Appendix G: Benefits of Automation

TII210 MetroLink Operations Advisor

The Benefits of Automation

Transport Infrastructure Ireland

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Introduction

The MetroLink project is being designed to make full use of automation in the operation of trains (fully unattended operation i.e. Grade of Automation Level 4), at the control centre and in the operation of stations. TII requested that the Operations Advisor produce a report that illustrates the benefits (compared to a conventional metro system) that this level of automation brings to the operation of the MetroLink system.

This paper explains the benefits of automation through:

- An illustration of a typical “day in the life” of an automated metro;
- An explanation of the benefits of automation;
- An explanation of the components of automation.

Contents

1. A Day in the Life of an Automated Metro

It's 3am in the MetroLink Service Control Centre. The Service Plan for the coming day (a Friday) is being automatically reviewed by the control centre computer systems. In the past, railways had timetables; even frequent, metro-style railways, which were so frequent that customers would simply arrive on the platform safe in the knowledge that they'd never have to wait more than a few minutes, had timetables. These timetables weren't for the benefit of the customers, but rather were to ensure that there was a driver available for every train, developed to fit into the starting and finishing times of shifts, meal breaks and breaks required for safety after a certain number of driving hours. With trains that no longer require a human driver on-board, these restrictions have disappeared and so has the need for a timetable. Instead, a service plan guarantees customers a minimum service level during operating hours that can flex to manage the actual demand experienced each day. Today, there is a rugby match at the Aviva stadium; Ireland are playing Wales and a crowd of 50,000 is expected. Kick-off is at 7pm, and based on previous customer flow measurements, the control centre systems are able to modify the service plan, to ensure adequate capacity will be provided between the airport, Dublin City Centre and connections to the rugby ground at the southern end of the MetroLink route.

At 05:00 the system starts up; all maintenance staff have reported themselves clear of the track and that they have left their work sites safe for trains to operate so the traction power can be switched on. The automated systems perform their integrity and safety checks, and report all systems are healthy and ready for service. The intelligent CCTV system that covers every part of the track performs an automated check that the track is free from obstructions. Trains within the depot and at sidings at the south end of the line are remotely awoken and perform an automated self-test. As the trains each report themselves healthy, the control centre system allocates them to timed departures to start the day's service plan. As it is a cold morning, each train has automatically switched on its saloon heating in advance, ready to welcome the first passengers with a comfortable journey. The Customer Service Agents (CSAs) who have just booked on for their shift are directed to board the trains before they leave the depot. As well as being an efficient way to spread CSAs around the system, ready to interact with customers, the CSAs take this opportunity to perform a further inspection of the track and tunnels to identify anything out of the ordinary that might require further investigation. The control centre system then instructs further trains to join the service, calculating when they should leave the depot to avoid conflicting with the trains already in operation and creating an even headway service for passengers.

The automated systems are constantly on the watch, monitoring system performance and passenger trends, and frequently making almost imperceptible changes to optimise system performance. By 07:30, the control centre systems notice a trend in the open data, reported from sensors on the road network, and MetroLink's own sensors on the vehicle entrance to Estuary Park and Ride, which is filling up more quickly than usual; possibly people want to start work earlier and finish work earlier so they can meet friends before the rugby match this evening. The automated systems rapidly plan and action their service adjustments to match this earlier peak. A tighter headway will be needed to maintain passenger comfort levels, and an additional train is released into service earlier than previously planned.

At 08.30, the control centre staff receive a call from a customer help point on a southbound train travelling towards O'Connell Street station; a young lady has fainted on the train. The control room assistant speaks directly with the alerting passenger and assess the situation via the on-train CCTV. The nearest CSA is immediately located, through the tracking technology on their smart device, on a northbound train entering O'Connell Street station. They are immediately sent a message to disembark and cross to the opposite platform, so they are ready and waiting on the southbound platform when the incident train arrives. Meanwhile the control room assistant requests an ambulance to the station through a hotline to the emergency services control centre. The control room assistant instructs the control system to hold the southbound train at O'Connell Street station whilst the CSA investigates. The CSA's first aid training is supplemented by real-time advice from paramedic-trained support staff who can see whatever the CSA can see through the CSA's head-worn camera. The fainted lady comes around and appears unharmed and is able to stand and walk. The CSA assists the lady onto the platform and helps her to a seat in a private station area to rest and await the paramedics. All told, this incident has resulted in a 4-minute delay to the incident train, and also affected several trains behind, but the control centre systems started mitigating this delay as soon as the train with the casualty was held; they identified, evaluated and proposed a range of plans to the control room supervisor based upon the location and estimated duration of this type of incident. The supervisor selected a plan that reversed one train behind the incident train, from southbound to northbound at the Glasnevin crossover to ease congestion and launched a spare train northbound from Charlemont sidings to fill the gap in service in front on the incident train. As the trains delayed by the incident travel southbound to Charlemont, one of them is taken out of service to replace the spare train, ready for any further disruption. Within ten minutes, the service is back to normal, and customers at the north end of the line remain unaware of any prior disruption. The control centre staff take a moment to reflect on how such an incident would have played out prior to Communications Based Train Control (CBTC) and manually driven trains. Using the old technology with fixed block signalling, the service disruption would have been seen for the rest of the morning peak, because of the need to transport spare drivers to the right places, and to make gradual manual adjustments to uneven headways. Instead, the fully automated system takes everything in its stride with the minimum of fuss.

At 13:15, an alarm on the Remote Condition Monitoring (RCM) system at the control centre indicates that a crucial set of points at the turnback sidings beyond Estuary Park and Ride station has started to operate more slowly than usual. The points are still working, but the automated system is always on the lookout for early signs of failure, so that issues can be fixed before a failure occurs. The control room supervisor immediately responds by accepting the automated system recommendation to minimise train movements over that set of points. The data generated by the RCM is automatically routed to the maintenance technician at the depot, who reviews the data and rapidly confirms that although the points are operating more slowly than usual, they are still safe and reliable and can stay in commission, but will be prioritised for maintenance that night.

At 15:00, the control centre systems determine from an open data feed that a large number of flights are being delayed due to fog over the Irish Sea; this means that a lot of the Welsh rugby fans will be delayed, changing the previously planned MetroLink service patterns. Now, there will be a later but more intense peak of traffic between the airport and the rugby ground. To match this demand, the control room supervisor agrees with the maintenance staff that vehicles currently scheduled for maintenance can be returned to service over the next hour, enabling an increase in capacity. Between 16:00 and 16:30, the additional trains are injected into the service from Dardistown Depot. The control centre systems have calculated how these can join the train service without causing disruption. By 16:30, the train service operating is more intense than MetroLink’s usual peak service, making use of the additional capacity that was built into the system ready for future increases in customer demand.

By 17:00, rugby fans are arriving in droves. For most of them it is the first time that they have travelled on MetroLink, but they are able to find their way around due to the electronic wayfinding signage, which is also displaying messages welcoming the Welsh fans. This signage begins within the airport itself, ensuring that visitors are aware that there is a faster and more reliable route to the city centre than joining the long queues for buses and taxis. The fans are in good spirits, but as they board the trains they tend to hold the doors for their friends, causing very slight delays to each train. Fortunately, the Automatic Train Regulation subsystem can manage this by constantly calculating and implementing imperceptibly small changes to the train departure times and train speed profile between stations; this keeps the train service regularly spaced and prevents small perturbations leading to larger delays. The flexibility of CSA deployment, afforded by automating the trains and stations, means that they can be concentrated at the Airport station, where the Welsh fans are getting onto MetroLink, and at St. Stephen’s Green and Charlemont stations, where all fans are arriving close to the stadium.

When the rugby kicks off at 19:00, everyone has got to the ground in time. While the rugby fans across both nations follow a closely-fought game, the MetroLink control system is also following the game through open data – this is just as well, as a rare tied score pushes the game into extra time, delaying the exit crowd by half an hour, and resulting in another update to the service plan. With the Irish team eventually emerging victorious, the fans start to pour out of the stadium and back to Charlemont station. Again, MetroLink CSAs are ready at the station to direct and assist the fans, and the customer information systems display essential wayfinding information and real-time next train and journey-time data. The service plan has ensured that the sidings beyond Charlemont station are full of trains before the fans arrive, so that a very intense northbound service can be run by combining these spare trains with the trains reversing at the station. The train loadings are high as fans spill out onto the platforms, and whilst the regular MetroLink users are aware of the station signage indicating individual car loadings on the next arriving train, the visiting fans have to be encouraged by the CSAs to move down the platform to ensure everyone can board.

As the evening draws on, the fans celebrate and commiserate throughout the centre of Dublin. At 22:30, a report is received that someone has been rather ill over part of a northbound train. The control room supervisor is able to observe the situation via the on-board CCTV, and immediately instructs the control system to undertake a train changeover. As the train reaches Estuary Park and Ride station, it is taken out of service for cleaning and a spare train from the sidings replaces it; the issue has been swiftly resolved with no service impact.

As the returning revellers reach their destination MetroLink stations, they are pleased to see taxis waiting outside. This is more than good fortune; a simple app powered by the MetroLink open data feed has helped local taxi businesses position their vehicles according to the number of customers forecast to be exiting at each station. This is good business for the taxi company and a happy outcome for the fans since it has just started to rain.

By 00:45, the service has been gradually reduced and closed down as planned, and the stations are secured remotely after CCTV has been used to check that they are clear of customers. While cleaners start to clean the stations, maintenance on the wayside infrastructure can begin. Top priority is given to investigating the points at Estuary sidings that were reported as operating slowly. Using the diagnostic process shown on his smart device, the maintenance technician quickly identifies that the issue is a worn motor brush, and the entire motor module is quickly replaced so that the brush replacement and testing can happen in MetroLink’s workshops. It is estimated that the point motor would have carried on operating for at least another week before it would have caused a failure, but through the Remote Condition Monitoring system, that future point failure will never be realised. The amount of wear on the motor brush, and the number of point operations since that brush was last replaced, are logged in the asset management system to improve the accuracy of the predictive maintenance regime.

Meanwhile, the control centre systems have recorded the customer flows reported by station and train-based sensors, and the open data feeds showing air travel, road usage, the progress of the rugby game, and even the weather through the day, and have processed this to improve the prediction quality of demand patterns for future events.

The MetroLink system is prepped and ready for another unique day that will no doubt present the automated control systems with a new set of challenges to test their never-ending patience.

2. Real World Benefits of Automated Metros

Part 1 of this paper, whilst presenting a light-hearted look at the day in the life of an automated metro system like MetroLink, does serve to illustrate the many benefits of a fully automated and driverless system. Many of these benefits are achieved by utilising autonomous systems and computer power to concentrate on what these systems are good at – fast, reliable, consistent and untiring reaction to monotonous and routine events that require a calculated and deterministic response. This technology relieves humans to concentrate upon the things that we are good at – dealing with people and making decisions that require more than a comparison of calculated results.

The benefits of a fully automated railway include increased capacity, reduced costs, better environmental performance and increased customer and employee satisfaction. This section analyses those benefits from a variety of viewpoints, and briefly looks at the technologies that make this happen.

Some of the key benefits of an automated metro system are shown in Figure 1 and are discussed in the following sections:

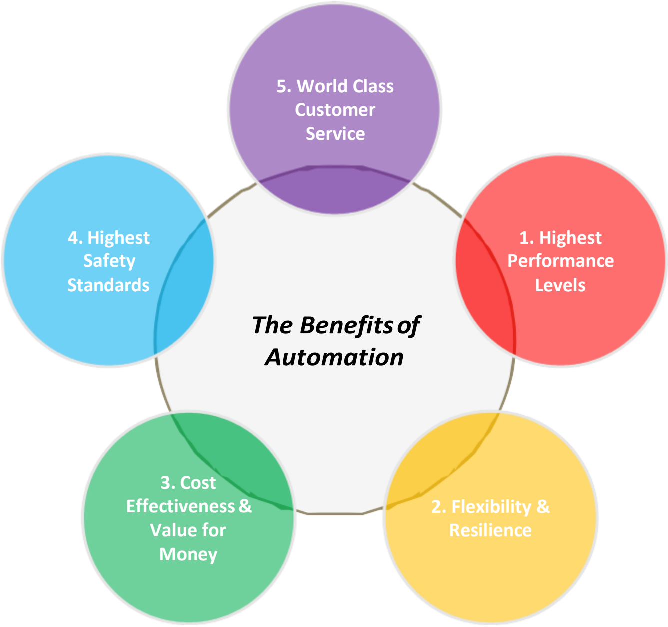

Figure 1: The Benefits of Automation

2.1. Highest Performance Levels

Computers are better at driving trains than humans. This is because automated systems are always attentive, do not take breaks, can manage huge amounts of information, and can react immediately with incremental small (or large) changes to ensure performance is always optimised. This reality has led to increasing levels of automation being introduced as computing has become more capable.

The control of railway systems has evolved greatly over the last two centuries. Railway control serves two purposes; firstly, to ensure the safety of trains on the network, and secondly, to enable efficient train movements and operations. In the early days of railways, train control was based upon little more than working to a timetable. Quickly the concept of visual signals controlling fixed blocks of line were introduced. Signalling systems evolved to become more capable, but still leaving the control of the train entirely to the traincrew. Next, a greater degree of integration allowed control systems to take over responsibility for managing key train functions. Lastly, train control systems evolved to enable full control of all train driving functions, with or without crew members present. The different stages of train control functionality are commonly termed Grades of Automation (GoA) and are described on a 5-point scale as shown in Figure 2.

	GoA0	GoA1	GoA2	GoA3	GoA4
Description	*Line of sight; no ATP*	*Manual driving with ATP*	*ATO; driver in the cab*	*ATO with a train attendant*	*ATO with no on-board staff*
Starting Train	Driver	Driver	Automated	Automated	Automated
Stopping Train	Driver	Driver	Automated	Automated	Automated
Door Operation	Driver	Driver	Driver	Train attendant	Automated
Degraded mode operation	Driver	Driver	Driver	Train attendant	Automated
Examples	*Trams*	*Mainline trains*	*LU Victoria line*	*Docklands Light Railway*	*Airport People Movers, Paris Lines 1/4/14, Barcelona Lines 9/10*

Figure 2: Simplified Grades of Automation

Achieving higher Grades of Automation requires a holistic approach, with the train control system supported by other systems in the wider railway environment (including the provision of walking routes and lineside fencing) and appropriate operational procedures.

The benefits of moving from each Grade of Automation to the following Grade of Automation are described in Figure 3.

Increment	Benefits
GoA 0➔1	Safety – protection from human error Capacity – signalling allows closer running
GoA 1➔2	Capacity – more consistent operation enables denser sustainable service Journey time – optimised driving at line speed reduces runtimes Efficiency – power/wear-efficient operation, coasting, eco-driving, comfort
GoA 2➔3	Staff visibility – train staff now visible to passengers to assist, reassure & check tickets Staff reduction – no need for separate revenue control team Capacity – no need for dedicated driving cabs Simpler termini – fewer berths required to reverse a given service level
GoA 3➔4	Flexibility – no need for a timetable – run a service plan (variable in real time) instead Resilience – recover service without worrying about staff location or driving hours Staff reduction – integrate train and station teams Reduced wayside staff facilities (mess rooms, toilets etc)

Figure 3: Incremental benefits of Increasing Grades of Automation

By providing signalling and train protection (GoA0→1), the railway becomes safer through the elimination of human error. The use of technology to communicate movement authorities and set routes also adds significant capacity to the railway.

By providing automated train operation with a driver still in the cab (GoA1→2), the automated control of train speed enables each train to follow the optimum speed profile more accurately than a human driver would achieve, thus reducing journey time, ensuring consistent operation, which avoids service instability, and allowing the most efficient speed profile to be selected to maximise energy efficiency.

If the onboard member of staff is enabled to move from the cab (GoA2→3), they are more visible to customers in the saloon, and can provide assistance and reassurance, while checking tickets. This means that there is no longer the need to employ a separate revenue protection team, leading to staff cost savings. As there is no longer a requirement for a dedicated cab, this space can be reused for additional customer seating/standing, adding approximately 5-10% capacity to each train; dependent upon the train configuration. Should the train need to be driven manually (e.g. due to a system failure) this can be achieved using a driving panel at the front of the train. As the driver need no longer “change ends” to be at the front of the train in the time between moving into a reversing berth and moving out in the opposite direction, the train can reverse more quickly, and this leads to a potential reduction in the number of reversing berths required to reverse a given service frequency at each terminus.

If the staff member needs to no longer be on the train (GoA3→4), then it is possible to move from a timetable-driven system to a service demand-driven system, as once the system is at a turn-up-and-go frequency from the customer's point of view (typically 6 trains per hour (tph) or more) the primary benefit of the timetable is for crew management. Once the timetable has been dispensed with, service regulation is simpler; it is possible to optimise customer service without having to consider driving hours or overtime management; and it becomes possible to vary the service level to respond to real-time demand. It is possible to use data sources including traffic flow detectors on the approach to the Estuary Park and Ride; data on airport arrivals/departures; data on delays on the wider road network; data on planned sporting and cultural events; and even weather forecasts to predict the customer flow every day in advance, and implement a service to meet that demand, generating the greatest benefits and the lowest operating cost.

To operate the 30tph service that Dublin will need, automatic operation (GoA2+) is required. With good discipline, manual driving can be used up to 28tph, but beyond that, delays in response times and lack of driving consistency will cause service instability and chronic delays. The reduction in variability from automatic operation allows a stable service to operate with a reduced recovery margin (the difference between the theoretical and practical capacity) enabling a more intensive customer service to operate on the same underlying signalling capacity.

GoA3 and GoA4 increase capacity further by reducing the time taken to reverse trains in a siding as there is no longer a requirement for a human driver to walk from one end of the train to the other for it to change direction. This means that an intensive service can be reversed off fewer sidings, reducing the cost and disruption of operating at high service frequencies, while enhancing reliability (fewer point machines and a less complex track layout) and sustainability (less embodied carbon and smaller construction sites).

GoA4 means that no additional platforms are required at termini stations to allow crew changes, comfort breaks and cope with the variability that humans introduce to a system (staff being 30s late for a shift can have significant consequences on the capacity of a high intensity service). A GoA4 system does not require these extra platforms as there are no on-train staff to consider.

2.2. Flexibility & Resilience

Fully automated driving enables MetroLink to operate a demand-based rather than a timetable-based service (as traincrew management is no longer a constraint) and enables service levels to be dynamically adjusted to meet the real-time (or predicted) demand.

While railways are often considered to be a system composed of many subsystems, they are themselves subsystems of the bustling cities that they serve. They should be able to interface with other subsystems of that city in real-time to deliver the best possible customer experience.

Many other parts of the city generate real-time data that indicates how the customer demand might change. These include:

- Airports, which generate real-time data on flight arrivals and departures, including delays;
- Road systems, which generate real-time information of traffic flow and incidents;
- Sports facilities, which generate real-time data on upcoming events, anticipated attendances and the progress of those events;
- Weather forecasts, which are a good indication of the proportion of people who will choose to walk, drive or take the train;
- Other transport modes (e.g. Irish Rail) that will deliver information on train arrival/departure times, delays and incidents.

Increasingly, these data sources are "open data" – readily available real-time data in a standardised format. Information from publicly available websites can be used, and private data feeds can be agreed with other parties.

MetroLink will also generate its own data; for example, traffic flow measurement on the vehicle entrance to Estuary Park and Ride station will give a good indication of the customer demand that will appear on the platform in 5-10 minutes' time, once the arriving customers have parked their vehicles and walked to the platform. Customer counting technology can also be integrated to count the number of customers entering a station from each entrance, and to monitor movements towards North & South platforms.

This wealth of information allows the control system to build a model of customer demand tailored to every individual day, and to keep refining it throughout the day in response to real-time changes in inputs. It will be used to develop and implement the most appropriate service plan, considering the need to maintain the trains and wayside equipment. Fully automated train operation means that this can happen without the need to review staff availability or duty hours.

With this technology, not only can unusual crowds for sporting events be catered for efficiently, without the cost and energy wastage of over-provision, but if that event runs into extra time or there is external disruption, it allows the plan to evolve and be re-optimised in real-time. It moves from a railway that can handle pre-planned events to a railway that is pre-enabled to handle real-time scenarios.

With every day of service, the system can review the actual customer demand against the predicted customer demand and use machine-learning techniques to refine its models so that the next prediction will be more accurate. This enables this constant optimisation to occur with minimal human effort.

2.3. Cost Effectiveness & Value for Money

Automated systems bring several advantages that contribute to Cost Effectiveness & Value for Money:

- More capacity & performance from fewer assets;
- Reduced staff costs;
- Ease of change & upgrade.

2.3.1. More Capacity & Performance from Fewer Assets

Automation enables precise optimisation of railway operations, whether in the operation of an individual train, the optimisation of a train service, or the ability to minimise the amount of infrastructure to meet a required level of capacity.

Automatic driving will make most efficient use of coasting while maintaining journey time and capacity requirements, and therefore reduce the use of traction power. Automated driving can also co-ordinate train movements to make the most effective use of traction power savings through regenerative braking. The smoother operation and reduced use of braking will reduce wear on system components, reducing the embodied carbon in replacement parts and maintenance activities.

As fully automated trains do not require human drivers, train moves to locate drivers (e.g. bringing them back to a depot for the end of a shift or a meal relief) are eliminated, and the ability to change the service pattern to reflect actual demand eliminates energy wastage due to over-provision of train services. Facilities for drivers at stations can be reduced, removing the embodied carbon associated with their construction and the ongoing energy use of associated station facilities (lighting, heating, kettles etc.).

Station automation promotes energy efficiency through the switching of station facilities (e.g. lighting, heating, escalators) in response to measured light levels, temperatures and customer demand, rather than to a fixed schedule, or when a station supervisor notices that action is required. Stations and the depot may include microgeneration (solar and wind power) where possible, and this will be monitored by the same automation system to ensure peak performance is maintained, and to synchronise the use of energy while it is most abundant.

MetroLink forms only one part of many customer journeys but is designed to optimise sustainability for the entire journey. For example, the installation of electric car charging facilities within the carpark at Estuary Park and Ride and open data that enables taxi services to position vehicles proactively at stations, will accelerate the adoption of more sustainable modes of transport for onward journeys. The provision of real-time information for modes including mainline, LUAS and bus services within MetroLink premises, will assist customers to make informed decisions about how to continue their journey after alighting from MetroLink services. Where there is disruption on these other transport modes, announcements will be made on board MetroLink trains so customers can make alternative travelling arrangements, minimising their own disruption while avoiding further compounding of the disruption on the other transport modes.

By running a high-quality, reliable metro service, MetroLink will attract customers away from other more polluting forms of transport. Automation is key to delivering a service quality and capacity that will attract customers from other modes of transport.

2.3.1.1. Automated Station Systems

MetroLink stations will be fully automated and require no on-site staff in normal operation, although roving CSAs will be available to assist customers where required and to resolve any issues.

The SCADA (Supervisory Control and Data Acquisition) systems will monitor all station systems for any faults or alarms while controlling lighting, ventilation and lift/escalator systems to maximise energy efficiency. Stations facilities will include:

- Full CCTV coverage monitored from the control centre;
- Help point systems allowing immediate assistance from staff at the control centre;
- Real-time customer information though platform and ticket-hall displays and the public address (PA) systems.

An advantage of this remote-control philosophy is that if a station needs to be evacuated in an emergency, the same level of station control can be maintained without leaving a member of staff in an unsafe situation in a station control room.

2.3.1.2. Automated Control Systems

The MetroLink control centre will have full visibility of the MetroLink operation, covering the train service, station services, maintenance activities and utilities. The control centre technologies will include:

- Automatic Train Supervision to monitor and control train movements, including operating the service plan in real-time;
- Automatic Service Planning to analyse real-time data sources and propose the most efficient service plan to meet the projected demand;
- Automatic Train Regulation to automatically identify small service perturbations and make imperceptible changes to train departure time and speed profiles to maintain a stable service;
- Station SCADA to monitor and control the station environment, including customer information systems, CCTV, help points, lighting, heating/ventilation, fire systems, and lifts/escalators;
- Tunnel SCADA to monitor and control the tunnel environment including trackside CCTV, fire detection, ventilation, lighting, access control systems, intrusion detection systems and pumps;
- Decision Support to support control centre staff in identifying, developing and deploying the most appropriate response to operational incidents. This includes communicating with other members of MetroLink staff (e.g. CSAs) via their smart devices;
- Video Analytics to constantly analyse all incoming video feeds and identify scenarios of interest, including unattended items, loitering, movements in non-customer areas (including the trackside environment) and overcrowding. This will ensure more effective supervision of activities on a reduced number of screens compared to traditional control facilities that require vast banks of screens.

These technologies will all be holistically presented to the control centre staff through a unified interface that maximises cross-system automation. This will reduce the operator workload, allowing the human controlling these systems to think strategically and communicate with wider stakeholders.

2.3.1.3. Automated Asset Management

MetroLink will be provided with a modern, intelligent asset management system to record the “single source of truth” configuration and history of each asset, to manage reported faults, and to schedule maintenance (based on time, usage and reported condition) to maximise reliability but minimise costs.

Remote condition monitoring systems on both rolling stock and wayside assets will communicate data back to a data warehouse; this will be analysed in real time to give the earliest possibly indication of failing assets (in some cases recommending and prioritising an operational or maintenance intervention) and building MetroLink's knowledge of long-term asset performance trends, so that future investments may be targeted efficiently to eliminate sources of unreliability.

The system will also enable the digital storage of asset data (including circuit diagrams, manuals etc.) to ensure fully up-to-date information is available wherever it is required, including at the trackside through first-line maintenance technicians' smart devices.

This system will also be used for scheduling track access so that the most efficient use can be made of the time during which customer services are not running.

The asset management system will hold sufficient data to enable Building Information Management (BIM) functionality, with the ability to export data to create a "digital twin" of the railway that shall enable simulations of both railway operations (e.g. to plan future services or explore the benefits of proposed enhancements) and to plan (and communicate the plan) for maintenance activities, such as track replacement, where a sequence of activities must occur in a compressed timescale and a constrained physical environment.

Both operational costs and reliability will be optimised through a modern approach to asset management and maintenance:

- Remote condition monitoring will identify failures before they impact service, providing rich diagnostic information in the event of an unexpected fault. This enables a proactive rather than reactive approach to maintenance, reducing repeat failures and the costs associated with replacing components unnecessarily due to misdiagnosis.
- The provision of backup ("redundant") systems enables the service to continue in the event of a failure and for that failure to be investigated and rectified within a longer timescale than would traditionally have been the case. As well as reducing customer disruption, this reduces the need for on-call maintenance technicians throughout the operating day, as failure resolution can now be time-shifted to when technicians are available.
- A new approach can be taken to scheduling preventative maintenance, reducing the costs from over-maintaining. Some assets will retain time-based maintenance to comply with legislation whereas others will be maintained based upon measured usage or condition. Some assets may even be allowed to run to failure on the basis that there is a backup system that will ensure that this does not impact railway operations.
- A modern asset management system will be deployed so that the asset history is fully known, preventative and reactive maintenance activities are captured accurately and all relevant information (manuals, diagrams, fault history) is in the palm of the front-line maintenance technician, who is also supported by a colleague through their smart device (camera/earpiece) when required.
- The use of multiskilled operations and maintenance staff enhances efficiency and reduces the time taken to get the right skills to the right location; the telemetry enables staff to undertake a broader range of activities, as colleagues with specialist knowledge will be available to support them as they carry out activities.
- The ability of the CBTC to support bidirectional working will allow services to continue around maintenance and fault resolution where appropriate; this reduces the need for system closures and hence customer disruption. This can also reduce the costs of some maintenance activities as it enlarges the available working window every night, improving productivity. Control centre systems will allow for this type of work to be planned around customer demand, implemented safely, and for changes to the platforms at which trains will call to be communicated to customers via station audio-visual information systems.

2.3.2. Reduced Staff Costs

The impact of increasing levels of automation on staff headcount is illustrated in the Figure 4:

	GoA2	GoA3	GoA4
Drivers / train attendants	One per train	One per train	None required; replaced by roaming CSAs
Spare drivers / train attendants	Yes Physical Needs Relief (PNR) & spare	Yes PNR & spare	No Run unmanned trains
Revenue control staff	Yes	No Use train attendants	No Use train attendants
Roving station assistants	Yes	Yes	No Use train attendants
Anticipated headcount saving (vs GoA2 on roles stated above)	**-**	**15-20%**	**35-45%**

Figure 4: Indicative headcount savings through increasing Grades of Automation

Figure 4 demonstrates how GoA4 offers an indicative 35-45% saving in staff headcount when compared against an equivalent GoA2 operation; noting that staffing costs are one of the greatest components of operational expenditure for a railway. This is achieved while improving customer service compared to that which would be delivered on a traditional railway.

Operational costs are also reduced due to the automated control of driving; this reduces the rate of wear on both the train (e.g. reducing the frequency at which brake pads need to be replaced) and the infrastructure (e.g. reducing rail wear.) It also reduces the railway's energy consumption through the intelligent use of coasting rather than motoring towards a point where a heavy brake application will be required.

2.3.3. Ease of Change & Upgrade

Railway infrastructure has a very long design life, and to ensure that the full life is achieved, it must stay maintainable and upgradable as the needs of the railway evolve. The use of digital technologies such as CBTC enable changes to be made in software as they are less dependent upon hard-wired physical assets such as signal heads and track circuits. By choosing technologies carefully (including commercial off-the-shelf technologies) and defining clear interfaces between subsystems, the future cost and disruption associated with the upgrade of these systems can be minimised.

2.4. The Highest Safety Standards

Public mass transit systems absolutely must deliver safe transport environments for their users and staff. Witness the media and public outcry when any public transport system fails and causes injuries. The opportunity for failures must be designed out, and significant investments are made in eradicating safety risks that arise either through system design or operational procedure.

Fortunately, rail accidents are vanishingly rare, and when they do occur rigorous investigations are mounted. In nearly all cases, accidents arise because humans are unpredictable, have lapses of concentration, may be slow to act, get tired, distressed or distracted, and make mistakes. These human shortcomings do not apply to computer-based automated systems, which characteristically excel at dealing almost instantaneously with monotonous tasks in a repetitive, predictable and unwavering way. Automated systems do not arrive late for work, do not stop to answer the phone, do not need toilet breaks, and never fall asleep on the job.

However, whilst great advances are constantly being made with automated systems, they continue to lack several critical human qualities, meaning that humans can be expected to remain a critical component of the overall safety system. These unique human qualities include situational awareness, perception, making decisions using incomplete and unexpected information, self-learning, and intuition. The key benefit of automated systems is that automated systems can be left to reliably make routine and deterministic control decisions, avoiding human error making, and freeing humans up to deal with the unexpected and non-routine. By making this resource allocation, safety can be significantly improved.

2.4.1. Normal Operation

During normal operation, automated systems will be undertaking the basic functions of routing trains and supervising the service to identify the first signs of an anomaly; these systems can do this faster and with a lower error rate than a human operator, and without the risk of distraction. This significantly reduces the risk of incidents being initiated by staff error, and gives the control centre staff the ability to take a wider view of the service and the infrastructure, potentially identifying issues that an automated system would be less likely to detect, and being able to intervene before they threaten the safety of the railway.

Modern automated systems allow a degree of data and control interoperability as a result of the speed and processing power of automated systems that has been impossible in the past using manual systems. Automated systems can monitor a much wider range and quantity of inputs, make comparisons with significant amounts of historical data, and identify input sensor trends that a human may miss, resulting in failures being predicted long before a device fails potentially causing a safety hazard.

The greater flexibility of a fully automated system (e.g. allowing trains to quickly reverse away from an incident without waiting for a human driver to “change ends” and use a manual process to gain authority to drive in a direction that traditional signalling would not allow) brings additional safety benefits.

2.4.2. Degraded Mode Operation

System events that occur outside of MetroLink control and system failures may result in the need to operate in a degraded mode. Examples of external events may include localised power supply outages, critical passenger illness, public demonstrations and the like. System failures may include localised mechanical or electrical breakdowns. Both classes of issue result in a situation of asset denial. When asset denial occurs, automated systems offer multiple safety benefits.

Firstly, the computational power of automated systems means that the feasibility and expected performance of alternative degraded mode strategies can rapidly be assessed and presented to a human operator for informed selection. Automated systems can make these assessments very quickly and with outcome certainty that a human operator could never replicate.

Secondly, automated systems allow transition to a degraded mode to occur much more quickly and smoothly than a manual controlled system would allow. Automated systems enable a much more controlled changeover of service patterns, whilst the lack of train drivers removes entirely the time-consuming issue of driver location and reassignment (which introduces additional safety risks).

The automated control systems can enable the control centre staff to focus on understanding the nature of an incident, setting the strategy to manage that incident, and communicating with customers and external agencies, rather than having to concentrate on authorising individual train movements, as is the case with less automated railways.

2.4.3. Emergency Situations

By their very nature, emergency situations are individually unexpected and unpredictable – otherwise they would not occur. An emergency situation represents a risk to human safety or asset condition and must be detected and dealt with as quickly and effectively as possible, whilst avoiding the unnecessary injection of new hazards and risks. Examples may include smoke and fire, accidents, or potential accidents such as the detection of a trespasser. Dealing with an emergency situation may allow a degraded mode of operation to be put in place, either as a form of emergency risk mitigation, or following resolution of an emergency situation because of asset denial. Often emergency situations will result in temporary full or partial system closure and controlled evacuation.

Automated systems incorporating multiple sensors can detect and react to a wide range of emergency situations much faster and more reliably than a human operator manually monitoring sensor outputs and displays. This reliability and speed of response represents a major increase in safety performance.

In addition, automated systems can action remedial measures faster and with more accuracy than human operators can achieve. In the case of smoke and fire, smoke extraction fans can be automatically turned on to draw smoke away from passengers. The correct automated messages and signage can be initiated and synchronised with the emergency mitigation measures put in place, and passenger communications can be localised at individual stations; an unachievable workload for human operatives.

The control systems will automatically identify where trains need to be held in stations or reversed away from an incident; appropriate audio-visual customer information will automatically be sent to each train to ensure that customers are aware of the actions being taken; this is essential to avoid confusion resulting from unexpected movements, and the potential operation of customer emergency alarms.

Remote supervision can safely be used to evacuate a train stranded between stations. After ensuring that train movements in the area have been inhibited and power has been turned off, the detrainment ramp at the appropriate end of the train can be remotely deployed to allow customers to access the track slab, and on-train audio-visual announcements will guide customers to use the ramp. The progress of customers can be monitored using both the on-train and wayside CCTV, and specific advice given to any customers experiencing difficulties.

To co-ordinate responses to emergency conditions, a highly resilient communications network is required; this ensures that the control centre can continue to view on-train CCTV and disseminate customer information, even after a significant system failure or infrastructure damage. This technology is becoming standard for new high-capacity railways, particularly through tunnels, and therefore the additional resilience measures required to make it fit for a fully automated railway represent a minor additional cost.

All operational staff (including CSAs, maintenance technicians and their supervisors) will be trained in manual driving. In the case of failure of automated driving systems, operational staff will either already be on-board the train or can rapidly make their way from an adjacent station and will manually drive the train to the nearest station to allow customers to alight.

The constant oversight of trains and wayside infrastructure by remote condition monitoring systems ensures that conditions that could lead to an unsafe situation are detected at the earliest possible opportunity and investigated; this means that the majority of unsafe situations or reliability issues are corrected prior to customers being exposed to risk. In many cases there are redundant backup systems so if there is any concern about the integrity of a primary system, the backup system can be deployed with no loss of service, allowing the primary system to be investigated.

2.5. World Class Customer Experience

A world class customer experience is founded upon multiple pillars that underpin the transport service. To be counted as world class, each of these customer service expectations must be met:

- Smooth, efficient & trouble-free journeys;
- Comprehensive information & communications;
- Complete journey connectivity;
- Efficient remedies when things go wrong.

2.5.1. Smooth, Efficient & Trouble-Free Journeys

Railway systems are complex, and like all complex systems, do suffer from performance degradations and breakdowns that have a direct impact on passengers. These failures may be the result of an equipment suffering a breakdown, perhaps from a failed component; or may be due to external factors such as a grid power outage or a flooding event. Frequently however, failures are a result of human error, a lack of human responsiveness, or staff unavailability.

By taking humans out of the loop as much as possible, automated systems can largely avoid failures resulting from human errors and shortcomings. They also remove the variability of human response times and personal preferences, leading to a higher capacity, more consistent railway operation, using analysed and agreed best-practice for every decision.

Automated systems are also better able to deal with equipment failures, and some forms of external influences, through automatically switching to redundant systems with instant service reconfiguration. This enables component failures to be dealt with at times when the customer service will not be disrupted (e.g. overnight) and with less time pressure on the maintenance technician, leading to more in-depth diagnostics and higher-quality corrective work, significantly reducing the risk of a future repeat failure.

By utilising the highest levels of automation on monitoring, detection and control, the passenger benefits from the very highest levels of performance, resilience and responsiveness. In addition, passengers benefit from the additional flexibility to be gained from releasing train services from staff shift patterns, and safety-related working time limits, that result from the need for train crew. If staff are late, it delays the train service, and the human operators (whether driving a preceding train or using a train to get into position for their next duty) will also be delayed; clearly this can form a vicious circle that causes minor delays to propagate into major disruption.

Automated driving will be smoother than traditional manual train operation as hard brake applications will be reduced by the intelligent use of coasting; this will generate customer perception of improved ride quality. The train service reliability will be improved by removing the delays and the vicious cycle of service degradation caused by human operators not being in position.

The automated train regulation system will ensure that small service perturbations are managed before they can grow into larger service disruptions; customers will perceive that trains will reliably arrive at regular intervals, and customer load will be evenly spaced between trains.

2.5.2. Comprehensive Information & Communications

People have two characteristics that really matter in terms of customer service. Firstly, we can be approachable, warm and helpful and customers value human interactions in many situations. Equally, people can be late, inattentive, misinformed or overloaded. Automated systems struggle to provide that human touch when passengers really need it. However, for many simple passenger needs, such as simple information provision, passengers often prefer the accuracy, efficiency and immediacy that an automated system can provide. This is particularly true of recent generations, who have very few reservations about gaining information and communicating via their mobile phone or other smart devices.

The key to comprehensive communication is to combine the very best characteristics of automated systems and humans to match the needs and demands across all passenger demographics and all operational scenarios.

By using automation to move staff from driving cabs and station control rooms to customer-facing roles, the customer perception of staff presence is increased despite the actual number of staff decreasing compared to a traditional railway. This ensures that customers regularly see operational staff around the system and can have queries needing human interaction efficiently resolved.

Staff presence also contributes to the perception that MetroLink is a safe environment. By discouraging vandalism and anti-social behaviour, staff presence also reduces the gradual degradation of the physical MetroLink environment. The availability of staff to perform revenue control duties (and visibility of staff even when they are not performing revenue control duties) will be a major deterrent to ticketless travel, hence boosting farebox revenue.

The customer-facing public address and electronic display boards on trains, platforms and around stations will work together to create an audio-visual customer information system. This coherent source of information will ensure that customers with hearing or visual impairments still receive a full range of relevant information. This information can be made available in multiple languages where required, and will be made available via an open data feed so that customers can also receive information on their smartphones; this enables customers to use specific assistive technologies or translation software to read the information to meet their individual needs, and to plan their journey from before they leave their front door. The open data feed also allows real-time service information to be shared across multiple applications, allowing intermodal data-sharing, journey planning and facilitating multi-modal fare collection.

2.5.3. Complete Journey Connectivity

Automated systems enable a move towards door-to-door journey planning and mitigating the customer impact of disruption on other modes of transport involved in a journey by publishing and importing data from these systems. Customers can check the service on MetroLink from anywhere using their smartphones; the same published data can drive cheap, easy-to-configure customer-facing displays on other modes of transport (including at Dublin Airport) in in cafes and shops close to MetroLink premises. Similarly, MetroLink can provide information on other modes of transport through displays on their infrastructure (and in the case of significant disruption, via on-train displays) so that customers can make informed decisions to vary their intended route to reflect disruption on other transport modes. This may include providing information on road conditions to customers as they arrive at Estuary Park and Rise station. Third party apps will be able to draw upon this published data to suggest the most efficient routes across Dublin in real time under all service conditions in the same way that the satnav in a car responds to real-time traffic conditions when selecting and updating a route.

Common ticketing is a great customer attraction, allowing passengers to take the greatest advantage of a switch to public transport journeys. This attraction is enhanced further when integrated fare policies offer further incentives, such as automated maximum daily fare caps, and automated off-peak usage reductions.

2.5.4. Efficient Remedies When Things Go Wrong

However reliable a railway is, it needs to be able to deal efficiently with variability from sources beyond its control, such as customer action and external events, or just equipment failure. CBTC has a significant advantage over traditional signalling technologies as it provides minimum train separation and highest capacity under all operational conditions; while the traditional technologies are typically optimised for normal and close-to-normal operation. This enables recovery of normal service conditions in the minimum possible time. Automated decision support systems rapidly provide control centre staff with multiple service recovery options evaluated for their relative benefits, ensuring that the best strategy can be selected to regain normal service.