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Delivering capacity and service resilience from modern Communication Based Train Control (CBTC) railway systems.

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SUMMARY

To achieve optimum service capacity and resilience on a modern railway requires a thorough understanding of the environmental characteristics of the railway, the operational constraints and an ability to balance the safety and the performance of the railway in terms of service regulation, management and release of train movement authorities, train spacing and relative movements and operational speeds, particularly across key junctions and the interaction between the automatic train control systems and the train traction and braking systems.

The presentation addresses these issues in a systematic manner with a vision of the railway of the future and how modern technology and processing power could be integrated to achieve the optimum railway performance.

Specific areas addressed using service examples include:

- *Balancing the operational and technical aspects of the railway*
- *Management of open section adhesion levels*
- *Management of the vehicle train interface and passenger comfort*
- *Optimising railway performance by ensuring that fleet utilisation is maximised*
- *Harnessing data from the myriad of centralised and distributed computer systems*

It is hoped that the paper will promote thought about how to optimise railway performance by blending railway operational experience and technical advances such that operators, engineers and service planners can help their railways achieve their passenger service and business objectives.

1 INTRODUCTION

The inspiration for writing this paper is having spent significant time in the control centres with operators running the systems and seeing that there are opportunities where we, as the engineers, can support them in providing an enhanced passenger service through making improvements to the system and also facilitate high quality feedback to the service planning teams.

This paper is not designed to provide a 'one size fits all' solution but rather a number of options and possibilities that could be used to achieve better service resilience. It is based on 35 years in the railway industry working with operators, service planners, business clients, maintenance and engineers on projects, design, implementation and operation of systems.

2 DEVELOPING OPTIONS FOR A WHOLE RAILWAY SOLUTION

It is not possible to cover all aspects of service resilience in one paper so the author has selected five areas that could be engaged to improve service resilience. The aim through the paper is to start to weave these threads together so that hopefully the reader will start to visualise how some of the thoughts and possibilities described could be of use for their specific railway operation application.

2.1 Balancing the operational and technical aspects of the railway

To achieve a robust overall railway solution requires thinking through operational and technical issues, such as platform detrainment, dwell and crew changeover times and the service patterns to ensure that potential pinch points on the railway are alleviated by considering operational and technical aspects holistically to achieve practical operational performance.

To take a real-world example, there is a specific location as shown in Figure 1 Complex Site Operational and Technical Layout; where the operational and technical constraints converge to present a very real opportunity to introduce service delays due to blocking back approaching the station in Direction of Travel 1, specifically:

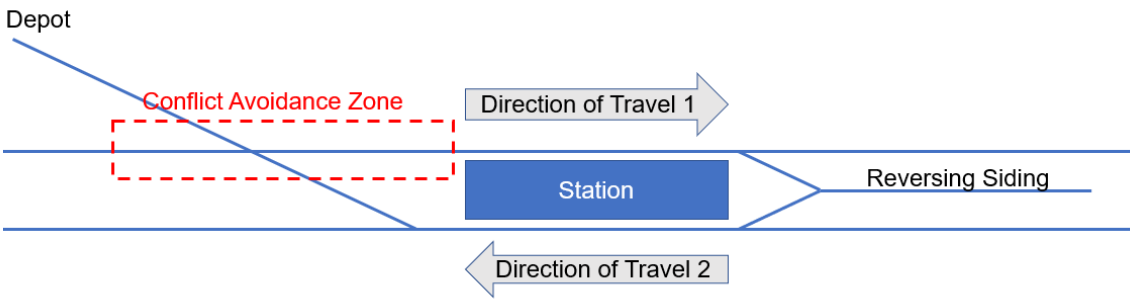

Figure 1: Complex Site Operational and Technical Layout

2.1.1 The specific challenges of this site include:

- A flat junction diamond crossover that allows trains to and from the depot and requires a Conflict Avoidance Zone to keep trains a further distance away approaching the station to avoid blocking train moves into and out of the depot. This no stopping area can also be present where there is a complex flat junction that creates a potential traction gaping risk to three and four rail conductor systems.
- A station that has extended dwells due to a combination of passenger detrainment times for trains entering the sidings and also crew changeovers as is often the case where crew depots are located close to the train depots.
- A reversing siding where entry and exit moves must be carefully synchronised with mainline moves to avoid creating blocking back in either Direction of Travel 1 or 2
- If an additional reversing train arrives in Direction of Travel 1 while the siding is already occupied, then there will be a compounded blocking back in Direction of Travel 1.

2.1.2 To develop a balanced solution requires the operational and technical teams to work closely together on a solution, for example:

- Operationally, it may be possible to schedule crew changeovers in a way that coincides the crew change with the reversing moves such that only one rather than two dwells are lengthened. In addition, it may be possible to deploy additional station resources to assist with minimising dwell times during peak hours. The other major operational contribution is to monitor the service carefully to avoid closely following trains being routed into the reversing siding when there is disrupted or re-scheduled operation.
- From a control system perspective, it may be possible to speed up the routing through to the platform by ensuring that a train waiting at the Conflict Avoidance Zone is routed immediately when a train is detected leaving the Station in Direction of Travel 1.
- From a signalling perspective, there is much that can be done:
    - Review the local site conditions and, if a reasonable argument can be made for adhesion levels, then maximise the service brake rates in the area, both on the mainline and entering the siding

- Bring the train approaching the station in Direction of Travel 1 as close as possible to the fouling point of the scissors crossover by allowing the train to use the overlap across the diamond crossover and then auto-releasing the overlap once the train is proved stationary
- Review the speeds across the points into and out of the reversing siding with the track design authority. These speeds are generally constrained by passenger comfort with the risk of derailment only applying at a significantly higher speed. Often by applying a conservative track maximum velocity and then compounding by applying a further set of conservative assumptions on the signalling system, the speed across these points is significantly reduced with a significant detriment on service capacity.
- Consider the supervisions for the siding entry – often there are speed restrictions and low brake rates applied to manage risk, where tightened supervision for positional uncertainty and traction inhibit and brake interventions could be used to justify that the risk is acceptable without creating a performance disbenefit. It is also worth checking to see if eliminating a specific failure mode, such as by duplicating speed measurement equipment, could further assist with the risk argument for retaining performance.
- Signal the layout so that a following train uses the overlap into the sidings to berth at the Direction of 1 platform concurrently with the train move ahead into the platform. This means that the point logic will need to work in the appropriate manner and that the Safety Distance will need to be suitable for the following train to fully berth in the platform when the train ahead has reached the berthing location in the sidings. This may require optimisation of the site data, such as speed limits and brake rates to achieve the best overall railway performance, as a future development perhaps systems could apply conditional brake rates for siding and mainline move to support this.

2.1.3 Having optimised these areas, it is worth considering other areas that can contribute to the successful operation of the site:

- Scheduling of the railway is critical to ensure that recovery time is available in the right locations to assist with the junction synchronisation during late running and disrupted service.
- Either stepping back of crews or auto-reversal of trains during peak periods.
- Using CCTV images rather than physical checks to confirm that trains are detrained prior to entering the siding and enhanced passenger announcements both before and at the station on the trains and on the platform during detrainments
- Allowing trains to be available for siding departure as soon as the driver has switched ends and is available at the Direction of Travel 2 end of the train, either through a cab based signal or track based plunger or even through the control system being notified that the cab for Direction of Travel 2 has been activated and is in a suitable mode to leave the siding.
- Control system enhancements and junction management to predict and alleviate forthcoming blocking of the junction either automatically or through decision support to the operator. This could vary train routing or timings to mitigate a forthcoming delay event an hour or more before the event will happen so that the controlling actions can be done in a convenient and timely way and thus have minimal effect on the railway.

The last two areas that I would stress under this are to develop and utilise:

- High quality static and dynamic performance models and simulations that allow the performance to be optimised and tested dynamically through different scenarios and to help develop the operational and technical solution and supporting safety case
- Harnessing the power of modern control and regulation systems to analyse and provide immediate feedback on the performance of the junction so that the operation and technical aspects of the junction can be continually understood and improved.

2.2 Management of open section adhesion levels

The importance of adhesion management and optimisation cannot be overly stressed in the achievement of safety and service performance objectives on a modern Communications Based Train Control (CBTC) railway, which includes Automatic Train Protection (ATP) and Automatic Train Operation (ATO), where the trains are closely spaced using some form of Moving Block Signalling (MBS) such that every area of the railway has to configured for local site and environmental considerations.

If the assumed achievable braking rates, commonly referred to as Guaranteed Emergency Brake Rates (GEBRs), are set too high then the safe operation of the railway could be compromised however if they are set too conservatively then the performance of the railway will be significantly degraded.

There is also an increasing move towards using both reduced service brake rates and acceleration rates and even temporary speed restrictions as an operator configurable measure to mitigate times of poor adhesion or even where poor adhesion is predicted.

These are often applied for precautionary reasons and there is often a risk averse approach to removal of them as operational and maintenance staff are judged on individual service failure events, such as a slide related delay, and not on the overall performance of the railway. This culture is driven by the operational measurement regimes which typically are concerned only with control centre recorded delays starting at one to five minutes and do not consider the very substantial and cumulative impact that a large number of small delays can have on a railway.

For example, application of low service brake rates can degrade the journey time on a railway by 10% causing late running to either occur or at the very latest not to be recovered in a timely manner. Applying a traction constraint would further aggravate such delays and further compounded as the junctions, such as discussed in 2.1, are running out of synchronisation adding further delays.

At the centre of resolving this issue is consideration is the fundamental question of how to model and calibrate adhesion levels and then ensure that appropriate train, signalling, control, track-based measures work together to deliver the most effective possible Adhesion Management Regime (AMR).

The following are some thoughts on how adhesion levels can be monitored and strategies to optimise braking curves and performance through flexing the braking profiles and brake application levels to match the geographical and environmental characteristics of the railway and using service performance data to support the operational and technical cases.

2.2.1 Today's railway – make the most of what is available

- Harvest operational data and data from the train on-board signalling and brake systems to develop a 'heat map' of adhesion across the railway. Use this to understand the totality of the current performance and then develop individual site solutions that deliver the best service performance benefit.
- Figure 2 shows an example where this approach has been applied in practice, with a combination of improved track vegetation management, traction gel applicator adhesion modifiers placed at strategic locations on the braking curve and a combination of speed restrictions and brake rates employed to ensure that as far as is possible braking, particularly at the key point of brake initiation, is kept at the locations where the best adhesion levels are available. A modified version of this has been considered where the trains use the generally better adhesion levels in level and generally vegetation free platform area.
- Additionally, the train control systems were upgraded such that the on-board signalling system for normal service operates using the tachometers at the rear of the train for positioning such that the better friction levels at the rear of a train during braking to ensure a greater resilience against slide events and the Automatic Train Operation system was modified such that it was better able to manage wheel slide by maintaining a smoother braking profile at time of wheel slide initiation.

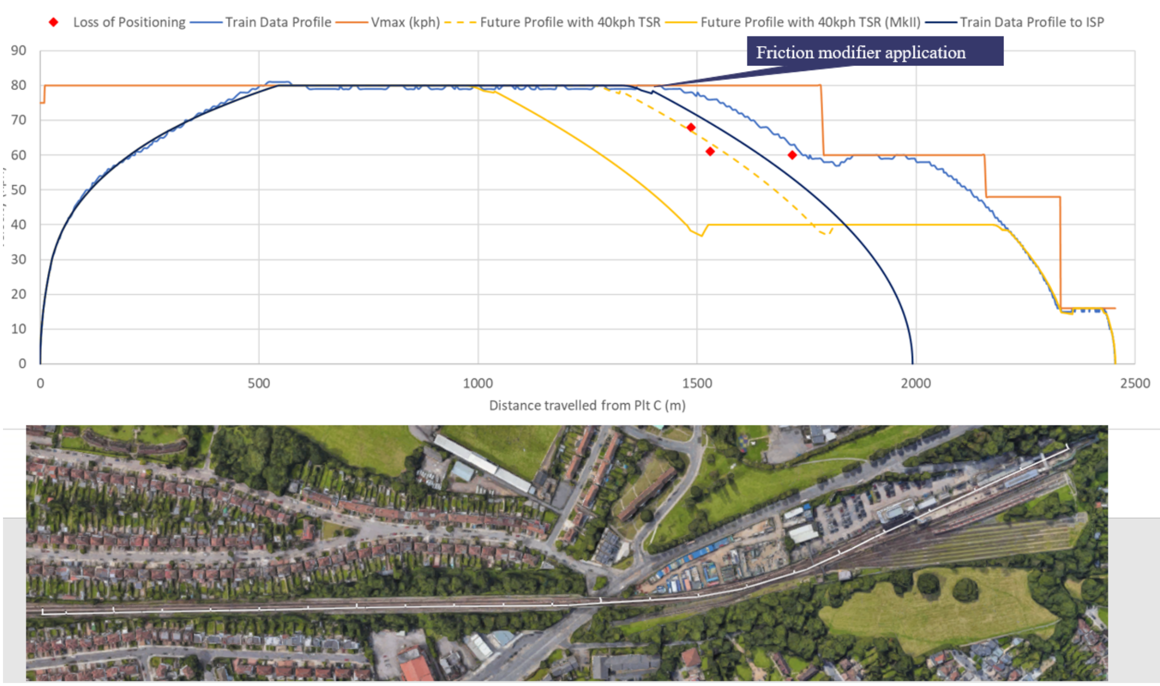

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Figure 2: Using Site and Performance Data to Optimise an Inter-Station Run

2.2.2 Harness the power of modern technology:

- **Modern Positioning Systems** – this is still a development area for the use of on-board train positioning systems using camera and sensors' such as optical imaging, LIDAR and RADAR. Such technology could not only eliminate or, at least reduce, the need for wayside equipment, such as balises, but critically allow the trains to maintain positioning better and thus would allow better train control during poor adhesion conditions,
- **Modern Braking Systems** – All wheelsets are monitored on modern braking systems allow accurate wheel slide detection and wheelset specific braking forces to be applied and a more reliable and stable reference speed for the whole train. During slide events, the brake pressure is actively controlled on a per wheelset basis and harvesting this data can be used to provide a much better proxy for both the train as a whole, down to the specific wheelsets along the length of the train thus improving understanding of achieved adhesion levels. This feedback from braking systems could be used to dynamically shift brake balance (ABS, EBD for trains), provide improved dynamic information to the ATO system and map adhesion levels across the railway.
- **Modern Wheel Condition Monitoring Systems** – the railway industry is moving towards all wheelsets being individually monitored with three axis accelerometers. This allows for wheel, bearing, suspension and track characteristics to be understood and also provides discrete information on individual slide events and wheel damage which can be used to identify and mitigate where wheel damage occurs and characterise the adhesion and ride relationship
- **Modern CBTC ATO Systems** – These provide a high-resolution position for the train and precise information on the sensor input and control outputs. This information can be used to help build the adhesion map, characterise the train system performance ad analyse and mitigate wheel damage events.
- **Modern Sanding and Adhesion Management Systems** – There has been significant advances in adhesion management ranging from the utilisation of on-board variable rate sanders, on-board friction modifiers through to track-based gel applicators

Putting all these things together shows the need for a thought out and integrated approach to the development of the whole railway solution for adhesion management. For existing railways, there is the possibility to make improvements using the available systems or to deploy targeted additional improvements. Where there is a broader deployment of technology, such as Line Upgrades which constitute new trains, signalling and control systems and often track improvements, the opportunity should be taken to take a step-back at inception stage and consider the total solution that best optimises the safety and performance of the railway.

2.3 Management of the vehicle train interface and passenger comfort

The next major element of achieving the best possible safety, performance and cost-effectiveness of a railway is to use modern modelling techniques supported by service condition monitoring of key aspects to ensure that speed profiles achieve the best railway performance whilst balancing passenger comfort and track safety and condition issues. Examples of the type of areas where it is worth considering carefully for benefits that could be accrued from changing the approach to defining and managing track speeds and train operation include:

2.3.1 Operating speeds, especially across points and junctions

- Standards for the setting of track speeds are highly prescriptive and for each type of track form with consideration of track form type, alignment and switch configuration to define the maximum speed and cant to be applied to the track. The Achilles heel of these standards is that generally they do not discriminate between the constraints for safety (derailment or over-turning), passenger comfort and asset condition management. This leads to a principle that the track speed generated must never be exceeded even though in a lot of cases there is no significant safety risk and from analysis of actual operating speeds, passenger comfort is acceptable at higher speeds.
- One specific issue when developing an upgrade solution was that the speed across points into the headway critical reversing siding was signed at 10 mph (16km/h) for the Train Operators driving under the conventional colour light signalling system (where speed control depends on the Train Operator). This speed limit was being fed through to the re-signalling as a velocity that should not be exceeded. After reviewing the design of the points, it transpired that the design speed was actually 23 mph (37km/h) and 10mph had been placed on the siding as part of an operational simplification programme so that all such junctions were set at 10mph.
- The challenge to increase the speed from both the track standards and the pre-existing speed limits is that the onus is to demonstrate that there is not a safety issue where the track standard does not discriminate the sub-constraints and often the reason for imposing a speed limit have long since been forgotten.
- An exercise was performed to review actual speeds on a conventionally driven railway with speed control only at critical locations, such as entering termini, and a modern CBTC railway with continuous speed control and ATO operation. This was supported by an analysis of the derailment risk for different site and track configurations and the speed supervisions and controls. The study showed that there is significant scope to safely increase speed limits, especially at key junctions.

2.3.2 Understanding and managing real world operational speeds and passenger ride:

- Track speeds tend to be calculated and tracks canted on a one-time theoretical basis with no feedback mechanism as to the actual speeds being operated in service or the levels of passenger ride comfort that are being achieved in practice.
- As discussed under section 2.2.2, the modern trains and control system have substantial information that can be used to inform the discussion on acceptable track speeds and flag up early warnings where the track speed is deviating substantially from the basis of the track design.
- A good example of this is with the scheduling system. For a modern high frequency metro system, the control and regulation system is attempting to regulate the train service to the nearest second. Traditional timetables are specified at 15 second intervals which works well when on a less intense railway as the Train Operators will generally receive a proceed aspect and dive at line speed.
- With the modern, high frequency metro however there are potentially some significant scheduling and system interactions that affect the trains speeds:
    - Where the schedule allows extra recovery time or where the 15 second level of granularity puts extra time in an inter-station link, the trains will consistently run that link at a lower speed, for example 30 km/h in a 60 km/h link. This can undermine the basis for determining the track cant arrangement and cause excessive wear in the low rail.

- A similar effect can be seen at pinch points, such as described in section 2.1, where trains frequently come to a stop approaching the pinch point thus similarly undermining the basis for determining the track cant arrangement

2.3.3 Train speed and passenger comfort

- On a typical metro train, during peak hour operation, there could be up to 1,000 passengers of whom a significant proportion will have mobile phones fitted with a three-axis gyro and accelerometers.
- This contrasts with metro trains generally which do not have ride monitoring equipment fitted with the exception of either very modern trains or those that have been retro-fitted with sensors for conditioning monitoring.
- This is a major gap and a major opportunity. Were the trains to be fitted with ride monitoring equipment then it would be possible to undertake a review of passenger ride comfort levels in terms of accelerations experienced and make informed decisions on where the track speeds could be amended or tweaks made to the scheduling to ensure that railway performance and passenger comfort are optimised.
- As an example where this would be helpful is the case of a speed restriction at a key pinch point which was ostensibly required due to a 'kick' on the last carriage as it cleared the points. Riding the last carriage a number of times confirmed, no such 'kick' was felt or measured using a mobile phone recording accelerations and the logs were checked to confirm that these were full speed runs. Tran data from multiple trains could be used to dispel such assertations and allow the point speed to be increased.

2.3.4 Using conditioning data to ensure speed limits are set correctly and optimised

- The placement of speed restrictions on modern signalling systems is generally through track analysis and maps that use geographical chainage to provide the locations and speeds required. This is then interpreted by the signalling engineers into a logical map of the railway and the speed limits transposed into data that will add a level of either uncertainty or rounding to ensure that the total plausible position of the speed restriction is covered.
- The signalling system itself will generally add an extra layer of caution to mitigate the possibility that any part of the train at any point is exceeding the track design limit and the train itself will have level of traction lag and jerk control that will further slow the acceleration of the train as the rear of a train clears a speed restriction.
- This entire process is deemed to meet the safety requirement as several layers of conservatism have been added on through the process however the process is open loop and the effectiveness and efficiency with of the speed restrictions characteristic in practice is not assessed.
- With on-train condition monitoring equipment, it should be possible to characterise the relevant element of the train entering the or leaving the track form for which the speed limit has been imposed. For example, for a set of points, the critical point is when the leading wheelset reaches the switch blade and the train is clear when the last wheelset clears the switch blade.
- Applying such a closed loop approach could yield benefits in terms of safety by identifying should a speed restriction not be achieving its intended purpose and in terms of performance where it is found that the assumptions have caused an overly restricted run profile in a key area for capacity.

The aim of this section has been to start to draw together the concept that, using modern integrated technology and careful analysis, it should be possible to use modern modelling techniques, calibrated and proven using real world train performance and condition monitoring data, to revisit the way that track speeds are designed and implemented and thus concurrently improve the safety and performance of the railway.

2.4 Optimising railway performance by ensuring that fleet utilisation is maximised

One of the most significant costs for any line upgrade tends to be the rolling stock procurement and there is often a requirement to procure small numbers of high unit cost specially built trains to enhance the capacity for existing lines.

The quantity and need for additional rolling stock can be mitigated by consideration of all the factors that contribute to the fleet service requirement, including stand time in termini and sidings, inter-station run times and platform stopping and dwell times, lost time through service operation and continuous monitoring of the railway to provide timely indications of either congestion or time being lost on the railway during operation.

2.4.1 Stand time in termini and sidings

Frequently there is significant stand time allowed for crew changes and recovery in terminus and sidings, the amount varying with the operational philosophy of the railway operator and the specific railway characteristic and service requirements. This can be reduced by using operational stepping back of Train Operators and provision of additional crew management and supporting facilities on the relevant platforms

2.4.2 Inter-Station Run Times

Inter-station run times can yield the best benefits for enhancing service with the minimum number of trains and specifically by circulating the trains more rapidly. It is always worth focusing on the fact that a metro will be as slow as the slowest train operating on the railway. The following are some possible options for allowing the scheduling to utilise shorter timetables run times:

- Minimise time lost due to blocking back at pinch points as discussed under section 2.1 of this paper
- Minimise time lost due to the use of reduced brake and traction rates as a precaution against unknown adhesion and sub-optimal adhesion control as discussed under section 2.2 of this paper
- Optimise the operational speeds and guideway data as discussed under section 2.3 of this paper
- Monitor for substandard train traction performance as shown in Figure 3 below. Algorithms were introduced as part of the predict and prevent regime that identify any trains where the performance was below that expected so that they could be scheduled for rectification works
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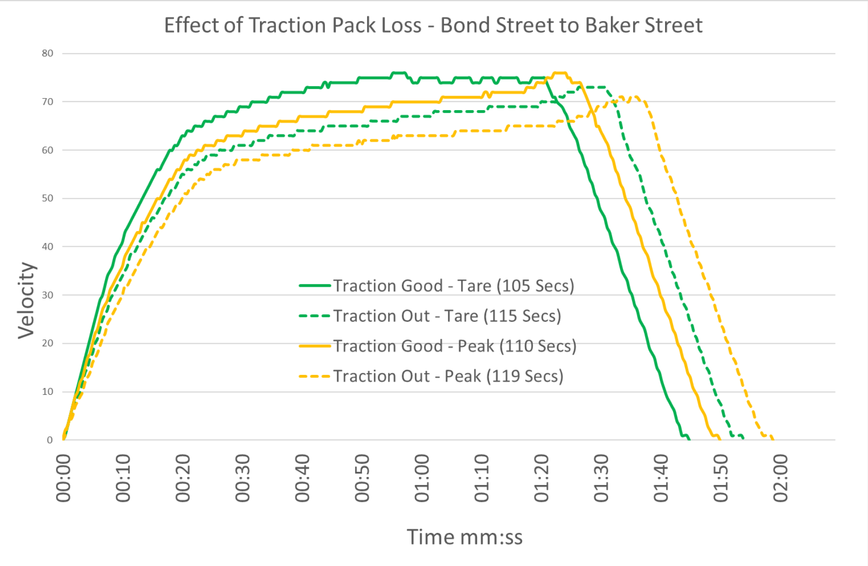


Figure 3: Characterising good and sub-standard train traction performance

- Monitor for Train Operator performance both in terms of promptness of platform departure and service profiles when operating in manual and provide guidance as appropriate
- Finally for inter-station runs, it is worth considering some of the system lags, service acceleration and braking rates and jerk rates applied to the rate of change of acceleration. Frequently the values applied for these are

historical from old technologies and sometimes both the signalling on board control and train traction packs apply rate of change to acceleration and braking that services to compound as slower acceleration and unwarranted lag in the brake response systems which creates other train control issues.

2.4.3 Platform Stopping and Dwell Times:

- **Platform entry –** the ideal characteristic for entry and stopping at a platform is to stay on the full-service brake rate and then only apply the final stopping brake at approximately one second before the train comes to a stop. On some railways, this flare out stage at very low speed can mean that the train rolls for an average of approximately 7 seconds which is a significant impact on both the platform re-occupation and run times providing both an immediate and potentially cumulative impact on run time.
- **Door enable** – standalone correct side door enable systems were fitted to a number of fleets over the years where modern CBTC systems were not operating. These standalone door-enable systems typically used a simple beacon or loop for final positional certainty and a low speed relay (typically set at around 2 mph). When both the loop or beacon was detected and the speed below the predetermined threshold, the doors would be enabled for release by the Train Operator.
- In context, 2 mph is approximately 0.9 m/s and assuming that the brakes are applied at this point then the train will be stationary by the time the passenger saloon begin to open and these system can be clearly seen in operation on the train logs and the author is not aware of any service issues that have arisen with this arrangements
- The modern systems by contrast generally require the train to be proved stationary by diverse means before facilitating the door enable function and this can be up to around two seconds after the train has physically come to a standstill due to positional system processing and reporting lags this potentially losing up to three seconds per station stop over the system that they replaced. It would be worth revisiting if there is an argument to initiate the door enable on the new systems sooner using their knowledge of the train position, speed and brake force being applied.
- **Auto Door Open** – this could assist in reducing driver response time to opening doors however should be treated with caution if a secondary detection system is required as part of the technical safety case as the lag in the secondary detection system may be greater than the average Train Operator response time
- **Auto Door Close –** this could be used to eliminate Train Operate variations however the application is more complicated as the culture of the city where it is deployed is vital to its success or otherwise and also the door timings are challenging to judge as too short and there is a hazard of trapping people in doors and too long and capacity may actually be lost on the railway.
- **Auto Depart** – again, this could reduce delays due to Train Operators pressing ATO start buttons however does require consideration of passenger safety issues at the Platform Train Interface

2.4.4 Lost time through service operation and continuous monitoring of the railway.

There is a fundamental opportunity to move metro operations to a mindset of statistical process control where the service is continually monitored against a benchmark of good performance.

The traditional monitoring measure of a recordable one- or two-minute delay by the line controller needs to move to a mindset of continually monitoring all aspect of the railway performance at a second by second level and identifying any causes of lost time so that:

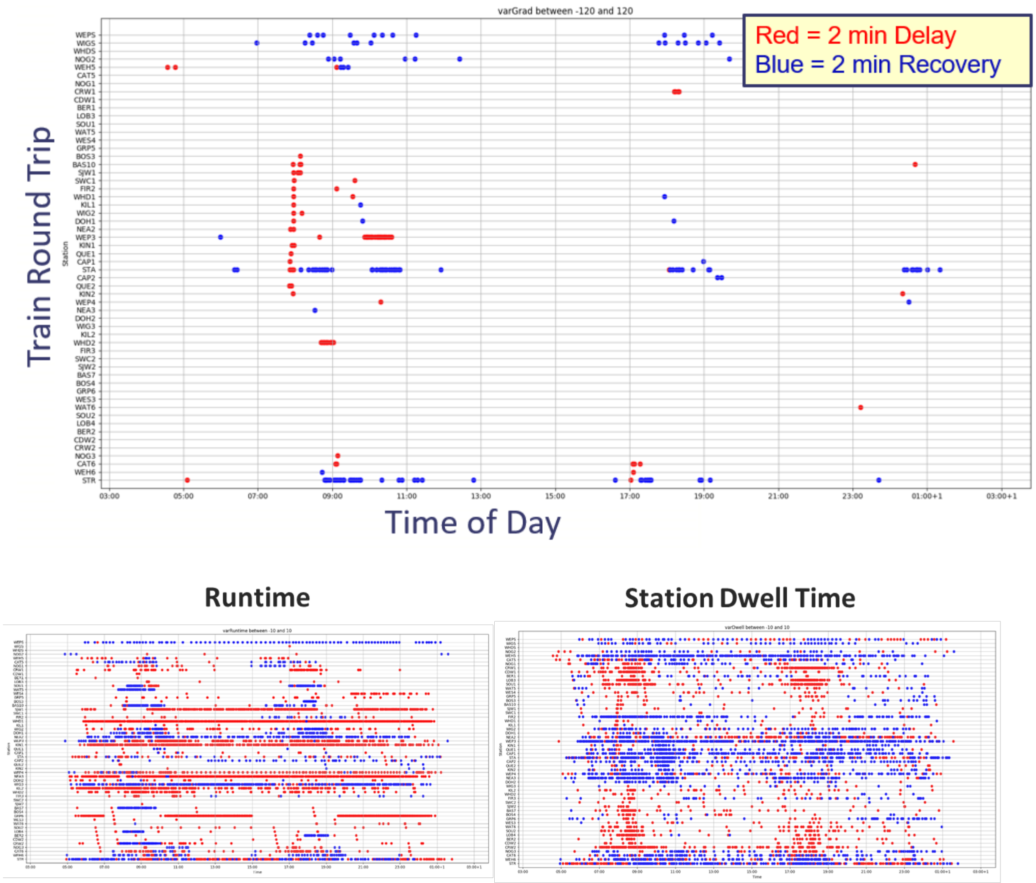
- All delays to service or opportunities to improve run time are rigorously analysed to seek continuous improvement in the achieved run times and thus effective use of the operational fleet
- Continuous monitoring is used to understand the pre-cursors to fleet failure events moving to condition based maintenance to improve fleet availability and predict and prevent to minimise service disruption and thus time lost due to fleet failures during service operation – this is a subject in it’s own right.

2.5 Harnessing data from the myriad of centralised and distributed computer systems

The final section of this paper is dedicated to the need to fully characterise the actual performance of the railway and allow amendments to be made to the operational practices, service schedule timings and regulation, control, signalling and rolling stock systems data. This is needed to continually improve the performance of the railway and empower operators with a high-level overview of railway performance and an understanding of how the railway performance can be made more resilient by both preventing, minimising and recovering from service perturbations.

2.5.1 Characterising the performance of the railway

- Characterisation of the railway can be undertaken using simulators and these are an excellent method of being able to run a full service in a laboratory environment as a way of understanding, developing and tuning the system running an intense service and working through a myriad of alternative service patterns and abnormal and disrupted service scenarios to understand how the railway performs and recovers.
- From the perspective of this paper, consideration is given to how this good work can be continued through into service operation. Somewhat like golf, the effectiveness of the swing must depend on the follow through, in this case ensuring that real railway performance is monitored, analysed and continually improved using the power of the data that is available to understand and investigate service performance.
- The snapshots below show the output from an in-house service analysis tool that views a day's operation.



Substantial cumulative delays due to sub 2 minute threshold events

- Individual delays due to technical, passenger or operational event
- Pinch-points on the railway particularly during perturbation
- Slow running train or repeatedly delayed during dwell

Figure 4: Output from railway service analysis tool

- As well as providing definitive information on the service delays that had been recorded by the line controllers, the service analysis tool has proved to be very effective as it allows issues to be identified, such as:
    - Unrecorded operational and technical issue, some of the technical system issues creating delays of up to 7 minutes
    - Unrecorded impacts of blocking back at junctions, with multiple trains losing up to six minutes whilst waiting for the queue to clear
    - Unrecorded issues with the generation and release of extended reservations that was causing trains to be held unnecessarily whilst waiting for other train movements
    - Reassignment of trains earlier in the day leading through to a service delay to consecutive trains being routed to the same siding later in the day
    - A high-level picture of all trains running slowly whether due to traction issues, operator response times or higher than expected dwell times
- In short, the analysis combined with a detailed review of individual time lost events provides the opportunity to continuously hone the performance of the railway taking a comprehensive and objective overview starting with a breakdown of all time lost and working through to identify and implement appropriate scheduling, operational and technical improvements.

2.5.2 Lost time and Recovery Time

- One of the powerful attributes of this type of analysis is to judge how effective the scheduling strategy has been in terms of using recovery time to optimum effect when recovering service and also the effective use of termini and reversing sidings in ensuring that trains are not being held due to occupancy conflicts.

2.5.3 Development of immediate feedback and relevant Key Performance Indicators

- Historically service analysis has been the preserve of the train planning departments when analysing the service and system performance and the role of the operational and technical support staff has been to manage and address issues as they arise on a case by case basis in service.
- Generally operational staff will get the feel for the system and find workarounds for what are fundamentally system issues that could be improved either through scheduling, system or simply data changes to the system.
- As an example, when analysing the performance during a service day, it is evident from the operational commands that can be seen on the control system replayer that certain control centre operators have recognised the issues with siding reoccupations and long reservations and place strategic holds on trains approaching the area that prevent the delays occurring.
- For the future it would be useful to provide regular service analysis to the Service Manager either live or at the end of each operational shift and empower them to use the service analysis the intuitive understanding of themselves and their teams to start to drive forward for improved service resilience.
- This especially applies to making sure that the benefits of the workarounds that they have developed are incorporated back into the systems to start to build in additional operational expertise to the base system.

3 CONCLUSION

Ultimately this paper and the associated presentation aim to bring together a vision of how the railway operation, scheduling and performance can be developed in an integrated manner with continuous process control. This can be applied in the same way as for modern manufacturing processes, including taking a proactive approach to understanding the human and system contributions, and maintaining a continuous and immediate feedback loop to hone and improve the operation, scheduling, performance and systems design of the railway.