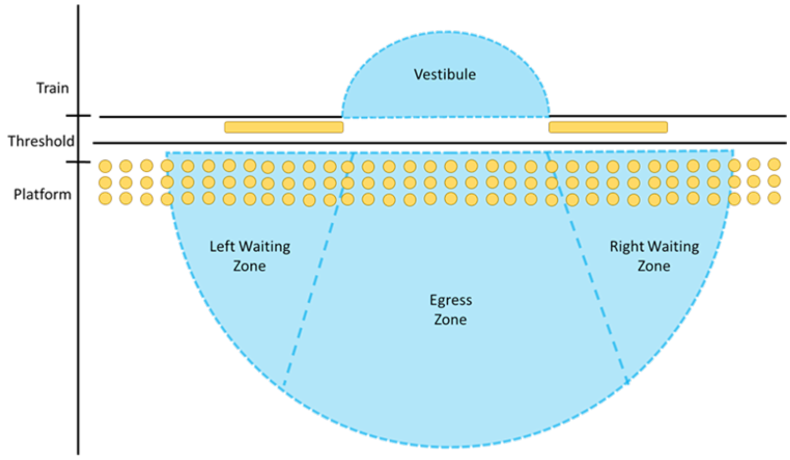
Moreover, what constitutes an actor depends on the given scenario of congestion. These actors can include strategic operations when considering a whole of station perspective, or a specific operating procedure enacted by the individual staff member. It can also focus on the behaviour of operating equipment like a train door. In the example DwellTrack, the language and structure created is used to describe the behaviour of trains, doors, passengers, and operating staff which are the key actors included within the state machine that emerged from the OMLTT process.

The terminology used to define the state of an object, as well as how these states transition sequentially, is relatively intuitive for both train movement and door configuration e.g. train arriving or door open. However, the state of passengers becomes more complex. This is because passengers, while waiting for a service are not actually stationary. They make micro movements which in actuality have a big impact on the flows of egress and ingress during a dwell event.

An example of the passenger tracks shown previously in figure 3b give light to the inconsistency of individual movements. As a result, passenger states are defined through their spatial proximity to the carriage door which has been sectioned in zones which in turn infers a passenger's state. These zones/states are listed below and shown in figure 6. This additional output also highlights what theory and literature should be consulted to inform better understanding of current passenger dwelling behaviours.

- Vestibule area (inside the train near doors)
- Egress Zone (on platform in front of carriage doors)
- Left Waiting Zone (to the left of carriage doors away from egress zone used by alighting passengers)
- Right Waiting Zone (to the right of carriage doors away from egress zone used by alighting passengers)

Figure 6. Spatial locations for passenger states



5.0 Findings and Recommendations

5.1 Findings

Through the retrospective study of DwellTrack's development process, it is evident that three key tasks where undertaken to assist designers and engineers to transition form early concepts through to development of the CCD tool – thus achieving service realisation. It is also evident that these methods emerged as a part of the process, addressing the issues of misaligned stakeholder needs as they arose.

The time dedicated to developing these methods, determining what form each output should take, and applying them to the CCD tool was a long and arduous process. Several iterations of the activities where documented throughout the entirely to DwellTrack's development indicating that the initial methods where insufficient for the needs of robotics researchers.

Moreover, the revisitation also indicates an iterative and dynamic behaviour to meaning mapping process with some tasks falling at specific stages, while others occurred simultaneously. For example, determining the use-spaces was the first task undertaken and seldom revisited. In contrast, the OMLTT was revisited several times in parallel with determining the IDS and occurred both before, and after service realisation was achieved.

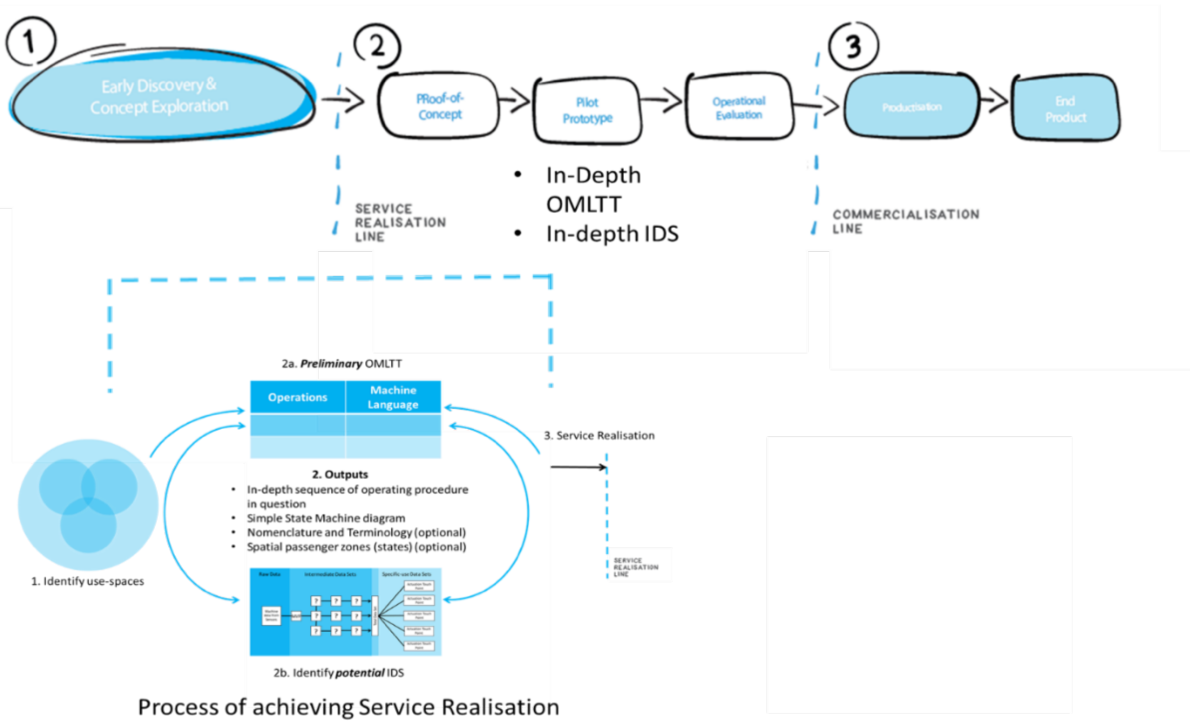
Given that robotics engineers continued to use the OMLTT during the prototype design and testing phases it indicates that these BTMM activities can be used in as both a preliminary and technical activity. The preliminary BTMM outputs set the foundation for robotics engineers to continue through to the in-depth development stages as efficiently as possible.

5.2 Recommended Process

In light of the above findings, this paper proposes to streamline the BTMM process in order to assist RPI system researchers to achieve service realisation efficiently and effectively. This process, shown in figure 7, integrates the three key BTMM activities, the corresponding outputs, and how this process effectively sits within the wider UTS Innovation Model.

The BTMM framework proposed also emphasises the importance of engaging with the fundamental steps prior to achieving service realisation in order to capitalise on time savings when progressing through the technology development process. Engaging with these activities will lay the groundwork for an in-depth continuation of these methods in second phase development fast tracking the technology for commercialisation, and therefore real-world application.

Figure 7. UTS Innovation Model with Behaviour to Meaning methods



6.0 Conclusion

In conclusion, this paper aimed to articulate the significance of achieving service realisation through the streamlined process of behaviour to meaning mapping. It effectively described the challenges in realigning stakeholder needs in developing technologies as part of the RPI system. Moreover, the evidence presented in this paper also signifies the importance of behaviour to meaning mapping methods in achieving service realisation for RPI system technologies. The challenges faced in achieving SR is a direct result of integrating the current system state and passenger behaviours, with the capabilities of new robotics technology to supplement the day-to-day operations of rail service providers. Complications also arise due to the competing needs of stakeholders, designers and engineers who sit within different areas of expertise.

These challenges were previously faced in the development of DwellTrack. Through a retrospective study, key methods for overcoming the disconnect in knowledge were identified and proposed as a behaviour to meaning mapping process for achieving service realisation. By introducing a streamlined process for achieving service realisation, it provides an opportunity to bridge the gap in knowledge, expedite and optimise the development and testing phase of the UTS Innovation model. This in turn has significant implications for the commercialisation of the RPI system technologies that are needed to support the operations of increasingly congested train stations. It also provides current researchers with a systematic way to explore the potential of new RPI system technology ideas.

With regards to limitations, use of behaviour to meaning mapping methods has only be used to achieve service realisation in the development of DwellTrack. Therefore, future works will look at further refining the process by applying it to the more complex operating and congestion scenarios presented through the RPI system research program. It is envisioned that further application in various congestion scenarios will lead to the emergence of more behaviour to meaning mapping methods.

7.0 Acknowledgements

The authors would like to acknowledge the Australian Research Council Linkage Grants program that provided the resources and opportunity to realise the founding ideas that lead to the later RPI System research program. We would especially like to acknowledge and thank Mike Ayling and Downer Rail who we have worked with over the last 4 years to develop Dwell Track. Support from the Rail Manufacturing Cooperative Research Centre during this period without which the technology would not exist. Jay Kronenberg and the rail engineers from Queensland Rail, including Craig McGlaughlin (who believed in the technology right from the start), provided opportunities and now a technology that we hope will do them proud. Finally, we would like to thank Susannah LeBron and Tony Eide and the great team at Sydney Trains for giving us access to some of the toughest passenger congestion management problems anyone could ask for. We wish to thank them for their commitment to customer service, which is at the heart of RPI System technology. This research is supported by an Australian Government Research Training Program Scholarship.

8.0 References

Caraian, S., Kirchner, N., Colborne-veel, P. & Branch, R. 2015, 'Moderating a robot’s ability to influence people through its level of sociocontextual interactivity categories and subject descriptors', *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*, pp. 149–56.

Colborne-veel, P., Kirchner, N. & Alempijevic, A. 2015, 'Towards more train paths through early passenger intention inference', *Australasian Transport Research Forum 2015 Proceedings*.

Collart, J., Kirchner, N., Alempijevic, A. & Zeibots, M. 2015, 'Foundation technology for developing an autonomous Complex Dwell-time Diagnostics (CDD) Tool', *Australasian Transport Research Forum 2015 Proceedings*, no. October, p. 13p.

D’Acierno, L., Botte, M., Placido, A., Caropreso, C. & Montella, B. 2017, 'Methodology for determining dwell times consistent with passenger flows in the case of metro services', *Urban Rail Transit*, vol. 3, no. 2, pp. 73–89.

Dorst, K. 2015. Frame innovation: create new thinking by design. Cambridge, MA: MIT Press

Hannes, E., Kusumastuti, D., Espinosa, M.L., Janssens, D., Vanhoof, K. & Wets, G. 2012, 'Mental maps and travel behaviour: meanings and models', *Journal of Geographical Systems*, vol. 14, no. 2, pp. 143–65.

Karekla, X. & Tyler, N. 2012, 'Reduced dwell times resulting from train-platform improvements: The costs and benefits of improving passenger accessibility to metro trains', *Transportation Planning and Technology*, vol. 35, no. 5, pp. 525–43.

Kelley, J., Ko, D.H., Mazza, L. & Robinson, S.E. 2016, 'Reducing dwell time: London Underground Central Line', Worcester Polytechnic Institute.

Kirchner, N., Alempijevic, A. & Virgona, A. 2012, 'Head-to-shoulder signature for person recognition', *2012 IEEE International Conference on Robotics and Automation*, pp. 1226–31.

Kirchner, N., Alempijevic, A., Virgona, A., Dai, X., Plöger, P.G. & Venkat, R.K. 2014, 'A robust people detection, tracking, and counting system', *Australasian Conference on Robotics and Automation, ACRA*, vol. 02–04–Dece, pp. 2–4.

Kirchner, N., Caraian, S., Colborne-veel, P. & Zeibots, M. 2015, 'Influencing Passenger Egress to Reduce Congestion at Rail Stations', *Australasian Transport Research Forum 2015 Proceedings*, no. October, pp. 1–15.

Lawson, B. 2005, *How designers think — the design process demystified*, Architectural Press, Oxford UK.

Patil, S., Patruni, B., Potoglou, D. & Robinson, N. 2016, 'Public preference for data privacy – a pan-European study on metro/train surveillance', *Transportation Research Part A: Policy and Practice*, vol. 92, pp. 145–61.

Puong, A. 2000, 'Dwell time model and analysis for the MBTA red line', *Massachusetts Institute of Technology Research Memo*, pp. 1–10.

Seriani, S., Fujiyama, T. & Holloway, C. 2017, 'Exploring the pedestrian level of interaction on platform conflict areas at metro stations by real-scale laboratory experiments', *Transportation Planning and Technology*, vol. 40, no. 1, pp. 100–18.

Virgona, A., Kirchner, N. & Alempijevic, A. 2015, 'Sensing and perception technology to enable real time monitoring of passenger movement behaviours through congested rail stations', *Australasian Transport Research Forum*, vol. 1, no. October, pp. 1–14.

Wiggenraad, P.B.L. 2001, 'Alighting and boarding times of passengers at Dutch railway stations', *TRAIL Research School, Delft*, no. December, pp. 1–21.