Incorporating service reliability in public transport design and performance requirements:

International survey results and recommendations

Workshop 1. Developing an Effective Performance Regime

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ABSTRACT

Public transport passengers consider service reliability a key quality aspect. However, in most countries, actual services are not perceived as very reliable. To gain insights in how public transport authorities deal with (improving) service reliability and planning, an international survey was performed. This survey showed that there is little attention paid to service reliability during the design of the network and the timetable. In addition, it illustrated that little consistency exists in approaches. In addition, a second survey in The Netherlands was performed, showing how public transport authorities deal with service reliability in relation to concession requirements and incentive regimes. The main findings are that consistency is lacking on this topic, even within the Netherlands, and that little attention is paid to passenger impacts of service reliability in concession requirements. This may result in services that do not match the (implicitly) required level of service reliability. These surveys also demonstrated that there is no consistency in the definition of service reliability. We illustrated that this may lead to different levels of quality concerning these indicators, while actual quality is constant. In this paper, recommendations are presented to improve concession requirements as well as the design of network and timetable, both aiming at enhanced service reliability.

1. Introduction

Service reliability is a key quality indicator for public transport and has become increasingly important over the last decade. However, in most countries, actual services are not perceived as very reliable. In Van Oort (2011), a framework as well as cost-effective planning instruments are presented to improve the level of service reliability from a passenger perspective. The key to finding potential improvement instruments was analysing Big Data of both vehicle performance (AVL data, see for instance Hickman 2004) and passenger flows (APC data, see for instance Pelletier et al. 2011). To gain insights in how public transport authorities deal with (improving) service reliability and planning, an international survey was performed. This survey showed that there is little attention paid to service reliability during the design of the network and the timetable. In addition, it illustrated that little consistency exist in approaches. In this paper we illustrate the consequences of this inconsistency. A second survey in The Netherlands was performed, showing how public transport authorities deal with service reliability in concession requirements and in incentive regimes. In this paper, the results of these two surveys are illustrated. Furthermore, recommendations are presented to improve concession requirements as well as the design of network and timetable, both aiming at enhanced service reliability.

2 Two surveys on public transport service reliability

2.1 Introduction

To gain insight into how public transport authorities and operators currently deal with service reliability, we performed two surveys. The first focused on service reliability in relation to design of public transport. The second focused on the role of service reliability in tender requirements. Both surveys are described in the following sections in more detail. The next sections present the main findings of both surveys.

2.2 International survey

In Van Oort (2011), the results of an international survey of service reliability we performed are presented. The objective of the international survey was to learn about reliability and planning topics in several cities in different countries. The survey demonstrates how public transport operators quantify service reliability in practice, and provides insights into design guidelines that might affect service reliability. The survey consisted of a questionnaire that was sent all over the world. Responses were received by almost 30 authorities and operators. Table 1 shows the respondents.

Table 1. Participating cities and systems in international reliability survey

City	PT Type		City	PT Type		City	PT Type
Amsterdam	Metro, tram, bus		Gothenburg	Tram		Rouen	Tram, bus
Barcelona	Metro, bus		Halle	Tram, bus		Salt Lake City	Light Rail
Berlin	S-Bahn, tram		Hong Kong	Light rail		Stockholm	Metro, bus
Brussels	Tram		Lolland	Bus		Stuttgart	Rail
Chicago	Metro, bus		London	Tram, bus		Santa Cruz de Tenerife	Tram
The Hague	Light rail, tram, bus		Milano	Bus, tram		Vienna	Metro, tram, bus
Dresden	S-Bahn, tram		Minneapolis	Bus		Zurich	S-Bahn
Dublin	Tram		Rotterdam	Metro, tram, bus			

2.2 Dutch survey on tender requirements

The second survey was held in 2012 in the Netherlands under supervision of KPVV, the Dutch Knowledge Centre on Transport. The survey consisted of two parts: desk research and interviews. The desk research was performed by analysing a random selection of recent tender documents, with specific attention to service reliability. Figure 1 shows the regions of which the tender documents were investigated. In total, we analysed 22 tender documents. Both, rail and road bound transport were part of the selection.

Figure 1. Investigated regions in the Netherlands

In addition to the desk research we performed interviews with a selection of twelve Dutch public transport authorities. These are:

- Province of Flevoland
- Province of Friesland
- Province of Gelderland
- Province of Limburg
- Province of Noord-Holland
- Province of Overijssel
- Province of Utrecht
- Province of Zeeland
- Region of Arnhem and Nijmegen
- Region of Eindhoven
- Region of Groningen and Drenthe
- Region of Twente

The interview topic was how public transport authorities deal with service reliability (improvements) in general, with specific regard to performance requirements and monitoring regimes.

3. Service reliability

Service reliability is the certainty of service aspects compared to the schedule as perceived by the user and is one of the most important quality aspects of public transport (Van Oort 2011). Actual vehicle trip time variability (i.e. service variability) affects service reliability and passenger travel time. The impacts of unreliable services on passengers are:

- average travel time extension

- increased travel time variability
- a lower probability of finding a seat in the vehicle.

Literature shows that, for urban public transport, substantial attention is given to ways to improve service reliability at the operational level (see for instance Osuna and Newell 1972 and Muller and Furth 2000). Potential service reliability improvement instruments also exist during the public transport design stages. We found five potential planning instruments. At the strategic level, these instruments are:

- Terminal design (Van Oort and Van Nes 2010)
  The configuration and number of tracks and switches at the terminal determines the expected vehicle delay and thus service reliability.

- Line length (Van Oort and Van Nes 2009a)
  The length of a line is often related to the level of service variability and thus service reliability.

- Line coordination (Van Oort and Van Nes 2009b)
  Multiple lines on a shared track may offer a higher level of service reliability than one line (assuming equal frequencies).

The following instruments may be applied at the tactical level:

- Trip time determination (Van Oort et al. 2012)
  In long-headway services, scheduled vehicle departure times at the stop, derived from scheduled trip times, determine the arrival pattern of passengers at their departure stop. Adjusting the scheduled trip time may affect the level of service reliability and passenger waiting time.

- Vehicle holding (Van Oort et al. 2010)
  Holding early vehicles reduces driving ahead of schedule and increases the level of service reliability. The design of the schedule affects the effectiveness of this instrument.

The terminal design instrument relates to (new) rail lines with tail tracks as terminal or short-turning facilities. For high-frequency, distributed lines, we recommend compact tail tracks with double crossovers directly after the stop. Concerning (new) lines with a clear break point in passenger pattern, we recommend to split the line or to apply holding points. For long-headway services we propose to use the 35-percentile value for scheduled trip time. And if parts of lines are very crowded, we suggest investigating the effects of coordination. Our international survey showed that not all of these potential instruments are common use yet. None of the participants considered the impact of the length of the line on service reliability. With regard to trip time determination, most authorities and operators used large percentile values to determine trip time (50% or higher). Both surveys illustrated that, there is little attention to the impact of tactical design choices on operational quality. An important issue is lack of requirements concerning trip time determination. Although there is a strong relationship between the method of trip time determination and service reliability, most investigated Dutch tender documents only mentioned that trip times should be realistic. However, Van Oort et al. (2012) proved that too much buffer in trip times has a large impact on passenger travel times (due to early departures) and that too little buffer time creates many delays. Holding is a popular instrument (78% of the participants applies holding), but little attention is paid to the relation to trip time determination as well (while Van Oort et al. 2010 demonstrated a direct relationship). About 70% of the participants applies coordination and in case of tail track terminal, about 35% of the designs has double crossovers before the platform.

New Dutch data sources as “chipkaart” (APC) and “GOVI” (Dutch AVL data, see for instance Van Oort et al. 2013) are considered very promising by the participants. Big Data in public transport offers great opportunities to analyse past performance and find potential improvements.

4 Results service reliability measurement

4.1 Introduction

In order to improve service reliability, it is essential to monitor and predict the level of service reliability of a public transport system. For this we need proper indicators. The commonly used indicators which are supposed to express reliability do not completely focus on the impact on passengers of service reliability. In fact, they focus more on service variability of the system than on the actual impacts on passengers. This section presents the traditionally used indicators and introduces new indicators that enable enhanced quantification of service reliability.

4.2 Traditionally used indicators

Given the stochastic nature of public transport operations, statistical measures such as standard deviation or percentiles are logical indicators for service reliability. A typical example is the coefficient of variation of headway, as shown by Equation 1 (Cham and Wilson 2006). This indicator may relate to an aggregate characteristic of a public transport line, or a branch served by a set of public transport lines. Equation 1 shows the coefficient of variation of actual headways per stop, but in practice expressing this indicator on line level by calculating the average value over the stops, is also common. This way, the number of passengers per stop is neglected.

$$CoV(\tilde{H}_{l,j}^{act}) = \frac{StD(\tilde{H}_{l,j}^{act})}{E(\tilde{H}_{l,j}^{act})} \qquad (1)$$

where:

$CoV(\tilde{H}_{l,j}^{act})$ *= coefficient of variation of actual headways of line l at stop j*

$\tilde{H}_{l,j}^{act}$ *= actual headway of line l at stop j*

$StD(\tilde{H}_{l,j}^{act})$ *= standard deviation of actual headways of line l at stop j*

$E(\tilde{H}_{l,j}^{act})$ *= expected headway of line l at stop j*

In practice, however, the use of purely statistical measures is limited. Commonly used indicators focus either on punctuality, the extent to which the scheduled departure times are met, or on regularity, the variation in the headways.

From the perspective of the production process, the percentage of trips performed within a predefined bandwidth, is a useful reliability indicator. Equation 2 expresses this type of indicator for average departure deviation for a complete line. Observed data is used to determine the relative frequency of deviations within a bandwidth. This indicator represents to which extent the production process requirements are met. The next section will present actual used values of $\delta^{\min}$ and $\delta^{\max}$. Obviously, these values are of great influence on the level of service reliability calculated.

$$P_l = \frac{\sum_{j=1}^{n_{l,j}} \sum_{i=1}^{n_{l,i}} P_{l,i,j}(\delta^{\min} < \tilde{D}_{l,i,j}^{act} - D_{l,i,j}^{sched} < \delta^{\max})}{n_{l,i} * n_{l,j}} \qquad (2)$$

where:

P_l = relative frequency of vehicles on line l having a schedule deviation between $\delta^{\min}$ and $\delta^{\max}$

Pl,i,,j = relative frequency of vehicle i on line l having a schedule deviation between $\delta^{\min}$ and $\delta^{\max}$ at stop j

$\tilde{D}_{l,i,j}^{act}$ = actual departure time of vehicle i on stop j on line l

$D_{l,i,j}^{sched}$ = scheduled departure time of vehicle i on stop j on line l

$\delta^{\min}$ = lower bound bandwidth schedule deviation

$\delta^{\max}$ = upper bound bandwidth schedule deviation

$n_{l,i}$ = number of trips of line l

$n_{l,j}$ = number of stops of line l

Punctuality may also be defined as the (average) deviation from the timetable at a specific stop, a set of stops, or for all stops of a line. The latter is shown by Equation 3 (Hansen 1999).

$$p_l = \frac{\sum_{j}^{n_{l,j}} \sum_{i}^{n_{l,i}} \left| \tilde{D}_{l,i,j}^{act} - D_{l,i,j}^{sched} \right|}{n_{l,j} * n_{l,i}} \qquad (3)$$

where:

p_l = average punctuality on line l

Please note that this formulation has an important shortcoming. It does not indicate whether vehicles depart too early or too late, which has a large impact on passenger waiting time. If only a set of stops is considered, the location of the stops may be of influence.

Irregularity is used to express headway deviations. Hakkesteegt and Muller (1981) introduced the PRDM (Percentage regularity deviation mean), which shows the average deviation from the scheduled headway as a percentage of the scheduled headway. The calculation of the PRDM is shown in Equation 4. This equation shows the calculation of the

PRDM per stop. Taking into account all the stops, a calculation of the PRDM for the total line is also possible.

$$PRDM_{l,j} = \frac{\sum_{i} \left| \frac{H_{l,i}^{sched} - \tilde{H}_{l,i,j}^{act}}{H_{l,i}^{sched}} \right|}{n_{l,j}} \tag{4}$$

where:

$PRDMl,j$ *= relative regularity for line l at stop j*
$H_{l,i}^{sched}$ *= scheduled headway for vehicle i on line l*
$\tilde{H}_{l,i,j}^{act}$ *= actual headway for vehicle i on line l at stop j*
nl,j *= number of vehicles of line l departing at stop j*

All of the presented measures focus purely on characteristics for the supply side, although it should be noted that indicators for punctuality and regularity are linked with assumptions on the arrival pattern of travellers, i.e. arrivals based on the timetable and uniformly distributed arrivals respectively. More important is the fact that these measures make no distinction between stops having a high demand or a low demand. Punctuality and regularity have a strong influence on waiting time and are thus most important for stops having large numbers of passengers boarding the vehicles. Furthermore, these indicators do not quantify the impact the variability has on travellers, such as the extra travel time as discussed in the previous section. The next section will present the results of the surveys concerning the use of these indicators.

4.3 Indicators in practice

The previous Section dealt with quantifying service reliability. More than one method/indicator is used in practice to present the level of service reliability. Both in theory and practice, analysts tend to focus on supply-side indicators which do not illustrate the actual service reliability, but rather show the output variability of the system. Most applied measures focus on departure time deviations. Mostly, early and late vehicles are treated as the same. The departure time deviations may be calculated per line or network, including all or only a few stops.

Another way to express schedule adherence is the percentage of vehicles' schedule deviations within a certain bandwidth. Equation 2 showed how to calculate this indicator (in which δmin and δmax represent the lower and upper bound respectively). This method is very common in heavy railways. The Dutch Railways, for instance, used to periodically present the number of trains departed not later than 3 minutes from 32 main stations in the Netherlands until 2010 (i.e. δmax = 3 min.). Most heavy railway companies in Europe use 5 minutes as a maximum (Landex and Kaas 2009, Schittenhelm and Landex 2009), as the Dutch railways do currently. In the U.S., even 30 minutes delay is considered being on time (Bush 2007). Among the urban public transport industry, sometimes the bandwidth has a lower boundary value as well (i.e. δmin), which means that driving ahead of schedule is considered explicitly. For example, vehicles are considered punctual when they depart between 0 and +5 minutes compared to the schedule (Nakanishi 1997). Of the participating cities in the international survey, 74% use a bandwidth to quantify and analyze schedule adherence, while 21% use the average punctuality. The results of the survey showed that only London has another way of measuring the difference between schedule and operations, being excess journey time (Van Oort 2009b).

Besides different indicators (average punctuality, bandwidth punctuality and regularity) the boundaries of the bandwidth are not uniform (see Figure 2). This figure shows the different values used by the participants of the international survey, where every line corresponds to the boundaries of one city or system. It is shown that three cities do not even use a lower boundary value (indicated as -5 minutes). The maximum boundary value ranges from +1 to +6 minutes. These differences in bandwidth obviously have a large impact on the percentage of on-time vehicles. Setting the requirement for excess variability thus determines the quality of operations. If a broad bandwidth is set, excess variability will be small for instance. Figure 3 shows the results for the Dutch survey. One major difference with the international results is that there is a lower boundary (no early departing) in almost all cases. On the other hand, the maximum boundary is higher in some cases. However, from a passenger perspective, late vehicles tend to affect travel times less than early vehicles. With regard to penalizing unpunctual vehicles, in 18% of the investigated tender documents, a penalty regime was applied.

With regard to penalizing a service quality level for being too low, not all experiences were satisfactory. First of all it is hard to precisely define an ambitious yet achievable level of service. Authorities tend to set too high standards, from the perspective of operators. When a penalty is proposed or applied, much discussion starts on how the data is achieved and processed. In addition, it is very important to distinguish who is responsible for which part of unreliability: as shown in Van Oort 2011, several sources together create variability and unreliability. Some of them are under the responsibility of the operator and some under the public transport authority and/or infrastructure manager.

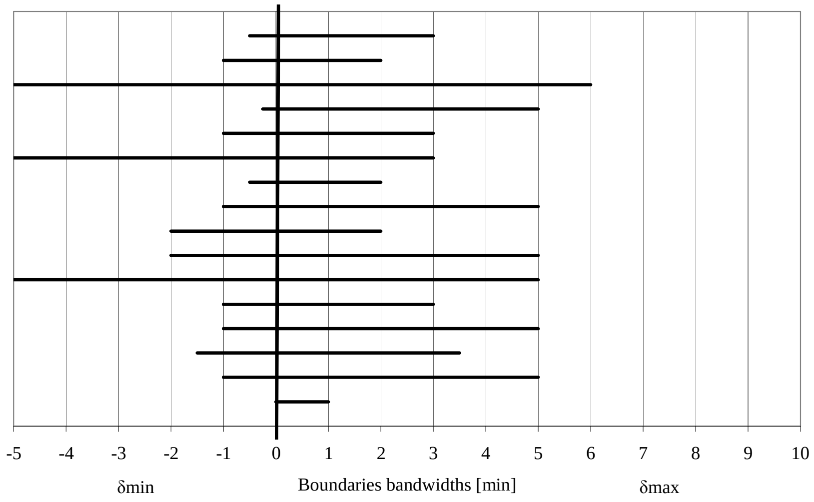


Figure 2. International survey: Boundaries of bandwidths applied in sample cities, to measure departure reliability at stops

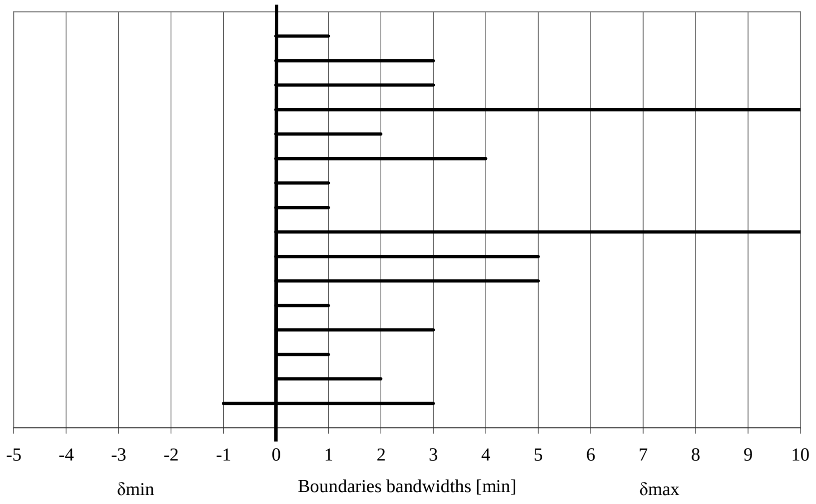


Figure 3. Dutch survey: Boundaries of bandwidths applied in sample cities, to measure departure reliability at stops

Besides differences in indicators and boundaries, locations of measuring service reliability differ among the participating cities as well. Sometimes, only departure at the terminal is considered or just the main stops. Figure 4 shows the response on the question of where to measure service reliability (i.e. departure time deviations). In the Dutch survey, we find that in 18% of the investigated concessions punctuality was measured at the first stop, in 27% at the last stop and in 23% at the main transfer points.

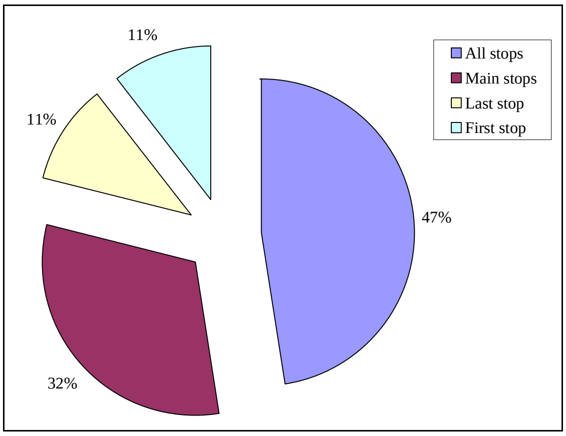


Figure 4. Locations used to measure service reliability (i.e. departure time deviations)

These results show that there is no uniform method applied in practice to measure service reliability, although this quality aspect is considered very important. Besides, the focus in practice is mainly on the supply side of public transport. Only Transport for London uses indicators showing the effects of unreliability for passengers, being excess journey time. These survey results support the statement of Van Oort (2011) to introduce a new indicator for reliability namely the average additional travel time per passenger. In literature, the need for a more passenger-focused indicator is recognized as well (e.g. Landex and Nielsen 2006, Mazloumi et al. 2008 and Frumin 2009).

4.4 New service reliability indicator

Several traditional quantifications of service reliability, such as punctuality and regularity, have a lack of attention for passenger impacts. Traditional indicators focus too much on the supply side of public transport, which does not allow a proper analysis of passenger effects. To deal with the shortcomings of traditional indicators, we developed a new indicator, being the average additional travel time per passenger. This indicator translates the supply-side indicators, for instance punctuality, into the additional travel time that a passenger on average needs to travel from the origin to the destination stop due to service variability. The average additional travel time may be calculated per stop or per line and enables explicit consideration of service reliability in cost-benefit calculations, since the level of service reliability may be translated into regular travel time. More insights on this indicator are presented in Van Oort (2011).

4.5 Limitations of service reliability definitions used in practice

The previous sections showed that there are many methods to illustrate service reliability and that these methods are applied differently in practice. In this section, the impacts of the measurement location and the definition of punctuality are analyzed. To show the effects of using these different methods, a case study is conducted using empirical data of tram lines in The Hague in The Netherlands. All tram lines are analyzed and data of rush-hours on working days in April 2007 are used. Figure 5 shows the impact of different measurement locations on service reliability. This figure illustrates the difference between measuring only at the first stop, at a central stop or at all stops. Figure 4 already showed that all of these methods are regularly applied in practice. To express service reliability, a bandwidth of timetable deviation of -1 and +2 minutes is used. The figure shows per tram line the percentage of vehicles departing on the specific stop(s) between these boundary values. It is shown that the different methods do not yield consistent results. The punctual trip percentage per tram depends on the measurement method and the order of tram lines differs per measurement method as well. Line 2 in the direction of KS and line 11 SH prove for example to be the most reliable lines using the first stop measurement, but if only a central stop is investigated, line 2 LL and line 1 SN are more reliable. If all stops are inserted in the calculation, line 11 HS is the most reliable line. This case proves that different methods do not yield comparable results and thus a consistent method is recommended.

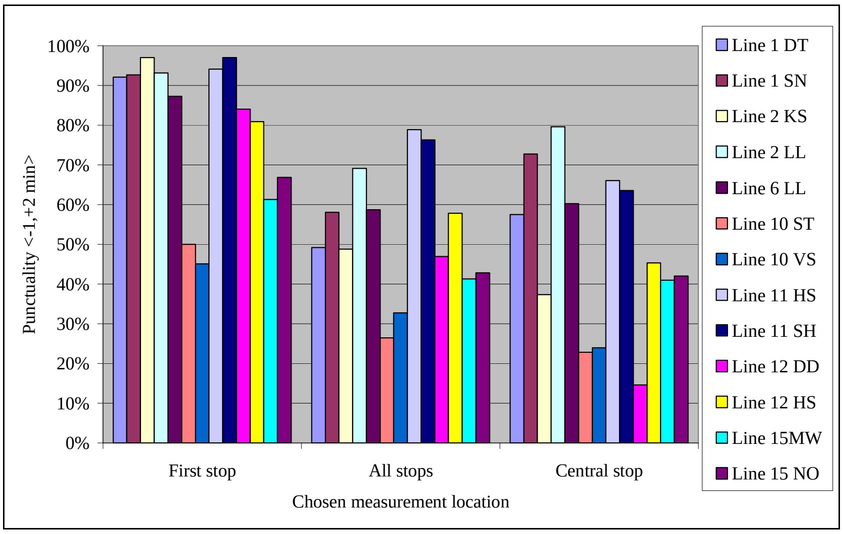


Figure 5. Punctuality <-1,+2> of tram lines in The Hague using different measurement locations

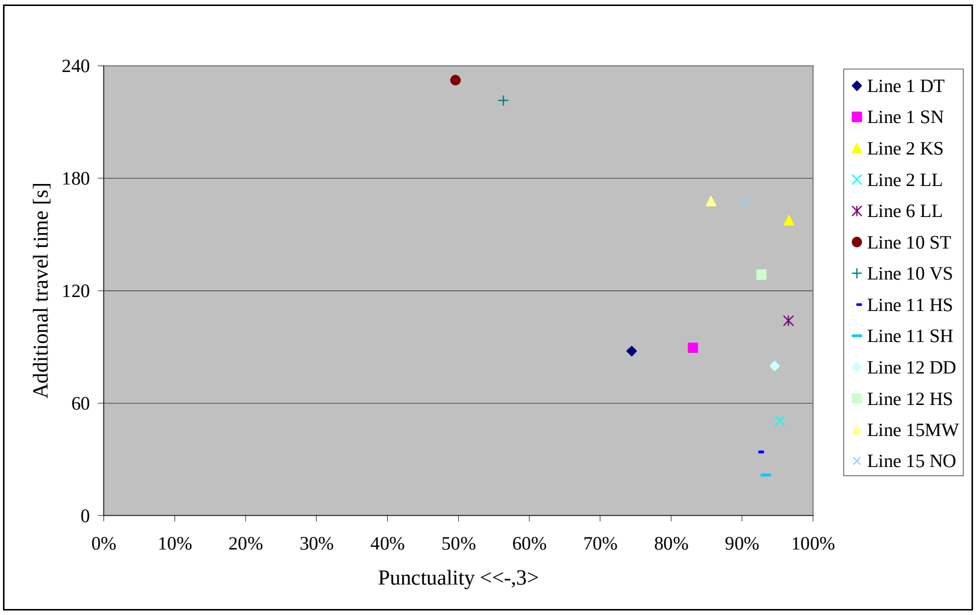
Besides the location of measurement, the indicator used is also of great importance and influence. As stated in Section 4.2, punctuality is a supply-focused indicator which is commonly used in urban public transport. The definition of punctuality differs among cities and countries as well, as mentioned in the previous section. In Van Oort (2009), a new indicator, additional travel time, was introduced. This indicator enables an improved illustration of the level of service reliability; the focus is on the passenger, there is only one definition and it is comparable to travel time.

Figures 6 A, B and C show a comparison between three definitions of departure punctuality found in the international survey and additional travel time for actual tram lines in The Hague. The used definitions of punctuality are (calculated for all trips at all stops):

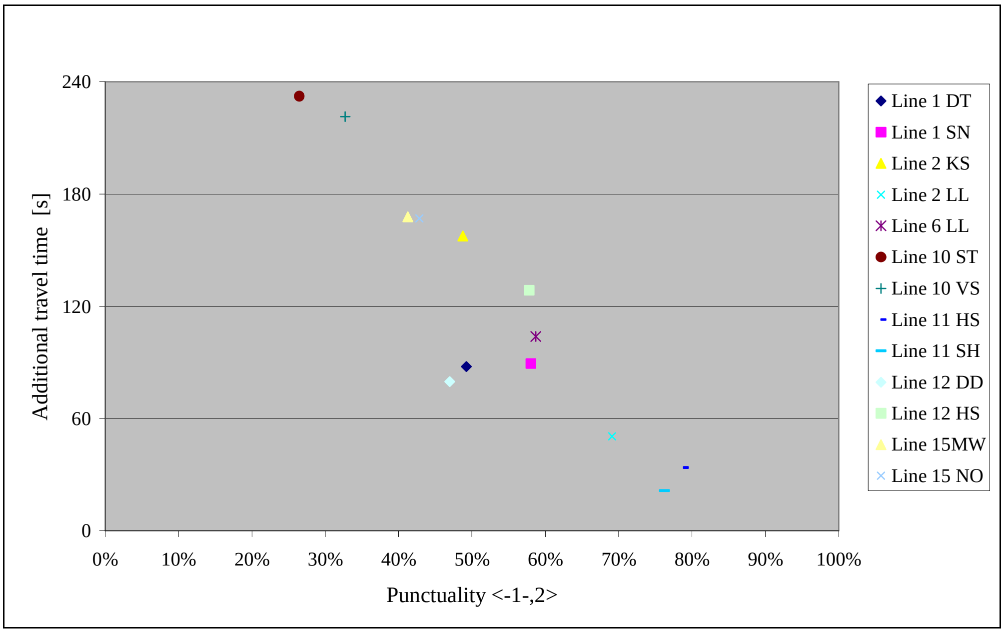
A The percentage of schedule deviations that is less than 3 minutes late;
B The percentage of schedule deviations which is both less than 2 minutes late and more than 1 minute early;
C The absolute average of the deviation.

Although these figures roughly show a linear relationship between these indicators and the additional travel time, the order of tram lines regarding the highest reliability differs per indicator. For example, line 15 MW has a low reliability using category B (<-1,+2>; only 40%), but a high reliability in category A (<<-,+3>; 85%).Tram lines with many early departures score better on reliability when no lower boundary is used.

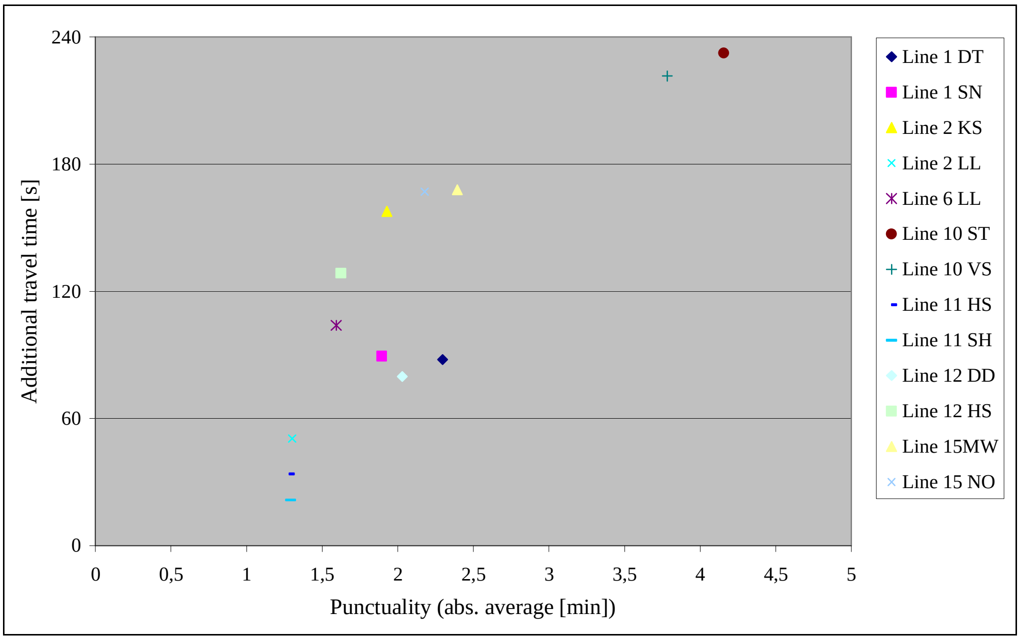
Another example of inconsistency is line 2 KS, which has a better reliability than line 1 SN if category B is used. However, the additional travel time per passenger is higher in the first line, so the passenger's experience will not be aligned with the common indicators result. Looking at Figure 6 C, it is illustrated that line 12 DD and 2KS have about the same value of punctuality, but the average additional travel time per passenger of the latter is about two times higher. The level of service reliability thus depends on the chosen definition. The additional travel time only has one definition and is better suited to addressing the level of service reliability of a specific line or network. This indicator really shows the impact on passengers.



A: Punctuality as a percentage of vehicles experiencing a departure deviation smaller than +3 minutes (no lower boundary)



B: Punctuality as percentage of vehicles experiencing a departure deviation between -1 and +2 minutes



C: Punctuality as absolute average of departure deviation

Figure 6. Calculated additional travel compared to three types of punctuality measurement

6. Conclusions and recommendations

This paper dealt with service reliability and how public transport authorities deal with this important quality aspect during design and tendering of services. We presented results of two surveys of the reliability practices of public transport authorities. One of the main conclusions is that most of times, service variability of vehicle performance is measured and monitored but a focus on passenger impacts is lacking. Second, there is no consistency in the definition of service reliability. We demonstrated that this may lead to different levels of quality concerning these indicators, while actual quality is constant.

We would recommend taking passenger interest more explicitly into account while setting indicators and objective of service reliability. In short headway services, regularity makes more sense than punctuality. Taking the actual number of passengers into account while aggregating the scores is also recommended. We demonstrated that our newly introduced indicator, additional travel time, represents the level of service reliability in a good way, considering factors that are neglected by traditional indicators, e.g. driving too early and passenger boarding patterns.

The additional travel time was calculated for the tram lines in The Hague and compared to the indicators found in the international survey (presented in the previous section). It was demonstrated that no consistent result is possible, since different kinds of indicators are used. The location of measuring that differed between cities proved to be important too. This inconsistency may lead to wrong conclusions. Our indicator of additional travel time incorporates the mentioned factors enabling a more complete and consistent quantification of service reliability. Finally, if we are able to really monitor and analyze the passenger oriented indicators, we will find potential improvement measures and enhanced service quality will be achieved.

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