RETT2 Final Report – A Field Test for Service Regularity Improvement

“Tänk på Avståndet”

Oded Cats

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Acknowledgements

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Summary

Service reliability is one of the main determinants of public transport level of service. The current strategy in Stockholm is to hold buses at few control stops along the route in case they are early with respect to the timetable. However, in the case of high-frequency services, the level of service depends on regularity rather than punctuality.

Trunk line 1 in Stockholm’s inner-city was the subject of this project because it is a representative high-demand inner-city line that runs through the city center. An analysis of the current performance of line 1 concluded that the current strategy is not effective in preventing bus bunching. Alternative holding strategies were assessed using BusMezzo, a transit operations simulation model.

The conclusions from the simulation study led to the formation of a joint working group of SL, Keolis and KTH with the purpose of testing the proposed holding strategy on line 1. The field demonstration is known as RETT2 project. The project designed, tested and evaluated the new system designed to improve service regularity. The experiment was designed to improve service regularity by holding if the distance from the preceding bus is shorter than the headway from the successive bus and adjusting driving speeds as much as possible while disregarding the schedule as well as the planned headway. The preparations to the field trial included embedding an additional performance indicator based on the distance from the preceding and succeeding buses was into the BusPC screen that is located at the driver’s cabin on all buses.

The experiment took place from October 8 to October 31. A before-after analysis was conducted based on automated vehicle location and automated passenger counts data. The following results are reported:

- A more regular service pattern prevailed with fewer cases of very short or very long headways. The share of bunched buses decreased by 13-24%.
- A decrease of 20% in headway variability was measured during the entire day which means that regularity improved by 20%
- Excess waiting time due to poor regularity decrease by 38% and 11% reduction in the extra time that travellers need to budget for the trip. This translates to savings of almost a minute per passenger.
- Waiting time savings from running the new strategy on line 1 during a single month amount to at least 2.25 million SEK
- Passenger loads deviation from the ideally even load were cut by half and hence the existing capacity was better utilized
- Even though the new strategy disregards the timetable, service punctuality remained at the same level for the westbound direction and improved by 9% for the eastbound direction. This affects positively driver scheduling.
- The total time spent at stops was 10% shorter and was spread much more evenly over stops along the route which implies better utilization of stop
capacities. However, the average total vehicle running time remained unchanged, while its variability decreased.

- Drivers reported a better working environment with less stress because of the cooperative scheme that allows drivers to help each other

The results from the demonstration suggest that the strategy should become the common practice on all high-frequency bus lines in Stockholm. Based on the experience from this project, the following recommendations are made in order to manifest the full potential of the new system:

- A longer field trial
- Revising the bus signal priority to be based on regularity. Give priority to buses that need to shorten their headway from the preceding bus and avoid giving priority to buses that need to increase their headway from the preceding bus
- Display only the regularity indicator on the BusPC screen to avoid confusion
- Avoid interlining between headway-based and schedule-based lines.

Such measures also have the potential to improve running times and the utilized capacity. New regularity-based measures should then be embedded in future agreements between public transport agencies and operators for this kind of service.
Sammanfattning

Pålitlighet är en av de viktigaste faktorerna för kollektivtrafiken. Den nuvarande strategin i Stockholm är att bussarna vänta vid några (regler) hållplatser i fall de är tidigare än tidtabellen. För linjer med hög turtäthet är dock regulariteten viktigare för pålitligheten än tidtabellhållningen.

Stombusslinje 1 i Stockholmsinnerstad undersöktes i detta projekt eftersom den går genom City och har hög efterfrågan och turtäthet. En analys av den nuvarande strategin visade att den inte är effektiv för att undvika "hopklumpningar" (bunching) som leder till väsentliga problem med regulariteten. Olika åtgärdsstrategier utvärderades med hjälp av BusMezzo, en kollektivtrafiksimeringsmodell som utvecklats på KTH. En realtidsstrategi som reglerar tidsavstånd mellan bussar och som tillåter kontinuerlig anpassning av hastigheter och reglering på vilken hållplats som helst, visades vara den bästa strategin.


Fältförsöket började den 8:e oktober och fortsatte till och med den 31:e oktober. En före-efter undersökning gjordes med hjälp av BussPC och ATR data. Resultaterna visar att den nya strategin ger:

- Ett bättre monster av tidsavstånd med färre mycket korta eller mycket långa tidsavstånd. Andelen av ”bunchade” bussar sjönk med 13-24 %.
- Variationen på tidsavstånd minskade med 20 % för hela dagen som innebär att regulariteten ökade med 20 %
- Extra väntetid på grund av bristande regularitet minskade med 38 % vilken betyder att passagerarna behövde budgetera 11 % mindre väntetid. Det betyder en vinst av nästan en minut per passagerare.
- Den förbättrade regulariteten innebär en välfärdsvinst på minst 2 miljoner SEK under försöksperioden (en månad), bara på grund av minskade väntetider på stomlinje 1
- Passagerarna blev jämnare fördelade på bussarna, vilket minskade trängsel ombord med hälften och betyder ett mycket bättre utnyttjande av bussarnas kapacitet.
• Även om det nya systemet ignorerar tidtabellen, så blev tidtabellhållningen 9% bättre i riktningen mot Frihamnen och ligger på samma nivå som förut för riktningen mot Essingetorget. Detta påverkar även omloppstiderna positivt.

• Hållplatstiderna minskade totalt med 10 % och fördelningen mellan hållplatserna blev mycket jämnare som innebär ett bättre utnyttjande av hållplatsernas kapacitet. Den totala omloppstiden var dock oförändrad medan variationen minskade.

• Förare tycker om den nya strategin och berättar att det skapar en bättre arbetsmiljö med mindre stress, eftersom den nya strategin gör att de hjälps åt för att åtgärda fördröjningar på linjen.

Resultanterna från fältförsöket visar att strategin är mycket framgångsrik och bör bli standard på alla busslinjer med hög turtäthet i Stockholm, framförallt stombusslinjerna. Baserat på erfarenheterna från detta projekt rekommenderas för att uppnå systemets fulla potential:

• En längre fältförsöksperiod
• Signalprioriteringen som anpassas till regularitetssystemet. Ge prioritet till bussar som behöver minska tidsavståndet till bussen framför och undvik att ge prioritet till bussar som behöver öka tidsavståndet till bussen framför
• Bara regularitetsindikatorn ska visas på BussPC skärm för att undvika förvirring
• Stomlinje-rena tjänster. Undvik i schemaläggningen att blanda mellan regularitetstyrda med tidtabellstyrda linjer.

Dessa åtgärder kan också förbättra snitthastigheten och kapaciteten. Nya regularitetsmått bör ersätta punktligheten i det framtida förhållandet mellan huvudmän och operatörer för denna typ av tjänster.
1. Introduction

1.1 Background
Service reliability is one of the main determinants of public transport level of service. In the context of high-frequency urban lines, unreliable service results in long waiting times, bunched vehicles, long delays, uneven passenger loads and poor capacity utilization. In addition, more reliable public transport performance can also imply lower operating costs and more efficient crew management. Public transport operating environment is very uncertain. Sources of uncertainty include dispatching from the origin terminal, travel time between stops, and dwell times at stops.

Public transport control strategies consist of a wide variety of operational methods designed to improve public transport performance and level of service. Holding strategies are among the most widely used aiming at improved service regularity by regulating departure time from stops according to pre-defined criteria. The design of holding strategies includes the stops where control is exercised, the conditions under which holding is used, and the amount of holding time. The stops where holding may take place are known as time points.

The current holding strategy in Stockholm is based on service punctuality. Therefore buses hold at time points if they are early with respect to the timetable. This is the common practice among bus operators. However, in the case of high-frequency services, the level of service depends on regularity rather than punctuality. As passengers do not coordinate their arrival with the timetable and arrive randomly at stops, the main operational objective should be to maintain even headways between consecutive vehicles. Improved service regularity is associated with shorter waiting times and reduced crowding conditions at stops and on-board. As service becomes more regular, passenger loads are expected to be distributed more evenly between bus vehicles.

The evaluation of holding strategies has to take into consideration its impacts on various measures of performance. For example, potential reductions in passenger waiting times could be hindered by implying additional delays to passengers on-board. Moreover, the implications on operation and management costs have to be taken into account. The distribution of total vehicle running time is an important determinant of fleet assignment and therefore operational costs. In addition, schedule adherence is an important concern for driver scheduling reasons at terminals and driver relief points.

1.2 Project approach
The project first conducted a detailed analysis of the current performance of trunk bus line (‘Stombusslinje’) 1 in Stockholm’s inner-city. Alternative holding control strategies were analysed by simulating the operations of line 1. The results of the simulation model suggested that the most promising strategy is to hold buses that their headway from the preceding bus is shorter than their headway from the succeeding bus.
Figure 1 presents the timeline of RETT2 project. The project started on February 2011 when the conclusions from the simulation study led to the formation of a joint steering group of SL, Keolis and KTH with the purpose of testing the proposed holding strategy on line 1. The field experiment design built up on the experience from a previous project called RETT (‘Regularitet på stomlinje ett’) project is line with its service regularity objectives. Hence, the project presented in this report is known as RETT2. The first phase included discussion on the detailed of the experiment design and the analysis of strategy's robustness. This was followed by preparations for the field-trial which involved the preparation of information material and its dissemination as well as system functionality tests. The field test took place on October 2011. The last phase of the project included the integration of data sources and their analysis, feedback from various parties, documentation and recommendations for further actions.

Figure 1: Project timeline

The RETT2 project originated from a research idea and analysis coupled with the experience of practitioners. The joint working group was necessary in order to design and carry out the field demonstration, which is hopefully not the end of the process. The results of this experiment are expected to be followed up by a discussion on the prospects of a full-scale implementation.

The outline of the report is as follows: the results of the pre-studies are presented in Chapter 2. The details of the field experiment design and preparations are given in Chapter 3. The results of the experiment with respect to various performance
measures such as regularity, punctuality and travel times as well as the feedback that was received are presented and discussed in Chapter 4. The report concludes with an overall assessment of the project followed by recommendations for a full-scale implementation on Chapter 5.
2. Pre-studies

2.1 Line 1 description
The backbone of the bus network in Stockholm inner-city consists of 4 trunk lines. These lines account for approximately 60% of the total number of bus trips in this area (SL 2006) and are characterized by high frequency, articulated vehicles, designated lanes at main streets, high level of signal priority and real-time arrival information at stops. Line 1 was chosen for a multi-perspective assessment of control strategies because it is a representative high-demand inner-city line that runs through the city center. It runs with a planned headway of 5-7 minutes during most of the day and 4-5 minutes during the morning and afternoon peak periods. The line includes 33 stops on the eastbound direction route (ER) and 31 stops on the westbound route (WR).

Holding control is currently applied at three time point stops on each direction (Figure 2): Fridhemsplan, Hötorget and Värtavägen. Two stops-Fridhemsplan and Jongfrugatan - are used for driver relief point.

![Figure 2: The route of bus line 1 in Stockholm](image)

2.2 Performance analysis
The performance of line 1 was analysed by based on detailed and comprehensive Automated Vehicle Location (AVL) data for a week of regular operations in May 2008. A comprehensive analysis is available at Ólafsdóttir (2011). The main findings are:

- The share of on-time departures deteriorates along the route from a level of above 70% at the origin terminal down to 35% towards the end terminal
- A considerable share of the buses (10-20%) depart early from time point stops, in contrast to the operational policy
- High variations in headways between departures from the origin terminal (15-18% of headways less than 2 minutes and more than 10% longer than 7 minutes)
- The coefficient of variation of the headway doubles along the route from an already high level of 0.6 to 1.2

Hence, it was concluded that the current holding control is not effective in preventing bus bunching.

Ingemarson (2010) conducted an analysis of line 1 running times before and after the introduction of priority measures and congestion charge in Stockholm. She found that running speeds remained unchanged. These findings should be interpreted in the context of the current schedule-based control. Timetables are not merely a reflection of running times but rather an important determinant of running time. Under the current holding strategy, drivers follow the timetable both through holding at stops and speed adjustments between stops. Hence, as long as the timetables do not reflect the updated traffic conditions, buses would not exploit them.

2.3 Simulation study

Alternative holding control strategies were evaluated using BusMezzo, a joint car traffic and public transport simulation model (Cats 2011). It is a dynamic public transport operations and assignment model which was developed to enable the analysis and evaluation of public transport performance and level of service under various system conditions and advanced public transport systems (APTS). The model represents the interactions between traffic dynamics, public transport operations and traveller decisions. The different sources of public transport operations uncertainty including traffic conditions, vehicle capacities, dwell times, vehicle schedules and service disruptions are modeled explicitly. An important feature in the context of this project is that the model is capable of evaluating real-time control strategies.

The representation of the public transport system in BusMezzo consists of individual vehicle runs and their respective routes and timetables. Dwell time at stops can take different functional forms. Each stop could be defined a potential time point stop implying that the holding strategy under consideration determines the departure time based on the dynamic system conditions. BusMezzo represents vehicle schedules and hence the potential propagation of delays from previous trips. Buses progress in the traffic network and enforce capacity constraints so that denied boarding passengers have to wait for the next vehicle. Passenger demand can be represented at several levels of detail depending on the application of interest and data availability. In all cases, passenger demand is time-dependent. The intermediate (‘mesoscopic’) level of representation enables to model the detailed interactions between control strategies, headways, passenger arrival process, dwell times, delays and trip chaining at the system level.
The operational characteristics of line 1 were represented in the simulation model based on detailed analysis of the empirical data (Larijani 2011). Three holding strategies were evaluated: the current practice of schedule-based control; enforcing a minimum headway of 80% of the planned headway from the preceding bus and; a strategy based on maintaining even headways relative to the preceding and succeeding bus. In addition, each of these strategies was evaluated for the case of the three time points that are currently used as well as for the case that all the stops could potentially be used for service regulation (Cats et al. 2011).

The implementation of a control strategy at all stops is facilitated by the fact that all buses in Stockholm are equipped with a computer that is called BusPC and is located at the driver's cabin. This system enables radio communication with the control center, receiving text messages and the automatic display and recording of real-time information based on the AVL system. The software is provided and supported by INIT. The current display shows the three next time point stops or terminals and the scheduled time at these stops. In addition, a measure of schedule adherence is shown continuously. It is calculated based on the actual location of the bus. A plus sign indicates that the bus runs ahead of the schedule and a minus sign indicates that the bus runs behind schedule. The scheduled adherence measure is given at the half minute level.

The combination of a real-time headway-based holding strategy designed to improve service regularity by seeking uniform headways along the line and the consideration of each stop as a potential time point was shown to be the most promising strategy as it spreads the control mechanism over the entire line and prevents the propagation of discrepancies.

The overall robustness of the proposed strategy was analyzed with respect to human factors and BusPC design. The potential impacts of practical consideration for the implementation of the proposed strategy were evaluated using the simulation model. The following factors were incorporated into the control strategy in BusMezzo (Cats et al. 2012):

- **Driver display preciseness** – exact time difference in seconds vs. half minute level as provided by BusPC
- **Compliance rate** – the share of bus drivers that follow the control strategy with the remaining drivers assumed to consistently disregard the strategy and depart without holding
- **Maximum holding time** - an upper bound for the holding time at each time point

The proposed strategy exercised a high robust with respect to driver compliance, presumably due to its cooperative nature where adjacent vehicles can correct for a non-complying vehicle and mutual corrections. In an additional test of compliance error at the stop visit level (low awareness or stop-specific constraints that are not associated with a particular driver), the performance of the strategy was only negligibly affected as
even the same vehicle can correct itself at the next stop if needed. However, the introduction of maximum holding time comes at a higher price in terms of reduced service regularity. It is a practical constraint as long holding times are unacceptable by passengers on-board. The preciseness of the BusPC display adds another disturbance into the system that reduces the effectiveness of the holding strategy compared with the hypothetical case of ideal holding conditions. It is important to keep in mind that all these design factors hinder also the current operations and should be regarded as a sensitivity analysis. Furthermore, possible speed adjustments between stops were not modeled in the simulation model. Hence, the results may underestimate the benefits from the continuous cooperative nature of the proposed strategy.

2.4 From a simulation to a field test

The analysis of the simulation results highlights potential benefits from implementing the proposed even-headway strategy. The analysis suggests that implementing this strategy on trunk line 1 will have positive impacts on reliability and hence on passenger waiting times, crowding levels, and fleet operations, while maintaining the schedule adherence in general, and at the relief points in particular.

The simulation model is a useful tool for assessing the impacts of potential control strategies. However, actual implementation of the design of the proposed control scheme involves complications that require careful consideration. Although a number of previous studies have indicated the benefits of holding strategies based on numerical or simulation analysis, a number of implementation studies have also shown that these benefits are not always realized in practice. Previous reports on field trials of control strategies designed to improve service regularity showed limited results. It is important therefore to examine the lessons that could be drawn from previous attempts to improve service regularity.

A previous project of regularity on line 1 (RETT) was conducted by SL and Keolis on 2002-2003 (SL 2003). A field-trial took place on the fall of 2002 with the following measures: 1.5 dedicated dispatchers for line 1 at the control room; 2 mobile traffic ambassadors instructed drivers at stops and 2 reserve buses were allocated. The dispatcher at the control room was the only person that had access to real-time AVL data. The dispatcher instructed the mobile traffic ambassadors how to regulate the service with the objective of improving the regularity. Moreover, the control strategy was defined vaguely with no clear holding criterion. The project had limited results as there were indications that the regularity improved slightly while the number of late departures increased. A major hindrance of the previous RETT project is that the current incentives scheme that is based on measures of punctuality was in place during the field experiment.

A field study in Chicago reported by Pangilinan et al. (2008) investigated a control strategy equivalent to the proposed even-headway strategy. The trial was also based on a dedicated dispatcher at the control room and supervisors located at key
stops along the route. As in the case of RETT project, the supervisors passed on the dispatcher instructions to the drivers with only the dispatcher having direct access to real-time AVL data. The authors found that the dispatcher workload did not allow him to detect, not to mention respond to, every service regularity problem even after they simplified the conditions that require intervention. They concluded that this was the main limitation that hindered their field study. Nevertheless, service regularity during the trial period improved compared with the previous unsystematic control scheme.
3. Experiment description

3.1 Design
The experiment was designed to improve service regularity through regulating continuously along the line based on the new headway indicator by:

- **Holding** if the distance from the preceding bus is shorter than the headway from the successive bus
- **Adjusting** driving speeds as much as possible
- **Disregarding** the schedule

Enabling holding at each stop prevents the accumulation of irregularity instead of resolving it only at the next time point stop further downstream.

3.2 Measures
A series of measures were taken in order to facilitate the experiment. Measures can be grouped into four categories:

- Embedding a regularity-based indicator to the BusPC display
- Guarantee that the organizational environment supports the experiment
- Prepare and disseminate information regarding the new working routine
- Allocate and train personal for monitoring the performance

3.2.1 BusPC display
The implementation of the proposed strategy is facilitated by the capability of the BusPC to display a headway-based measure\(^1\). The additional indicator refers to how far the bus is from being exactly in the middle between the proceeding and the succeeding buses. An indicator with a plus sign indicates that the bus is too close to the bus in front while a negative one means that the bus is too close to the bus behind (see Figure 3 for an illustration). If the bus is exactly in the middle then the indicator displayed is zero. This measure can be embedded into the BusPC screen and is behaviorally consistent with the current practice as “plus” requires waiting or slowing down and “minus” to speed up.

A functionality test of the system was conducted successfully on September 1. However, the initial kick-off date (September 17) had to be postponed due to a technical problem as the driver display did not work for line 1. The technical problem was resolved by INIT on September 30. Both schedule-based and headway-based indicators were displayed during the entire trial period.

\(^1\) This measure was never activated before by any of the bus operators that use the system provided by INIT.
Regulating the dispatching from the origin terminal can potentially prevent some of the initial variability introduced already at the beginning of the route. The results of Pangilinan et al. (2008) suggest that headway-based dispatching from the origin terminal plays an important role. However, bus lines do not operate as a closed system and headway regulation at dispatching may be complicated in real-world operation conditions since drivers and vehicles are circulated between lines. Hence, it was decided that departures from origin stops only are to be regarded as time points both in terms of schedule and headway. In other words, buses may depart later than the timetable in case the headway from the preceding bus is too short. This is aimed to prevent the departure of bunched buses from the origin stop.

3.2.2 Organizational
The current contract conditions between SL and Keolis could potentially introduce an impediment for a field trial since they are based on service punctuality. Hence, the current incentive scheme was not enforced during the experiment. SL agreed to wave off all penalties associated with the operations of line 1 and all the potentially affected lines (lines that are interlinked through driver scheduling) during the trial in order to reassure that the project will not result in penalties for the operator and to enable regularity-based operations to prevail.

The driver union gave their support to the experiment. In a meeting with the leaders of the driver union on August 23, they expressed their concern that the project may increase the workload of drivers and hence impact their already high level of stress. However, the union agreed to support the project because they are interested to examine whether the new strategy can potentially improve driver working conditions.

3.2.3 Information
A large share of the preparations to the field trial involved the preparation and dissemination of information material to all the relevant personal and above all to the approximately 600 drivers that drive on line 1 during a single month. Based on discussions within the working group the following information channels were used:

- *Information seminars* – meetings were held with depot and control room managers. The depot managers provided inputs on the final layout of the information material.
• **Brochures** – conveying an explanation of the project (see Appendix). The brochures were personally disseminated to drivers at depots, posted on message boards at depots and posted in driver cabins on buses that run on line 1.

• **Personal laminated cards** - personally disseminated to drivers at depots. Contained the most concise and practical information.

• **Compendium** – a more comprehensive description was given in the form of a compendium that was available at coffee rooms at depots.

• **Newsletter** – information on the project was available on the driver union newsletter.

• **BusPC remainder** – a text message popped up on the BusPC screen every 40 minutes during the field trial period (only on buses that run on line 1).

### 3.2.4 Monitoring

The field trial included the following monitoring mechanisms.

• **Dedicated dispatchers** – Three dispatchers rotated as dedicated dispatchers for line 1 in Keolis control room. The role of the dedicated dispatcher is to monitor the performance, send reminders, communicate with drivers and initiate interventions in case of need. The dispatchers were trained by the control room personal as they were new to the dispatching role. In addition, training was provided by KTH with respect to the project and how to handle various situations such as overtaking, dispatching and incidents.

• **Traffic ambassadors** – Following a suggestion by the driver union, six traffic ambassadors were allocated for the project. The ambassadors rotated at the two driver relief stops along the line: Fridhemsplan and Jungfrugatan. They were responsible to smooth operations at these stops and make sure that drivers take the breaks they are entitled for.

• **Performance monitoring** – AVL data was extracted and analyzed regularly during the field trial in order to investigate the impact of the project and to consider if it needs to be refined. Measures of performance were calculated and were used for instructing dispatchers.
4. Evaluation

The evaluation of the experiment is compounded from two parts: a before-after data analysis and feedback from all involved parties.

4.1 Before-after data analysis

4.1.1 Analysis description

AVL and automated passenger counts (APC) data was extracted in order to conduct a before-after performance analysis. AVL data was available for all the buses running on line 1 from September 17 to October 31. APC data for all the buses equipped with the passenger counting system was extracted for the same period. The database was filtered to include only bus trips that took place on weekdays and departed from the origin terminal between 7AM and 7PM. During this time period line 1 runs with a frequency of 5-7 minutes. This results in a database that contains approximately 8,000 AVL and 600 APC records per day.

The data collection period could be divided into the following three periods:

- ‘Before’ period
  - Weeks 38 and 39 (September 19-23, 26-30)
- ‘After’ period
  - Weeks 41 and 42 (October 10-14, 17-21)
  - Week 43 (October 24-28, 31)

Note that week 40 (October 3-7) is excluded from the analysis because the new display was already activated but the field experiment was not yet completely restored.

The introduction of a new operations routine was expected to require an adjustment period. Indeed, an analysis of the data indicated that there are significant differences between weeks 41-42 and week 43 within the experiment period. Hence, the following analysis of the results distinguishes between these two periods. Note that the presence of dispatchers decreased considerably between these two periods: from 78% of the time on the first two weeks down to 37% during the last week of the experiment.

The following caveats should be made when comparing the different analysis period:

- Unknown share of buses did not have signal priority due to a technical problem with some of the recently bought buses
- Unknown differences in traffic conditions, in particular on Kungsgatan
- There are differences in passenger demand
- No traffic incidents (e.g. accident, street closure, bus breaks down) were observed or reported
- No extra buses (‘flexbussar’) were deployed
4.1.2 Regularity
A preliminary analysis of the impacts of the experiment on service regularity examined vehicle trajectories. Figure 4 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 September 21 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 October 31, 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.

Service regularity was analyzed by constructing the distribution of all headways upon departure from all stops. Headway distribution is presented separately for the entire day (7:00-19:00) and the afternoon peak period (15:30-18:00) (Figure 5). 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) compared with fewer cases of very short or very long headways which reflect bus bunching. This trend is further illustrated in Figure 6 by aggregating the results to 3 or 4 headway categories for the afternoon peak period and the entire day, respectively.
Figure 4: Bus trajectories on the afternoon peak hour of September 21 (above) and October 31 (below)
Figure 5: Headway distribution for the entire day (7:00-19:00, above) and for the afternoon peak period (15:30-18:00, below)
Figure 6: Share of headways within a certain interval (in minutes) for the entire day (7:00-19:00, above) and for the afternoon peak period (15:30-18:00, below); before period (blue) and after: v43 (green)
The coefficient of variation of the headways is used as a measure of service regularity. A value of zero indicates perfect ideal regularity with all headways having the exact same value. This measure was calculated for each stop separately and then averaged in order to assess the overall performance along the line. The average values are presented in Table 1 for the two time periods and both line directions. The percentages indicate the reduction in headway coefficient of variation compared with the before period. A reduction of 10-20% was measured in all cases.

A significant share of headway variability is embedded in the scheduled headway as planned in the timetable. The range of headways that are scheduled between 7:00 and 19:00 results in headway coefficient of variation of 0.18. The equivalent figure for the peak period is of course lower since the headways are almost uniformly short. Hence, the reduction in headway variability could be normalized to account for that. The average normalized decrease is 18-26 % for the entire day period and 11-19 % for the afternoon peak period.

Table 1: Coefficient of variation of the headway

<table>
<thead>
<tr>
<th></th>
<th>Entire day (7:00-19:00)</th>
<th>Afternoon peak period (15:30-18:00)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eastbound</td>
<td>Westbound</td>
</tr>
<tr>
<td>Before</td>
<td>0,662</td>
<td>0,658</td>
</tr>
<tr>
<td>After: v41-v42</td>
<td>0,614</td>
<td>0,610</td>
</tr>
<tr>
<td></td>
<td>-7,3%</td>
<td>-7,3%</td>
</tr>
<tr>
<td>After: v43</td>
<td>0,539</td>
<td>0,570</td>
</tr>
<tr>
<td></td>
<td>-18,6%</td>
<td>-13,4%</td>
</tr>
<tr>
<td>Scheduled headway</td>
<td>0,184</td>
<td>0,172</td>
</tr>
<tr>
<td>Normalized reduction of After v43</td>
<td>-25,8%</td>
<td>-18,1%</td>
</tr>
</tbody>
</table>

The above figures of coefficient of variation provide an aggregate measure for comparison. However, it is important to analyze how service irregularity evolves along the line, as presented in Figures 7 and 8. The dashed black line indicated the variability level that is induced by the timetable and is considered as the benchmark. Service irregularity escalates along the line in all cases but to different degrees. The last week of the experiment manifested consistent improvement in regularity over the before period. A decrease of 20% in the measure of headway variability was measured for most of the route.
Figure 7: Service regularity along the route on the eastbound (above) and westbound (below), 7:00-19:00
Figure 8: Service regularity along the route on the eastbound (above) and westbound (below), afternoon peak period (15:30-18:00)
Headway variability when dispatching from the origin stop is an important determinant of service regularity along the line as it is difficult to correct for large initial deviations. Headway variability at the origin stop remained at the same level for the eastbound afternoon peak period and decreased by 16% for the westbound route after an increase during the adjustment period. A pronounced decrease was obtained for the entire day period. Headway coefficient of variation decreased by 16 to 24% for the eastbound and westbound routes, respectively. The higher impact on the entire period day is presumably due to the higher initial scheduled headway variability (Table 1). The new strategy allows smoothing consecutive uneven planned headways in case it is feasible in terms of driver and vehicle scheduling. Note that departures from the origin stop were subject to both schedule and headway control regulations and hence restricted the potential improvement in dispatching regularity.

The objective of the experiment is to regulate bus service in order to prevent the bus bunching phenomenon. The definition proposed by the transit capacity and quality of service manual (TCRP 2003, p. 3-48) is used in this analysis with the share of bunched buses been calculated as the share of headways that deviate from the planned headway by more than 50%. The planned headway during the afternoon peak period is 5 minutes. Hence, headways that are either shorter than 2.5 minutes or longer than 7.5 minutes are regarded as bunching. Figure 9 presents the share of bunched buses at each stop along the route before and during the experiment. There is a noticeable reduction which is most pronounced after the first stretch of the route, in line with the general trend observed in Figure 8. The experiment decelerated the rapid rise in bunching. The share of bunched buses decreased on average by 24% on the eastbound and 13% on the westbound with some stops seeing a decrease of more than 40%.
Figure 9: Share of bunched buses along the route on the eastbound (above) and westbound (below), afternoon peak period (15:30-18:00)
Public transport performance varies considerably from day to day. Figure 10 presents service regularity for five weekdays on the last week before the experiment and the five last days of the trial. There is a clear difference between the two periods. Recall that 0.18 is the benchmark level of the scheduled headway (Table 1). There is one particular day on the experiment period (October 27) that is much less regular than its counterparts. The dispatching regularity is very poor during this day for an unknown reason. However, the new strategy results in much better in keeping the bunching phenomenon at bay. In fact, the coefficient of variation of the headway at the origin is the same as on the worst day before the trial but by the end of the route it is at the same level as the best day on the before period. Hence, the new strategy seems to be robust, although it is not possible to draw definitive conclusions based on the existing dataset.

Figure 10: Service regularity along the route on the eastbound, 7:00-19:00 (each line corresponds to a weekday)
Service regularity is an important determinant of passengers’ waiting time. Passenger waiting time is made up of three components:

- **Minimum waiting time** – the average waiting time if the service is perfectly regular with all the headways at all the stops having the exact same value is exactly half this headway, assuming that passengers arrive randomly at stops.

- **Excess expected waiting time** – the expected waiting time is influenced by headway variability and is approximated by:

  \[
  E(w) = \frac{\bar{h}}{2} \cdot (1 + CV_h^2)
  \]

  Where \( \bar{h} \) is the average headway and \( CV_h = \frac{\sigma_h}{\bar{h}} \) is the coefficient of variation of the headway (\( \sigma_h \) is the respective standard deviation). Hence, the excess expected waiting time is \( \frac{\bar{h}}{2} \cdot CV_h^2 \).

- **Extra budgeted waiting time** – if passengers will arrive at stops based on the expected waiting time they will be late to their destination on every second trip. It is assumed that passengers accept a probability of 10% to be late and hence their extra budgeted time is equivalent to the difference between the 90th percentile of the headway distribution and the expected waiting time (Furth and Muller, 2006). Note that a share of this waiting time component will be experienced further downstream (e.g. transfer stop, final destination).

Passenger waiting time components were calculated for the entire-day period. First, the relevant statistics (average, standard deviation and the 90th percentile) of the headway distribution were calculated for each stop separately. Second, the average number of boarding passengers was extracted from the APC data. Third, the waiting time components were calculated for each stop and averaged over the total number of boarding passengers. Figure 11 presents the results for both analysis periods. The minimum waiting time remains unchanged as the planned headway has not changed between the two periods (\( \bar{h} = 350 \)). The excess waiting time decreased by 38% as regularity improved along the line. The extra budgeted waiting time was reduced by 11% due to a smaller share of extremely long headways, as evident in Figure 5. In summary, the total waiting time was 10% shorter during the experiment.
The improvement in service regularity led to a reduction of 54 seconds in the average passenger waiting time. Based on the number of boarding passengers and the number of vehicle runs per day, the total time savings were calculated (Table 2). A study on travel time costs by the Victoria Transport Institute (2009) recommended using the hourly wage as the value of excess travel time in public transport for personal trips and the 120% of the wage for business trips. An average hourly wage of 145 SEK is used based on the national central bureau of statistics (SCB). Hence, the daily (7-19) waiting time savings from introducing the new strategy is approximately 98,000 SEK. Time savings sum up to 2.25 million SEK a month, assuming 23 working days. Note, that this calculation does not account for the higher value-of-time associated with waiting time in comparison to in-vehicle time. Thus, social welfare gains from running the new strategy on line 1 during a single month are at least 2 million SEK due to the nominal savings of waiting time only.

Figure 11: Passenger waiting time, 7:00-19:00
Table 2: Waiting time savings

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After: v43</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A single passenger</td>
<td>522,7</td>
<td>468,7</td>
<td>54,0</td>
</tr>
<tr>
<td>(seconds)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A single vehicle run</td>
<td>25,9</td>
<td>23,3</td>
<td>2,7</td>
</tr>
<tr>
<td>(hours)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A single day (7-19)</td>
<td>6535,8</td>
<td>5860,6</td>
<td>675,2</td>
</tr>
<tr>
<td>(hours)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.1.3 Punctuality

Although passengers do not coordinate their arrival with the timetable for high-frequency services, punctuality remains an important measure of performance due to its implications on operations. Deviations from the schedule imply delays to driver shifts at terminals and driver relief points.

The regularity control during the trial period disregarded the timetable as well as the planned headway along the route. Hence, it is particularly remarkable that on-time performance during the trial period did not fall from the previous level that was obtained by focusing on service punctuality (Figure 12). The share of on-time, early and late arrivals is shown for the before period (dashed lines) and the last week of the trial (solid lines). On-time performance is defined by SL as departing within the time window of 1 minute ahead of schedule and 3 minutes behind schedule. In fact, it even improved for the eastbound from an average level of 57% to 62%, a relative improvement of 9% (Table 3). An analysis of the punctuality at key stops (origin and destination stops, time point stops, driver relief stops) reveal that the new strategy did not change or improved the on-time performance in most cases. This implies that even if the punctuality-based penalties would have remained in place, the operator would have not need to pay more penalties due to the new strategy.

Schedule adherence is particularly important at driver relief points and origin/destination stops as drivers transfer for other lines, start or end their shifts. The results in Table 3 are in line with the feedback received from the control room dispatchers, traffic ambassadors and the driver union which reported that they did not encounter problems with driver scheduling due to the trial. Schedule adherence distribution was analyzed for Fridhemsplan and revealed that are no substantial differences between the two analysis periods. The average delay prior to the field trial was 86 seconds compared with 59 seconds during the trial. In addition, the standard deviation of the delays decreased from 153 to 123 seconds.
Figure 12: On-time performance on the eastbound (above) and westbound (below), 7:00-19:00
Table 3: On-time performance at key stops

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After: v43</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eastbound</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>57</td>
<td>62</td>
</tr>
<tr>
<td>Essingetorget</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Fridhemsplan</td>
<td>61</td>
<td>59</td>
</tr>
<tr>
<td>Hötorget</td>
<td>52</td>
<td>59</td>
</tr>
<tr>
<td>Värtavägen/Jungfrugatan</td>
<td>41</td>
<td>48</td>
</tr>
<tr>
<td>Frihamnen</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td><strong>Westbound</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Frihamnen</td>
<td>91</td>
<td>89</td>
</tr>
<tr>
<td>Värtavägen/Jungfrugatan</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Hötorget</td>
<td>56</td>
<td>53</td>
</tr>
<tr>
<td>Fridhemsplan</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td>Essingetorget</td>
<td>42</td>
<td>44</td>
</tr>
</tbody>
</table>

4.1.4 Vehicle travel times

The AVL data was used also for the analysis of bus travel times. The control strategy can potentially impact both dwell time at stops and running times between stops. Note that dwell times are measured as the time that the bus stands at the stop and hence includes passenger service time as well as holding time.

The total dwell time along the route decreased by 10% after the adjustment period as is evident in Figure 13. Interestingly, the total dwell time increased immediately after the introduction of the new strategy by 6%. However, a reduction of 60-80 seconds compared with the before period was measured during the last week of the experiment.
The reduction in total dwell time was achieved by a much more even distribution of dwell times over stops along the route. This is clearly evident in Figure 14 which compares dwell times at stops for the three analysis periods. Dwell times are almost evenly distributed along the line on the last week of the experiment as drivers may hold whenever needed without having to wait for specific regulation stop further downstream. Dwell times are shorter at most stops specially compared with stops that are normally used as time point stops. This may help to ease stop capacity problems that are manifested at these stops. During the adjustment period dwell times increased, in particular in stops that involved interaction with traffic ambassadors (‘Fridhemsplan’ and ‘Jungfrugatan’).

It is important to note that even though every stop is a potential time point, the total dwell time at stops decreased. This is due to the fact that only few stops are actually used for regulation on each single trip. Figure 15 shows the variability of dwell times at stops along the line between different trips. It provides an insight on the striking difference in dwell time patterns. The highest dwell time variability is typically exercised at time point and driver relief stops as different buses require very different holding times. However, during the experiment different bus trips used different stops as time points and had to hold there for shorter time. Hence variability in dwell times decreased for time point stops but increased for all other stops.
Figure 14: Average dwell time at stops on the eastbound (above) and westbound (below)
Figure 15: Standard deviation of dwell time at stops on the eastbound (above) and westbound (below)
Unfortunately, dwell times savings did not lead to overall shorter vehicle running times (Figure 16 and Table 4). The 90th percentile of the total running time distribution remained at the same level; hence there are no indications for potential benefits in terms of fleet size. However, running time variability decreased. In particular, there were fewer cases of very short or very long bus runs during the experiment. Lower running time variability is positive from both passenger and operator perspectives as it improves the reliability of total passenger trip time and increases operational certainty for operators.

Table 4: Total bus running time (eastbound/westbound; in minutes)

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After: v43</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>53,79/48,75</td>
<td>53,78/49,19</td>
<td>0%/+1%</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>5,14/5,01</td>
<td>4,35/4,89</td>
<td>-15%/-3%</td>
</tr>
<tr>
<td><strong>90th percentile</strong></td>
<td>59,40/55,45</td>
<td>59,03/55,83</td>
<td>-1%/+1%</td>
</tr>
</tbody>
</table>
Figure 16: Total bus running time on the eastbound (above) and westbound (below)
4.1.5 Crowding

The availability of APC data for a 10% sample of the fleet enables the analysis of the impacts of the experiment on passenger loads. The bus bunching phenomenon is associated with uneven passenger loads as the leading vehicle is expected to be overcrowded followed by an underutilized bus. In addition to its inefficiency, an uneven load has implications on the experienced crowding conditions as overcrowding conditions will occur more often and by definition be experienced by more passengers. This is equivalent to the effect of irregularity on the expected waiting time. In contrast, more regular service is expected to result in a more even distribution of passengers on buses.

Crowding variations were analyzed by using the perfectly even load profile as a benchmark. Since demand varies over the analysis period, an average load profile was constructed for each analysis period for the peak afternoon period. If passengers were perfectly distributed over buses then this load was observed on each single bus run. However, loads vary due to both demand and supply variations. For each bus run \( k \), the deviation from the average load at stop \( j \) on analysis period \( t \) was calculated as follows:

\[
L_{dev}^{t,j,k} = (L_{j,k}^{t} - \bar{L}_{j}^{t})
\]

Where \( L_{j,k}^{t} \) is the observed load and \( \bar{L}_{j}^{t} \) is the average observed load over all peak period trips during the relevant analysis period.

The average deviation is used as a measure of crowding variability. Figure 17 presents the deviation from perfectly even loads along the route. A load that is identical to the average one would be represented by a horizontal line on the x-axis. It is evident that crowding fluctuated the most on the before period while loads were more evenly spread during the experiment. **The average deviation is more than twice higher on the before period compared with the last week of the trial.** For example, a passenger on-board the bus between Sankt Eriksplan and Stureplan will experience crowding that is closer to the average one by 5-6 passengers. The impact is especially noticeable for Gärdet with 10 passengers closer to the ideally even load, as this is a common transfer stop from the Tunnelbana to line 1 and hence subject to high demand fluctuations. The magnitude of these differences corresponds to the decrease in headway variability (Figure 5) as this is the underlying determinant.
4.2 Post-trial feedback

Feedback from different parties that were involved in the experiment is essential in order to gather information on their experience and perception. This is complementary to the data analysis as it provides insights on aspects that are not subject to measurements. Feedbacks were provided through informal conversations (e.g. with drivers and dispatchers), during formal meetings and a dedicated post-trial feedback meeting.

The following provided their feedback on their experience during the field experiment in the dedicated meeting on November 10, 2011:

- Operations manager: Jonas Charanck
- Control room dispatchers: Jan Hallberg, Mikal Björn and Lars Johansson
- Traffic ambassadors: Bo Rodhe and Katarina Ollas-Alfvin
- Driver union representatives: Anders Fredmark and Tomas Fahlen
- Customer relations: Bo Nathorst-Westfelt

All the participants said that they are in favor of implementing the regularity-strategy on all the high-frequency lines in Stockholm (blue lines and the some of the red lines). The main issues that were discussed are:
Drivers' acceptance - positive reactions were received among drivers. There was an adjustment period of approximately 4-5 days, in particular with drivers that are very much used to the previous working routine. New drivers were more willing to try new things. Afterwards, drivers started to like the new system and said that working under the headway control was less stressful, more relaxed. Operations became harmonic, keeping ‘fem minuter trafik’. The process started to roll smoothly. There was an accumulative understanding of the interdependence among drivers. Even drivers that typically have a bad attitude and were sceptic towards the experiment started to see the benefit in cooperating with the experiment. Drivers of other lines (2 and 3) became aware of the experiment and wanted to participate on the trial as well. Towards the end of the trial, drivers asked why the new system does not continue. It was proposed that drivers that participated in the trial would help marketing and informing about this strategy among other drivers. Drivers could be asked to sign up for it.

Drivers' compliance – there is a well-known problem with a group of drivers that drive too fast and disrupt the performance of their fellow drivers. The traffic ambassadors also reported some problems with them at the beginning of the trial.

Adjustment period and information – The dissemination of information could have been better by coordinating it with the union. The best way to inform drivers is through direct information seminars. The brochures were insufficient and some of the drivers did not grasp the logic behind the headway indicator. Confusion and lack of information around the beginning of the trial and when it was prolonged.

Driver scheduling – none of the participant encountered driver scheduling problems due to the experiment. Preferably, drivers should be assigned to blocks that are made up of exclusively headway-based or schedule-based operations.

Control room – dispatchers reported that there was very little need for control room interventions. Hence, their presence in the control room decreased gradually. Based on working hours report from the operations manager, the presence of the dedicated dispatcher in the control room decreased from 78% of the time during the first two weeks (v41-v42) to only 37% of the time during the last week (v43). In the beginning they had to remind drivers from time to time but after a while they did not encounter misinformed drivers, except of weekend drivers. After an adjustment period they did not have to respond much, mostly observed the performance.

System functionality – was not perfect. It sometimes took up to 30 minutes for the headway-indicator to appear on the BusPC for new blocks that were initiated.

BusPC display - drivers and traffic ambassadors argued that only the headway indicator should appear on the BusPC display.
• Traffic conditions - line 1 is the most problematic bus line in terms of traffic conditions. Kungsgatan is very unreliable. Worse than line 4 that runs around the inner city. There were no major traffic incidents or disruptions during the trial period. The new bus vehicles that do not interact with the bus signal priority sensors were assigned on line 1 since the summer. It was estimated that it could potentially prolong the total run time by approximately 5 minutes.

• Passengers' response – traffic ambassadors reported that they received positive comments from passengers that said that line 1 works better now. Customer relations did not receive any complaints from passengers during the trial period regarding the experiment.
5. Conclusions

5.1 Project assessment

The field experiment realized the expected benefits from introducing the proposed regularity-based holding control. The evaluation of the project consists of detailed before-after data analysis and feedback from various parties.

The project was successful in achieving its prime objective: service regularity improved substantially. 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%. This led to 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. The more regular service also resulted in more even passenger loads with the deviations from the ideally even load being less than half the size they were before the experiment.

The evaluation of the field experiment considered also the impacts on travel times. The 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. However, 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).

Service punctuality was still an important measure of performance as schedule adherence is necessary for vehicle and driver scheduling reasons. 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. It is worth noting that if the normal penalties mechanism was applied during the experiment, Keolis would have had to pay a smaller penalty than if the schedule-based control was in place.

The share of buses that arrived on-time to the last stop increased on both directions. Hence, driver scheduling was affected positively by the new strategy as drivers have the same or higher probability to make it on-time for their break or next trip. 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. The experiment was not immune to limitations that led to the following lessons:

- Importance of an adjustment period – the performance of the first two weeks differs significantly from the third and last week. It is not possible to determine whether the last week manifested the full potential of the trial.
• *Imperfect driver compliance* – the analysis of driver compliance on both before and after periods showed that driver compliance is not perfect. This is presumably partially due to misunderstandings and traffic conditions. A more effective information campaign may further improve driver cooperation.

• *Importance of dispatching regularly from the origin stop* – the variability of headways upon departure from the origin stop play a key role in determining headway regularity further downstream. Hence, it is worthwhile to concentrate on targeting dispatching regularity. A large share of this variability is due to the planned headway variation.

• *Dual display should be avoided* – the display of schedule-based and headway-based indicators simultaneously was a potential source of confusion.

• Technical problem with bus signal priority may have undermined the potential reduction of total vehicle running time along the line

• *Limited need for monitoring* – control room dispatcher and traffic ambassador presence was helpful when the new strategy was just introduced. The field experiment suggests that it is not necessary to allocate dedicated personnel for monitoring the new strategy in the long run.

**5.2 Recommendations for further actions and studies**

All involved parties: the public transport agency (SL), bus operator (Keolis) and the driver union agree that the trial was successful and the results are promising. Hence, there is a consensus that the strategy should become the common practice on high-frequency lines in Stockholm (prominent candidate lines are: 1,2,3,4 and 76).

The next step is to design the full implementation of the new regularity-based operations. The preparations for an implementation study should consider the best conditions to realize the full potential of the strategy. The following recommendations are made based on the experience gained during this experiment:

• An extended field-test period will allow to investigate the full-potential of the new strategy after the performance stabilizes. Furthermore, it will allow studying how robust the new strategy is with respect to events such as traffic incidents.

• The variability in headways upon departure from the origin stop is a key factor in maintaining high regularity along the line. If ready to depart, drivers should depart based on the headway-based indicator as for any other stop. Interlining between headway-based operations and schedule-based operations should be avoided.

• Revise the bus signal priority to be based on regularity rather than punctuality – the priority criterion should be consistent with the control strategy. The same measure that is used for control should be used for signal priority: give priority unless if the headway from the preceding bus is shorter by a certain threshold from the headway to the succeeding bus. This is expected to contribute to further reductions in passenger waiting times and more even crowding levels. Moreover,
this is a complementary measure that will provide the regularity-based operations a ‘pushing’ mechanism in addition to the ‘holding’ one.

- Display only the new regularity-based indicator on the BusPC screen
- The stability of the BusPC system has to be further tested before a full-scale trial is to take place
- In light of the conclusions of Carrel et al. (2010) from their study on control room dynamics, it is important to modify the dynamic display at the control room so that it is consistent with the headway indicator. Hence, it is preferable that the control room color display will be based on the headway indicator for those lines for which it is applied.

A study on implementing the regularity-based control and using it as a common practice has to consider the introduction of new regularity-based measures of the performance. These measures have to reflect public transport performance objectives adequately and could potentially be embedded in future agreements between public transport agencies and bus operators.
References


Appendix: Information brochures

"Tänk på avståndet"

17 september till och med 19 Oktober pågår ett fältförsök för att få bättre regularitet på linje 1.

En särskild indikation på Buss-PC skärmen kommer att berätta för dig hur du ligger till i förhållande till framförvarande och efterföljande buss. Du ska försöka ligga precis i mitten.

Som vanligt betyder:

'+': sanka ner, vänta vid hållplatserna

'-.': snabba på (självklart enligt trafikregler och säkerhet)

'0': perfekt, precis i mitten

Du ska följa den nya indikationen (röd cirkel i bilden) och ignorera tidtabellshållningen och skytarna vid hållplatserna.

Tack så mycket för din medverkan och "Tänk på avståndet".

Keolis
RETT – kontrollanter står vid avlösningshållplatserna FHP och JGU och kontrollerar din tid enligt schema. Till skillnad från trafikvärderar så har kontrollanten befogenheten att kontakta drift vid exempelvis rastsprickor och spruckna avlösningar.

Hur ska du som förare bli bemöttd vid olika situationer:

Rastspricka:

- Du som förare skickar som vanligt via PC:n, *sen -10/-15* i god tid
- Trafikledningen kontaktar drift och meddelar att du är sen och att din rast är i fara
- Vid avlösningen lämnar du över bussen till avlösande förare och går upp till rastlokalen för att ta dina 10 minuter
- Driften kontaktar dig, antingen via din mobiltelefon eller telefonen som finns i lokalen och ger dig information om hur ditt nästkommande omlopp ska lösas

Ej avlöst:

- Du som förare skickar som vanligt via PC:n, *ej avlöst* och meddelar RETT – kontrollanten om att du ej är avlöst
- Du får svar från trafikledningen om att du kan lämna bussen och ta din rast
- Bussen plockas ut ur RETT systemet
- RETT – kontrollanten kontaktar drift om att avlösare saknas

Sen till parkerad 1:a:

- Du kommer fram till bussen och kontaktar trafikledningen
- Du får information från trafikledningen om var du ska gå i trafik
- Bussen sätts in i RETT – systemet igen