Identifying and Reducing Performance Uncertainty in UK Railway Timetables

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Abstract

As capacity utilisation increases on Britain's railways, providing punctual and reliable train services is an increasing challenge, and the industry faces increasing levels of knock-on, secondary delay. The situation is complicated by variability in and uncertainty about the relationships between planning headways, margins and running times and the underlying technical values, and thus the supplements and buffer times that are available. This paper describes initial, top-down analysis of timetable and performance data undertaken to identify recurring performance problems, as indicated by extended running times and dwell times, and their locations and times of occurrence. Further work is required to identify the detailed mechanisms of delay generation and propagation, the findings of which can then be used to improve the quality of timetables and, where necessary, the underlying planning criteria.

Keywords: Timetables; Performance; Allowances; Primary Delays; Secondary Delays

1 Introduction

As demand increases and Britain's railway network approaches capacity, it becomes increasingly challenging to operate trains reliably and punctually, and, in particular, there is an increased risk of secondary delays propagating across the network. In such circumstances, it is particularly important to be able to predict the likely performance resulting from a new timetable. However, while it is possible to calculate the passenger and freight capacity of a given timetable, and the predicted revenue associated with a new timetable, it is not generally possible (in the context of practice in Britain) to easily determine and quantify the predicted punctuality and reliability of a timetable, even if it complies with the industry's established rules for timetable planning, and particularly if it operates close to network capacity. Although there are approaches like OnTime [1] available elsewhere to predict the performance of a timetable, the work described in this paper aims to assist with the production of feasible timetables that perform predictably well and maximise the use of the available system capacity.

Following this introduction, the background to and the objectives of the work are first described. The intended methodology and the data used are then summarised. The analysis undertaken and the results obtained are set out in the main body of the paper, in section 4. The results and findings are summarised, and further work outlined, in section 5. Finally, conclusions are drawn, followed by acknowledgements and a list of references.

2 Background and Objectives

2.1 Background

The timetable planning and development process in Britain is set out in Network Rail's Operational Planning Rules [2], which include the Engineering Access Statement and Timetable Planning Rules (TPRs) for a given timetable year. The TPRs include minimum train running and separation criteria such as sectional running times (SRTs), headways, junction margins and platform reoccupation times, specified to the nearest 30 seconds. These specified minimum values include running and dwell time supplements and buffer times between successive train movements, but do not state them explicitly. In principle, if a timetable complies with the industry planning rules, there should be no timetable-related primary delays (i.e. all trains should be able to achieve their scheduled running and dwell times reliably and consistently). It is also reasonable to expect individual timetable-related secondary delays to be small, although the cumulative, propagated secondary delays may be quite large and extensive, particularly in peak traffic periods in the vicinity of network bottlenecks, as they approach their capacity limits.

However, there is some uncertainty about the relationships in the timetable between the SRT, headway, margin and other values specified in the TPRs, and the underlying technical values. A 'one size fits all' approach tends to be taken, and elements of the times used are alternately rounded up and down to the nearest half-minute when calculating cumulative SRTs, to avoid excessive 'padding' in the final values, meaning that some specified values may be difficult to achieve in operating practice. There is also some variability in the way that running time supplements are applied and specified in the timetable. In some cases, they are allocated at the approaches to termini and major intermediate locations and specified explicitly in the working timetable (WTT); in others, they are distributed along a train's entire journey as a proportion of the relevant running times, and not explicitly specified. The latter approach is more consistent with the concept of 'zones of compensation and concentration' [3], helping to ensure that trains arrive at junctions and stations at the right times and in the correct sequence.

Additionally, the opportunities for and risks of secondary delay transmission in Britain are being increased by the introduction and expansion of cross-city train services. Historically, train services typically ran to and from a set of termini ringed around central London (as is also the case in Paris and Moscow, for example, and was formerly so in Berlin), and serving different parts of the country. However, this approach causes capacity constraints due to turnaround time requirements, and also requires interchange for access to the city centre and for cross-city travel. Examples of these 'through' main line services include cross-London trains in the forms of Crossrail (and potentially Crossrail 2) and Thameslink, linking previously-separate networks east and west and north and south of the city, respectively, and also cross-Manchester services.

Delays of three minutes or more on Britain's railways are subject to investigation and attribution, and the reason for the delay and the organisation responsible are (where possible) identified and liable to the payment of compensation to Network Rail and/or other affected operators. However, 'sub-threshold' delays of less than three minutes are not generally attributed or investigated, reducing the understanding of their causes and consequences. The actual timings of each train are recorded to the nearest 30 seconds and compared with the planned values at each timing point, in the form of industry 'Lateness' data (more precise timing data is available for some parts of the network, depending on the signalling and control systems in use).

2.2 Objectives

The overall objective of the work described in this paper is to improve understanding of the sources and causes of primary delay (running and dwell time exceedances) and secondary delay (primary delays in excess of the available buffer times between train services, and also 'upstream' secondary delays in this category). This objective is being pursued by the analysis of standard industry lateness data in conjunction with timetable data and the associated criteria in the railway industry Timetable Planning Rules.

Based on the results of initial, largely manual analysis, it is planned to extend and automate the process, to increase the scope and speed of network coverage, and the understanding of timetable-related performance issues, and changes to the timetable planning process and underlying rules required to improve timetable feasibility, robustness and stability.

In addition to this empirical analysis of timetable and performance data, following typical analytical practice in Britain, the work presented includes the investigation of the potential to apply established international approaches to the assessment of secondary delay and capacity use. These include the Method of Schwanhäußer [4], [5], as applied by Deutsche Bahn (DB) using the STRELE approach, and more general data and process mining techniques. The objectives of these general approaches include:

- the identification of critical parts of the network, i.e. locations, services and times of day that are particularly vulnerable to service perturbations and delays
- the identification of hidden problems
- the identification of timetable related patterns
- the provision of assistance to timetable planners
- the identification and suggestion of small adjustments that may be beneficial

3 Methodology and Data

It was initially intended to undertake 'traditional' empirical analysis of actual, historic delay data in parallel with the application of the Method of Schwanhäußer [4], [5] to evaluate expected levels of secondary delay, and to compare the results. However, it was found that the TPR criteria and the Lateness data lacked the detail and precision required for successful application of the Method of Schwanhäußer, and more general data mining and analysis approaches using MATLAB 2018a [6] were therefore used instead, and the detailed empirical analysis was postponed, pending initial general results.

The original plan was to focus on the four-track section of the South West Main Line (SWML) between Basingstoke and London Waterloo, used predominantly by South Western Railway (SWR) passenger services, and forming part of the Wessex route and Southern region of Britain's railway network. SWR's network map is shown in Figure 1, with London Waterloo at the top right/north-east, and the network extending to the south and west. Most of the network is double-track, with some single-line sections, branches and extremities. Minimum service frequencies between origin-destination pairs are 1-2 trains per hour (tph), and increase as the lines and services converge towards Waterloo.

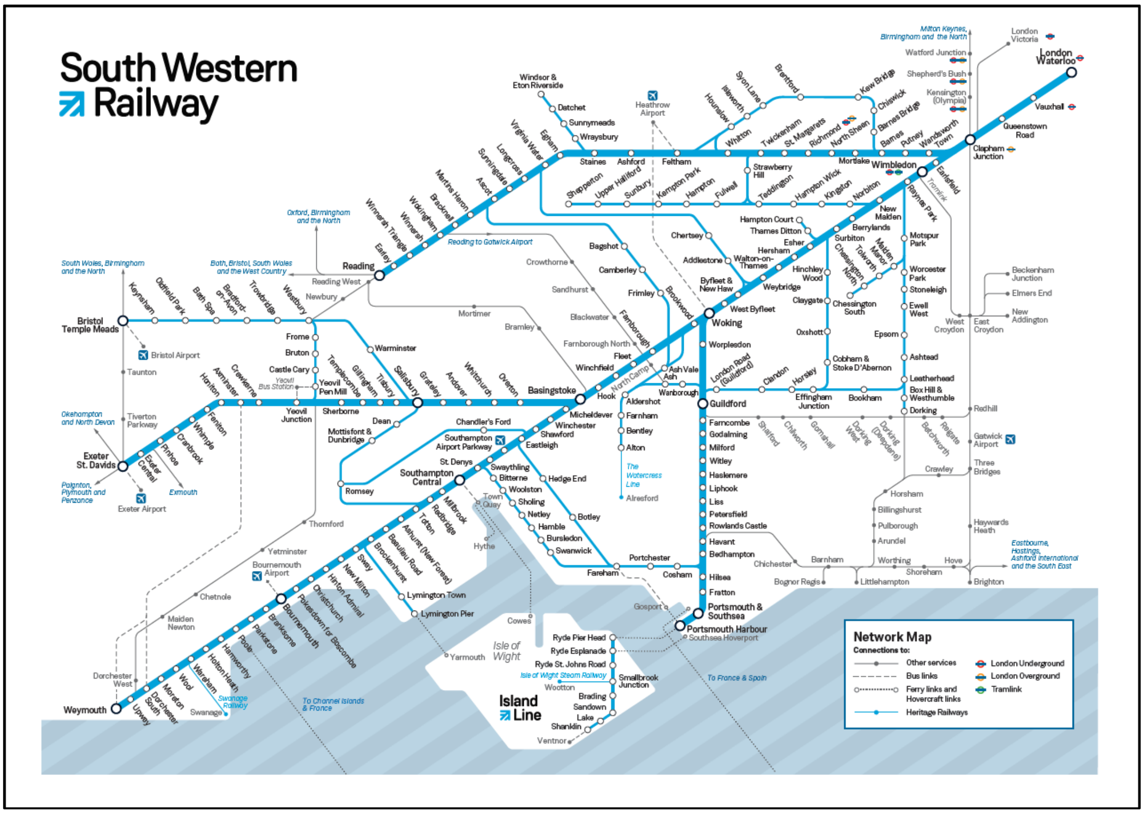

Figure 37: SWR Network Map [7]

However, contrary to the original plan, the initial general analysis indicated a relatively low level of running time and dwell time exceedances on this section of the network. This is possibly because of the intensity of service (the Up Fast line between Woking and Waterloo carries up to 27 tph in the weekday morning peak period, and is the busiest section of main line railway in Britain) and consequent focus on performance. This is an interesting and useful finding in itself.

Timetable and performance data was obtained from Network Rail, and the relevant minimum planning headway, margin, dwell and other times are available from Network Rail's Timetable Planning Rules (TPRs). For the reasons described above, the initial work used only the performance data, which consists of a year's Lateness data for SWR services. SWR shares parts of its network with other passenger and freight train operators, and the analysis therefore focussed mainly on those sections of the network where SWR is the sole or dominant operator, and there is little or no interaction with other timetabled services. The Lateness dataset is recorded to the nearest 30 seconds and includes traffic records between the timetable changes on 10 December 2017 and 09 December 2018. It contains almost 20 million entries, of which 4.4m actual time recordings are missing for reasons which are unclear. Excluding these and other incomplete records from the dataset leaves almost 14.9m records (74.6% of the dataset) available for further investigation.

4 Analysis and Initial Results

Further analysis was undertaken to produce (i) summary statistics for service punctuality, the distribution of node- and link-based records across the network, the distributions of changes in lateness for dwell and running times, and (ii) ranking of changes in lateness by location, and detailed analysis of a route section and station.

4.1 Punctuality – summary statistics

Punctuality is one of the main key performance indicators (KPIs) for a railway system. The punctuality statistics for all network nodes, including stations, junctions and other timing points, in the cleansed dataset are summarised in Table 18 and Figure 2.

Table 18: Cumulative Delay Distribution for various Punctuality Thresholds

Lateness [min]	<0	≤0	<1	<3	<5	<10	<15
Cumulative Percentage of Entries	35.5%	50.9%	59.0%	79.1%	87.8%	95.3%	97.6%

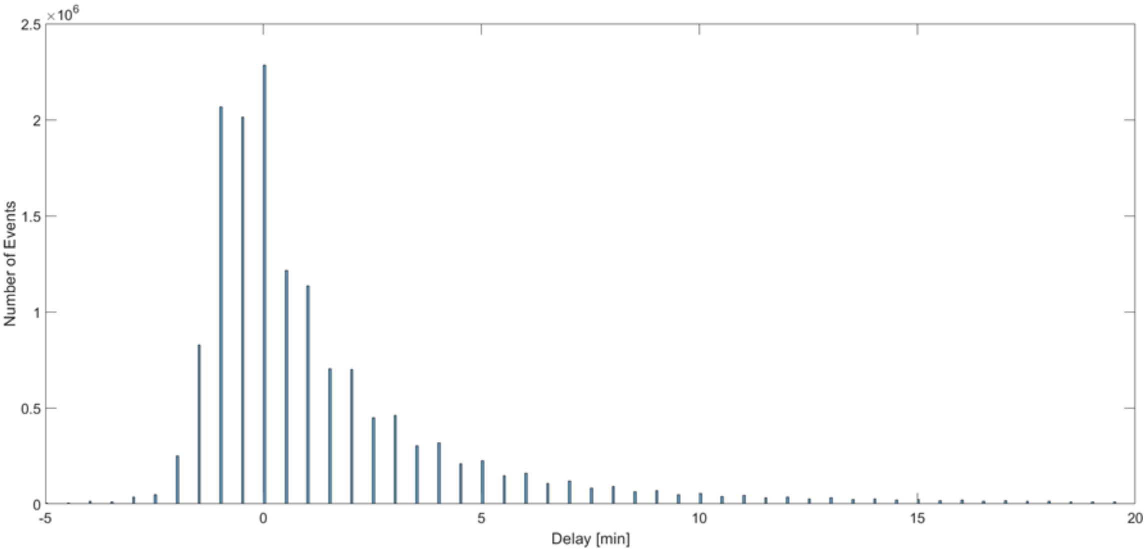

Figure 2: Delay distribution for the South Western Railway Network in the 2017-18 timetable period

As indicated above, these results are for all recorded locations and not only stations. However, considered in terms of the new industry performance metrics [8], it can be seen that 59% of trains arrive at recorded locations on time (i.e. within one minute of their scheduled times), and 97.6% arrive within 15 minutes. As well as trains being delayed and running late, many trains run ahead of schedule and arrive early at recorded locations. In the dataset more than one third of the trains run ahead of time, which in consequence can lead to undesired conflicts in the train paths, and may indicate spare capacity.

In order to focus on the most relevant, busiest locations in the network, those nodes with fewer than 3,650 records (i.e. fewer than ten trains per day on average, ignoring the effects of data cleansing) were excluded from further analysis.

The number of recorded entries for the remaining 188 nodes, or vertices, in the dataset, including stations, important junctions and other timing points, are shown in Figure 3. It clearly shows that there is a small number of locations (i.e. major stations and junctions, like London Waterloo, Clapham Junction, Wimbledon and Woking) with large throughputs of train services, and thus a disproportionate impact on the performance of the overall network.

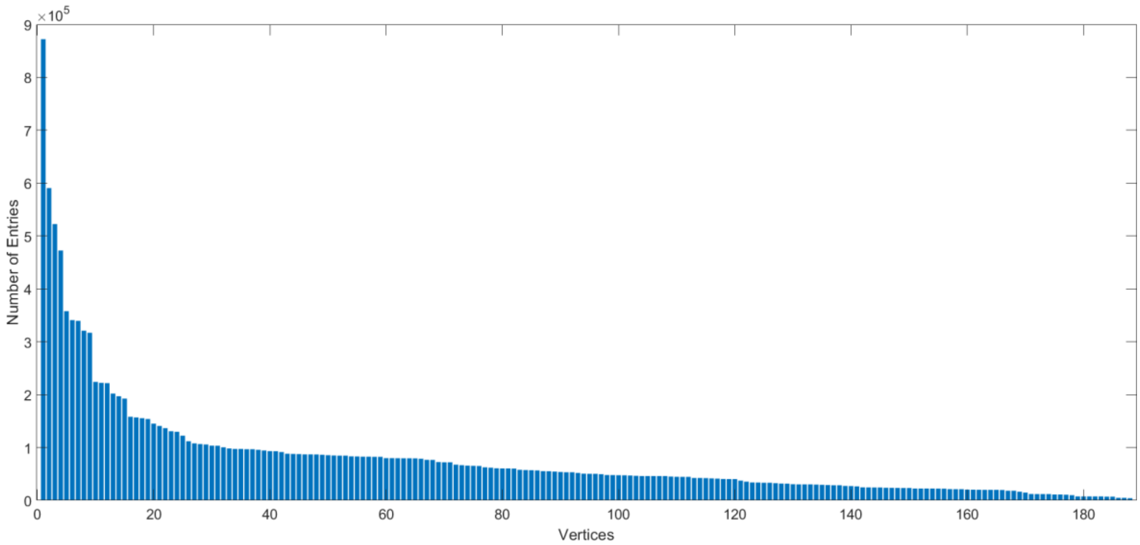

Figure 3: Number of entries for the observed nodes/vertices in decreasing order

After the removal of incomplete and low-frequency entries in the dataset, there were 587 edges, or links between nodes/vertices remaining. These include 'self-loops', or links 'connecting stations to themselves', corresponding to dwell times. The numbers of records corresponding to these are shown in descending order in Figure 4.

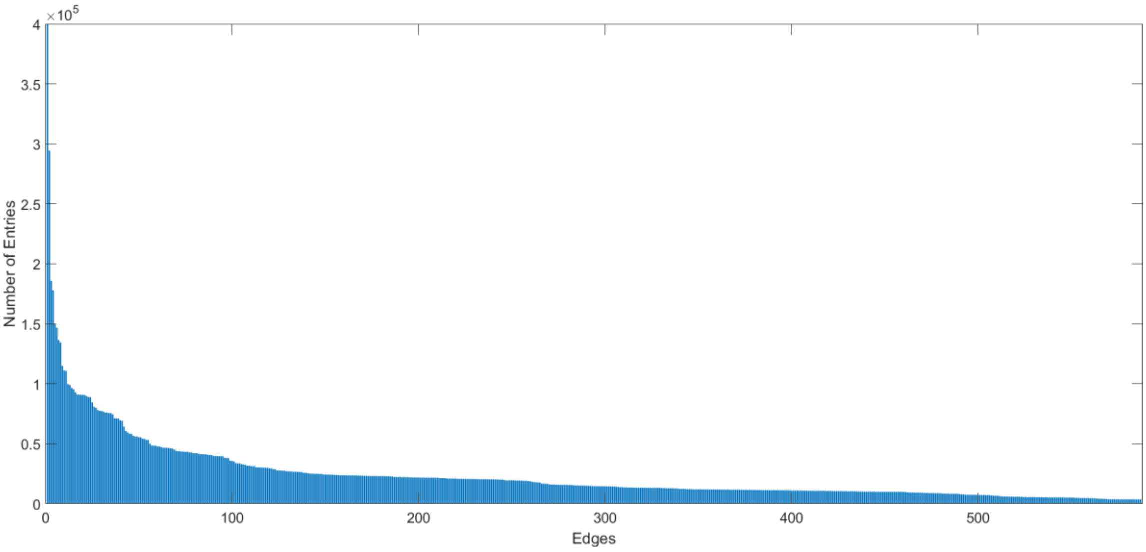

Figure 4: Number of entries for the observed edges in decreasing order

As indicated above, Lateness data is recorded to the nearest 30 seconds. Recorded timings are based on signal berth occupation times and pre-defined 'offsets' to arrival, departure and/or passing times at timing points. Precision of recording varies from manual record-keeping in a dwindling number of old semaphore signal boxes, to timings to the second in modern signalling and control systems, but rounded as necessary for Lateness output purposes.

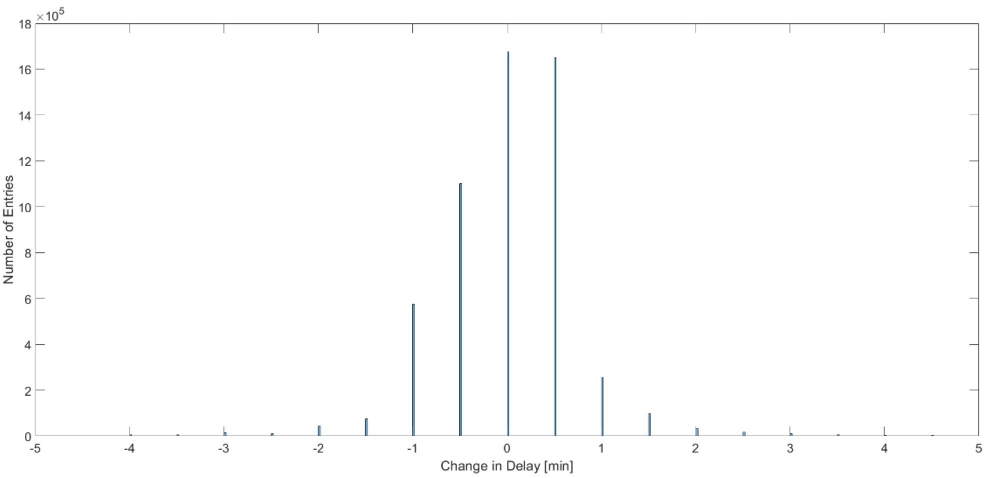

Figure 5: Delay evolution for dwell times

In Figure 5, the delay evolution (i.e. increase or decrease in lateness) at recorded stations in the network is shown. Of the 5.6m entries reflecting dwell times, 37.3% correspond to an increase in lateness due to extended dwells at stations and 7.9% of the dwell times are at least one minute larger than planned. On the other hand, in 32.8% of the cases the actual dwell times are shorter than the planned ones. Since trains will not normally leave a station prior to their scheduled departure times, this shows that dwell times can be and often are reduced in order to recover from previous delays.

Figure 6 illustrates the equivalent evolution of delay for sectional running times. In 35.8% of cases, the actual running time exceeds the planned running time, and, in 17.1% of cases, by at least one minute. Conversely, 29.1% of the recorded movements are faster than planned in the schedule: this is an undesirable situation, as it may cause conflicts and delays along the line, especially at junctions. It could be due to consistent delays causing drivers to drive aggressively, or to rounding of scheduled times in the timetabling process. Delay decreases of more than a minute are a strong indicator that the timetable does not reflect actual running times.

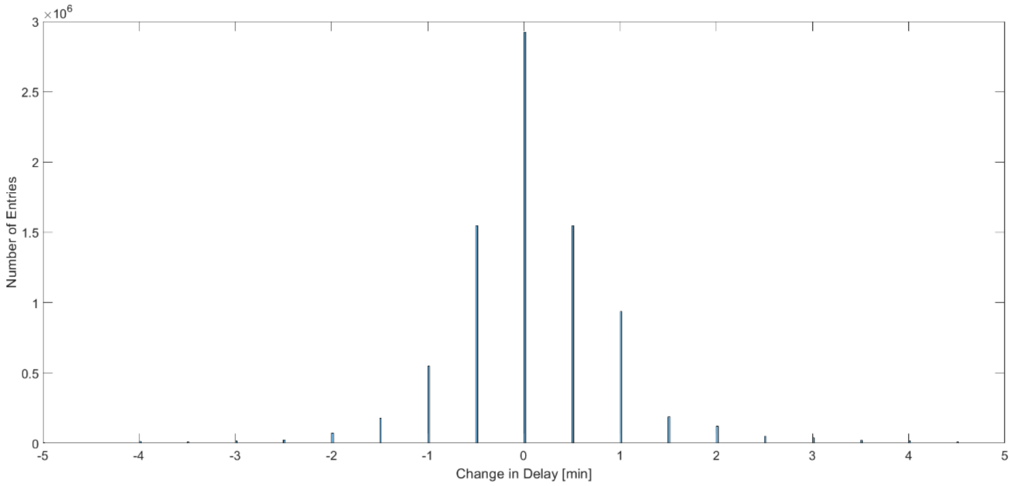

Figure 6: Delay evolution for sectional running times

4.2 Punctuality – detailed analysis

The previous results were investigated further to identify stations and route sections which contribute the most primary or secondary/knock-on delays within the network. In the following station abbreviations, so-called TIming Point LOCations (TIPLOCs) are used. These are limited to seven characters and refer to points relevant for the timetable. A list in [9] is available to decipher the following stations.

In Figure 7, the top 25 'delay sections' are presented and sorted by percentage of trains delayed, percentage significantly delayed (i.e. by at least one minute), and number of entries (i.e. trains) by delay/route section. Sorting by the percentage of delayed trains reveals location pairs between which a large proportion of the trains is shown as delayed. However, this can be misleading, as in the case of "CHSSS-CHSSN" (Chessington South – Chessington North, the first station pair at the end of a suburban branch line). Here, 78% of the trains are shown as delayed, but none of them is delayed by more than a minute. This, together with the location, suggests that there may simply be a discrepancy between the scheduled and achievable running time, due to rounding in the timetable. Providing an additional 30s of running time would enable 100% punctuality for trains on this section and there is no obvious reason for not doing so – if the 'downstream' schedule requires the specified timings at Chessington North, the departure time from Chessington South could be made earlier by 30s, assuming the turnaround times permit it.

From	To	% delay	% sig. del.	# entries	From	To	% delay	% sig. del.	# entries	From	To	% delay	% sig. del.	# entries
'HAMPTON'	'FULWELL'	99.9%	18.7%	11606	'ROMSEY'	'MOTFONT'	84.0%	80.6%	5262	'WATRLMN'	'VAUXHLM'	75.1%	49.2%	149476
'EPSM'	'EWELW'	98.7%	29.2%	20996	'EFNGHMJ'	'BOOKHAM'	78.2%	78.2%	9949	'VAUXHLM'	'WATRLMN'	21.9%	17.5%	146730
'DRCHS'	'WOOL'	98.1%	68.5%	9860	'RDNG4AB'	'RDNGSJN'	76.8%	76.8%	14441	'HCRTJN'	'SURBITN'	54.4%	25.3%	111170
'WOKNGHM'	'BRACKNL'	96.9%	23.2%	14501	'DEAN'	'MOTFONT'	75.9%	75.9%	5268	'NEWMLDN'	'SURBITN'	24.8%	23.6%	99707
'ALDRSJS'	'ASHH'	92.9%	15.9%	10592	'WSORAER'	'DATCHET'	75.4%	75.4%	12004	'SURBITN'	'NEWMLDN'	15.2%	9.6%	98967
'HCRTJN'	'HNCHLYW'	92.8%	1.8%	11687	'WEYMTH'	'DRCHS'	74.9%	74.7%	9806	'WDON'	'RAYNSPK'	54.1%	4.0%	92969
'HONITON'	'AXMNSTR'	92.2%	34.5%	6176	'BKNHRST'	'BOMO'	82.8%	69.8%	16759	'RAYNSPK'	'WDON'	40.5%	34.5%	91077
'NETLEY'	'HMBLE'	90.4%	21.8%	3673	'HCRTJN'	'WOKING'	79.2%	69.6%	42878	'ERLFLD'	'WDON'	6.1%	6.1%	91008
'ASHD'	'LETHRHD'	88.8%	1.5%	19049	'DRCHS'	'WOOL'	98.1%	68.5%	9860	'CLPHMJM'	'ERLFLD'	5.9%	5.7%	90821
'REDBDGE'	'BKNHRST'	87.9%	55.1%	8069	'WDON'	'ERLFLD'	64.5%	63.4%	88856	'SURBITN'	'HCRTJN'	7.1%	6.6%	90729
'PCHESTR'	'FAREHAM'	86.4%	5.3%	8338	'STAINES'	'EGHAM'	63.4%	61.8%	27603	'VAUXHLM'	'CLPHMJM'	15.2%	15.1%	90619
'EXMOTHJ'	'EXETERC'	85.6%	10.5%	5823	'STRWBYH'	'TWCKNHM'	63.6%	60.1%	14075	'CLPHMJM'	'VAUXHLM'	13.0%	13.0%	89682
'BARNES'	'CLPHMJM'	85.4%	15.2%	12841	'VRGNWTR'	'EGHAM'	59.7%	59.0%	25701	'WDON'	'ERLFLD'	64.5%	63.4%	88856
'SYONLA'	'BNTFORD'	85.0%	0.0%	20464	'COSHAM'	'FAREHAM'	58.7%	57.6%	5384	'ERLFLD'	'CLPHMJM'	16.6%	16.5%	88831
'ROMSEY'	'MOTFONT'	84.0%	80.6%	5262	'BSNGSTK'	'WATRLMN'	56.1%	56.1%	11902	'WOKING'	'WOKINGJ'	39.4%	33.9%	79942
'STDENYS'	'SOTPKWY'	83.9%	12.5%	22850	'BARNES'	'RICHMND'	57.0%	56.1%	27763	'WOKINGJ'	'WOKING'	48.5%	41.9%	78046
'MRTLKE'	'NSHEEN'	83.1%	0.8%	21880	'GUILDFD'	'WANBRO'	55.1%	55.1%	10548	'WDON'	'CLPHMJM'	72.9%	47.2%	77474
'BKNHRST'	'BOMO'	82.8%	69.8%	16759	'REDBDGE'	'BKNHRST'	87.9%	55.1%	8069	'NEWMLDN'	'WDON'	20.0%	18.6%	76778
'TWCKNHM'	'WHTTONJ'	81.5%	11.6%	15125	'SURBITN'	'TDITTON'	53.9%	53.9%	11923	'CLPHMJM'	'WATRLMN'	51.0%	36.0%	76002
'FELTHAM'	'HOUNSLW'	80.7%	7.5%	12062	'NINELMJ'	'VAUXHLM'	61.7%	51.5%	56702	'CLPHMJM'	'WDON'	20.4%	6.4%	75559
'MOTFONT'	'ROMSEY'	80.1%	13.2%	5295	'REDBDGE'	'SOTON'	59.4%	51.0%	22145	'WDON'	'NEWMLDN'	19.1%	17.3%	75488
'HCRTJN'	'WOKING'	79.2%	69.6%	42878	'TOTTON'	'BKNHRST'	63.5%	50.6%	8766	'WATRLMN'	'CLPHMJM'	47.4%	24.6%	74456
'EFNGHMJ'	'BOOKHAM'	78.2%	78.2%	9949	'WATRLMN'	'VAUXHLM'	75.1%	49.2%	149476	'QTRDBAT'	'CLPHMJM'	40.3%	38.8%	71226
'CHSSS'	'CHSSN'	78.1%	0.0%	11050	'TWCKNHM'	'STRWBYH'	49.8%	48.6%	14883	'NINELMJ'	'QTRDBAT'	36.6%	34.6%	71036

% delay	percentage of entries with actual time exceeding planned time
% sig. del.	percentage of entries with actual time exceeding planned time by at least one minute
# entries	number of entries for the relation

Figure 7: Extract of the results for running time delay evolution sorted by percentage of delays, percentage of significant delays and number of entries

Sorting the records by percentage of significant delays reveals further information. For instance, on several route sections the percentage of delayed trains and the percentage of significantly delayed trains are equal. Further investigation may indicate that a section is highly vulnerable to knock-on delays, or the scheduled running times cannot be achieved. Interestingly, this phenomenon affects sections with low, moderate and high traffic levels. Furthermore, it is noteworthy that many of those sections with high delay probability are unlikely to be monitored in detail, as they are not among the main lines of the network (this supports the observation made above, about the relatively good performance on the busiest section of the SWML).

The number of entries/trains gives further insight, since delays in those sections have a large impact on the network as a whole. Unsurprisingly, all of the 25 sections with the highest recorded throughput are on the SWML. Although performance on the line is relatively good, possibly due to particular attention to performance detail by the infrastructure manager and dominant operator (SWR), punctuality on the line is mixed. It is notable that approximately 50% of the starting trains (WATRLMN-VAUXHLM, i.e. London Waterloo to Vauxhall) are delayed by at least one minute, possibly reflecting conflicts on the approaches to Waterloo, or late arrival of inbound trains and insufficient turnaround time.

Dwell times are scheduled to provide the necessary time for passengers to alight from and board trains. In Figure 8, data for the top 25 stations and dwell times are presented and sorted in a similar manner to Figure 7. It initially appears that the required dwell times are better reflected in the timetable than the running times.

From	To	% delay	% sig. del.	# entries	From	To	% delay	% sig. del.	# entries	From	To	% delay	% sig. del.	# entries
'SWNWICK'	'SWNWICK'	96.7%	27.8%	3692	'BOXHAWH'	'BOXHAWH'	87.6%	59.1%	4858	'CLPHMJM'	'CLPHMJM'	13.3%	10.3%	399556
'REDBDGE'	'REDBDGE'	91.2%	11.5%	12280	'PINHOE'	'PINHOE'	90.0%	54.7%	10411	'VAUXHLM'	'VAUXHLM'	5.7%	5.5%	294436
'PINHOE'	'PINHOE'	90.0%	54.7%	10411	'FRBRMN'	'FRBRMN'	47.3%	46.5%	42325	'WDON'	'WDON'	5.8%	5.7%	185899
'BRANKSM'	'BRANKSM'	89.8%	5.7%	23530	'BNTEY'	'BNTEY'	45.5%	44.8%	9917	'ERLFLD'	'ERLFLD'	63.6%	1.1%	177875
'BOXHAWH'	'BOXHAWH'	87.6%	59.1%	4858	'WOOL'	'WOOL'	43.7%	43.2%	14966	'RAYNSPK'	'RAYNSPK'	57.6%	8.7%	136531
'LIPHOOK'	'LIPHOOK'	84.1%	8.8%	10536	'WBYFLET'	'WBYFLET'	65.6%	37.7%	48528	'WOKING'	'WOKING'	11.4%	10.4%	134384
'HILSEA'	'HILSEA'	82.6%	5.6%	39602	'BOTLEY'	'BOTLEY'	54.9%	35.2%	15216	'SURBITN'	'SURBITN'	20.6%	8.8%	114894
'DEAN'	'DEAN'	82.2%	6.4%	5264	'SWNWICK'	'SWNWICK'	96.7%	27.8%	3692	'PUTNEY'	'PUTNEY'	7.5%	7.3%	110758
'LISS'	'LISS'	80.9%	7.8%	10524	'CBRK'	'CBRK'	64.4%	23.4%	11183	'TWCKNHM'	'TWCKNHM'	4.9%	4.1%	96563
'ASHH'	'ASHH'	79.0%	3.4%	21050	'GUILDFD'	'GUILDFD'	23.3%	22.0%	42860	'RICHMND'	'RICHMND'	11.6%	11.0%	95379
'TMPCMB'	'TMPCMB'	78.5%	18.4%	13976	'HASLEMR'	'HASLEMR'	40.7%	20.7%	35866	'BARNES'	'BARNES'	59.1%	8.1%	84533
'WINETGL'	'WINETGL'	76.5%	2.6%	26478	'BOMO'	'BOMO'	22.0%	20.5%	30365	'QTRDBAT'	'QTRDBAT'	68.0%	1.1%	80850
'MRTLKE'	'MRTLKE'	75.4%	2.4%	43338	'SLSBRY'	'SLSBRY'	25.0%	19.9%	13831	'FELTHAM'	'FELTHAM'	5.0%	4.8%	77208
'MALDENM'	'MALDENM'	74.5%	7.6%	22294	'ALDRSHT'	'ALDRSHT'	20.2%	19.4%	43796	'STAINES'	'STAINES'	16.0%	15.6%	75960
'ADLESTN'	'ADLESTN'	74.4%	2.5%	22181	'TMPCMB'	'TMPCMB'	78.5%	18.4%	13976	'NEWMLDN'	'NEWMLDN'	61.8%	3.7%	71014
'ERLY'	'ERLY'	73.8%	2.4%	26477	'PTRSFLD'	'PTRSFLD'	20.6%	18.1%	35658	'MOTSPRP'	'MOTSPRP'	51.9%	1.3%	64326
'WINERSH'	'WINERSH'	73.4%	2.6%	26501	'BSNGSTK'	'BSNGSTK'	21.0%	17.9%	54077	'FRATTON'	'FRATTON'	23.2%	17.1%	60661
'BITERNE'	'BITERNE'	72.9%	1.7%	3659	'ASCOT'	'ASCOT'	18.4%	17.8%	31645	'BSNGSTK'	'BSNGSTK'	21.0%	17.9%	54077
'NRBITON'	'NRBITON'	72.8%	1.8%	46209	'FRATTON'	'FRATTON'	23.2%	17.1%	60661	'EGHAM'	'EGHAM'	31.8%	3.3%	53228
'SUNNGDL'	'SUNNGDL'	72.5%	2.9%	31217	'GDLMING'	'GDLMING'	19.7%	17.0%	18640	'VRGNWTR'	'VRGNWTR'	72.1%	15.0%	53208
'VRGNWTR'	'VRGNWTR'	72.1%	15.0%	53208	'FARNHAM'	'FARNHAM'	19.1%	15.9%	23073	'ASFDMSX'	'ASFDMSX'	56.3%	0.9%	50089
'KEWBDGE'	'KEWBDGE'	72.0%	1.1%	39616	'STAINES'	'STAINES'	16.0%	15.6%	75960	'WBYFLET'	'WBYFLET'	65.6%	37.7%	48528
'MLFORD'	'MLFORD'	71.7%	3.4%	9937	'COSHAM'	'COSHAM'	15.6%	15.0%	26909	'TEDNGTN'	'TEDNGTN'	65.7%	14.2%	48421
'STDENYS'	'STDENYS'	71.6%	12.8%	27018	'VRGNWTR'	'VRGNWTR'	72.1%	15.0%	53208	'HAMWICK'	'HAMWICK'	60.0%	1.5%	48309

% delay	percentage of entries with actual time exceeding planned time
% sig. del.	percentage of entries with actual time exceeding planned time by at least one minute
# entries	number of entries for the relation

Figure 8: Extract of the results for dwell time delay evolution sorted by percentage of delays, percentage of significant delays and number of entries

There is, however, still a proportion of stations for which the actual dwell times are at least 30 seconds longer than planned. If, for these stations, the share of dwell time extensions that exceed one minute is relatively small, it is a clear indication of a situation where timetabling can be improved, and adding 30s to the dwell times for affected trains should reduce the extent of delays and their propagation.

Sorting by significant delays, the comparison to running times shows that the situation is less dramatic in this case. One of the reasons could be that due to the number of staff involved and the nature of dwell times, they are easier to monitor and any necessary adjustments can be made quite easily. In contrast to running times, different rolling stock types (assuming similar internal layouts and door locations) are unlikely to affect dwell time durations.

Sorting the results by the number of dwell times indicates that the busiest stations tend to perform relatively well, although busy suburban stations like Earlsfield and Raynes Park, where arriving morning peak trains tend already to be heavily loaded, are unsurprisingly prone to frequent, minor dwell time extensions. There is thus considerable room for improvement, since even small, but systemic, exceedances can inflict secondary delays on large numbers of trains.

4.3 Detailed analysis of a section

The Vauxhall-Clapham Junction section, close to the terminus at London Waterloo, is one of the busiest sections of the South Western Railway network, with separate tracks for suburban, main line and Windsor line train services. The following analysis was performed for trains with scheduled stops at both Vauxhall and Clapham Junction. The section is of particular interest and relevance, since delays occurring here are likely to propagate to other trains as secondary delays and can spread across the network. The data used for sections 4.3 and 4.4 is filtered for weekdays only, so that data for (less busy) weekends do not skew the analysis and results.

The average delay for trains after a scheduled stop at Vauxhall is 1.82 minutes. This number is discouraging and indicates that trains are ‘getting off to a bad start’, as Vauxhall is the first scheduled stop after starting from the terminus at London Waterloo. The situation deteriorates further by the time the trains arrive at Clapham Junction, where they are delayed by an average of 2.12 minutes. Since the lines between Vauxhall and Clapham Junction are largely segregated, with minimal interaction with other lines, it seems likely that there may be insufficient scheduled running time in the timetable.

Most of the trains have a scheduled running time of 4 minutes. However, due to the varying acceleration characteristics of different train classes, not all trains are able to reach the next stop within the scheduled time. Figure 9 suggests that there are approximately 10 to 15% of trains throughout the day whose punctuality would improve if their scheduled running times were increased by one minute. The significant increase in delayed trains beginning at 17:00 is almost certainly due to interactions between successive trains as traffic builds up in the evening peak. The observed excessive running times are therefore either due to the rolling stock additionally used and/or due to congestion at stations and trains waiting to enter them. Between 18:00 and 19:00, the actual average running time is 4.45 minutes whereas the average scheduled running time is still 4 minutes.

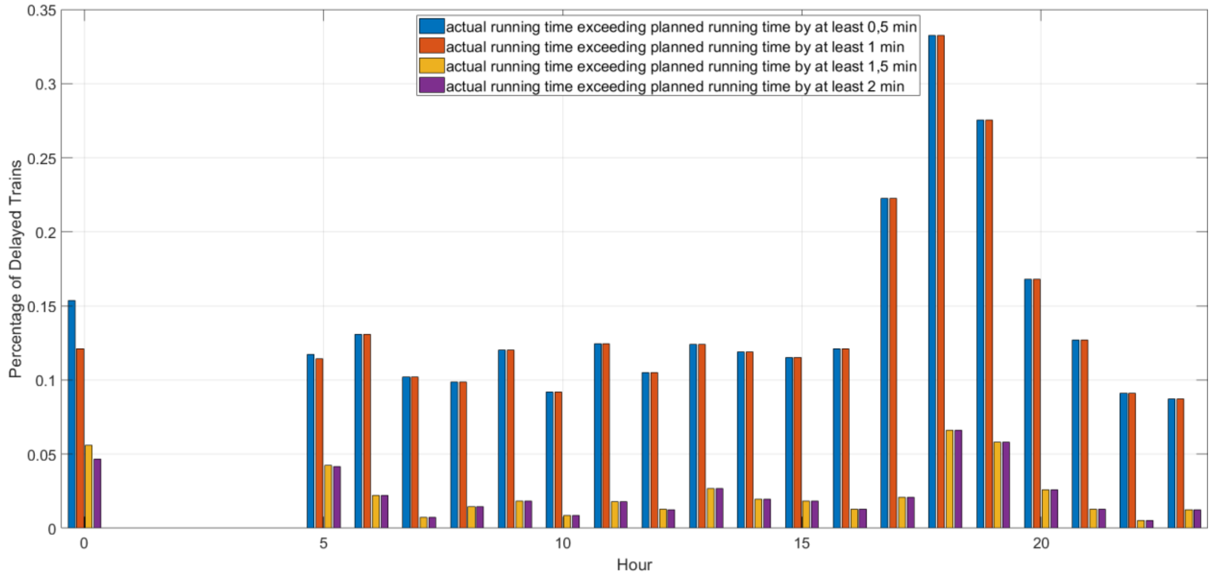

Figure 9: Average delay probability for Vauxhall – Clapham Junction depending on time of day

4.4 Detailed Analysis of a station

Barnes station was chosen for further analysis for two reasons. First, it is served by eight local tph during the off-peak, and is located in the busy suburban area of London, close to Clapham Junction, and thus vulnerable to delay propagation. Second, it shows a significant difference between trains being delayed in general and trains being delayed significantly, i.e. by at least one minute.

For stopping trains, the average delay on arrival is 1.09 minutes and on departure 1.22 minutes. Hence, there seems to be a systemic delay increase. This assumption is supported by Figure 10, which shows the change in delay to trains stopping at Barnes station by time of day.

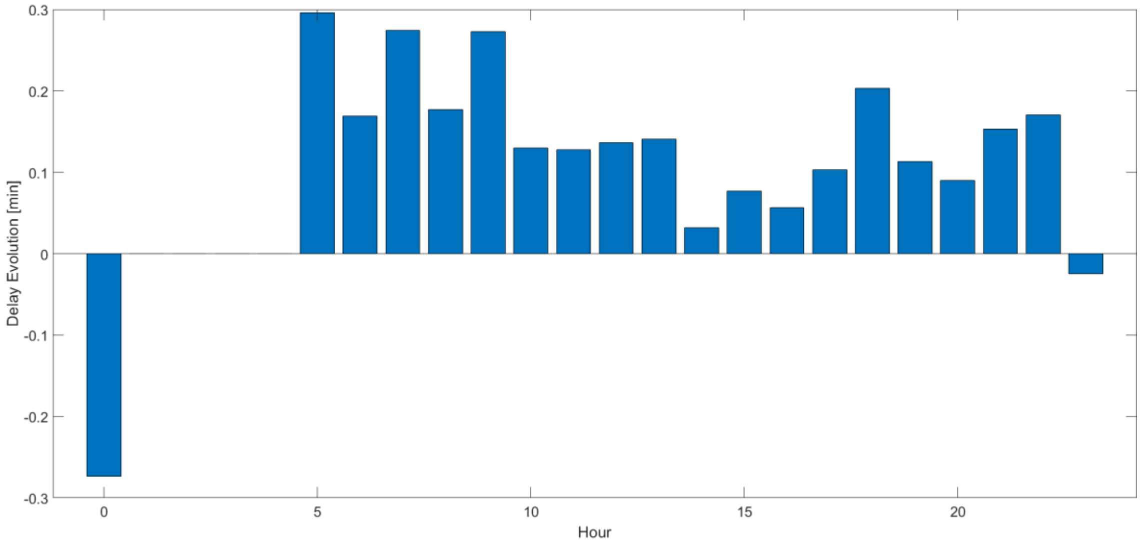

Figure 10: Average delay evolution for Barnes station according to time of day

The question remains whether it would be beneficial to adjust the dwell times and, if so, to what extent it would reduce the incurred delays. Figure 11 shows the percentage of delayed trains by time of day and extent of delay.

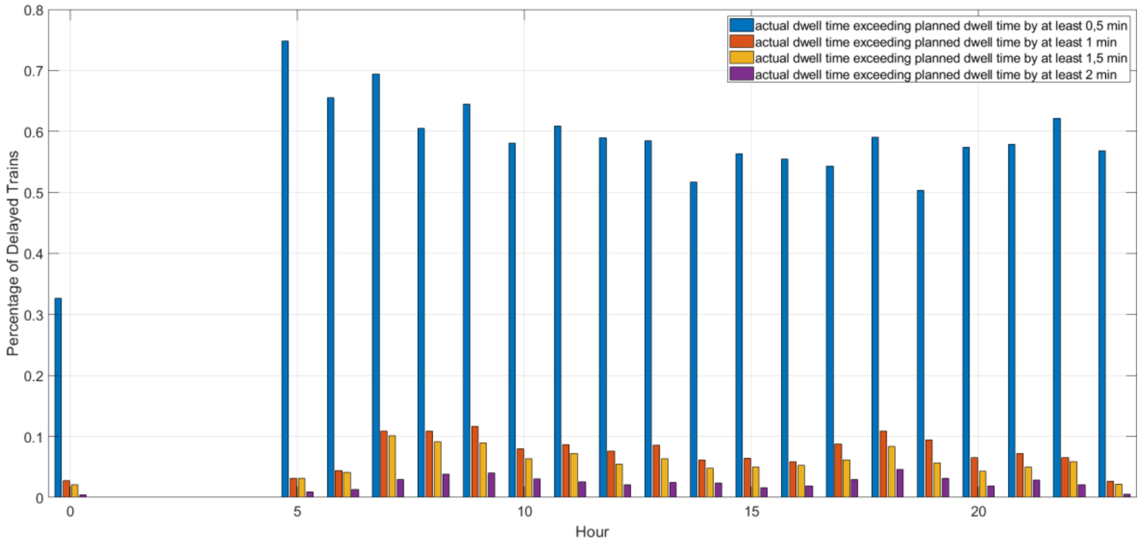

Figure 11: Average delay probability for Barnes Station depending on time of day

Based on these results, an additional 30 seconds of dwell time would reduce the proportion of trains experiencing increased delay from 58.7% to 8.0% on average. A further 30s increase of the dwell time would not be as beneficial as the first, reducing the proportion only to 6.2%.

The effects of the peak periods are not particularly clear in Figure 10, whereas the percentage of trains in Figure 11 delayed by at least one minute clearly shows the rush hours to and from London. The additional trains operated during the peak periods make it difficult to increase dwell times by more than 30 seconds, since this would consume scarce system capacity.

5 Findings

Recorded performance (lateness) data for South Western Railway train services between December 2017 and December 2018 was used to analyse performance on the network and to identify consistent apparent flaws in the timetable.

The potential for the application of the Method of Schwanhäußer to the data was investigated, with a view to using this established approach to predict secondary delays. However, it was found that the timetable planning criteria and the recorded performance data lacked the necessary precision and detail to enable this. In particular, the lateness data neither includes detailed infrastructure information nor does it include train-specific information. The planning rules, e.g. for headway times, are in this respect quite generic and cover large areas. Due to these shortcomings in data availability, a more general data mining and analysis approach was used.

The initial analysis indicated the distribution of various levels of lateness within the system, and illustrated the distribution (and concentration at certain, major locations) of train movements across the network. The analysis then focussed on these busier locations to identify general trends in the evolution of delay in running times and dwell times. It was found that delays are consistently increasing on network links and at stations, but typically by relatively small amounts (i.e. 30s or less), indicating that amendments to the timetable and the underlying planning criteria would be beneficial to timetable feasibility and overall performance. These findings were confirmed by more detailed analysis of running times and lateness changes on the route section between Vauxhall and Clapham Junction, close to the terminus at London Waterloo, and of dwell times at the busy inner suburban station at Barnes, close to Clapham Junction.

These findings are useful, in that, despite the approximate nature of the available data, they confirm that there are consistent, recurring and systemic performance problems on the South Western Railway network, and identify and consider in more detail some of the most seriously affected parts of the network. This provides the basis for further investigation and the development of measures to address these timetabling and performance problems.

6 Further work

Having identified the general findings and relationships (especially in respect of actual vs. planned running and dwell times) using the 'top-down' analysis described above, more detailed, 'bottom-up' analysis is required to investigate the relationships between timetabled running and dwell times, the values specified in the planning rules and the performance of the timetable as operated.

7 Conclusions

The difficulty of providing punctual train services on railways operating at high levels of capacity utilisation is clearly illustrated by the analysis and findings described in this paper. The results indicate that scheduled running times (possibly due to rounding of time values) and dwell times often cannot be achieved in practice. The situation is complicated further by the fact that this same lack of precision precludes or limits the use of some established methods and tools for the analysis of timetables.

The findings are useful, in that they clearly identify some of the sources of performance variations and problems. However, the industry faces the challenge that, by extending running and dwell times to improve performance, the frequency of service may have to be reduced, and capacity thus lost, which is particularly problematic during peak periods.

Further work is required to provide more detailed understanding of the relationships between the timetable, the underlying planning rules and performance, to identify whether and how the rules should be amended to maximise punctual and reliable capacity, and the extent to which capacity may have to be sacrificed to achieve improved levels of punctuality and reliability.

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