

What Building a Tangible Model Taught Me About the Real Railway

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SUMMARY

Having been requested, a tangible railway model was required to train operators, maintainers and terminal staff through the roleplay of complex procedures, and to enable stakeholders unfamiliar with the railway to understand operational changes. In this paper, I shall discuss the impact that the building of a tangible railway model had upon the resilient delivery of a multidisciplinary transit system capacity upgrade project and what I learnt along the way.

The paper gives technical descriptions on the underlying system elements that facilitated the functionality of the model and discusses the benefit of giving aspiring signalling engineers the opportunity to develop an understanding of core signalling principles through hands-on experience.

1. INTRODUCTION

As an individual at the beginnings of my career, I have a lot to learn; however, few opportunities have provided such a greenhouse for growth as building a physical railway model, so here is what I learnt and why I think it's worth sharing in the context of resilience.

In this paper, I shall discuss how during the delivery of a multidisciplinary transit system capacity upgrade project and through the partnership between a railway organisation and an airport, a novel approach to sharing knowledge and installing resilience was adopted. Using no more than a credit-card-sized computer, a few microcontrollers and other readily available components, we created an accurate automated physical railway model and fully-fledged signalling system to assist operational integration and impart resilience.

1.1. The Airports

Airports are laying plans for expansion. They estimate rising passenger numbers and seek capitalisation of retail opportunities brought about by the predicted growth of air travel and the likelihood of ever-larger aircraft in the future. It's, therefore, no surprise then that competition is fierce and greater than ever rail transport links connect cities to their sometimes multiple satellite airports leading to an increased choice for air passengers choosing between competing Airports. However, operational resilience issues, such as the 2018 disruptions at London Gatwick following several drone sightings (BBC News, 2018) and the knock-on operational disruption at Heathrow Airport following a British Airways IT failure (BBC News, 2017) attract the press and ensure that the market remains alert to the inefficiencies of the organisation trying to bring value to its customers.

As is the case within the railway, during times of operational disruption, ensuring passenger welfare should be a major consideration and key priority, principally as failure to do so is the main motivation behind creating operational resilience. However, in large organisations, aligning major stakeholders in a tactical approach to target improved resilience is a challenge and necessitates effective cooperation between all aspects of the Airport: the airlines, dispatchers, aviation technicians, emergency services and countless airport support divisions.

2. HEATHROW AIRPORT T5+

Heathrow Airport Limited (HAL) is one of the many airports with visions of expansion, not least its Terminal 5 (T5) – originally designed to handle 35 million passengers a year, it already serves 32.8 million as of 2018, just 10 years after its opening (LHR Airports, 2019). As is the case in other densely populated areas, the most significant challenge when increasing capacity through the system is the movement of people within it and in the case of airports, this is the movement of passengers to and from aircraft. This challenge led to the development of a variety of terminal configurations with the intention of maximising passenger-processing capacity per area of land and the reduction of walking distances for passengers (Shen, 1992). Whilst relatively low-cost walkalators (slow-moving conveyor mechanisms) reduce travel times for passengers across a short to medium distance, such systems quickly reach their limitations when deployed within large airports, especially those with multiple terminals or satellites as is the case at Heathrow T5.

The technological development of the Automated People Mover (APM) made it possible to meet the challenges discussed – this is the technology that HAL deploys as the main transportation medium to convey air passengers

between satellite terminals at T5 and is referred to as the Track-Transit System (TTS). The proprietary APM system which HAL deploy for its TTS is the Bombardier Innovia APM 200. However, 10 years on, the need to increase capacity and reduce overcrowding within the TTS has been realised and whilst this is an Airport wide programme called Heathrow Terminal 5+, the subject of interest for this paper is the TTS.

2.1. Track-Transit System Capacity Upgrade

The TTS features a fleet of driverless, rubber-tired, transit vehicles which are controlled remotely by an operator from a central control room. These transit vehicles are situated along a running slab guideway comprising of two parallel single-lane guideways (north and south) that connect the main terminal (Terminal 5A), which provides the central passenger processing capability, and the departure/arrival gates at satellite terminals (Terminals 5B and 5C). The station platforms are in a triple-platform configuration with a combination of both side and centre platforms; trains, therefore, arrive and depart on both sides of the platform. As the system is hosted in airspace tunnels, the interface between T5A and the satellite terminals is one of high-security importance. The role of the TTS is not only to convey passengers between terminals but to segregate secure and non-secure passengers. It is, therefore, necessary to have dedicated platforms for both departures and arrivals to ensure the integrity of the passenger security approvals process. This is achieved through the operation of selective door openings which open onto selected platforms dependant on the status of the passengers.

At present, the TTS primarily operates a multi-car train formation comprised of two four-car vehicles which travel along a simple route layout configuration in which the vehicles shuttle back and forth between T5A and T5C. The deployment of parallel guideways permits dual shuttle operations and counterflow by allowing two trains to operate on the adjacent single-lane guideways (Figure 1). The second single-lane guideway provides diversity and inherent availability throughout the operation of the system. However, despite the innate increase in availability as a result of the diverse second parallel guideway, such operations fail to achieve a full service in times of disruption. For instance, if one train becomes inoperable blocking a section of the guideway the other train can maintain a level of service; however, this will be at roughly half of that previously achievable which is often unacceptable during peak operations. When analysing the resilience of this configuration, one must first consider the ability of the system, humans included, to maintain full service and performance under fault conditions. As already discussed, on technical grounds this is very difficult, if not impossible. The second element of resilience is the ability of the system to fail in a controlled and safe manner by reducing the level of service. Operationally it is very easy to see how this can be achieved due to the diversity of the two guideways: simply a single shuttle service can remain operational whilst the second-lane guideway is cleared of the fault.

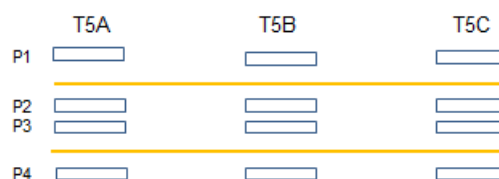


Figure 1: Shuttle Service

In light of the anticipated increase in demand, and approaching the maximum designed capacity of Heathrow T5, the TTS is already under pressure to provide the desired level of service during peak hours. Scenarios such as those described above have led to situations involving passengers being left behind on platforms and overcrowding on both trains and platforms, exacerbated by the limited resilience to maintain full system performance.

Furthermore, shuttle operations offer relatively low service frequency in comparison to more complex operations with more trains on the system at a given time. They also promote and respond poorly to waved passenger flow which regularly occurs in real rail services, especially those responding to the discrete arrivals and departures of aircraft. Fluctuations in the flow of passengers should be minimised where possible in favour of more continuous flow patterns as waves greatly affect train delays, increase passenger waiting time and result in potential delays.

2.1.1. The Operational Change

Simply put, when you want to move more people through an existing system that is already operating at its allowable capability, one must consider new ways of delivering the additional capacity. To address these issues, the airport is working on a project to increase the capacity of the TTS and improve the service levels by reducing wait times, platform congestion and improving operational resilience.

The proposed solution: an operational transformation to allow for the effective simultaneous running of up to four four-car vehicles, with smart selective platform entry at T5A and T5C dependant on the occupation status of the north and south platforms. This is made possible through two existing sets of intermediate crossovers between stations in close proximity to T5A and T5C. This and the bidirectional capability of the vehicles allows vehicles to travel in a loop by reversing direction and transversing between the two parallel guideways, as indicated in Figure 2 – normal operations of the loop are in an anticlockwise direction. Operating the system in this manner offers much greater route flexibility and enables temporary rerouting of vehicles around a problem section which would otherwise disrupt service. Added to this, with four four-car vehicles, rather than two four-car vehicles, in operation, the loop service increases total system capacity and reduces passenger waiting times and overcrowding. It also enables finer tuning of the service performance allowing it to respond to varying passenger demands. Further to this, the TTS has three maintenance roads beyond T5C (one on the north guideway and two on the south guideway). It is the project's intention to signal the north light road to facilitate the stabling of a hot-spare vehicle to improve contingency response and increase system availability for quick responses to changes in service demand or disruption. This and with the availability of a greater service frequency, the system can deliver a more continuous flow of passengers to each terminal; thus, reducing wave patterns leading to knock-on delays.

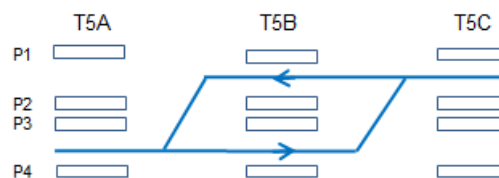


Figure 2: Loop Service

One must consider the increased reliance on the switches for loop operations and, therefore, the increased necessity for reliability and availability of the assets. Such requirements call to safeguard against system unavailability and plan for appropriate and informed maintenance routines which the project aims to realise through techniques such as remote condition monitoring.

3. THE OPERATIONAL RAILWAY MODEL

To satisfy the requirement for operational readiness, an innovative and novel approach was taken adumbrated by the request of a tangible railway model of the TTS at Heathrow T5.

3.1. Goals and Objectives

Having been requested, a tangible railway model was required to train operators, maintainers and terminal staff through the roleplay of complex procedures and to enable stakeholders unfamiliar with the railway to understand operational changes.

Key objectives being:

1. Develop a train service model to identify short and longer-term capacity increase options;
2. Enable early onboarding and engagement with project stakeholders and install a thinking environment culture to share knowledge and improved understanding through improved communications;
3. Provide an accurate automated physical model on which to train operational staff (signal operators, maintenance, terminal staff and emergency services) in the execution of different scenarios in response to varying railway system environments and situations, and test operational readiness;
4. Create a piece that engages with the wider Heathrow community that can be showcased at schools to promote Heathrow, the studying of Science, Technology, Engineering and Mathematics (STEM) subjects and to inspire the next generation of engineers.

3.2. The Railway Model Concept

To achieve the best compromise between aesthetics for stakeholder engagement, Objective 2, and visibility for training purposes, Objective 4, a flat-topped model was chosen over a more 3D “architectural” model. The model, as can be seen in Figure 3, was printed with railway infrastructure including platforms, ventilation and escalators.

The guideway was constructed using N scale track; N scale is a popular model railway scale of 1:160 and has a 9 mm gauge; this provided the greatest compromise between model length, availability of components and reliability.

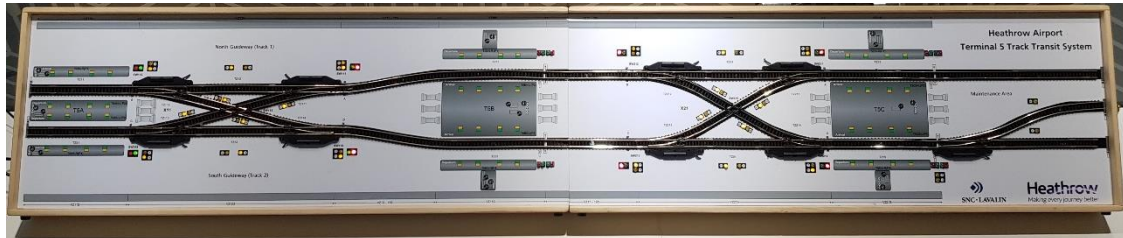


Figure 3: Tangible Railway Model

To add further realism to the system, the project designed and 3D-printed vehicle chassis to model the Bombardier Innovia APM 200 vehicles used on the TTS.



Figure 4: 3D-printed APM Vehicles

3.3. The Signalling System

Powering the model is fully-fledged signalling control system, designed using no more than a Raspberry Pi (credit-card-sized computer), a few Arduinos MEGAs (microcontrollers) and other readily available commercial off-the-shelf components. The architecture was designed to closely resemble that of the real system (Figure 5) and, where possible, use signalling principles inherited from the real railway.

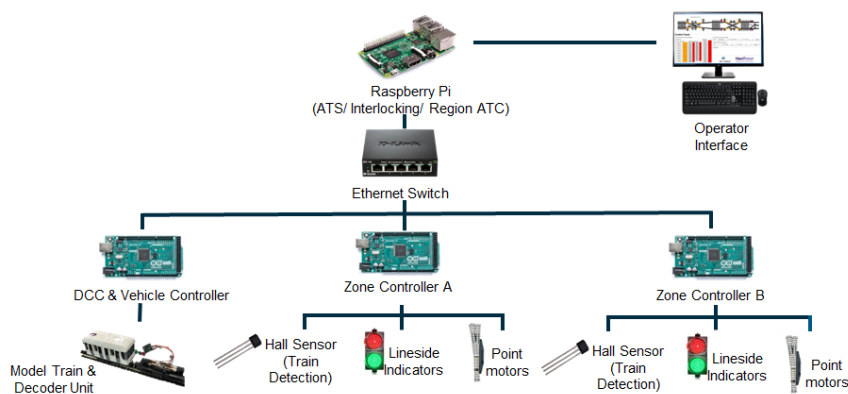


Figure 5: Control System Architecture

At the centre of the system is the Raspberry Pi, this contains the integrated Automatic Train Supervision (ATS) and Interlocking system to prevent conflicting routes through the safe issuing of movement authorities. This was achieved through:

1. Route setting - checking of route availability dependant on train location, locked routes status and the route being requested by the ATS;
2. Aspect and point control – no point lock or detection and no lamp proving provided;
3. Route release – following the completion of the set route.

The movement authority granted by the Interlocking includes the train identity, speed and direction information which is transmitted to a Vehicle Control Centre (VCC) – implemented on an Arduino MEGA. It is the role of the VCC to translate movement authority information into Digital Command Control (DCC), this is the standard for operating model railways digitally. DCC enables signals to be transmitted along the track to the individually addressable vehicles, this allows vehicles on the same electrical section of track to be independently controlled.

The responsibility for controlling the trackside assets falls to the two regional Zone Controllers, also implemented on Arduino MEGAs through use of their 54 digital input/output pins. As is the case with the real railway, trackside assets include switches, aspect signals, route secure indicators, platform door and flood gate barrier indicators, as well as a train detection and monitoring system. The train detection is implemented using Hall-Effect sensors which are interfaced to the Zone Controllers through use of the Arduino MEGA's interrupt pins; the Zone Controllers report train locations back to the interlocking and ATS systems. All of this is connected via an Ethernet backbone providing a path for the exchange of information between the different railway control systems.

The signal operator's interface is provided through a Visual Display Unit (VDU) which is also hosted on the Raspberry Pi and coded in Python in a Linux environment. The user interface informs operators of the status of the railway with information such as a full track plan, train locations, switch statuses and signal and route set indicators. Interpreting this information, the operator is able to request sub-routes and automated routines to control the operational railway. Added to the application is the ability to run it as a standalone simulation package to provide greater flexibility during demonstrations. The developed of this software simulation for hardware components of the model (interlocking and train movement) enabled the user interface development to continue in parallel with hardware development.

4. DISCUSSIONS

4.1. What I Learnt About the Big Railway

Within this section, I shall discuss the opportunity that building this railway model gave me to leave the chalk talk behind and develop my understanding of resilience and the big railway through invaluable hands-on experience.

4.1.1. Signalling the Railway

Let me start by immediately confessing: having no more than 2-years' experience within the railway signalling industry and having yet to complete my IRSE examinations, I cannot claim to have anywhere near the sufficient level of competency to be left to my own devices to create the control logic and signal a real railway. However, there can be no misunderstanding that the building of this railway model provided me with the "greenhousing" to give it a darn good go.

Prior to starting this project, my understanding consisted of no more than a couple of buzz words and measly descriptions of subsystems: 'hum yes, interlockings, they are SIL4 and stop trains from crashing into each other'. And yes, with even just a couple of months' experiences, this description could be easily improved upon. But how long would it take for the necessary opportunity to present itself for hands-on development experience of a safety-critical control system such as an interlocking product? Diminishing are the days of non-proprietary relay logic where through physical components and circuit diagrams one could learn the circuit functionality and signalling principles they uphold. Instead, more likely, now the core principles are hidden in millions of lines of code, under multiple levels of automated tooling and packaged within a single black box – or probably more accurately blue if you're from the UK. Without this hands-on experience, truly understanding the core principles behind such a system's functionality would be near impossible, if it isn't already difficult enough. In fact, when was the last time a new interlocking product, along with its associated logic and core principles, was developed and introduced within the UK? Quite probably as far back as the 1980s with the introduction of Solid State Interlocking (SSI) by British

Rail, GEC-General Signal and Westinghouse Signals Ltd. And how old would I have had to have accessed this opportunity? My guess is somewhere in my 70s.

All this is not to say the industry has been dominant in this time, quite the contrary. But the opportunity I was given to build a model railway and develop a signalling system from the foundations up gave me the direct exposure to the challenges encountered by my predecessors, an experience I might never have had otherwise had. I tackled countless challenges facing engineers who developed these signalling control systems 30 years ago: accounting for count discrepancies during train detection, determining when to release route locking, managing control system interfaces, route prioritisation and ensuring a spatial envelope around each train considering both converging and opposing train movements to name just a few.

4.1.2. Embedding Industry Innovation

Through creating this operation railway model, we re-expressed and demonstrated not only the challenge but the solution. The technique of re-expression such as this can effectively prevent assumption-making and promote the reaction to new stimuli. Through the creation of the tangible model we were able to provide a new and engaging stimulus for its audience, and from good stimulus comes audience creativity and future innovation. Whilst the stimulus does not give the answer and is not an idea in itself, the project set the precedence for creativity and provide fresh context and perspective. We embedded innovation from one organisation to another and effectively communicated complex operational changes to diverse audiences and removed incorrect assumptions. Such assumptions included the requirement to build additional infrastructure in the form of crossovers to achieve the operational upgrade, this was incorrect. The TTS was originally commissioned with all the necessary infrastructure; however, to this day HAL had only operated the system in a single and dual shuttle configuration.

Revolution is creativity at its most provocative. It is the deliberate challenging of the rules and assumptions that exist. Often our ability to form innovative ideas is limited by the rules that define our particular stream of thought and in the case of the railway, one of the things I learnt very quickly is that the railway has lots of them. Our minds continually judge ideas and stimuli to try and make them fit with what we know already. Revolution is all about deliberately breaking the rules and, therefore, the first step in revolutionary thinking is to be aware of the rules which already exist. As detailed in Section 4.1.1, the building of the operational railway model enabled me to build my understanding of signalling principles from first principles and hands-on experience. Providing future generations of signalling engineers this experience will enable them to better challenge the rules and assumptions of today as the industry evolves with the increasing capabilities of technology and changing customer demands.

4.1.3. The Value of Tangible Evidence During the Design Process

It is of significant importance that a correct and sufficient level of client information is granted during the early stages of any design process; from written documentation, computer modelling and tangible evidence, it is vital that such information is referenced to ensure the successful verification and validation of a project. The medium selection in which to adduce client information often passes by with little more than an obliging glance at the options available, if at all. Forms such as the well-known written document has great benefits as a permanent record to present ideas of complex matters; however, it lacks the flexibility to be dynamic to its audience; once written, the message is set with no direct relation established between the writer and the reader; its success as written communication relies heavily upon the correct pitching of the author to the intended audience and the competency of the reader. Computer modelling goes some way to addressing this, it enables interactions and simulations of real-life scenarios in a rapid and safe environment, granting its audience the capability to run scenarios tailored to their understanding. It can, however, lead to poor understanding of the physical system and unless one is already engaged with the investigations and possesses the required knowledge to understand the computer-simulated model it can create significant barriers to audience engagement.

The practice of providing tangibles in the form of system scaled models is an often underrepresented medium for the communication of information to clients. Physical models can have a significant impact and facilitate increased levels of engagement with those with less knowledge or those with less time. During the early stages of the Heathrow T5 TTS system capacity upgrades, a variety of communicating methods were permitted. The client recognised the value of diverse mediums of presenting design information, upon which informed decisions could be made using information that all parties could understand and validate.

The operational railway model provided tangible evidence to guide actions and decision-making activities for client leadership during option selection, system definition and application condition stages of the design process. It

imparted increased levels of confidence that the outcomes documented during project conception could be satisfied in the designs to follow, evidenced by its demonstration of improved system capacity and its contribution towards securing an £80m+ fleet upgrade. In organisations where a multimillion-pound operational simulator fails to satisfy the cost-benefit compromise, alternative, more tangible models can provide relatively much greater benefits against their associated cost.

4.2. Delivery of Resilience

System resilience is no foreign concept to the railway industry, but perhaps not as familiar as concepts such as reliability, availability or safety. Despite this, we must accept that whilst continued effort to ensure reliability and maintain high availability of railway services through robust design and contingency planning is important, disruptions happen and will undoubtedly continue to. We must also consider how organisations and clients can be better informed to make decisions on investment and deliver an improved operational railway bolstered by a collaborative resilience strategy.

Here is what I learnt about resilience over the course of this project:

4.2.1. Operational Resilience

To build an operationally resilient system one must install organisational competencies to control these operations. Through these competencies, the system (including operators) should be capable of both predicting and reacting to situations of difficulty to ensure an operational railway that provides continuous value to its users.

During any commissioning and handover stage, two very separate objectives must be satisfied. Firstly, it must be demonstrated that the system is ready to be put into service and secondly that the operators are ready to accept and operate the system. The latter especially necessitates the need for further installation of resilience to inform operation, maintenance and terminal staff, as well as wider stakeholders of the TTS who may be unfamiliar with railways and the changes to service patterns. Thus, Objective 3 of the operational railway model: provide an accurate automated physical model on which to train operational staff (signal operators, maintenance, terminal staff and emergency services) in the execution of different scenarios in response to varying railway system environments and situations and test operational readiness.

The operational change from shuttle operations to loop inherently improves the availability of the system and on the surface the resilience also; however, with the added system complexity the human element plays an ever more significant role in the system's ability to maintain a full service and fail in a controlled manner through service reduction.

Take the signal operators as an example, operations to date have only ever exposed them to simple single and dual shuttle operations. Whilst the technical aspects of the system lacked the availability and resilience to maintain full service under certain fault conditions, the operators could easily control a fault on the system and retain a level of service. With these operational upgrades to a loop service the system now has the potential availability and resilience to maintain a much high level of service during fault conditions; however, to realise these, operators require further training to adapt under stress and respond to arising fault conditions within a more complex system.

From this, the system may be ready to put into service; however, a rigorous training programme, during the early stages of development and throughout, is required to impart the competence and knowledge required in order to ensure that operators are ready to put the system into service, this is a major consideration when assessing operational readiness. Introducing new operations into a complex system emphasizes the need for the swift adoption of better practises to ensure operational readiness: to better measure operational preparedness of operations and maintenance staff to accept the new railway asset.

Through the development of tangible models such as described, operational readiness can be improved through the early engagement and training of staff. Training meetings utilising the railway model could provide knowledge of runtimes, dwell times, equipment response times, fleet availability, service patterns, route familiarisation and multi-agency emergency plans. Amongst more, the items listed will aid the delivery of a resilient system and contribute to achieving operational readiness through a scenario testing programme facilitated using a safe and engaging physical railway model environment.

4.2.2. Project Resilience

As necessary as operational resilience is, it constitutes just one part of the multi-variable systems engineering resilience equation which cannot be satisfied considering operational resilience alone. The technical exercise of creating resilience – most often attributed to the technology and operational resilience of the system but not solely – is lessened if one appreciates that resilience is increasingly about the better understanding of system vulnerabilities throughout the entire systems engineering process. It is, therefore, more an exercise in imparting knowledge by the collective and collaborative engagement of an organisation's employees and project stakeholders throughout the whole system lifecycle, not simply during the implementation and operations stages. For stakeholders with less technical knowledge or less time, it can be extremely difficult to generate the necessary engagement and knowledge sharing when complicated written documentation and "death by PowerPoint" are the prevalent means of communicating ideas. However, if realised at the design development stage and collaborative engagement for the project is achieved, resiliency can be effectively installed within not just the system but within the project tasked with delivering it. This increases the likelihood of project success despite the adversities brought about by inherent risk, uncertainty and complexity of multi-disciplinary projects.

In the case of the TTS capacity upgrade project, there were many key stakeholders within HAL whose expertise, understandably, do not completely align with the operations of the railway. Through presenting information in an easy to understand tangible such as the railway model, the project increased widespread internal dialogue and created networks for shared knowledge. At stakeholder engagement events, when demonstrating the model and the new operations of the system, the audience found themselves in an environment in which they could step back and watch; they granted themselves the time to remove internal urgency and freely think about the operational changes of the TTS and what was being presented to them. The audience took the time to relax and compose themselves bringing the balance and coherence required to form incisive questions and remove untrue assumptions that distorted their thinking. Deepening the relationships between HAL's employees and wider project stakeholders was considered as one of the primary successes of the operational railway model and was a "quick win" in much larger project to deliver an £80m+ fleet upgrade.

5. CONCLUSION

As the industry moves towards an ever more sophisticated future it brings with it an inherent increase in system complexity. This calls for more effective competency management of individuals, project teams and stakeholders to ensure the successful delivery and operation of a resilient system.

The Heathrow TTS railway model provided a novel method for communicating operational changes to operators and stakeholders in a way that was engaging and easy to understand. It enabled the building of competency in a safe hands-on environment through the development of my own knowledge of signalling principles and through the future scenarios training for operators and maintainers. Such activities will enable the increased availability of the loop service to be realised and aid operational readiness to allow HAL to operate a more resilient TTS service with even greater capacity.

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