RETT3 – Final Report

A Field Experiment for Improving Bus Service Regularity

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The RETT3 project is the result of cooperation between three parties: SL, Keolis Sverige and KTH – Royal Institute of Technology, Sweden. The report, which constitutes the main deliverable of this project.

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Executive summary

Service reliability is as one of the most important performance factors for both passengers and operators. In the context of high-frequency services, reliability needs to be interpreted in terms of regularity rather than punctuality. Real-time information on the location of other buses could facilitate a headway-based control strategy that seeks to keep buses as evenly spaced as possible.

The RETT3 project is an extended demonstration designed to provide sufficient ground to analyze the implications of a new real-time control strategy that aims to mitigate bus bunching. The project considers the applicability of such a system and its impacts on the level-of-service, operations and the working environment and draws conclusions on future implementation.

 RETT3 tested a package of regularity-oriented operations during the autumn of 2012. The project dealt with many challenges such as radio communication problems which limited its success. Service regularity has improved even though the implementation conditions were far from ideal. The coefficient of variation of the headway was much more stable along the line. The extra waiting time passengers experienced due to reliability problems decreased overall by 5-10% with a decrease of up to 45% at some stops. The two main drawbacks that hindered the project performance were several system functionality problems and persistent timetable constraints. The recurrent technical problems have made it very difficult for drivers to follow and trust the system. The project proved however to be an important instrument for gearing the operations towards regularity, identifying and investigating related implementation issues.

The project also considers the introduction of new regularity-based measures of performance. These measures have to reflect public transport performance objectives adequately and could potentially be embedded in future agreements in the public transport sector.
**Sammanfattning**

Pålitlighet i kollektivtrafiken är en av de viktigaste faktorer som berör både passagerare och operatörer. I samband med hög turtäthet handlar pålitligheten snarare om regularitet än om punktlighet. Realtidsinformation om lokalisering av andra bussar skulle underlätta en tidsavståndsbaserad kontrollstrategi som syftar till att hålla bussar så jämnt allokera som möjligt.

RETT3 projektet är en utökad demonstration utformad för att ge tillräcklig grund för att analysera konsekvenserna av en ny realtidsstyrstrategi som syftar till att minska busshopklumpning. Projektet avser att testa tillämpningen av ett sådant system och dess effekter på servicenivå, verksamhet och arbetsmiljö och dra slutsatser om ett framtida genomförande.


Projektet avser också att införa nya tillämpliga mått på prestanda. Dessa åtgärder måste återspeglar kollektivtrafikens allmänna mål på tillräckligt sätt och skulle kunna vara inbäddad i framtida avtal inom den offentliga transportsektorn.
1. Background

1.1 Problem description

Reliability is acknowledged as one of the most important performance factors for both passengers and operators. Service reliability could be considered either in terms of punctuality or regularity. In the context of high-frequency services, passengers typically arrive at stops randomly without consulting the timetable. Therefore, service regularity is the main determinant of passenger waiting time rather than on-time performance and measures to improve waiting time must focus on keeping even headways between buses rather than adhering to the schedule.

Ideally, all buses would be equally spaced along the line resulting with even intervals between successive bus arrivals. However in reality there are many factors that hinder buses from running regularly. These factors include variations in travel conditions, driver behavior and passenger demand. Moreover, buses do not even depart from the first stop regularly. These factors are of course interrelated through the relation between the headway between consecutive buses, the number of waiting passengers and dwell times as well as the propagation of delays from one trip to the following one. A bus with long headway will have to pick up more passengers causing it to be further late while the succeeding vehicle increasingly catches up.

This process leads to the well-known bunching phenomenon. The bunching problem is an example of a positive feedback loop that reinforces itself. If no measures are taken, it will escalate along the line. In the case of Stockholm, all of the inner-city trunk lines (‘stombusslinjer’) have an average planned headway of 5-6 minutes during most of the day (7:00-19:00). In order to prevent the deterioration of service reliability along the line, buses in Stockholm use several regulation stops (also known as time point stops) along each line (see Figure 1). The current control strategy in Stockholm is designed to improve service punctuality by holding buses that run too early relatively to the timetable at few selected stops, known as time point stops.

Figure 1: Stockholm inner-city trunk bus lines (‘stombusslinjer’)
The current schedule-based strategy may also benefit regularity in some specific cases but is overall counterproductive as far as regularity is considered. It is indeed not uncommon to see the blue buses in Stockholm bunched in pairs and even triples. More regular services imply shorter travel time for travelers and a higher level of travel satisfaction. Furthermore, they have the potential to utilize the capacity more efficiently and reduce operational costs.

1.2 Project context

1.2.1 RETT2

RETT3 is a follow-up study that builds on the recent experience of RETT2 (Available at: http://www.ctr.kth.se/mezzo/RETT2_Final_Report.pdf)\(^1\) - a joint SL, Keolis and KTH project - which has demonstrated the benefits from applying a new control strategy on trunk line 1 in Stockholm inner-city. The impacts of this strategy were first analyzed by BusMezzo\(^2\) - a transit simulation model developed by KTH. The evaluation of the project consisted of detailed before-after data analysis and feedback from various parties.

Figure 2 presents a time-space diagram of successive bus departures during the afternoon peak hour for representative days of the before and after periods, respectively. It is evident that service was very irregular on 21-Sep-2011 with increasingly bunched buses. Almost all bus arrivals at stops are in pair or triple along the second half of the route. Very short headways are followed by headways that are excessively long, by up to 2.5 longer than the planned headway. A very different pattern emerged on 31-Oct-2011 the last day of the experiment. Buses depart more regularly from the terminal and maintain more even headways along the route. Holding times are evident in some (but not all) cases that the headway from the preceding bus is shorter than the headway from the successive bus. The bunching phenomenon is not completely eliminated but is clearly reduced.

\(^1\) See also the report in Dagens Nyheter: http://www.dn.se/sthlm/enkel-teknik-kan-losa-anhopning-av-bussar

Figure 2: Bus trajectories along line 1 FE on the afternoon peak period before (above) and after (below) the introduction of RETT2

Service regularity was further analyzed by constructing the distribution of all headways upon departure from all stops, Figure 3. It is evident that a more regular service is obtained: a larger share of the headways is concentrated in the mid-range of planned headways (4-7 minutes) compare with fewer cases of very short or very long headways which reflect bus bunching.
In summary, the main findings were:

- Headway variation decreased for the peak period as well as for the entire day along the entire line for both directions by 11-26%. In addition, the share of bunched buses decreased by 13-24%.
- A decrease of 38% in the excess waiting time and an extra budgeted waiting time that is shorter by 10% compared with the before period.
- More even passenger loads with the deviations from the ideally even load being less than half the size they were before the experiment.
- Total dwell time along the line decreased by 10% and a dwell times were much more evenly spread along the line as each trip involved holding at different stops.
- The overall average bus running time remained unchanged. The variability of total running time reduced during the trial, mostly due to smaller tails (very short of very long runs).
- The on-time performance improved by 9% on the eastbound and remained at the same level on the westbound.
- The share of buses that departed on-time from the origin stop, driver relief point and key stops remained at the same level or increased.
- The share of buses that arrived on-time to the last stop increased on both directions. This was also reflected in the feedback received from drivers as they found the new working routine to be less stressful.

It is important to stress out that the project benefits were achieved without an investment in infrastructure or technology. The performance and level-of-service was improved by introducing a new operations strategy seeking to even out headways by holding.

1.2.2 Related projects
The RETT3 project is part of SL focus on improving service performance on the trunk lines by various complementary means such as signal priority, dedicated lanes, snow cleaning priority and boarding
regimes among others. These activities are in line with Stockholmsstad accessibility strategy (‘Framkomlighetsstrategin’).

It should be highlighted that the above improvements are also expected to contribute significantly to better bus regularity and are regarded as supplementary actions that would support the proposed strategy. In particular, the following actions will mitigate the escalation of irregularity along the line in addition to the travel time benefits associated with them:

- Shortening the boarding time per passenger by changing the fare collection method. Allowing boarding from all doors will help improve regularity significantly as was also found in a simulation study.
- Reducing the number of stops by consolidating stops. This is considered by an ongoing parallel SL project on accessibility improvements on the inner-city trunk lines (‘Framkomlighetsförbättrande åtgärder Stombusslinje 1-4’).
- Reducing the variability in travel time between stops by providing better bus priority on roads and intersections. Ongoing efforts to improve bus signal priority would also benefit regularity, in particular if the headway-based priority logic is used.

Measures to improve service regularity are thus aimed to minimize the consequences of imperfect bus accessibility and variability in traffic conditions and passenger demand at various stops.

1.3 Organization

The project team consisted of participants from SL, Keolis and KTH. In order to make sure that the project team includes all the necessary expertise, it must include persons working within the following domains:

- Production management and operations planning – including driver and fleet scheduling
- Information and communication systems – in particular, intimate familiarity with the BussPC system
- Data systems and report generation – with respect to BussPC and ATR systems
- Traffic control – including control center routines and software and traffic signal communication
- Analysis – experiment design, data analysis, measures of performance, simulation models
- Business models – contract considerations and incentive schemes

SL led, funded and coordinated the project. In addition, SL interacted with INIT and carried out system lab tests. In addition, SL provided the automatically collected data. Keolis deployed various resources for the project including driver scheduling, traffic ambassadors and dispatchers personal and was responsible for disseminating the information. In addition, persons working with operations, production planning and the control center were involved on Keolis side. KTH advised the experiment design, participated in the preparations, carried out the prior-analysis, monitored, analyzed and evaluated the project.

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All parties were engaged throughout the project – in the planning, troubleshooting and implementation phases. Project team meetings were held regularly with additional representation dependent on the discussion topics. In addition, the project involved from the outset the driver union. This was one of the lessons taken from the previous RETT2 project. Union representatives from both depots (Hornsberg and Söderhallen) were part of the project team and provided valuable input in project meetings.

1.4 Objectives
The promising results of the RETT2 project led to a consensus that the new strategy should be further tested prior to its full implementation. This has led to the design of a follow-up study known as RETT3 which is summarized in this report.

The current project is an extended demonstration designed to provide sufficient ground to analyze the implications of a new real-time control strategy that aims to mitigate bunching by keeping buses as evenly spaced as possible. The objectives of RETT3 are as follows:

I. **Demonstrate the applicability of real-time headway-based control strategy** – conducting an extended experiment in order to collect a sufficient amount of data and not least important experience and skills for analyzing the new strategy. Furthermore, testing it on more than one line will allow studying the implications of various operational and trafficking conditions.

II. **Provide better conditions for running regularity-based operations** – by reducing the impact of timetable constrains (e.g. interdependency with low-frequency lines) as much as possible through clean-operations. Moreover, complementing the holding control strategy with additional actions such as enhanced transit signal priority and control room operations.

III. **Develop new regularity-based measures of performance** – the proposed measures will reflect public transport performance objectives adequately while considering their implications on the business model. These measures could potentially be embedded in future agreements between SL and operators.

The remainder of this report summarizes the efforts, design, results and conclusions related to a project for improving service reliability on trunk lines 1 and 3 in Stockholm, known as RETT3.
2. Experiment design

2.1 Timeline

The project started on May 2012 and continued until January 2013. The project timeframe was motivated by the need to deliver project recommendations before the contract for the City is finalized. Therefore it was decided that the field experiment will take place during the autumn timetable, Aug 20 – Dec 9. The project timeline was as follows:

- May 12: SL-Keolis-KTH project group kicks off
- May-Jul: Simulation and empirical analysis, Experiment design (scheduling, information, system functionality)
- Aug: Traffic dispatchers and ambassadors training, Information dissemination
- Aug-Dec: Field experiment, On-going monitoring, analysis and refinements
- Dec 12-Jan 13: Assessment and feedback, Recommendations

Figure 4: RETT3 project timeline

2.2 Prior analysis

As part of the preparations to the field implementation, an empirical and simulation analysis of lines 1-4 was conducted by KTH.

2.2.1 Empirical analysis

The empirical analysis was based on automated vehicle location (AVL/BussPC) and automated passenger counts (APC/ATR) data from 15-Nov-2011 to 19-Jan-2012. Travel times and dwell times were analyzed for different routes and time periods. In particular, a statistical analysis investigated whether bus drivers adjust their speed in response to deviations from the schedule. This is of special interest to this project as drivers are encouraged to adjust their speed. The main findings were as follows:

1. Dwell times account for 25-30% of total travel time and driving speed is 18-20 km/h for all routes. Riding times between stops vary considerably along the routes but almost do not vary between different time periods of the day. Dwell times exercise a large variability at regulation stops.
2. Buses tend to first run behind schedule and then reduce their lateness before approaching a regulation stop (lower speeds are observed just prior to these stops for all routes). This suggests that time point stops are effective in enforcing drivers to adhere to the schedule by adjusting their riding times.
3. Drivers can and do adjust their speeds. Drivers take advantage of the real-time schedule indicator in the BussPC but their reaction is very dependent on the underlying control layout - locations where the performance is measured. Speed adjustments take place only in the proximity of time point stops.

2.2.2 Simulation analysis
The empirical data was then used for constructing a realistic representation of lines 1-4 and 76 in a transit operations simulation model, BusMezzo. The representation assumed no inter-line driving, the enforcement of scheduled-based departure from the first stop, no speed adjustment between stops and no signal priority. Hence, the simulation results may underestimate the impacts of the planned experiment. The simulation analysis compared the performance under the current (schedule-based) strategy with the proposed (even-headway) strategy for the morning peak period. The main results from the simulation model were:

1. Service regularity improved by 40% on average on Line 1 and by 19% on northbound of Line 3 with a marginal increase on the southbound (improved substantially for lines 2, 4 and 76). The regularity of line 3 was better to start with (as supported by empirical data). Bunching is reduced by 10% on average on Line 1 and 6% on Line 3. The share of headways that are within the 3 to 7 minutes range increased from 79% to 87% on average. The average waiting time per passenger decreased by 14% for Line 1 and remained almost unchanged for Line 3.

2. Sensitivity analysis shows that the proposed (even-headway) strategy is fairly robust to random incompliance since buses can compensate for each other. A more delicate representation of the BusPC system preciseness which is a half a minute level display obtains a more realistic performance result (headway coefficient of variation of 0.4-0.5).

3. The analysis highlighted the importance of regular departures from the first stop and speed adjustments. Moreover, operation at few key stops – Hötorget, Fridhemsplan, Fleminggatan, Slussen and Skanstull - was identified as especially important for service regularity as they induce high variability.

2.3 Implementation
The project applied the following measures for lines 1 and 3:

- **Decentralized control**: A headway-based indicator was displayed on the BussPC screen (either exclusively or along the schedule adherence indicator). A plus sign indicates that the bus is too close to the bus in front while a minus sign indicates that the bus is too close to the bus behind. Zero implies that the bus is perfectly in between the preceding bus and the successive bus. Drivers were encouraged to adjust their speed as much as possible and could decide to hold at stops whenever needed.

- **Minimal inter-lining**: For certain periods during the trial, drivers were assigned exclusively to a certain line during a given shift. This so-called clean-operation (rena tjänster) is aimed to isolate the impact of the experiment from other lines and relax the inter-lining scheduling requirements.
• **Adjusted signal priority**: The priority criterion was adapted to be headway-based\(^5\). Hence, buses get priority at signals unless the headway from the bus in front of them is shorter by more than 1 minute compared with the headway from the succeeding bus.

• **Active centralized control**: Experienced traffic dispatchers were dedicated to lines 1 and 3. They monitored and steered the operations from the control room (KTS). As part of the project, they had a couple of training sessions given by Peter Kronberg to apply active fleet management strategies, primarily short turnings and using reserve buses (‘flexbussar’).

• **Traffic ambassadors**: Traffic ambassadors were positioned at driver relief points (Fridhemsplan, Slussen and Jungfrugatan). Their role was to inform drivers, help drivers to take the breaks they are entitled for and are engaged in the experiment.

• **Information campaign**: Several waves of information were disseminated to drivers about changes in operations conditions during the experiment. Various information channels were used including brochures that were given at depots and posted in the driver cabin, BussPC pop-up messages and a note on the driver timesheet (körspec). In addition, information and training seminars were held for traffic ambassadors and traffic dispatchers.

The following caveats should be mentioned:

• Decentralized control functionality – Considerable technical problems have led to limited system effectiveness and influenced negatively drivers’ trust in the system. These problems are discussed in detail in Chapter 4.

• Signal priority functionality – The priority function does not work for some of the buses as well as at some intersections. SL and Keolis work together with Stockholm City to solve the remaining problems. Furthermore, the headway-based adjustment was confirmed by INIT but has not been verified in the field.

• Driver involvement - The project team planned initially to allocate a dedicated and exclusive group of drivers for the project in order to facilitate more effective information dissemination such as holding information meetings. Unfortunately, this proved to be very difficult from scheduling point of view and was therefore canceled.

• Fluctuations in congestion – It is difficult to say if there any differences in the background traffic level. The cycle time of line 4 which did not take part in the project increased by approx. 4% on 2012 compared with the corresponding period 2011. Construction works in Karolinska area (due to Norra länken) caused delays on line 3, especially in the direction from Karolinska to Södersjukhuset.

• The extent of active traffic control – We cannot assert the frequency and efficiency in which active traffic dispatching was used.

The field experiment was initially planned for the autumn timetable which took place between Aug 20 and Dec 8. However, the experiment consisted eventually of three separate periods (Aug 20-Aug 28; Oct 8-Oct 16; Nov 19-Dec 4) marked with green in the following time schedule:

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\(^5\) The current bus signal priority scheme in Stockholm is based on schedule adherence so that buses get priority unless they are early by more than 2 minutes with respect to the timetable.
The experiment was first introduced immediately after the summer break, which is the busiest traffic period. On the same day that the experiment was launched, many other public transport changes took place in Stockholm as well as high levels of congestion and absenteeism. It was then decided to suspend it from Aug 29. An analysis of the performance revealed that both speed and regularity either remained at the same level (line 1) or improved (line 3) compared with the same period the previous year.

Following these results, it was decided to have clean-operations also on line 1 for a certain period (this was planned from the outset for line 3). Keolis prepared then a new driver schedule with clean operations on line 3 from Oct 8 and on line 1 from Nov 19. The experiment was then reintroduced with clean-operations on Oct 8. Due to recurring technical problems the experiment was halted from Oct 17. These problems were identified, investigated and taken up with INIT. Finally, the experiment was launched again on Nov 19 with clean-operations on both lines and the BussPC display showing both schedule and headway adherence indicators. A heavy snow storm started on Dec 5 and led to major service disruptions across the region and the sabotage on many services.

### 2.4 Before-after analysis

#### 2.4.1 Measures of transit performance

The project was assessed based on a comprehensive data analysis and the synthesis of inputs and feedbacks from all involved parties. Data analysis consisted of automatic vehicle location (AVL) and automatic passenger counts (APC) data from BussPC and ATR systems, respectively. Data was extracted for the entire project period (20-Aug-2012 – 8-Dec-2012) as well as for the corresponding period from last year (22-Aug-2011 – 10-Dec-2011). This amounts to approximately 1.3 million data records for lines 1 and 3. The ATR data is available for approximately 10% of the trips.
The performance of lines 1 and 3 was evaluated by considering various measures of performance. The results of this analysis are presented in the following chapter. All of the results are for weekdays 7:00-19:00.

Alternative candidate indicators were formulated and reviewed. Five desired attributes were used in assessing them:

1) Straightforward calculation and interpretation
2) Comparability and capability to aggregate the results
3) Useful as input to performance evaluation
4) Provide insight into causes of problems
5) Representativeness of user perspective

After considering the above criteria for a range of indicators, the following regularity indicators were used in the analysis:

- **Headway coefficient of variation, CV(h)** – The coefficient of variation is the ratio between the standard deviation and the mean headway:

  \[
  CV(h) = \frac{\sigma_{\text{ActualHeadway}}}{\text{ActualHeadway}}
  \]

  It is a normalized measure of headway variability that takes the value of zero in the ideal case that all headways are equal. The higher the CV(h) the more irregular the service is. This is a robust statistical measure that provides a direct indication of service variability. The zero value corresponds to perfect reliability. However, it is not intuitive and may not be fully representative of users’ experience.

- **Headway adherence, HA** – the share of buses that arrives with a headway that is a certain percentage longer than the planned headway:

  \[
  HA = \text{probability}(\text{ActualHeadway} > \alpha \cdot \text{PlannedHeadway})
  \]

  This measure is easy to communicate as it is percentage-wise and comparable across lines and systems. Note that unlike the range of regular headways used in the analysis (Section 3), it accounts only long headways. The inclusion of short headways can be counter-productive and does not reflect passenger perception. The disadvantage of this measure compared with EWT is that it penalizes evenly all headways that satisfy the threshold requirement. In other words, headway that is 2 times longer than the planned headway has the same impact as a headway that is 60% longer. This measure also incorporates the impact of missed trips.

- **Average excess waiting time, EWT** – the additional waiting time that passengers experience due to irregular bus arrival. A perfectly regular service – where all buses are evenly spaced – will obtain EWT=0. It was also used in the analysis above. It is formally calculated as follows:

  \[
  EWT = \frac{\text{ActualHeadway}^2}{2 \cdot \text{ActualHeadway}} - \frac{\text{PlannedHeadway}^2}{2 \cdot \text{PlannedHeadway}}
  \]

  The first expression is the actual waiting time from which one subtract the theoretical waiting time that would have occurred if all buses were evenly spaced. Even though the calculation is not intuitive, the measure itself is easy to communicate as it is measured in

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time. Moreover, it is comparable across lines and systems. This measure also incorporates the impact of missed trips.

In addition, the analysis considered schedule adherence measures and vehicle running times (and the corresponding commercial speed). Furthermore, load profiles were investigated as well as the extent to which they vary from one bus to the other. A measure of utilization was used in order to assess the existence of redundant capacity.

### 2.4.2 Additional related analysis

In addition to the above transit performance analysis, two additional data collection efforts took place in relation to this project and have to be complemented and analyzed:

1. **Fuel consumption** measuring equipment was installed on 10 buses that run on line 3 starting from Nov 19. The fuel consumption under this period will be compared with later measurements without RETT. This investigation is motivated by the potential impact of the driving style with RETT and eco-driving.

2. **Driver stress levels** were measured by a dedicated questionnaire and heart rate variability measurements. Two KTH research assistants offer drivers at the relief point to participate on a voluntarily basis in the experiment by wearing a heart rate belt that is connected to a mobile GPS device. The measurements were taken on Dec 3-8 and hence do not reflect RETT conditions but rather the unusual working conditions related to the snow storm. This will be complemented with measurements that will be taken in March 2013. The analysis aims to gain better understanding on driver working conditions and the main stress factors.
3. Results and analysis

Service regularity was primarily analyzed by constructing the distribution of all headways upon departure from all stops. Headway distribution is a highly informative output as it allows observing what is the share of headways within each range of values. The planned headway is the focal value of the distribution and the variability it exercises reflects service regularity. The narrower the distribution the more regular the service is. The headway distribution provides therefore a useful evaluation tool that will become the core of the business model proposed later in Section 5.2.2.

Figures 5-10 present the headway distribution for both lines 1 and 3 on three time-of-the-day periods (7:00-19:00, 7:00-9:00 and 15:00-18:00) for two periods without RETT on fall 2011\(^7\) and fall 2012\(^8\), on RETT2\(^9\) and RETT3\(^{10}\). Both periods were used for comparison in order to improve the interpretation power. Moreover, it is believed that the periods during the fall of 2012 without RETT do not reflect neutral conditions because of potential project impacts (e.g. the presence of a dedicated traffic dispatcher, drivers’ awareness to regularity). Note that the value on the x-axis indicates the upper limit of the headway interval – the bars on the value ‘1’ correspond to the share of bus departures that were within the range of zero to one minute indicating extreme bunching where the bus is in great proximity to the preceding bus.

It is clear that headway distribution becomes more concentrated around the planned headway under RETT3 for both lines 1 and 3 and during all time periods. Nevertheless, lines 1 and 3 show distinctively different patterns. In the case of line 1, headway distribution is very similar when RETT was not active in 2011 and 2012. The share of very short or very long headways decreased significantly with RETT. At the entire day level as well as AM peak, RETT3 outperformed RETT2, while achieving slightly inferior results on the PM peak. In contrast, line 3 had very poor regularity on 2011 when considering the entire-day performance. Based on discussions with drivers and traffic dispatchers this is attributed to construction works in Karolinka (the AM peak does not exercise the same pattern perhaps because the construction work avoids impacting the morning traffic). The percentage of bunching on line 3 decreased with RETT.

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\(^8\) Lines 1 and 3: See non-RETT periods on Section 2.3 above

\(^9\) Relevant for line 1 only: 24-Oct-2011 to 31-Oct-2011

\(^{10}\) Based on the second phase of the experiment: See Section 2.3 above (this period seemed to suffer less to radio communication problems)
Figure 5: Headway distribution, line 1, All day (7:00-19:00)

Figure 6: Headway distribution, line 1, AM peak (7:00-9:00)
Figure 7: Headway distribution, line 1, PM peak (15:00-18:00)

Figure 8: Headway distribution, line 3, All day (7:00-19:00)
In order to further assess how regular the service is, the *share of regular headways* was defined as the percentage of headways that deviate from the planned headway by less than 50%. The range of regular headways is thus typically defined as headways between 3 and 9 minutes for line 1 and headways between 3 and 10 minutes for line 3. Figures 11-13 show the share of regular headways for both lines on each time-of-the-day period and the four conditions. The share of regular headways...
increased under RETT3 by 8% on average compared with the periods without RETT during fall 2012. Line 1 reached a daily average share of 67% regular headways with RETT3 while line 3 yielded 70%. As can be expected, peak periods are slightly less regular with the most noticeable difference for line 3 on the PM peak period, which is also the only instance where RETT did not improve the share of regular headways.

Figure 11: Share of regular headways, All day (7:00-19:00)

Figure 12: Share of regular headways, AM peak (7:00-9:00)
In order to gain a better understanding on how the regularity evolved over the experiment period, the coefficient of variation of the headway, CV(h), was calculated for each day. Figure 14 presents vividly the extent to which regularity fluctuates from one day to the other. However, headways varied to a much lesser extent during the autumn of 2012 compared with 2011.

Figure 14: Coefficient of variation of the headway for line 3 both directions during the entire autumn timetable 2011 and 2012 (RET periods are highlighted)
Service regularity was also analyzed along each route in order to investigate the propagation of irregularity. The following pattern was observed: trips start as evenly spaced from the first stop during the RETT experiment but have managed to remain at about the same level and therefore obtained a better regularity throughout most of the route. In contrast, the headway variability increases considerably along the line and buses arrived very irregularly at the last stop. This is illustrated in Figure 15 for line 1 for the second RETT period and the immediate preceding days. Headway regularity at the last stop is important from operator-perspective as the operator can predict better when buses will become available. Note that the relief point, Fridhemsplan, is where the change in trend takes place. Unfortunately the clean-operations did not lead to improvements in the regularity of departures from the first stop (see discussion in Section 4.2 below).

![Figure 15: Coefficient of variation of the headway along line 1 EF for five days without and with RETT](image)

The extent to which service regularity gets worse along the line is presented in Figure 16. In all cases, service regularity deteriorates more along line 1 than on line 3. The percentage corresponds to the increase in headway variability along the line (CV(h) at the first stop vs. the last stop) during the entire project period. It is clear that service regularity deteriorates to a significantly lesser extent when RETT was active for both lines by 18-30%.
Passengers waiting times are determined by service regularity. *Excess waiting time (EWT)* reflects the average extra time that passengers have to wait due to service reliability problems. If headways are perfectly even then EWT=0. Hence, it is a more intuitive and informative regularity measure which takes the user-perspective.

The average passenger waiting time increases along the line as the service becomes more irregular. Hence, the extra waiting time depends on the stop at which one waits. As shown in Figure 17, passengers that wait at the beginning of the line waited on average 20 seconds more than they would have wait if service regularity was perfect – all buses were evenly spaced. This is true under both periods – with and without RETT – as service regularity at the first stop was at the same level. However, after Fridhemsplan the two periods take a distinctively different trend with the extra waiting time without RETT being 33% longer than with RETT (up to 45% difference at some stops).
The excess waiting time was calculated and analyzed for the entire project period and the corresponding period the previous year. Figure 18 shows that waiting times were shorter when RETT was activated. Waiting times on line 1 were reduced by 8-11% with RETT. In the case of line 3, regularity was substantially worse in 2011. It seems like something was fundamentally different, most likely related to the construction works in Karolinska area and the rerouting of the line there. The already fairly good regularity was further reduced by 1-4% due to RETT.
Measures to improve service regularity could slow down the service. The project team was very aware of this potential threat and considered it carefully when designing and monitoring the project. The results show that the project did not compromise speed. The average commercial speed (from first stop to last stop including stop times) remained unchanged with 13 km/h on both line and both directions regardless of RETT and at the same level as the previous year. Similarly, the deviation from the schedule remained within a reasonable range so that drivers were about 1 minute later than without RETT at driver relief stops.

Dwell times at stops were also analyzed. Note that the data does not allow us to distinguish between passenger service time and holding time. The total dwell time along the route was 30 seconds longer on both directions on line 1 with RETT compared with the periods that had no RETT. This is most likely the result of some misunderstanding among drivers which waited for the indicator to become zero (see Section 4.3.1). In the case of line 3, the total dwell time at stops was essentially unchanged (15 seconds shorter on SK, 10 seconds longer on KS) and approximately 30 seconds longer in 2012 than in 2011.

Moreover, the dwell time distribution along the line remained very similar. It should be noted that in all cases dwell time is especially long at driver relief points – Fridhemsplan for line 1 and Slussen for line 3. In the case of the former it became 17 seconds longer while the latter became 30 shorter.

Service irregularity and bus bunching also result with great variations in passenger loads - the overcrowded leading bus is followed by an underutilized bus. Hence, a more regular service will result with a more even distribution of passengers over buses as was also found in RETT2. A more regular service implies therefore that passengers wait for a shorter time and have better on-board conditions. Even with better regularity, passenger loads vary dramatically from one bus to the other as evident in Figure 19. Note that buses that run with long headways are overcrowded while buses with short headways run with very low number of passengers on-board. This is the result of the positive feedback loop which creates the bunching phenomenon.

While the average capacity-utilization rate on line 1 may be 25% for the entire route (and 56% for seats-utilization), the utilization varies considerably over the route as well as between buses. One particular trip almost reaches capacity constraint while others never exceed the number of seats – even though they run in the peak period. In the case of line 3, later trips (departure time 17:00-18:00) are more crowded.
Figure 19: Load profiles on trips running on line 1 FE (above) and line 3 KS during the peak afternoon period (15:00-18:00), Oct 8-12, 2012; Darker lines correspond to later departure times; The average headway is displayed for each bus trip.
4. Discussion
The challenges experienced in this project with respect to project organization, system functionality, crew and driver scheduling are discussed below.

4.1 Project organization
The project team was able to jointly agree on the experiment design and discuss issues and problems as they unfolded. The participation of people with different roles and expertise contributed to a variety of perspectives and access to relevant knowledge. The driver union representatives provided valuable input from their colleagues throughout the project.

The project lacked however sufficient knowledge and access to the BussPC system and related technologies. Since the functionality of the system provided by INIT played a pivotal role in this project, the project team has made an attempt to directly involve them in the project but they claimed that this would be unnecessary because they already have an experience with a similar application. This is unfortunate, as INIT engagement in the project was unsatisfactory. It is believed that the project could have benefit from involving INIT from the project planning phase and allocate resources to their activities to ensure a greater commitment from their side. The lack of such engagement in this project hindered its implementation as technical problems were not solved and addressed promptly and thoroughly.

4.2 System functionality
The functionality of the technical system is of course crucial for the new strategy to be successful. Unfortunately, the project was subject to recurring technical problems that have led to limited system effectiveness and influenced negatively drivers’ trust in the system. One of the purposes of this report is to compile the technical problems that have been encountered throughout the experiment and how they have been tackled. It should be stressed that it is sometimes difficult to point out the source of the problem due to the complexity of the system. Some of the problems were solved while other remained unsolved until the end of the project. The following *hardware* system functionality problems were identified:

1. **Radio communication** – An upgrading of the Motorola radio system took place in parallel to the project. This was however not known to the project team until long into the implementation. The upgrading from the old system to a new system led to severe capacity problems in the radio system resulting with regular failures in radio communication between buses and the BussPC system. Even though this technical problem is exogenous to the project it affected it very negatively. The RETT strategy is more dependent on bus communication since a lost connection implies: (a) the figure freezes for the bus that lost connection and then updates once the connection is back; (b) the RETT indicator recalculates itself for all other buses and uses the remaining buses as references. Hence, the indicator for the bus in front and the bus behind will jump and get false figures and then once the connection is back will jump again, taking the intermediate bus into account. Moreover, a specific problem occurs between Karolinska and St Eriksplan and around Jungfrugatan as well as a general problem during the peak period due to a congested radio cloud.

2. **Updating frequency** – The existing system is incapable of handling a large amount of parallel processes. The current hardware is old and it is not available for sale anymore. The capacity limits and hence the low processing speed caused particularly problems when buses overtook each
other, which is unavoidable. Overtaking implies that a new pair of buses should be used as reference for regularity for both the overtaking (from positive to negative indicator) and the overtaken buses (from negative to positive indicator). This updating requires hence a sequence of processes which led to a very slow updating of the indicator and a too long lag between the actual occurrence and the appearance of the updated indicator. The project team discussed the issue of overtaking and agreed that it should be encouraged in case an empty bus is just behind an overloaded bus. It may be useful in such cases to have a feature in the system that will allow the control center to treat two bunched buses as a single bus by disregarding the late bus (e.g. the late bus logs off from the system and logs in as an extra trip). The impact of this solution on the reporting system has to be followed-up to make sure it registers correctly.

In addition, the following software system functionality problems were identified:

3. **Partial trips** – Early in the project it was observed that the RETT indicator is active only for complete trips. Planned and unplanned partial trips (such as flex buses) hence are not taken into account when calculating the RETT indicator. This influences not only these partial trips but also leads to false indicators for the remaining buses due to their exclusion. This problem was taken with INIT and they provided a new software update. It then turned out that it works only for trips that start from an intermediate stop until the final destination. However, it did not work for partial trips that start and end at intermediate stops. INIT has delivered yet another update which accounts also for these cases as well.

4. **Prognosis** – The calculation of the regularity indicator is performed and updated every 15 seconds. This prediction of the headway from the next bus is based on the same set of assumptions that are used for the real-time arrival information provision: (a) The travel time between bus current location and any downstream location is equal to the scheduled travel time; (b) Buses never leave prior to their scheduled time from time point stops (including origin stop). The combination of these assumptions implies that buses that run on-time or late will sustain their schedule deviation while buses that run early will arrive on-time in case there is a time point stops between the current location and the relevant downstream location, otherwise they will sustain their schedule deviation. Assumption (b) is taken into account also when calculating the RETT indicator, even though this assumption is of course not valid under RETT operations. It will cause the indicator to fluctuate after an early bus departs from a regulating stop since the prognosis scheme does not reflect the current strategy.

Two possible approaches to solve this problem were considered: (a) changing the prognosis scheme logic implemented by INIT. This was unfortunately not feasible within the project time limits; (b) Keolis will provide new timetable input so that the database will not indicate time point stops for prediction. This may still cause problems since a subset of the time point stops are used occasionally also as relief points. However, it is not clear what the implications of such a change are as this joint fundamental database is used for various purposes and systems. Moreover, it involves a long delivery time. Hence, the prognosis problem remained unsolved until the end of the project. It should also be notes that RETT could benefit from a more dynamic

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11 Shortly after the experiment finished, INIT informed the project team that it now made it possible to indicate whether regulation stops should be used for the prognosis or not and that this in the future will be defined at the line level.
prediction method. For example by using recent rather than planned travel times when calculating the expected headway from the next bus.

5. **Recovery time** – The prognosis of the backward headway is based on the current location of the succeeding bus even if it still runs on the previous trip. In other words, the prognosis considers the cycle route as a single trip. This caused the indicator to show a high negative value for the first few stops and then suddenly increased substantially. A discussion with INIT revealed that they have previously solved a related problem by allowing specifying a fixed recovery time at the turnaround stop (first/last stop for each direction). INIT provided this feature in a system update but unfortunately without any description on how exactly it has been embedded into the prognosis. However, it was unclear what would be an appropriate recovery time parameter and thus it was decided to start with 5 minutes and then adjusts it as necessary to guarantee that drivers will have a sufficient turnaround time. It turned out that it resulted with delays for other buses due to the incorporation of this recovery time into the predictions of all buses while it should be used in practice only by early buses as a maximum value. This problem could perhaps be solved by defining a link between two stops at the turnaround stop with travel time in between. Furthermore, when few buses wait at the turnaround stop the indicator will refer to fellow waiting buses. This may create confusion which bus shall depart first and require control center intervention (as they can check the corresponding scheduling for waiting buses).

In summary, radio communication systems are believed to be the most severe technical problem the project was subject to. INIT system requires few adjustments in order to turn it into a complete solution for regularity-based control. The discussion also stressed the growing need to establish a new method for operators to report their production to SL as the current system is outdated.

As mentioned in the experiment implementation description (Section 2.3), it was not possible to verify the functionality of the signal priority system. Regardless of the RETT project, the BussPrio system does not work satisfactorily and has several functionality problems at both the traffic signal and vehicle levels. Therefore we have a reason to believe that the adjustment of signal priority to be based on headways did not have a big mark on the project, although it could potentially play a very important role if functions properly.

### 4.3 Keolis personnel

The project was ultimately implemented by Keolis crew: drivers, traffic ambassadors and traffic dispatchers located at the control center. From the outset, it was acknowledged that the communication between Keolis personnel and the project team is crucial for project implementation. The communication has to work in both directions in order to steer the project and obtain a mutual understanding. The project team had continuous feedback from the field from multiple sources including regular updates from operations personnel and the control center, field visits and discussion with drivers and traffic ambassadors as well as discussions with driver union representatives.

#### 4.3.1 Drivers

Following the previous field experiment, RETT2, drivers expressed their satisfaction with the new strategy. In particular, they experienced the regularity-based operations to be less stressful because it is adaptive and allows them to help each other. The feedback from RETT2 also pointed out the importance of an initial adjustment period, better information, and preference to avoid inter-lining.
and have a single regularity indicator. This feedback was instrumental in designing the RETT3 experiment. Indeed, clean-operations were later introduced on both lines 1 and 3. Initially, only the headway indicator was displayed but then the schedule indicator was redisplayed due to the technical problems that the project encountered. As mentioned in the implementation description (section 2.3), the initial plan to have a dedicated group of drivers for this project that will be trained in person was unfortunately not realized.

Approximately a thousand drivers participated in the experiment through driving on lines 1 and 3 during the experiment period. The project team prepared an information campaign designed to inform, explain and motivate drivers with respect to the project. The primary information channel consisted of several waves of brochures that were handed at depot and posted at driver cabins with the most concise information. More comprehensive information was available in the form of a compendium distributed at driver coffee rooms. In addition, remainders on the ongoing project were posted on drivers schedule sheet and as regular pop-up messages on the BussPC screen. These information channels were utilized in order to assure that the project reach every single driver.

The information campaign described above was aimed not only to get drivers awareness and explain the new strategy but also to encourage drivers’ cooperation and engagement in the project. Most drivers tried to follow the project guidelines but couldn’t adhere to it due to system functionality problems. Few drivers however did not pay attention to the project. Moreover, the recurrent problems with system functionality influenced negatively drivers trust in the system. Its introduction simultaneously with the return from the summer break did not help either as it was perceived as a source of stress. Furthermore, the project required additional waves of information with changing guidelines which caused greater confusion. It was difficult to communicate the technical problems to drivers while they may experience it as not trustworthy, even if the overall performance improved.

The project team decided to meet with a group of drivers that have expressed their dissatisfaction with the project. Drivers were positive towards the idea to run high-frequency lines based on regularity objectives but were concerned about the unsolved technical problems, insufficient information concerning relief points and end stop, too little active management from the control center side, passive or missing traffic ambassadors during rush hours and stress at turnaround stops. The profound difference between driver experience on RETT2 and RETT3 is above all attributed to the technical system problems.

The discussion also revealed several communication problems that caused some drivers to believe that: the indicator refers only to the bus in front - was further emphasized in later information material (e.g. giving a pearl chain metaphor); they should wait as long as necessary until the indicator shows zero. It was then clarified that drivers are not expected to hold for long times and they should use their judgment and experience. This is presumably the reason why dwell times became slightly longer during the experiment (see Chapter 3); they should always wait until the scheduled departure time at the first stop, even when they do not have a relief point along the trip. It is however not clear how widespread these misconceptions were. There were no reported complaints on clean-operations or with respect to running late for driver change at relief points which is in line with the empirical analysis.

Any future implementation should of course make sure that drivers’ ability to take the breaks that they are entitled for is sustained. It is also sensible to set a minimum bus driving experience
requirement (e.g. one year) for these lines. The driver union has raised the following issues as necessary preconditions for implementing regularity-based operations:

- The accessibility for buses on city streets has to improve
- Signal priority has to function adequately
- Drivers shifts have to be constructed differently to allow more flexibility at relief points
- Drivers should have the option to express their preferences with respect to working on trunk lines (‘stombusslinjer’)
- Traffic control has to become more active and take advantage of its ‘helicopter-perspective’
- The technical problems must be solved

There is a wide agreement within the project team concerning these issues.

4.3.2 Traffic ambassadors
Traffic ambassadors were positioned at driver relief points - Fridhemsplan and Jungfrugatan for line 1 and Slussen for line 3 - and had direct access to drivers and could interact with them promptly and simplify local operations and communication. As part of the preparations for the trial and a lesson from RETT2, a special training session for traffic ambassadors was given. An additional meeting took place before the second experiment phase. All traffic ambassadors have a long bus driving experience and are highly familiar with the operations environment. Drivers where informed via brochures on the availability of traffic ambassadors and were encouraged to contact them for advice regarding their schedules, breaks as well as general concerns regarding the project. However, discussions and input from the ambassadors highlighted the following issues:

- Their working duty was not clearly defined and their time-allocation could have been more efficient (e.g. concentrate on peak periods)
- Lack of contact with the control center - would have like to have radio communication.
- Sometimes lacked up-to-date information

Their presence could have been better utilized if departures from relief points and turnaround stops were based on regularity (see Section 4.3.4 below). It should be stressed that traffic ambassadors are not an essential part of the RETT implementation but were expected to support the introduction of the experiment when information is a key issue.

4.3.3 Traffic dispatchers
As part of the preparations for the trial, special training sessions for traffic dispatchers were given in addition to an information seminar. The training given by Peter Kronberg from Movea concentrated on gaining better understanding of the underlying reasons for bus bunching, mitigation actions with focus on practicalities involved with applying overtaking (‘omkörning’), deadheading (‘tömkörning’) and short-turning (‘kortkörning’).

As part of the project, a dedicated dispatcher at KTS monitors only lines 1 and 3. Unlike usual conditions, it allows being more active and respond to traffic conditions. Traffic dispatchers stressed the complexity involved with taking proactive measures and that they have developed these skills throughout the project. They sometimes lacked resources under peak-period conditions.

Control center display could be improved to facilitate more active control. This includes adapting the color display to correspond to headway deviations for the relevant lines and upgrading the interface.
In addition, the display updating frequency appears to be insufficient. This causes a lag between the actual and displayed conditions and may cause dispatchers to respond slowly or to respond to conditions that are not fully up-to-date.

4.4 Clean-operations and driver scheduling
Schedule control has a profound impact on bus operations. The shift from scheduled-based operations to service that is focused on regularity requires to remove as many schedule constraints as possible from the working routine. These constraints are distributed along the cycle travel time and consist of three types (note that not all buses run cycle-wise, for example due to partial trips):

- Turnaround stops (start and end stops of the route) – Frihamnen and Essingetorget for line 1; Karolinska sjukhuset and Södersjukhuset for line 3.
- Regulation stops (time point stops) – Fridhemsplan, Hötorget and Värtavägen for line 1; Kronobergs gatan, Slussen and Skanstull for line 3.
- Relief stop (‘avlösning hållplats’) – Fridhemsplan (and sometimes also Jungfrugatan) for line 1; Slussen for line 3.

As illustrated in Figure 20, schedule-based control remained substantial even under the RETT3 experiment even though it was subject to a lesser intensity and frequency.

![Figure 20: Illustration of schedule-related constraints along the line, before (above) and after (below)](image-url)
The new strategy implies the removal of scheduled regulation stops along the route which are designed to improve service punctuality. Clean-operations – minimizing the interlining between headway-based and schedule-based services within a given driver shift – were motivated by common understanding that even departures from turnaround stops should follow the headway-based control rather than the timetable. However, the project timeframe did not allow developing an alternative driver scheduling that will allow greater flexibility in departure times. The need to adhere to driver schedules hindered not only the ability to follow headway-based control at relief stops but also at turnaround stops and along the route as schedule constraints sometime prevailed and drivers had to make sure that they will be able to replace each other at the scheduled time. Allowing flexible scheduling will imply minor deviations from the schedule of the same magnitude experienced today since punctuality remained at the same level.

Furthermore, the initial plan was to display only the regularity indicator without the schedule indicator. This however proved to be very problematic as long as drivers’ scheduling includes dispatching times from the first stop and driver relief stops. Approximately every third trip involves changing drivers at a relief point and this is timely coordinated under the existing scheduling system. This has also led to some confusion among drivers concerning the departures from the first stop. It was therefore decided to locate a traffic dispatcher at Karolinska in order to provide information to drivers, help dispatching and stand in communication with the control center. After a couple of days it was decided that it is necessary to have a traffic dispatcher rather than a traffic ambassador for this task.

Even though the full potential of clean-operations was hindered by schedule constraints at relief points and the fact that it coincides with the most pronounced radio communication problems, it is believed that clean-operations were instrumental in getting closer to operating based on regularity. The results however do not allow to draw definitive conclusions on the extent of its impacts.

4.5 Passengers information systems
The shift from focus on punctuality to regularity-based objectives for trunks line is motivated by their high-frequency which causes passengers to arrive almost randomly at stops without consulting the timetable. SL trunk lines’ timetables already refer to service frequency rather than a specific departure time for large portion of the service span. In the case of line 1 for example, the timetable states that buses arrive every 5 minutes during the morning peak period (7-9) and then every 5-7 minutes until the end of the afternoon peak (9-19). In contrast, SL journey planner provides travel information based on the detailed timetable database. This may mislead passengers that use SL journey as a pre-trip or en-route information provision.

It is suggested that the journey planner will provide specific arrival times only when a real-time prediction is available (e.g. information on the next bus arrival as displayed also at the stop). Otherwise, the journey planner should refer only to the average headway within the relevant time period. If regularity-based operations will become the common practice, then passengers should be informed about this change through the common information channels (e.g. digital on-board displays, leaflets posted at stops, SL website) to explain it and increase public acceptance.
5. Regularity-based incentives

Service reliability is a highly important determinant of the quality of service. Public transport authorities have an important role in steering service performance and providing the appropriate incentives to promote better service. Reliability could be defined and measured in terms of punctuality, regularity or running time variability. In the case of high-frequency services which run with an average headway shorter than 10 minutes, service regularity should be the key performance indicator. In order to move towards the long-term implementation of regularity-driven operations, new regularity-based incentives have to be embedded in future agreements between SL and operators.

As part of this project, contract-related issues and the procurement implications were investigated based on scientific studies, strategic reports and discussion with people from transit authorities, operators and other stakeholders in the industry. The new City contract provides an opportunity to distinguish between regularity-based assessment for high-frequency blue bus lines 1-4 and punctuality-based assessment for all other red bus lines. This implies running parallel systems with trunk lines (blue buses) based on regularity while other lines (red buses) follow punctuality.

5.1 Existing incentives

The current contract between SL and bus operators determines that the operator has to pay certain penalties, depending on the level of service offered and service punctuality is an important clause in the contract. SL has experimented with gross and net contracts with various incentive schemes related to adherence to planned production, punctuality, customer satisfaction survey, ridership as well as mystery customers who assess staff behavior, cleanliness and the quality of information. Punctuality is measured as on-time performance which is defined as the share of buses departing within the time window of 1 minute ahead of schedule and 3 minutes behind schedule from several key stops along the route known as regulation stops. The existing on-time performance indicator is associated with the following drawbacks:

1. **Does not reflect passenger perception of service reliability** – in the case of high-frequency lines, service reliability is experienced in terms of the waiting time which is determined by the regularity of bus arrival at stops.
2. **Does not capture the extent of service reliability** – each bus arrival is either on-time or not on-time based on how it stands with respect to the allowed time window. This implies a weak connection with passenger experience as only the share of on-time arrivals matters and not how late or early buses are - a bus which is 10 minutes late will have the same impact as a bus that is 4 minutes late. This is an inherit problem of a measure that is defined in terms of thresholds.
3. **Defined at the vehicle level rather than the passenger level** – the performance is measured with the single bus as the measurement unit. Hence, it does not account for the number of passengers affected by the observed performance.
4. **Fail to yield its objective** - An analysis of the performance of lines 1-4 revealed that the overall pattern is that the share of on-time departures deteriorates dramatically along the route to an unsatisfactory level.
5. **Does not address a substantial share of the trips** - The share of late departures is not affected by regulation stops as the current holding strategy does not handle buses that are behind schedule.
6. **Contributes to abrupt behavior** – The measure is based only on few stops along the line. There is evidence that drivers adjust their speeds just before approaching those stops in order to make it
within the desired time window. The share of early departures decreases at regulation stop due
to holding of early arrivals. However, this affect does not last with an immediate increase in
subsequent stops. Moreover, even at regulation stops a considerable share of the buses of 10-
20% departs early.

(7) May create counter-productive incentives - It is important to stress that timetables are not merely
a reflection of travel times but rather an important determinant of these times. In other words,
the measure uses the timetable as an exogenous reference point while it is in fact an endogenous
factor. Hence, as long as the timetables do not reflect the updated traffic conditions, buses will
not exploit them. This was evident after congestion charging and the priority package were
implemented in Stockholm (7).

(8) Is subject to regular adjustments – Since the timetable is used as the reference value it must be
occasionally adjusted and agreed by all parties. Timetables are designed based on historical data
and therefore it is difficult to attribute the deviations from service standards to factors which are
under the operator’s control.

(9) Requires to define benchmarks – Operators receive bonuses or penalties in case they exceed or
fail to reach the standard. This percentage rule may be weakly related to passenger satisfaction.
In addition, the on-time arrival window has to be per-defined.

5.2 Embedding regularity in the business model
SL undertakes an ongoing shift from a control-centered perspective to value-based management
perspective as is also reflected in its recent organizational and legal status changes. This could also be
reflected by enhanced service incentives. The introduction of regularity-based incentives can help to
resolve some of the above issues. Furthermore, the bus branch realizes that regularity will become
more important in future operations and that this would be reflected in future contracts.

It is important to emphasis that the chosen measures should be instrumental in promoting the
performance objective. It should encourage all parties involved to work towards the same desired
direction. The regularity indicators presented in section 2.4.1 are fairly easy-to-communicate and are
not data hungry as they require only the actual and planned headways which are readily available.
Their adoption will promote more dynamic allocation of resources, proactive control actions and the
adoption of control measures at terminals and along the route. The regularity measure will of course
complement other incentives in either a gross contract or a net contract. In particular, it should be
complemented by speed-related incentives.

We are aware of two large public transport authorities that already use regularity indicators to
evaluate bus operators - Transport for London (TFL) and Transantiago in Santiago, Chile; none of
them however applies a regularity control strategy as the one tested in this project. When comparing
the EWT for lines 1 and 3 against comparable lines managed by Transport for London it was found
that they perform slightly better than the best performs in London. This highlights that incentives
should be supported by the underlying operation strategy. After addressing the issues outlined in the
previous section, the RETT system will be an important enabler of better service regularity.

--Ingemarson M. (2010). Running times for bus traffic – A running time study of the bus rapid transit in the city
6. Conclusion and recommendations

6.1 Project assessment

The RETT3 project had faced many challenges and yielded a partial success. Service regularity has improved even though the implementation conditions were far from ideal. This was achieved without compromising the speed.

The project was an important instrument for gearing the operations towards regularity. It raised planning, operations and real-time management issues among all parties involved and contributed to a constructive discussion on how the performance can be further improved to reach the common objective of better service regularity on high-frequency lines. It was important to test the RETT system in the field in order to encounter, identify, investigate and hopefully also solve potential problems. Fundamental issues have been revealed and discussed in order to come with a coherent plan.

The two main drawbacks that hindered the project performance were:

- System functionality problems – the INIT system has certain defects that were only partially solved during the project. More importantly, the radio system was extremely unstable and caused to communication problems that had pronounced implications on the project. This was a great source of frustration as it was identified as the weakest link in the project as it lies largely beyond the project team domain.

- Remaining timetable constraints – the project removed the schedule anchors at time point stops along the route but schedule constraints remained at relief points and to a large extent also at first stops. This prevented the system from running continuously based on regularity and therefore manifesting the full potential of this strategy. This implies that the system still had two objectives – regularity and punctuality – that steered the system which are sometimes contradictory. This problem will remain as long as the current driver scheduling’s method is used.

The above problems have obviously affected negatively driver trust and cooperation with the project, in a sharp contrast to RETT2. This should not therefore be considered an independent issue but is rather attributed to the technical system problems. Nevertheless, drivers agree that high-frequency lines should run based on regularity.

6.2 Recommendations for further actions

There is a consensus among all involved parties that high-frequency buses should run based on regularity. Furthermore, it is agreed that the RETT strategy has a good potential. It is believed that the project team has gained better understanding of the problems which should be addressed in future implementations in order to further improve it. It is therefore agreed that the new control strategy should be implemented in the future subject to the following pre-conditions:

(1) Introduce regularity-based incentives to future agreements concerning the operations of high-frequency bus lines. This is essential for the long-term implementation of headway-based operations. It should be noted that SL does not necessarily have to specify the technology or the method, but rather encourage it by using appropriate incentives.
(2) The technical problems have to be addressed with a joint system perspective. The problems described in this report (Section 4.2) must be resolved by either developing the current system or using an alternative system prior to large-scale implementation. INIT system requires few adjustments in order to turn it into a complete solution for regularity-based control. These problems are highly inter-related and include both hardware (e.g. radio system capacity, system update frequency) and software (e.g. prognosis, recovery time) issues. Both ‘problem owners’ (SL, Keolis) and ‘system owners’ (INIT) have to be actively engaged in tackling these problems.

(3) Drivers’ duty has to be defined in terms of the shift timeframe and the dynamic allocation of driving blocks. This will solve the mismatch between planning and driver scheduling that was apparent during the project and will allow the continuous operations based on regularity. This is in line with the current working routine where departure times may differ little from the scheduled due to schedule deviations (‘flextid’). These deviations are expected to be of the same magnitude as experienced today since punctuality remained at the same level. The project team – including the driver union - is in agreement that this is needed and particularly important for better responding to changing traffic conditions. Under this operations scheme drivers will preferably not change between high-frequency and low-frequency lines during a given sheet (clean-operations). It is also recommended that all drivers will be assigned to trunk lines based on their preferences and whether they satisfy a minimum experience requirement.

(4) Active and proactive vehicle management strategies should be further developed. The control room should have better means and skills to take active and proactive decisions that will improve service regularity. This includes providing a more systematic training and tools that would facilitate vehicle management strategies such as visual display, purchasing or developing a decision support system which purposes alternative actions. In addition, the relaxation of existing limitations to more active management should be investigated such as potential short-turning locations and deadheading paths.

(5) Allow more flexible allocation of the production resources during the peak period requirement. The peak-period production requirement, number of buses allocated for a service, is currently defined by SL based on the rush-hour demand. This means that there are more buses than needed on the preceding and successive hours. Alternatively, these extra buses could be used as reserve buses that will be allocated dynamically by the control center wherever needed so that these available resources will be used in the most effective way.
The figure above was created by accounting for the frequency that various words appeared in the meeting notes taken throughout the project. It can therefore be claimed to represent what were the issues high on the project agenda.
Appendix – Current prognosis scheme

Background

The project team tried unsuccessfully to ask INIT to provide it with a description of the current prognosis scheme that is used for calculating the displayed headway indicator as well as for generating the real-time bus arrival information.

The description below is therefore an attempt by Oded Cats (KTH) to describe the most probable prognosis scheme that is believed to be implemented in the BussPC system. However, this has not been verified by the system developer. The description is followed by a more technical formulation.

Description

The calculation of the regularity indicator is performed and updated every 15 seconds. It requires the estimation of two headways: (1) the headway between the current bus and the previous bus and; (2) the headway between the current bus and the succeeding bus.

The calculation of the forward-headway is straightforward as it is simply the difference between the current time and the time in which the previous bus was in the same location.

The calculation of the backward-headway is more complicated as it requires predicting the time difference between the current time and the time in which the next bus will be in the same location. This prediction is based on the same set of assumptions that are used for the real-time arrival information provision.

The current prognosis scheme is based on the following assumptions:

- The travel time between bus current location and any downstream location is equal to the scheduled travel time
- Buses never leave prior to their scheduled time from time point stops (including origin stop)

The combination of these assumptions implies that:

- Buses that run on-time or late will sustain their schedule deviation
- Buses that run early will arrive on-time in case there is a time point stops between the current location and the relevant downstream location, otherwise they will sustain their schedule deviation

Note that the prognosis treats all the buses that run on the same line as a chain. In case the next bus has not started yet a trip on this direction, the prognosis refers to its location of the opposite direction.

Formulation

Bus trajectory could be represented as a vector of time stamps at an array of locations, typically stops. The trajectories of an ordered set of bus trips denoted $K_l$ on line $l$ during a certain time interval can be hence represented as a matrix. Let us denote this matrix as $\pi$ where $\pi_{k,s}$ is the time
where trip $k$ arrived at location $s \in S$. A subset of these locations ($\hat{S} \subseteq S$) are used for regulating the timetable. A corresponding matrix denoted $\Pi^s$ contains the scheduled trajectories for $K_1$.

The calculation of the regularity indicator for bus trip $k$ that just arrived at location $s$ is based on the calculation of the forward-headway and backward-headway as follows:

The calculation of the headway between the current bus and the previous bus is straightforward as it does not involve forecasting:

$$h_{k-1,k} = \Pi_{k,s} - \Pi_{k-1,s}$$

The headway between the current bus and the succeeding bus depends on the prognosis scheme since it is calculated as follows:

$$h_{k,k+1} = \Pi_{k-1,s}^p - \Pi_{k,s}$$

Where $\Pi_{k-1,s}^p$ is the predicted arrival time of run $k-1$ at stop $s$.

Let us denote by $m$ the last stop that has been visited by the next trip

$$m = \arg \max_{i=0,...,s} \{ \Pi_{k-1,i} : \Pi_{k-1,i} < \Pi_{k,s} \}$$

Where $\Pi_{k-1,0} = 0$

Case A: The next bus has already started the next run that will visit stop $s$ ($m \neq 0$)

A.1. If the bus is early ($\Pi_{k-1,m} < \Pi_{k-1,m}^s$) and there is an intermediate regulation stop ($\exists m \leq i < s, i \in \hat{S}$) then the predicted arrival time is simply the scheduled time.

$$\Pi_{k-1,s}^p = \Pi_{k-1,s}^s$$

A.2. Otherwise ($\Pi_{k-1,m} \geq \Pi_{k-1,m}^s$ OR $\Pi_{k-1,m} < \Pi_{k-1,m}^s$ AND $\forall m \leq i < s, i \in \hat{S}$), the predicted arrival time is calculated based on the scheduled remaining travel time:

$$\Pi_{k-1,s}^p = \Pi_{k-1,m} + \Pi_{k-1,s}^s - \Pi_{k-1,m}^s$$

In other words, it is assumed that the current deviation from the scheduled will be sustained.

Case B: The next bus has not started yet the next run that will visit stop $s$ ($m = 0$)

First, the predicted arrival time at the turnaround (last) stop, $\Pi_{k-1,1}$, is calculated as for Case A.

Second, a fixed turnaround recovery time, $\theta$, is inserted into the prediction as follows:

$$\Pi_{k-1,s}^p = \Pi_{k-1,1}^p + \theta + \Pi_{k-1,s}^s - \Pi_{k-1,1}^s$$

Finally, the regularity indicator shows the following:
\[
\frac{(h_{k-1,k} + h_{k,k+1})}{2}
\]

This implies that even headways correspond to an indicator of zero. Long front headway in conjunction with short back headway will induce a positive indicator, while a bus with a short headway in front and long headway behind will have a negative indicator.