Automatic Data for Applied Railway Management: A Case Study on the London Overground

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Abstract

In 2009, London Overground management implemented a new tactical plan for AM and PM Peak service on the North London Line (NLL). This paper documents that tactical planning intervention and evaluates its outcome in terms of certain aspects of service delivery (the operator’s perspective on system performance) and service quality (passenger’s perspective). Analyses of service delivery and quality, and passenger demand contribute to the development, proposal, and implementation of the new tactical plan. It is found that NLL trains were routinely delayed en route and excessive dwell time is major cause. Near-random passenger incidence behavior suggests an even headway service may be more appropriate for NLL. The confluence of these analyses is confirmed by the corresponding excess journey time (EJT) results. Based on longitudinal analysis, evaluation shows that on-time performance increased substantially and observed journey time (OJT) decreased with the introduction of the new plan. EJT decreases by substantially more than OJT for the line as a whole. Overall, the effects of this implementation appear to have been positive on balance. This case study thus demonstrates the applicability of automatic data generally, and certain measures and techniques in London Overground specifically, to support tactical planning of an urban railway.
1. INTRODUCTION

The London Overground network is for the most part circumferential, primarily orbiting London to the North and West, and is very much part of the integrated network of Transport for London (TfL) and National Rail services. Since the Oyster system, TfL’s automatic fare collection (AFC) smartcard system, controls entry to and exit from the public transport network, the individual passenger journey data it collects can potentially provide useful assistance for tactical planning for the London Overground.

Tactical planning for the Overground is a shared responsibility between TfL and London Overground Rail Operations Limited (LOROL), the contract operator of the London Overground. From 2008 to 2009, London Overground management researched, designed, and implemented a new tactical plan for AM and PM Peak service on the North London Line. This paper documents that tactical planning intervention and evaluates its outcome in terms of certain aspects of service delivery (the operator’s perspective on system performance) and service quality (passenger’s perspective).

Frumin (1) proposes various methods based on smartcard data for origin-destination (OD) matrix estimation, passenger incidence behavior analysis, and service quality measurement. The goal of this paper is to illustrate automatic data and these methods can be used to contribute to real-world tactical planning processes considering a range of decision factors and variables. It is presented as a case study in that most of the work it describes was conducted by other analysts and professionals. It depends heavily on in-person and e-mail interviews with key Overground managers and on research conducted for those managers by an industry consultant. It is descriptive in nature, rather than prescriptive.

Section 2 describes some aspects of the service plan, passenger demand, and operating performance on the North London Line at the time of the tactical planning exercise. Section 3 describes how understanding of and relationships between these factors was synthesized to guide the development of a revised tactical plan. Section 4 evaluates the outcomes of the implementation of this plan using longitudinal before-and-after analysis. Section 5 draws some conclusions regarding this evaluation, including its use of service delivery and service quality measurements.

2. THE NORTH LONDON LINE: SPRING 2008

This section describes some relevant information about the North London Line as of the Spring of 2008, first in terms of the existing service plan, next in terms of passenger demand, and last in terms of operating performance as expressed by different measures of service delivery and service quality.

2.1 The Service Plan

The North London Line (NLL) is the backbone of the London Overground network. It serves 23 stations running 28 kilometers circumferentially around central London from Stratford in the northeast to Richmond in the southwest. It connects to the Gospel Oak to Barking Line (GOB) at Gospel Oak station (GPO) and to the Watford DC Line (WAT) and West London Line (WLL) at Willesden Junction station (WIJ). It is by far the busiest Overground line, with the most frequent service and an estimated 58% of all Overground boardings (2). The NLL runs four (end-to-end) trains per hour (tph) over most of the day, with some segments receiving six tph during the peak periods. Figure 1 schematically illustrates the AM Peak (07:00 – 10:00) service patterns and frequencies on the NLL (and other Overground lines) in Spring 2008.
FIGURE 1 London Overground Spring 2008 AM Peak service patterns and frequencies

Figure 2 uses a time-distance plot to show the published AM Peak timetable for the NLL in Spring 2008. This plot shows a regular 15 minute headway (4tph) service making all stops westbound from Stratford to Richmond and eastbound from Richmond to Stratford. This regular service is augmented by occasional irregular additional services that split some of the 15 minute headways into two smaller headways. These irregular services include:

- “Camden shuttles” that run approximately hourly between Stratford (SRA) and Camden Road (CMD) (departing Stratford at 07:59 and 09:31);
- “Clapham specials” that run approximately hourly between Stratford and Clapham Junction (CLJ), diverting from the NLL to the WLL (not shown in plot) at Willesden Junction (departing Stratford at 07:11 and 08:30);
- one full NLL service from Stratford to Richmond (RMD) at 09:02.

This timetable was developed before TfL and LOROL controlled the Overground network, when it was a standard National Rail concession operated by the Silverlink TOC. David Warner (3), a planner in TfL London Rail, noted that the Camden shuttles were added in 2004, and the Clapham specials in 2006. Oliver Bratton (4), Head of Performance and Planning for LOROL, noted that “TfL was getting concerned about the overcrowding on the NLL. It therefore agreed to ‘buy’ additional services from Silverlink for the peaks.” To add the additional trips, Silverlink planners “put them into the existing schedule ... amongst the 15 minute service when appropriate.”

Describing the origins of this timetable, Warner (3) noted that “the service was entirely driven by the rolling stock available, and the incremental nature in which additional trains were added to the timetable. An overall view was not taken.” Bratton (4) discussed the timetable development process for the National Rail network more generally, noting that “typically, a timetable evolves. As more and more trains run, the timetable tends to ossify, becoming harder and harder to alter.” It appears from these comments that the highly irregular NLL peak period timetable was in place largely as a historical artifact. It was not the product of an analytical or data-driven tactical planning process.
2.2 Passenger Demand

2.2.1 NLL AM Peak Origin-Destination Matrix

Passenger demand for a public transport network can be expressed as a matrix of passenger origin-destination (OD) flows (an OD matrix). A methodology is developed to estimate OD matrices for railway networks from multiple automatic data sources, including passenger journey data from the Oyster smartcard ticketing system, automatic entrance counts from selected station gates, and on-board passenger loads estimated from loadweigh data. By applying this method to the London Overground network, a segment-level AM Peak OD matrix for the NLL is estimated and shown in Table 1. This matrix includes journeys that interchange with the NLL, but it “clamps” those journeys to the point at which they would make that interchange.

<table>
<thead>
<tr>
<th>Origin Segment</th>
<th>Destination Segment</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>NLLG</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GPO*</td>
<td></td>
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<tr>
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<td>NLLC</td>
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<tr>
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<td>63</td>
</tr>
<tr>
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<td>783</td>
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</tbody>
</table>

Cells highlighted in grey depend only on NLL service West of Willesden Junction.

* Includes flows interchanging between NLL and other Overground lines at these interchanged stations.
It is estimated that a total of 37,124 passengers use the London Overground on an average weekday AM Peak period. The NLL OD matrix in Table 1 shows that 22,112, or 60%, of all AM Peak Overground passengers use the NLL for some portion of their journey. The cells of Table 1 highlighted in grey indicate passenger flows which use the NLL only between Willesden Junction and Richmond (RMD), inclusive. They total 5,510 AM Peak passengers, or 25% of total NLL AM Peak patronage. In other words, 75% of all AM Peak NLL passengers use the NLL only between Stratford and Willesden Junction, inclusive.

2.2.2 Aggregate Load Profiles (NLL AM Peak)

Figure 3 plots the aggregate load profile for the NLL. The most salient observation to be drawn from these plots is that by far the largest aggregate link loads on the NLL during the AM Peak are westbound between Stratford and Highbury & Islington (HHY). The aggregate load starts at over 4,000 total passengers out of Stratford and grows at each successive station, peaking at close to 6,000 total passengers between Canonbury (CNN) and Highbury & Islington.

![FIGURE 3 NLL AM Peak load profile](image)

2.2.3 Passenger Incidence Behavior

Passenger incidence behavior refers to the act or event of being incident to a public service with intent to use that service. Frumin and Zhao (5) proposed a method to estimate incidence headway and waiting time by integrating disaggregate smartcard data with published time tables using schedule-based assignment and applied it to stations in the entire London Overground to demonstrate its practicality. The method was implemented in the free/open source software library Graphserver (6), which reads timetables in the widely used General Transit Feed Specification (GIFS) (7). In result, it is found that the temporal distribution of passenger demand on the North London Line was much less timetable-dependent than on the other London Overground lines. That is, passenger incidence behavior was more random on the NLL and less a function of the timetable. Figure 4 illustrates the difference of passenger incidence behavior between the NLL and the GOB in terms of the respective distributions of passenger incidence times (over a given headway) in the AM Peak.

The implications of these distributions in terms of their effects on passenger waiting time (with respect to the timetable) are also quantified. It found that the dependence on the timetable
observed on the GOB in the AM Peak reduced waiting time by 29% compared with purely random passenger incidence. On the NLL the comparable reduction was only 7.2%.

![FIGURE 4 AM Peak passenger incidence on NLL and GOB](image)

2.3 Operating Performance: Service Delivery and Quality

2.3.1 Public Performance Measure (PPM)

On-time performance (OTP), the fraction of services with schedule deviation within some threshold (8), is a widely used measure to characterize service delivery. Under the name of Public Performance Measure (PPM), this is the current measure of performance on the London Overground and all other National Rail services in the UK, with a train considered “on time” if it is less than 5 minutes late at the destination terminal (9). PPM is analyzed for the 52 weekdays from 31 March, 2008 through 10 June, 2008, inclusive. PPM for the NLL over this range of dates was 83% for the AM Peak period and 89% for the whole weekday. This was the worst of all of the Overground lines.

2.3.2 Running and Dwell Times

ACT, A British railway consultancy, was retained by LOROL to study operations on the NLL (10). They used automatic train movement data from the network's signaling and control system to analyze running and dwell times from April, 2007 through March, 2008, inclusive. As TfL and LOROL took control of the Overground network in November of 2007, this study included a period of substantial institutional and branding change on the NLL.

- Over the course of the study period, increases in terminal-to-terminal running times were observed in the AM and PM Peak periods in both directions.
- For both directions in the peak periods, the 80th percentile running time is between the running time in the timetable and the PPM threshold (i.e. timetable plus five minutes); the 90th percentile running time is above the PPM threshold.
- At the 80th and 90th percentiles, the peak period running time westbound (i.e. from Stratford) exceeds the peak period eastbound running time by just over two minutes.
- Dwell times increased (by an unspecified amount) over the course of the study period, especially during the peak periods.
As measured during only the first quarter (i.e. January through March) of 2008, there was substantial “dwell time loss” - station dwell times in excess of those specified in the working timetables. Nine out of the top ten westbound (i.e. from Stratford) scheduled services in terms of average dwell time loss were in the AM Peak period. Likewise, nine out of the top ten eastbound (i.e. from Richmond) scheduled services in terms of average dwell time loss were in the PM Peak period.

A statistical correlation was found, for individual station stops by individual scheduled services, between the length of the leading headway and the station dwell time.

From these observations, the consultants drew two important conclusions regarding service delivery on the NLL. Firstly, that running times in the timetable are insufficient, particularly for the AM and PM Peak periods. Secondly, that dwell times, and corresponding dwell time losses, were driven by passenger demand. The consultants provided only this analysis of current conditions and their conclusions as to what may have been causing those conditions. They did not offer any explicit recommendations on what actions should be taken to improve those conditions.

2.3.3 Train Congestion

Two types of train congestion were also observed on the London Overground network - that between Overground trains, and that between Overground trains and freight trains on the NLL. Bratton (4) noted that “turning trains at Camden was causing congestion on the network” between Overground services. This congestion has not been studied or quantified directly, only reported anecdotally by Overground management and operational staff. However, based on examination of the timetable in Figure 2, it is not hard to believe that such congestion was occurring. The two Camden shuttles that depart Stratford at 07:59 and at 09:31 both arrive at Camden Road within a few minutes of an eastbound train from Richmond. Under these circumstances, even slight deviations from schedule could cause congestion and delays to the trains from Richmond, to the Camden shuttle on its return trip to Stratford, and to the subsequent westbound train from Stratford.

It is of course also possible that the NLL suffered from additional types and instances of train congestion, especially at other junctions and at terminals. Congestion between Overground trains at Camden Road and other locations could have been identified and studied in further detail through the use of time-distance plots (11, 12, 13, 14). Such plots can be generated from automatic train movement data recorded by the Overground network’s signaling and control systems (that were used to study running and dwell times), rather than from timetables as in Figure 2.

2.3.4 Excess Journey Time

Wilson et al. first proposed a measure called “excess waiting time” (EWT) to indicate the waiting time experienced by passengers beyond what they would have waited had all headways been exactly as scheduled (15). London Transport then extend the EWT concept to the entirety of journeys, using “excess journey time” (EJT) to represent the difference between actual passenger journey times and journey times implied by the published timetable (16). Using a unified estimator of EJT developed by Zhao et al. (17), which is unbiased at the aggregate level regardless of the passenger incidence behavior (random incidence, scheduled incidence, or a
mixture of both), EJT for the NLL as of the Spring of 2008 was examined in detail. The relevant results can be summarized as follows.

- The NLL in the AM Peak had by far the most total EJT of any Overground line in any time period, followed by the NLL in the PM Peak.
- In terms of mean EJT (i.e. after normalizing by number of passengers) the AM Peak was the worst time period for the NLL.
- In terms of total and mean EJT, the NLL in the AM Peak had over twice the EJT in the westbound direction (i.e. Stratford to Richmond) as in the eastbound direction.
- Total EJT was severely unbalanced among individual westbound AM Peak scheduled services on the NLL. The five scheduled services with the highest total EJT were, in descending order, the 08:22, 07:52, 07:07, 08:52, and 07:37 trains from Stratford. These services had full 15 minute headways (at Stratford) and had substantially more total EJT than their respective shorter-headway leaders and/or followers.
- Mean EJT on the NLL was somewhat linearly correlated with PPM. However, the relationship was weaker in the AM Peak than for the whole day, and in the AM Peak for lower PPM values.

3. TACTICAL PLANNING INTERVENTION: THE CASE FOR EVEN INTERVALS

This section synthesizes the results of the previous section to explain the thinking behind a specific tactical planning intervention that was implemented on the NLL. It does so primarily from the perspective of the London Overground manager who was the driving force behind this change. This manager was influenced by the results of some of the early research from Frumin (1), and used some of these results to make the case to his stakeholders.

Certain factors in the decision to implement this change, such as complete costs and benefits, were not available for this case study. In addition, the manager's perspective is supplemented here by analysis drawn from the final results of this paper. In that sense, the case this section makes for the tactical planning change is not precisely the case that was made in practice. Nevertheless, it provides a context in which to illustrate the value of the methods used in this paper for using automatic data to support the tactical planning of an urban railway.

Of the results and analyses discussed in the previous sections of this paper, the key points that influenced the tactical planning intervention on the NLL are as follows. They are focused on the AM Peak period, in which, as of Spring 2008, the trains were routinely delayed en route, as reflected by running times substantially in excess of the timetable and by low PPM on-time performance scores. Excessive dwell times were found to be a major cause of en route train delays. Evidence existed to support the judgment that these dwell times were primarily a function of passenger volumes. Near-random passenger incidence behavior suggested an explanation for uneven passenger volumes and resultant uneven dwell times - when passengers arrive (even approximately) randomly, services with longer headways will serve proportionally more passengers. The confluence of these analyses is confirmed by the corresponding EJT results.

As described in Section 2.1, the typical approach to tactical planning on this network was to update the timetable incrementally. It became evident that more drastic measures were needed in this case. Specifically, that the timetable should be revised wholesale to provide as even headways as possible. Under the circumstances, it was proposed to achieve this by combining the NLL and WLL during the AM and PM Peak periods into an even 10 minute headway (6tph)
service between Stratford and Willesden Junction. From Willesden, alternating trains would go
on the NLL to Richmond and the WLL to Clapham Junction. This was referred to as the “3 + 3”
service.

The core idea behind this strategy was to balance passenger volumes across trains, thus
reducing dwell times and train and passenger delays. It was expected that passenger volumes
would increase on some trains (i.e. those with longer headways than in the current plan) and
decrease on others (i.e. those with shorter headways). While the change was not expected to
materially affect the total volume of passengers, the outcome was expected to be positive on
balance. The reasons for this are twofold.

Firstly, dwell times have been found to have a non-linear relationship to passenger
volumes (18, 19). This implies that, holding the total volume of passengers constant, the
decreases in dwell times on trains losing passengers (i.e. the existing 15 minute headway services)
would be larger than the increases in dwell times on trains gaining passengers (i.e. the shorter
headway services). Consequently, overall delays should decrease. Secondly, consistent with the
hypothesis of unbalanced on-train loads, it was anecdotally reported that some passengers were
unable to board overcrowded trains, and were be left behind on the platform. The most crowded
trains (with larger headways) would be less crowded and allow more (or all) passengers to board.
Passengers currently denied boarding by overcrowded trains would thus benefit substantially
while other passengers would benefit (from less crowded trains) or suffer (on more crowded
trains) to a lesser degree.

3.1 “3+3” Service on the North London Line

3.1.1 Headway Adjustment and Frequency Reallocation

The new tactical plan resulting from the above analysis was referred to as the “3 + 3”
service because it integrated the NLL and WLL into a single trunk-and-branch service for the
AM and PM Peak periods. It is effectively an even 20 minute headway (3tph) service between
Stratford and Richmond superimposed with an identically spaced service between Stratford and
Clapham Junction. The two services are offset by 10 minutes, yielding an even 10 minute
headway (6tph) trunk service between Stratford and Willesden Junction.

Figure 4 uses a time-distance plot to show the corresponding published AM Peak
timetable for the NLL. Table 2 summarizes the changes in the evenness and frequency of service
for each segment of the NLL and WLL.

| TABLE 2 NLL and WLL Service under the Spring 2008 and the “3 + 3” Tactical Plans |
|-----------------------------------------------|-------------------|-------------------|
| Segment Between                          | Spring 2008 Service (tph) | “3 + 3” Service (tph) |
|                                           | Core (even) | Add’l (uneven) | Total (even) |
|                                           | Core (even) | Add’l (uneven) | Total (even) |
| North London Line                        |              |                 |                |
| SRA ↔ CMD                               | 4            | 1-2             | 5-6 uneven     |
| CMD ↔ WIJ                               | 4            | 0-1             | 4-5 uneven     |
| WIJ ↔ RMD                               | 3            | 0-1             | 3-4 uneven     |
| West London Line                        |              |                 |                |
| WIJ ↔ CLJ                               | 2            | 0-1             | 2-3 uneven     |


The only part of the WLL and NLL to lose any service frequency under this reallocation was the western end of the NLL between Willesden Junction and Richmond. One additional shuttle trip over this segment was added for the entire peak period, but overall the headway increased from 15 minutes to 20 minutes (4tph to 3tph). Not surprisingly, this was the most contentious aspect of this plan. However, the OD matrix estimated in Section 2.2 shows that only 25% of the NLL passengers using the NLL in the AM Peak used this segment of the line. The “3 + 3” tactical plan thus reallocated service such that more passengers gained service than lost it. In doing this, it was able to establish a service pattern with even headways throughout the network that was easier for customers and operators to understand, remember, and use.

3.1.2 Running Time Adjustment

In addition to the headway and frequency changes, timetable running times were also adjusted. Bratton (4) described conventional practice in National Rail timetable development being to add running time between the penultimate and final stations on a line. This increases PPM scores (i.e. on-time performance) and increases the chance that a train will be in place for the beginning of its next trip, but has little effect on the fidelity of the timetable to actual operating conditions on most of the line.

In the new timetable, the running time between Stratford and Camden Road was shortened by 1-2 minutes on the basis that evening the headways would drastically reduce dwell times. The running time between Camden Road and Richmond was lengthened by 3-4 minutes to account for discrepancies found in the study by ACT (10). Both changes were effected through 1 minute adjustments en-route rather than in large blocks of time at the end of the line or segment of the line. The total running time between Stratford and Richmond was lengthened by approximately 3 minutes on average over the AM Peak period.

FIGURE 5 North London Line “3+3” timetable
3.1.3 Costs

Bratton (20) noted that the changes in service described here were for all intents and purposes cost-neutral. The reallocation of service frequencies and adjustments in running times were such that the “3 + 3” service could be operated at approximately the same costs as the existing timetable. No new rolling stock was required and only two additional crew members - conductors at an annual salary of $23 thousand each - were needed to fully staff the new timetable.

4. EVALUATION

“3 + 3” service went into effect on the NLL and WLL on Monday, 20 April, 2009. This section evaluates the outcomes of this tactical planning intervention, primarily through longitudinal analysis of measures of service delivery and service quality. These measures are taken for a period directly after the implementation, and compared to two periods before the implementation - one directly before and one a year earlier. The goal of this evaluation is to assess, to the degree possible, the causal effects on passengers and on the operation of changing the tactical plan. However, despite the large amount of data available, any number of uncontrolled factors may confound this analysis.

Because this evaluation is of a major change to the timetable, it is important to evaluate service quality in absolute as well as relative terms. Consequently, total observed journey time (OJT) is analyzed along with EJT. All else being equal, any change in OJT should be reflected in an equal change in EJT. However, any adjustment to the timetable will break this link.

Service delivery is evaluated primarily in terms of PPM and dwell times, the latter of which was analyzed in a follow-up study by ACT (21). Interviews with London Overground management are also considered.

This evaluation is focused on the NLL, and uses the GOB as a control since there were no substantial changes to the GOB timetable over this period. The GOB is not a perfect control in that it has different service and demand characteristics from the NLL, but it should be subject to similar universal influences such as weather, overall economic conditions, etc. The NLL is evaluated as a whole (including passengers in both directions) and also for the core market passengers traveling between Stratford and Camden Road in the westbound direction (i.e. towards Camden Road). This “NLL Core” market is analyzed separately because it is the only section of the line for which there was only a change in the evenness of headways in the peak hours and not a change in the overall frequency of service.

4.1 Evaluation Data

The following three study periods are analyzed to evaluate the effects of introducing “3 + 3” service. They are determined in part by data availability.

After2009: Weekdays from 20 April through 15 May and 1 June through 5 June, 2009, inclusive. This is 5 out of the first 7 weeks directly following the introduction of “3 + 3” service.

Before2009: Weekdays from 2 March through 13 March, 2009. This is a period of two weeks shortly before the introduction of “3 + 3” service.

Spring2008: Weekdays from 21 April through 16 May and 2 June through 6 June, 2008, inclusive. These are the weeks in 2008 corresponding to the weeks in the After2009 period.

Complete PPM and timetable data were available for these study periods. Observed and excess journey times (i.e. OJT and EJT) are measured from Oyster journey data. At first glance
the numbers in this table indicate increasing weekly ridership. However, this interpretation does not account for changes in the Oyster penetration rate among Overground riders. An increasing penetration rate would result in increasing volumes of Oyster data despite static volumes of overall ridership. This evaluation does not explicitly analyze total ridership on the Overground network or lines in question.

Line and segment running time analysis is drawn from the report by ACT (21). Unfortunately, ACT reported on changes in median rather than mean dwell times. Median values mask the effects of large outliers, which for a nonlinear phenomena such as dwell time are expected to be quite important, so changes in dwell time are not directly analyzed here.

### 4.2 Evaluation Results

Table 3 shows PPM, EJT, and OJT results for the three network segments for the three study periods. It shows the difference from \textit{Spring}2008 to \textit{Before}2009 to indicate the changes in performance between the time the tactical planning analysis was done and just before “3 + 3” was implemented. It shows the difference from \textit{Before}2009 to \textit{After}2009 with the hope of isolating the effects of introducing the “3 + 3” service.

The differences in EJT and OJT were tested in a single-sided difference of means t-test. All differences on the NLL and NLL Core were statistically significant at the 1% level. Differences on the GOB between \textit{After}2009 and \textit{Spring}2008 were significant at the 5% level, but between intermediate periods were not significant even at the 10% level.

On the GOB, the changes in all three measures were small - PPM fluctuated by 0.8% and returned to its original value of 95.5%, while EJT and OJT decreased by 0.08 minutes (6.3%) and 0.18 minutes (0.7%), respectively, between the initial and final study period. It is not unexpected that OJT and EJT did not vary by the exact same amount. While the changes to the GOB timetable were minor, OJT could be affected by slight shifts in (i) passenger incidence behavior, since EJT is calculated against scheduled waiting time; or (ii) the temporal distribution of ridership over the AM Peak, since running times in the timetable do vary slightly over the AM Peak. This illustrates some of the factors that may confound the longitudinal analysis for the NLL, if only to a small degree.

**TABLE 3 PPM and Passenger Journey Time Results and Comparisons for “3 + 3” Implementation**

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<tr>
<th>Study Period</th>
<th>GOB</th>
<th>NLL</th>
<th>NLL Core</th>
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<tbody>
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<td></td>
<td>PPM (%)</td>
<td>EJT</td>
<td>OJT</td>
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</tbody>
</table>

On the NLL as a whole, changes may be observed in all the calculated measures. PPM decreased (i.e. worsened) between the \textit{Spring}2008 and \textit{Before}2009 study periods by nearly 6 percentage points. ACT (21) found that over this time average train journey time from Stratford to Richmond increased by about 30 seconds.
OJT and EJT decreased (i.e. improved), by 0.81 minutes (3.1%) and 0.48 minutes (17.3%), respectively, over the 9 months between the first two study periods. For the NLL Core passengers, OJT and EJT decreased by 0.55 minutes (3.1%) and 0.94 minutes (40.3%), respectively. It is interesting to note in these cases that the changes in EJT and OJT, measures of relative and absolute service quality, were directionally opposite of the changes in PPM, a measure of service delivery.

It appears that there were substantial improvements to absolute and relative service quality on the NLL as experienced by passengers before the implementation of the “3 + 3” service. Bratton (20) attributes this primarily to “higher performing Network Rail infrastructure.” The 2008 TfL Investment Programme (22) indicates that $56.9 million of infrastructure upgrades were planned during this period. Much of this investment was in support of capacity on the NLL to an eventual 12tph. It is difficult to separate these capacity upgrades from investments that would improve infrastructure performance at the same level of throughput, but this figure indicates the intensity of the work that was done.

For the NLL, the comparison between the Before2009 and After2009 study periods should give the clearest insight into the direct effects of introducing the “3 + 3” service. PPM increased by over 12 percentage points while the average running time from Stratford to Richmond increased by just under 20 seconds. Unfortunately, ACT (21) did not report on the distributions of running times, so it is impossible to say how much the change in PPM is a result of improved service delivery as compared to the more generous standard set by lengthening the running time in the timetable. During this period, the average train running time from Stratford to Camden Road decreased by 50 seconds.

OJT decreased by an additional 0.18 minutes (0.7%) for the NLL as a whole and 0.36 minutes (2.1%) for the NLL Core, indicating improved passenger journey times. The changes in EJT, like those in PPM, are more difficult to interpret. For the NLL Core, EJT worsened (i.e. increased away from zero) while PPM and OJT both improved. This is not a surprise, as the running time between Stratford and Camden Road was shortened in the new timetable. OJT decreased but the scheduled journey times (SJT) decreased even more, so EJT increased. This illustrates one of the disadvantages of timetable-based measures of service quality such as EJT.

Given the substantial changes to the timetable, the effects of introducing “3 + 3” service may best be judged in terms of absolute service quality. The decreases in OJT suggest that the tactical planning intervention improved the experience of NLL passengers. The changes in OJT are 22.2% and 65.4% of the changes observed on the NLL and NLL Core, respectively, between the Spring2008 and Before2009 study periods.

Figure 6 plots total EJT by scheduled service for westbound passenger journeys on the NLL between Stratford and Willesden Junction in the Spring2008 period and the After2009 period. A comparison between the two shows a more even distribution of EJT across scheduled services during the height of the peak period. For example, in After2009 the differences between the services with the highest total EJT (the 08:09 and 08:39 trains from Stratford) and their respective leaders and followers is smaller, even in relative terms, than the same differences for the services with the highest EJT in Spring2008 (the 07:52 and 08:22 trains from Stratford).

Because the timetable and headways changed between these two study periods, incidence behavior was also examined, but no noticeable change in overall incidence behavior is found. Mean scheduled waiting time (which is part of the scheduled journey time against which EJT is measured) decreased by 0.1 minutes on the NLL Core and increased by approximately the same
amount over the entire NLL. These changes appear to be a function primarily of the changes to the timetable rather than changes in incidence behavior.

Abdul Salique (23), a TfL contract manager who represents TfL in its relationship with LOROL, was interviewed about the effects of introducing the “3 + 3” service. It should be noted that it is his job to hold LOROL to their contractual responsibilities while considering the experience of the Overground’s passengers to whom TfL is ultimately accountable. He noted that “overall it is good for passengers... There has been a lot of good passenger benefit to a greater number of passengers than those that have been disadvantaged”. “It has also improved train performance and has made the timetable more robust and easier to recover from... Overall I would say we could move more people during the peaks when we were a bit constrained before.”

![Graph](image)

(a) Spring2008

![Graph](image)

(b) After2009

**FIGURE 6 Total EJT by scheduled service, westbound, after “3+3” implementation**

5. CONCLUSIONS

The case study presented in this paper, provided a rich example of the use of automatic data to support tactical planning on the North London Line (NLL) of the Overground network. The analyses of this paper contributed to both the development of the new tactical plan for the
NLL and to the evaluation of the implementation of that plan. The effects of this implementation appear to have been positive on balance. This case study thus demonstrates the applicability of automatic data generally, and the data and methods used in London Overground specifically, for tactical planning of an urban railway.

Various measures of service delivery and service quality, all generated from automatic data sources, contributed to the tactical planning exercise that led to the “3 + 3” service. In terms of service delivery, dwell times, running times, and on-time performance were analyzed using train signaling and control data. They indicated that running times in operation were substantially longer than in the timetable, and that excess dwell time, particularly on certain scheduled services and at certain locations, was one of the main causes of increased running times. Service quality was analyzed primarily in a relative sense in terms of EJT as measured using Oyster journey data and the published timetable. EJT was found to add an element of the passenger's perspective to the tactical planning process. It can focus tactical planning attention to the segments of passengers who need it most, and can support and enhance analyses that have been initiated from the operator's perspective.

Two analyses of passenger demand also contributed to the tactical planning process. Passenger incidence behavior on the NLL was analyzed using Oyster journey data and the published timetable. It was found to be substantially more random than previously assumed, contributing to the decision to move the NLL to an even headway service. Also analyzed was the origin-destination matrix of overall AM Peak passenger demand on the Overground network, estimated from aggregate Oyster passenger volumes, automatic gateline entry counts, and manual on-board passenger counts. This OD matrix indicated that the proposed reallocation of some service frequency away from the western end of the NLL towards the eastern end would benefit more passengers than it would harm.

The confluence of these analyses contributed to the development, proposal, and implementation of the even headway “3 + 3” service on the NLL and West London Line (WLL) in the AM and PM peak periods. The development of the timetable for this service was also influenced by the key concept inherent in the idea of measuring EJT - that standards can be set and lateness can be measured at the level of individual passenger journeys or OD flows. This led the developers of the timetable to adjust running times throughout the length of the NLL rather than only at the end of the line as was typical on the National Rail network. In this sense, EJT can be a useful tool to help shift tactical planning practices which may be less oriented towards the passenger's perspective than is desired.

Service delivery and quality on the NLL were analyzed longitudinally to evaluate the effects of introducing the “3 + 3” service on passengers and on the operation. Because the timetable changed so drastically in the “3 + 3” implementation, an additional measure of absolute service quality was included in the evaluation. Observed journey time (OJT) was estimated using only Oyster journey data. This and other measures were analyzed before and after the introduction of “3 + 3” service. PPM increased substantially and OJT decreased (i.e. they both improved). EJT decreased by substantially more than OJT for the line as a whole and in fact increased for the core portion of the line, which was the portion towards which the “3 + 3” service was targeted.

These discrepancies were found to be because the “3 + 3” timetable had lengthened running times over the whole line and shortened them over the core portion. This highlights the relative nature of EJT, illustrating its value as a relative rather than absolute measure. EJT provides good information about how the passenger experience compares to the timetable, but
not necessarily a clear picture of how it has changed in an absolute sense. It is thus similar to on-
time performance, but measured for and weighted by individual passenger journeys.

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REFERENCE

1. Frumin M. Automatic Data for Applied Railway Management: Passenger Demand,
Master thesis, Massachusetts Institute of Technology; 2010.

2. Smales C. Unpublished interviews and electronic communications with Carol Smales,
Chief Transport Economist, TfL London Rail. 2010;

3. Warner D. Unpublished interviews and electronic communications with David Warner,
Senior Business Analyst, TfL London Rail. 2010;

4. Bratton O. Unpublished interviews and electronic communications with Oliver Bratton,
Deputy Operations Director, London Overground Rail Operations LTD. 2009;

5. Frumin M, Zhao J. Analyzing passenger incidence behavior in heterogeneous transit
services using smartcard data and schedule-based assignment. Transportation Research
Record: Journal of the Transportation Research Board (Accepted) 2012;

6. Graphserver. Graphserver: The Open-Source Multi-Modal Trip Planner [Internet].
2009; Available from: http://bmander.github.com/graphserver/

7. Google. General Transit Feed Specification [Internet]. 2009; Available from:


2008;

10. ACT. North London Line performance review for London Overground Rail Operations

Massachusetts Institute of Technology: 1999.

12. Rahbee A. Rail operations analysis and strategies for service quality improvement,
Technical report, Chicago Transit Authority. 2006;


Monitoring for High-Frequency Transit Lines. Transportation Research Record 1992;3–11.

17. Zhao J, Frumin M, Wilson N, Zhao Z. Unified estimator for excess journey time under heterogeneous passenger incidence behavior using smartcard data. Transportation Research Part C (under review; submitted in July 2012);


23. Salique A. Unpublished interviews and electronic communications with Abdul Salique, Plan Delivery Manager, TfL London Rail. 2010;

ABBREVIATION GLOSSARY

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AFC</td>
<td>Automatic fare collection</td>
</tr>
<tr>
<td>CLJ</td>
<td>Clapham Junction station</td>
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<tr>
<td>CMD</td>
<td>Camden Road station</td>
</tr>
<tr>
<td>EJT</td>
<td>Excess journey time</td>
</tr>
<tr>
<td>EWT</td>
<td>Excess waiting time</td>
</tr>
<tr>
<td>GOB</td>
<td>Gospel Oak to Barking Line</td>
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<td>GPO</td>
<td>Gospel Oak station</td>
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<tr>
<td>LOROL</td>
<td>London Overground Rail Operations Limited</td>
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<td>NLL</td>
<td>North London Line</td>
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<tr>
<td>OJT</td>
<td>Observed journey time</td>
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<tr>
<td>OTP</td>
<td>On-time performance</td>
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<td>PPM</td>
<td>Public performance measure</td>
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<td>RMD</td>
<td>Richmond station</td>
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<tr>
<td>SJT</td>
<td>Scheduled journey time</td>
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<td>Stratford station</td>
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<tr>
<td>TFL</td>
<td>Transport for London</td>
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<tr>
<td>tph</td>
<td>Trains per hour</td>
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<tr>
<td>WAT</td>
<td>Watford DC Line</td>
</tr>
<tr>
<td>WIJ</td>
<td>Willesden Junction station</td>
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<tr>
<td>WLL</td>
<td>West London Line</td>
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