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Assessment of mass transit turn-back capacity using dynamic simulation models

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Abstract

The line capacity of a mass transit railway is often governed by the frequency with which trains can be reversed at terminal stations and intermediate turn-back sites. Factors that influence the maximum reversing capability include the fixed geometry of the track layout, the characteristics of the signalling and train control system, the performance of the rolling stock, the platform dwell times, and the requirements for crew-changeover.

In tendering a given signalling and train control system for a new or upgraded railway, the signalling contractor must be able to verify that the turn-back headway specified by the railway administration is practicable. It is also necessary to have the means of both assessing quickly and demonstrating easily the effect on headway resulting from variations in design parameters.

The paper reviews the principal factors that limit turn-back capacity. It describes the application of simulation models that allow the operation of turn-back sites to be assessed in detail using graphical animation.

1 Introduction

The signalling contractor is typically responsible for delivering signalling and train control systems that must facilitate service train frequencies required by the railway administration. This is usually specified in terms of a steady-state design headway that includes given values of station dwell and recovery time. Newer contract arrangements, such as the London Underground Public-Private Partnership [1], involve the signalling contractor participating within a private consortium, in order to optimize the railway service as a whole. Incentive exists for the service performance, in terms of headway and journey time, to be maximized within the constraints of the fixed infrastructure. This brings into sharp focus the performance constraints of turn-back sites and other junctions.

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Studies aimed at predicting the maximum capacity for a particular railway are often limited to 'plain-track' scenarios. Such studies consider the minimum theoretical interval between the unimpeded arrivals of two trains travelling in the same direction at an intermediate station-stop. This involves the development of either analytical models or iterative simulation models. Analytical models tend to be restricted to ideal conditions in which, for example, level track and constant acceleration are assumed. Such models are often useful for gaining a quick assessment of the effect on headway of different train performance parameters. Bergmann [2] makes a notable contribution in this respect.

Iterative simulation models achieve greater accuracy by considering the detailed characteristics of the track, rolling stock and train control system. Such models are essential when assessing the headway achievable with transmission-based signalling (TBS) systems that work according to moving-block or distance-to-go principles. This is because the safety distance is dynamic, whereas for conventional block signalling systems it is fixed by the signalling layout, according to worst-case train speed. The characteristics of TBS systems are considered elsewhere by the author [3,4].

Improvements in train frequency predicted by plain-track models alone might not be achievable in practice due to the limited ability of a terminal station to reverse trains. Care has to be taken especially when predicting the capacity improvements resulting from the introduction of moving-block TBS systems. Here, a turn-back layout must be assessed in terms of its ability to reverse bunched trains.

An evaluation of the minimum headway for a given turn-back layout necessitates a careful timing analysis. This is based, primarily, on train performance curves, equipment response times and specified dwell and 'layover' times. Where fixed-block signalling is applied, the minimum headway is determined from transit times between fixed track locations. At minimum, this can be achieved 'manually' with the assistance of spreadsheet calculation tools. However, such a method is not generally feasible where TBS is applied due, to the dynamic nature of the overlap distances. It is therefore necessary to employ multi-train simulation in which the operation of the turn-back can be assessed in detail, under both steady state and perturbed service conditions. Such simulations must accommodate proprietary Automatic Train Control (ATC) algorithms.

For these reasons Westinghouse Signals have developed in-house simulation programs that model specific types of turn-back layout. These models drive real-time graphical animations that show the train-movements and ATC performance, in relation to the fixed characteristics of the layout. Such a representation is superior to traditional headway diagrams, which are often difficult to interpret.

2 Characteristics of mass transit turn-back layouts

The design of a terminal station layout involves many factors, some of which are in direct conflict. As identified by Mott [4], there is no ideal layout that is

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universally applicable. An optimum arrangement has to be arrived at that must take into account many considerations. These include the following:

- Required service frequency (trains per hour) and recovery margin
- Ease of use for passengers (arrangement of platforms)
- Potential level of route-conflict
- Cost of construction
- Reliability and required route redundancy
- Geometry of layout and resulting maximum permitted speed
- Crew changeover requirements
- Train stabling requirements
- Automatic Train Protection (ATP) overrun requirements
- Land-take requirements
- Requirement for unmanned moves using reversing tracks

For existing and well-established railways, opportunity for improvement is often very limited. For example, scope for extending terminal buffers beyond a platform, in order to allow a higher approach speed, is often severely restricted due to the existence of buildings and structures. Conversely, re-positioning the platforms further away from the buffers, as well as requiring expensive reconstruction, might force passengers to walk a greater distance.

The demand placed on a turn-back layout in terms of train frequency depends on the service pattern of the railway. Many mass transit railways extend from an inner-city area where passenger loading is high, into a suburban area where the loading is low. In order to reduce the fleet size and operating costs, a number of trains are turned back at certain intermediate stations, rather than working end-to-end. This reduces the demand on a terminal station, but in so doing, might transfer a capacity problem to an intermediate station.

Some typical layouts for terminal stations are illustrated in figure1 (a to c). These assume flat junctions, and are as follows:

a) Train-arrivals alternate between platforms 1 and 2 using a scissors crossover on the approach side of the station. A train having arrived at platform 1 waits a 'layover time' that is approximately equal to the service interval. During this time a following train arrives at platform 2, clearing the crossover and thereby allowing the train in platform 1 to depart.

b) All trains arrive at platform 1. Having completed a 'dwell' period for passenger alighting, each train moves empty into one of two reversing sidings. It then proceeds in the opposite direction to platform 2 where it completes a dwell period for passenger boarding.

c) Trains arrive at three platforms in turn, using a scissors crossover on the approach to platforms 1 and 2, and a single crossover to platform 3. An additional trailing junction is used for trains departing platform 3. Each platform layover time is approximately equal to twice the service interval.

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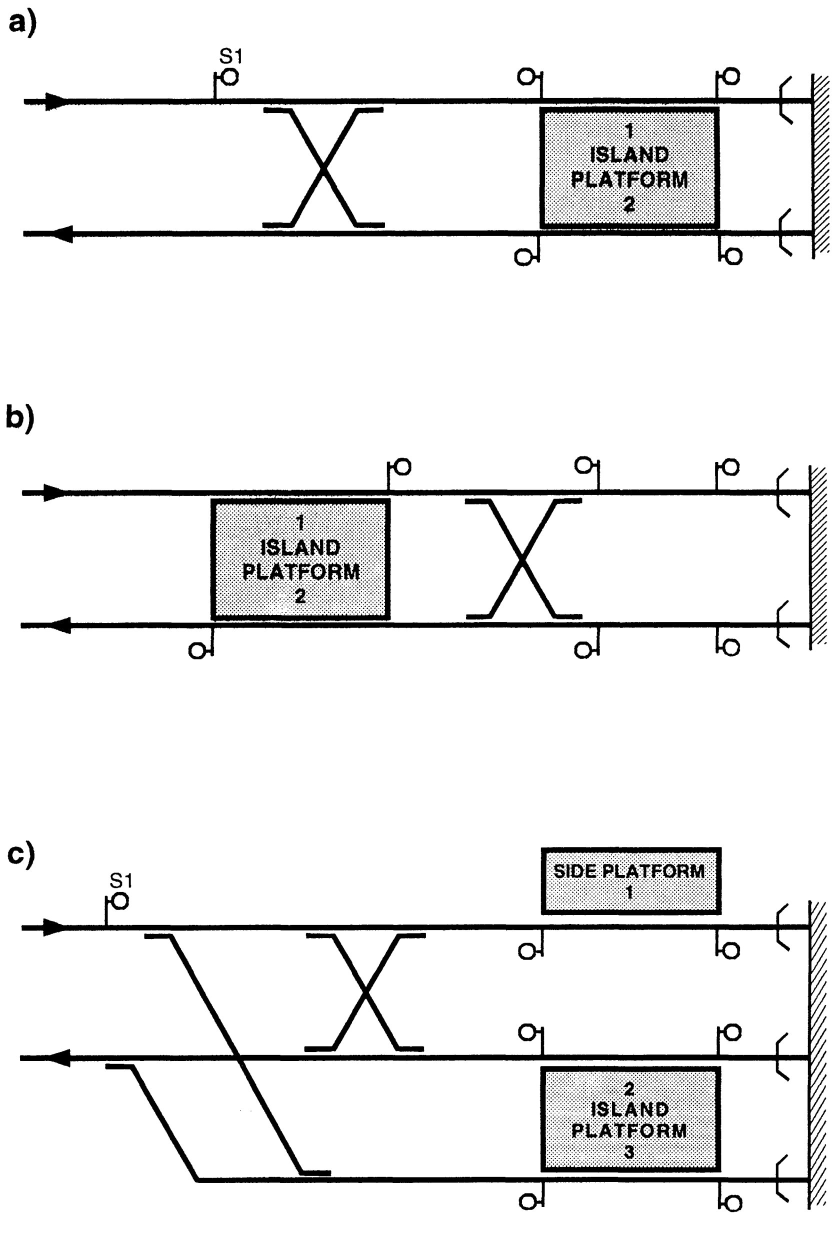

Figure 1: Typical terminal station track layouts

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3 Factors limiting turn-back headway

3.1 Configuration of track layout

The configuration of the track layout dictates the degree of route conflict. The layouts shown in figures 1a and 1c, for example, whilst saving on land-take beyond the station, when compared with that of figure 1b, impose a greater level of route conflict. In figure 1a, a route cannot be set from platform 1 until a train approaching platform 2, has cleared the crossover and released the conflicting route. The earlier the route can be released the better the headway. This depends on the permitted speed both through the crossover and into the platform. The permitted speed through the crossover depends on the turnout angle. A less acute turnout angle allows a higher speed but lengthens the crossover, thereby causing incoming trains to be checked by restrictive signals further out from the station.

The permitted speed into the platform depends on the available overrun distance, influenced also by the characteristics of the signalling and ATC system. Automatically driven trains maintain the permitted approach speed for as long as possible before demanding a single application of service braking. With manual control, however, drivers tend to be more cautious in approaching the final buffer stop, often making a number of repeated brake applications.

The configuration shown in figure 1b provides a better headway when compared to that of figure 1a. This is because trains do not turn back in the face of others approaching the platform. In addition, the turn-back move takes place partly while another train is dwelling at platform 1. However, in order for benefits in headway to be realized, the turn-back move has to be performed quickly. To minimize the turn-back time, 'step-back' working is often practised, in which a second crew boards the rear cab before the train moves into the reversing track. For new railways and upgrade works, an increasing tendency is for the reversing move to be specified as being fully automatic and unmanned. This gives the most rapid turn-back, and reduces the crewing costs. Under this method of working, the achievable headway is more likely to be limited by the passenger dwell times rather than the turn-back move.

3.2 Signalling and ATC system

3.2.1 Conventional fixed-block systems (train-stop or continuous ATP)

The signalling contractor is normally responsible for designing a block layout aimed at meeting specified design headway. This is in terms of signal positions, track-circuit joints and other equipment. Track circuit joints are positioned close to fouling points in order to allow routes to be released as quickly as possible. Signal overlap distances must assume local worst-case train performance. Where available overrun distances are limited, special timing track-circuits are often used that control track-mounted mechanical 'train-stops'. These are lowered to a non-restrictive state after a track circuit has been occupied for a pre-calculated time, based on the permitted speed. If a train enters the platform too fast then it is 'tripped' by a raised train-stop, thereby causing emergency braking. The overrun

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distance must therefore be based on the worst-case speed as the train-stop is struck. Unless measures are otherwise taken, such as inhibiting traction power, this must include the assumption that the train is undergoing full available acceleration as it is tripped.

Fixed block ATP systems based on continuously coded track circuits, also have to make provision for worst-case overrun conditions. Here the overrun distance must allow for a train entering the final track circuit at the coded maximum safe speed, while undergoing full acceleration.

3.2.2 TBS systems (moving-block and fixed-block distance-to-go)

TBS ATC systems based on 'moving-block' principles derive headway improvements from two main components. The first corresponds to that obtained from a continuous real-time calculation of the required safe braking distance, based on current measured values of speed and location. This is generally referred to as a 'distance-to-go' calculation. The second component corresponds to that derived from the frequently updated transmission of current train-location to a trackside processor. In the absence of a strict definition, it is generally acknowledged that it is the second feature that distinguishes 'moving block' from fixed block. The greater the update frequency, then the closer the approximation to a hypothetical pure moving block. Westinghouse Signals define a TBS system that otherwise derives train location from track circuits or axle-counters, as 'fixed-block distance-to-go'.

At terminal stations, the benefit derived from a high frequency of transmitted train-location is not fully exploitable due to the constraints associated with route-conflict. However, there are benefits resulting from a distance-to-go projection. These benefits are as follows:

- In the case of layouts of the type shown in figures 1a and 1c, an incoming train is not checked as early by the signal (S1) protecting the points. It is checked at a location based on the braking requirements for its current actual speed, rather than a worst-case overlap design speed.

- The required overrun distance is reduced because, as the train enters the platform, the remaining distance to the buffer stop is evaluated continuously in relation to the actual required safety distance. This is instead of being based on a worst-case track-circuit run-off speed. Stated alternatively, this means that trains may be able to enter an existing terminal platform or siding at a higher speed, thereby achieving a quicker turn-back.

- Trains can depart from terminal platforms as soon as junction sub-routes are released. No additional time is incurred waiting for full fixed-block signal sections to be cleared. This offers greater potential for recovery during service disruptions because, in principle, trains can be cleared from the terminal station more quickly.

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3.3 Dwell and layover time

The relationship between dwell-time and layover time depends on the type of layout. In the case of the layout shown in figure 1b, the minimum headway depends on the dwell times required both for passenger alighting at platform 1 and for passenger boarding at platform 2. A minimum dwell will exist at platform 1, governed by the time required for the turn-back move. The latter includes a layover time that corresponds to the time required to switch round the active cabs.

For the track layouts shown in figures 1a and 1c, an equal layover time is usually specified for each operational platform. During this time, arriving passengers alight, waiting passengers board, and the active cab is switched round. Under normal headway conditions, a train cannot depart until the next one has entered an adjacent platform, to the extent where it clears the crossover fouling point. The turn-back has to be managed carefully in order to maintain a regular headway The operational layover is critical, and has a narrow tolerance particularly when the terminal station in operating close to capacity. A train that departs too soon will prevent a route being set for an incoming train. Similarly, a train that departs late may will hold a route too long, and therefore restrict the approach of an incoming train. The operational layover time is therefore set directly by the required service headway.

4 Development and application of turn-back simulation models

4.1 Design aim

The aim of the development work was to provide an engineering model that combines the significant static and dynamic parameters that characterize the operation of a given turn-back site. These parameters include the following:

- Track layout geometry;
- Physical characteristics of the rolling stock;
- Performance of the traction and braking systems;
- Signalling layout and ATC system algorithms;
- Response delays associated with points, train detection, interlocking, route setting, and route releasing;
- Requirements for dwell and layover.

The model was to be solved on a time-incremental basis, with a level of accuracy that captures the significant time-constants associated, for example, with traction jerk limiting. It was aimed at predicting the minimum steady-state headway to the nearest second. In addition, the model was required to predict the effect on train movements during conditions of perturbed running, thereby demonstrating the benefits of one type of signalling and ATC system over another.

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4.2 Graphical considerations

In order to understand fully the factors that limit the turn-back capacity of a particular terminal station, it is necessary to provide a detailed graphical representation. This relates the dynamic variables associated with the train, signalling and ATC, to the static features of the layout. The static information includes the track layout, platforms, stop-markers, line-side signals, points, track circuit joints, track gradient profile, and speed restrictions.

The dynamic information includes train movement, occupancy status of track circuits, indication of routes set including lie-of-points, train speed, dwell count-down time and, where TBS is applied, ATC distance-to-go projections and Limit-of-Movement Authority (LMA).

The track layout is represented in terms of straight-line sections, consistent with signalling scheme plans. Such plans are usually scaled only along the track length (x-axis). The track separation (y-axis) is not scaled, thereby leaving sufficient space for annotation. For the animation, however, it is desirable to show consistent movement as trains traverse crossovers between different tracks. To achieve this, the same scaling has to be applied to both the x-axis and y-axis, in order to preserve the correct route-distance. This presents a problem when it is required to represent the entire area of the turn-back site on one screen view. This is because, when scaled down, the separation between adjacent tracks is in the order of several millimetres. This is too small to show the train movements and dynamic features clearly. Instead, therefore, the crossovers are graphically split at their mid-point, and separated by a suitable amount.

5 Typical application

A typical application of the simulation is illustrated in figure 2, which shows a ‘snap-shot’ of a graphical output. The particular layout simulated involves the use of three platforms in turn, to provide a 2-minute headway with a 4-minute layover time. It shows an area of track covering about 400 m, starting at a distance of 1.4 km from the previous station. The graphical area is divided into four main sections. Starting at the top, these correspond to the following:

- Simulation numerical values, giving current speed and target speed for a particular train, simulation time and real-time proportional factor;
- Speed versus distance graph, showing speed restrictions and train speed trajectories referenced to the leading end of each train;
- Track view, showing tracks (adjacent tracks split and separated), platforms, platform dwells, signals, track circuit joints, train length, routes set, ATC projections, TBS LMA’s and track circuit occupancy;
- Gradient profile with percentage values.

The particular view shows a train (number 4) dwelling at platform ‘UPT(1)’, with 20 seconds remaining. A second train (number 5) is dwelling at platform ‘UPT(2)’, with 142 seconds remaining. A third train (number 6) is entering

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platform ‘UPT(3)’, via the crossover between points 16 and 20. TBS train control is assumed, and ATC projections are shown extending from the leading end of train ‘6’ up to a location slightly short of the end of track circuit ‘AB’.

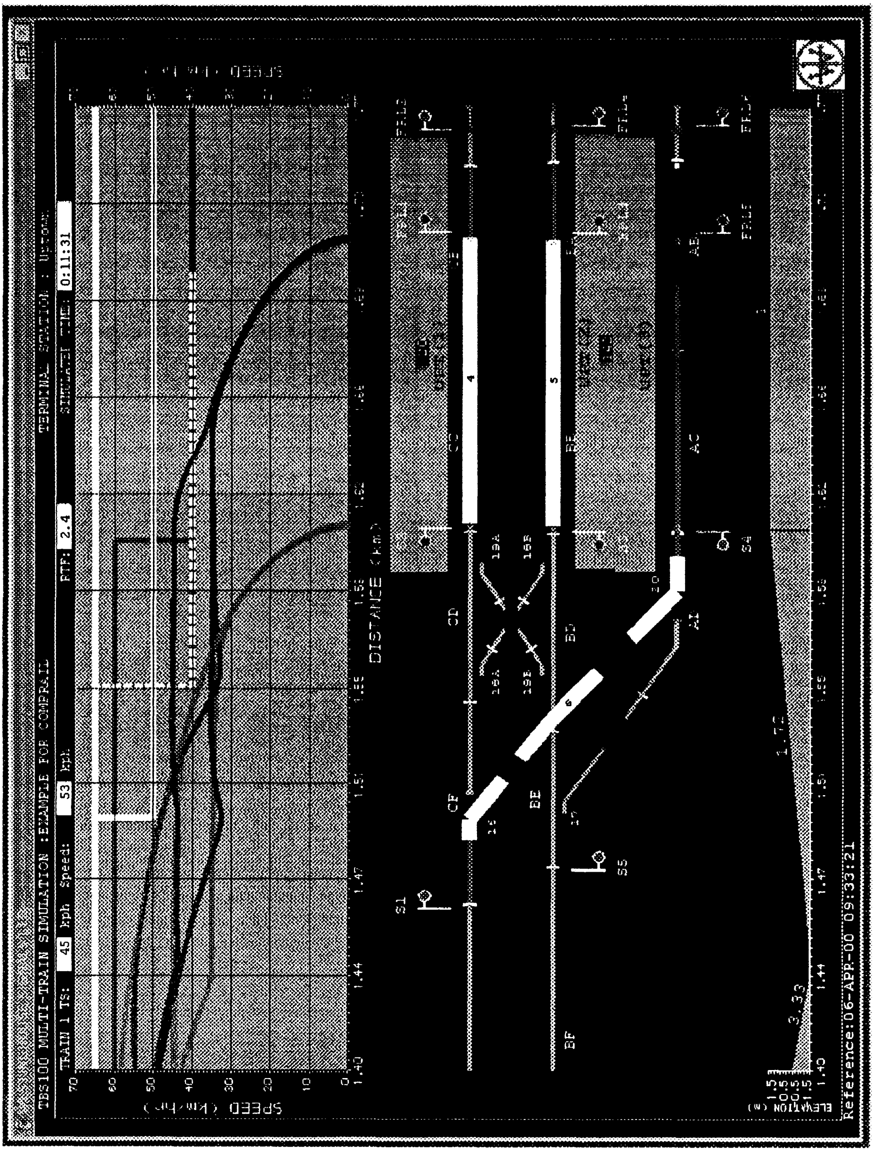

Figure 2: Example of simulation graphical output

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The view corresponds to a stable condition in which, for each route, consecutive trains follow an identical speed trajectory. This provides verification that this particular turn-back layout can provide a sustainable two-minute service interval.

6 Conclusions

The optimization of a turn-back layout is often a complicated design exercise that involves many requirements, some of which are in direct conflict. The paper has attempted to identify the importance of providing a tool that enables the signalling contractor to demonstrate how these factors constrain the frequency with which a given turn-back site can reverse trains. More specifically, such a tool is aimed at allowing the signalling contractor to verify graphically that a particular signalling and train control system can facilitate the design headway specified by a railway administration, for each turn-back movement. The tool must also allow for the optimization of the ATC system parameters.

The tool presented corresponds to a multi-train simulation that drives a scaled graphical animation. In application, this has enabled Westinghouse Signals to demonstrate headway and ATC system performance in support of tender presentations and recommendations for changes to existing layout designs.

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