# RELIABILITY IN TRANSPORT SYSTEMS: WHAT DO WE REALLY KNOW?

## PAPER FOR THE 26TH WORLD ROAD CONGRESS

## ABU DHABI 2019

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## ABSTRACT

During the last years, increasing attention has been paid to the notion of "reliability" in transport or "reliable transport systems". The various perceptions of reliability and the different status of scientific discussions concerning reliability all over the world are reflected by the results of an international survey. Diverse approaches for the forecast of reliability are introduced which offer the opportunity to incorporate reliability in transport modelling and subsequently in assessment procedures for new or extended transport infrastructures. Based on a literature review, values of reliability (VoR) are listed for selected countries, which made the necessary efforts. Finally, three case studies from Nigeria, Australia and France demonstrate the great variety of strategies for dealing with reliability in transport planning and science.

## 1. INTRODUCTION

Though transport planners and the public were putting reliability at the centre of attention concerning future transport and accordingly claims towards political stakeholders have been made to take actions for more reliable transport systems, we must realise that the (theoretical) knowledge about reliability is even internationally not exhaustive. Even the definition of the term is not intuitive and seems to differ from country to country.

The Technical Committee (TC2) "Road Transport System Economics and Social Development" of PIARC has established a working group concerned with "journey time and travel reliability". As a position-fixing for its activities, the working group initiated a survey within the PIARC community on the international standard of dealing with "reliability in transport systems". Our contribution will start with this picture of international definitions and experiences.

The underlying understanding of non-reliability can be the missing ability of a road link to provide a defined level of service for given "standard" traffic situations (excluding extreme weather situations, man-made attacks etc.). The alternative interpretation of non-reliability is the deviation of the realised travel time from the expected travel time. Within this concept the daily traffic jam between seven o'clock and eight o'clock in the morning can be reliable with a small standard deviation from the expected, even though frustrating travel time. The fact that reliability is mainly a key performance indicator (KPI) for the whole route from origin to destination has far-reaching consequences for transport modelling and project assessment. For the modelling aspect: travel times must be recorded for all possible routes between origin and destination for the time-period under consideration. For the assessment of route-related reliability: Using standard deviation sector by sector as measurand requires the non-correlation of incidents on adjacent links.

Following a theoretical excursion on how to describe reliability in a transport modelling context, values of reliability from different countries will be presented. With these two prerequisites – model-based indicators to measure reliability and the availability of VoRs –, reliability can be integrated in infrastructure assessment and especially in Benefit Cost Analysis (BCA). Consequently, the present contribution concludes with profiles of three exemplarily international project assessment studies incorporating reliability in their investigation.

## 2. SURVEY ON RELIABILITY

The aim of the „Survey on Travel Time and Reliability", which was sent to first delegates of the National Committees as activity of the Technical Committee A.2 "Road Transport System Economics and Social Development", was to collect information on "journey time" and "travel time reliability", and how this topic area is handled by the various member countries for road infrastructure assessment.

The survey consists of six partly closed, partly open questions on the understanding and/or treatment of the topic "reliability of transport systems" in the different countries. The poll was sent to 121 countries and 18 representatives responded (see the map, Figure 1), which represents a return rate of about 14.9 percent. In this study, no claim to representativeness is made, but the survey should be food for thought on transport reliability and give an overview of the international approach to the topic. In the following, the most important results are drawn and serve as opening to this article.

First, respondents should explain what is understood in their country as "reliability" in the transport sector and a definition was requested. We assume that respondents note the official view of their country and not the personal view. The evaluation found that a clear majority of definitions relates travel time with reliability, and terms such as consistency, punctuality, on-time or certainty are used as travel time attributes. For example, following definitions were given: "The ability of public transport service to operate on the particular infrastructure section with a relatively consistent travel time, independently of the time of the day or traffic situation" (Czech Republic). "For common carrier modes, reliability in general refers to some measure of on-time performance" (US). Another very common term is "variability", which expresses that a reliable transport system or mode of transport should have little variability in travel time. "The reliability could be defined as a low variability in travel time (almost permanent), which allows users to ensure their displacement in the time required (Chile)[*]. "Basically, it should mean the low variability in the expectable journey time (for professionals, planners)" (Hungary).

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[*] "La fiabilidad se podría definir como una baja variabilidad en el tiempo de viaje (casi permanente), lo que permite a los usuarios asegurar su desplazamiento en el tiempo requerido"

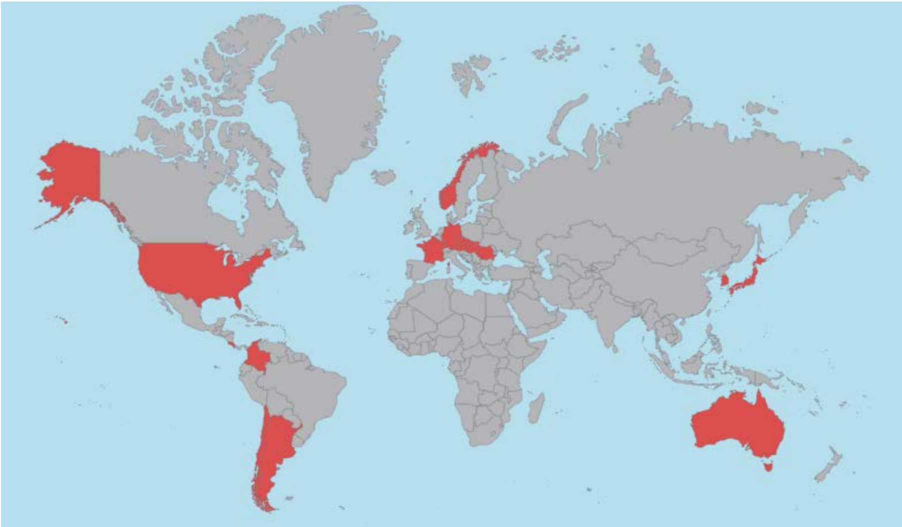

*Figure 1: Countries that responded to the survey*

Rarely a fixed, universal or official definition is given. It's more about descriptive explanations, what is meant by reliability. “There is no standard definition of reliability for transport systems in Norway. The term is often used when discussing how certain the travel time is” (Norway). “There is no public definition of reliability in Korea. But, the punctuality of train operation used to be a reliability” (Korea). According to Japan there is also no official definition of “reliability”: “generally, it is understood as the ability to stably supply transportation services” (Japan). Concrete reliability calculations were also provided. According to the Austroads Congestion and Reliability Review AP-R534-16 (1) for example, reliability is 1.44 standard deviation of peak travel time / mean peak travel time (Australia).

Apart from travel time, other features were emphasised. For example, talking about safety, which refers not only to the stability of the expected travel time but also to a "safe transport" in the sense of protection from danger, risks or injuries: “Reliability also implies a safe transportation system for users” (Canada)*. “(…) it is an essential factor for the evaluation of transport policies tending to achieve an increasingly efficient and safe transportation system” (Argentina)†.

In addition, it was asked if there were different understandings of reliability for different modes of transport, which 83.3% of respondents answered “no”. In the US, however, the definitions vary by mode, for example, in reports filed with the US Department of Transportation, commercial air carriers report a flight as “on time” if it arrives at the gate within 15 minutes of the published arrival time. The national passenger rail provider, Amtrak, uses a definition of “on time” arrival that is a function of the distance served. In comparation, a recent federal regulation (23 CFR 490.505) defines for highway modes “the level of travel time reliability for a given highway segment as the ratio between the 80th percentile travel time and the 50th percentile travel time, measured at intervals over the course of one year” (US). Furthermore, it is possible to use other definitions depending on the service provided.

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* “La fiabilité implique également un système de transport sécuritaire pour les usagers”.

† “…es un factor escencial para la evaluación de políticas de transporte tendiente a lograr un sistema de transporte cada vez mas eficiente y seguro”.

Even states, regions or localities can incorporate different definitions in their planning process.

In summary, the survey provides an overview on how reliability is understood in different countries and highlights the lack of an universal definition. The relation to travel time is preponderant with terms such as, certainty, variability, and punctuality. However, other characteristics of a reliable mode of transport are also citied, such as: user-orientated quality, robustness, availability, efficiency and the quality of real-time information. The following graph (Figure 2) shows the occurrence of different terms mentioned in the definitions given by the respondents.

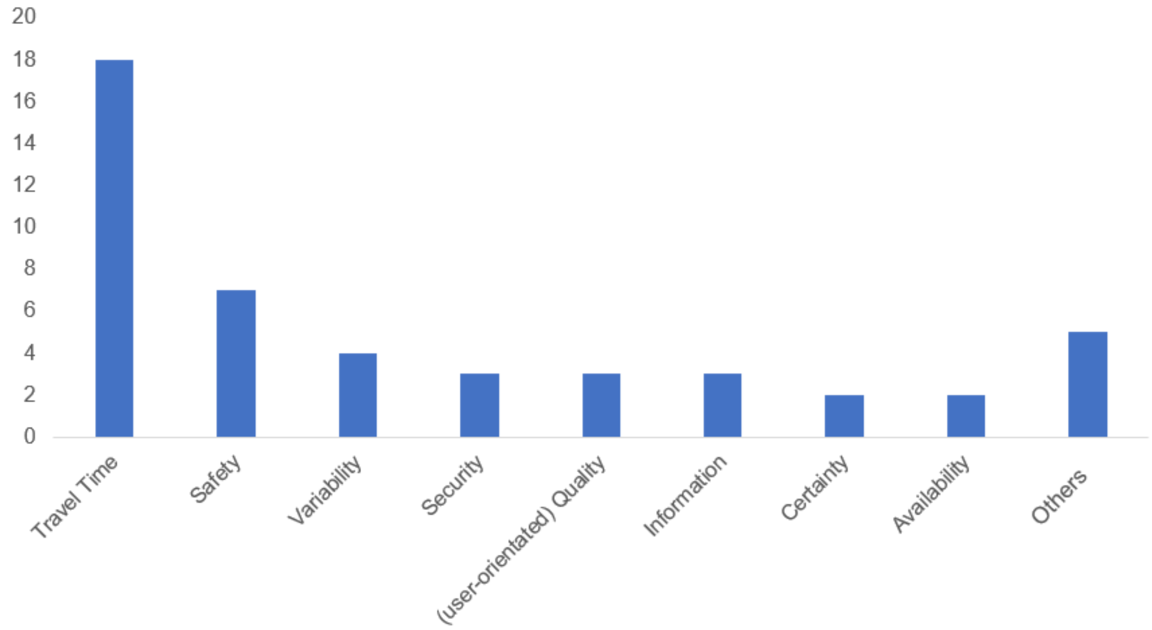


*Figure 2: Terms used in the definition of reliability and their occurrence*

When asked how important reliability is for transport planning in each country (multiple answers were possible), almost three-quarters (77.8%) stated that it is an important topic in practical use as well as an important academic topic (33.3%). Only 16.6% stated that it is of minor importance for practical use and 22,2% specified the same for academic researcher. It is also reflected in the fact that almost 70% of respondents said that there is research work in progress on traffic reliability in their country.

From a regional point of view, it can be said that in Europe the topic is important both in practical use and in research, especially in the northern and central European countries. In Central and South America, the topic is more important in practical use than in academic research.

When asked about the type of experience in applying reliability concepts, it is noticeable that there is mainly experience in integral parts of assessment procedures or guidelines on national or single project assessment level (almost three quarters). Very few respondents stated that there is experience in using reliability aspects for strategic statements.

Finally, respondents were asked about the general or public perception in their country of reliability for transport systems. Each country answered this question very differently. Some have commented on the image of the transport system, while others have discussed the importance of reliability for users. Here, a rather negative image of transport systems emerges, especially among emerging and transition countries, like in Costa Rica: „In general, it is considered a less reliable system …" (Costa Rica)*. "Also, regarding train services, there is not enough supply and there are few units, which can suffer accidents or damage, so it is more likely that services will be likely cancelled" (Costa Rica)†. "That is a critical issue mostly for the national rail services where severe delays and cancelled journeys occur quite often" (Hungary). Figure 3 demonstrates the distribution in percentage of the different answers.

On the whole, it is stated that reliability plays a major role and is considered very important. "Since roads are required to play a role of improving productivity in a population declining society, time reliability is important" (Japan). "The general perception is that reliability is of great importance for the travel experience. The term is particularly in focus for commuters by train but is also in focus in the road sector in winter season at mountain crossings and areas where landslides/avalanche may happen" (Norway). "Reliability of travel time is important for many users of the transport system, be they vehicle drivers, transit passengers, cargo carriers or even air travellers" (Argentina)‡.

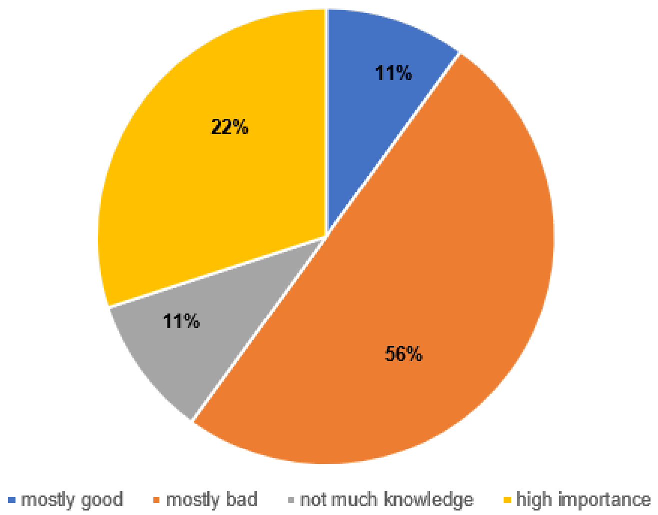


*Figure 3: General/public perception of reliability according to the survey, based on a population of 18 answers*

## 3. THEORETICAL ASPECTS

Travel time variability can be explained as the random, day-to-day variation of travel times, caused by different factors and incidents, which constitutes the unreliability of transport systems. Arup et. al. (2) divide travel time variability into: day-to-day variability (DTDV) and incident related variability, in which DTDV can be split into demand and capacity related variability. During the last two decades, a lot of research work ( (3), (4)) was done to measure reliability, to develop methods for forecasting reliability, to determine the value of reliability

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* "En general, se considera un sistema poco confinable."

† "Igualmente, en cuanto al servicio de tren, no se tiene una oferta suficiente y existen pocas unidades, las cuales pueden sufrir accidentes o desperfectos, por lo que es más probable que se cancelen servicios."

‡ "La fiabilidad del tiempo de viaje es importante para muchos usuarios del sistema de transporte, ya sean conductores de vehículos, pasajeros de tránsito, transportistas de carga o incluso viajeros aéreos".

(VoR), and, finally, to incorporate reliability aspects in infrastructure assessment, predominantly in Benefit Cost Analysis (BCA).

Three approaches are commonly reported in the scientific literature as the most adequate to measure transport reliability or unreliability, respectively. They all rely on the consideration of a whole route from origin to destination:

- standard deviation of travel time distribution
- anticipated buffer times to avoid delayed arrivals
- deviations from preferred arrival times in schedule bound systems (schedule delay) measured by frequency (percentage of arrivals) or extent (e.g. minutes of delay).

Following the intention of the present article, a short overview of the approaches and results of the integration of reliability in BCA of the German Federal Transport Infrastructure Plan 2030 (FTIP 2030) will be given. The reason for this example is that FTIP 2030 provides methods (including reliability) for assessing planned infrastructure projects for three transport carriers: road, rail and inland waterways (5).

The FTIP 2030 focuses on the concept of standard deviation for measuring reliability in the road sector (see Geistefeldt 2014 (6)). Here, the functional determination of standard deviation depends only on the volume-capacity ratio of a certain link and is set to “zero” for all volume-capacity ratios below 75%. The latter assumption simplifies the calculation as beyond this threshold the same speed is effective for passenger cars and trucks. The underlying understanding of non-reliability for this concept is the missing ability of a road link to provide a defined level of service for given “standard” traffic situations (excluding extreme weather situations, man-made attacks etc.).

$$s_R(x) = \begin{cases} 0{,}2\,(x - 0{,}75)^{1{,}7} \cdot \sqrt{\dfrac{L}{L_{Reference}}} & \text{for } x \geq 0{,}75 \\ 0 & \text{else} \end{cases}$$

being

x = volume-to-capacity-ratio of the section

$s_R(x)$ = section related standard deviation of travel time [h]

L = section length [km]

$L_{Reference}$ = reference length [km] (see below).

The FTIP 2030 functional determination of the standard deviation must be applied for each single link, although reliability is mainly a KPI for the whole route from origin to destination. To calculate reliability of a route as square root of the sum of the links’ variances, the non-correlation of incidents on adjacent links must be given. FTIP 2030 methodology recommends the calculation of a hypothetical reference length for the network under consideration based on the volume-capacity ratios, which guarantees the independence of incidents on neighboured links. The quotient of individual link length and reference length is applied to adapt the calculated standard deviation. The impact of the reference length on the value of the standard deviation is demonstrated in Figure 4.

In the rail sector, deviations from contracted arrival times in schedule bound systems (schedule delay) in frequency (percentage of arrivals) and extent (delays measured in e.g. minutes) are appropriate for measuring non-reliability. These delays can be replaced by (anticipated) buffer times to avoid delays. Calculating und using buffer times converts uncertain time losses with a big range into certain time losses, sparing a small risk of delay.

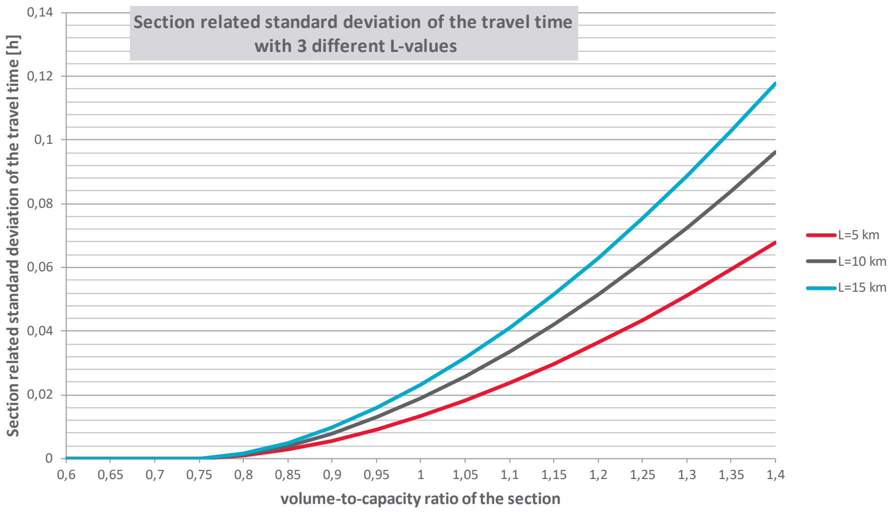


*Figure 4: Impact of the refence length on reliability measures (own illustration)*

Within the framework of FTIP the future rail network 2030 does not provide a deeply elaborated time schedule. Instead of this, standardised times for changing trains according to the classifications of trains involved are proposed. Moreover, it is assumed, that the design of the schedule contains sufficient buffer times to reach the desired destinations on time and to get connecting trains. The priority of passenger trains over freight trains in train operations supports this expectation. Finally, the influence of the age of the rolling stock, of all-weather hazards, man-made attacks etc. on reliability are not considered in the FTIP approach, as it is an assessment procedure for deriving a pure strategic implementation plan for transport infrastructure. Concisely, reliability is not captured for passenger rail transport at all.

For freight trains the modelling of reliability can be realised by an endogenous train line system between marshalling yards with defined transport times serving an artificial schedule. During the assignment process, waiting times on passing loops occur due to the number of prioritised passenger trains and the increasing volume of the freight trains. This modelling procedure generates the frequency of delay and the extend of delay for each origin-destination relation and each commodity group. Reference values for reliability are related to one percentage point of punctuality for one ton of a commodity group. Herewith, punctuality is defined as delay exceeding scheduled transport time by 20% and more. The reference values must be calculated for each relation and commodity group using the first derivative of the corresponding utility function.

To complete the section, it must be noted that transport time variabilities on inland waterways are not relevant to transport carriers due to the long delivery lead times. Reliability is mainly influenced by the water level fluctuations. There are special transport insurances, which pay for alternative transports (road or rail) in case of low water levels and corresponding low loaded drafts. Increasing figures of low water level incidents may reduce the profit of insurances. These costs are already considered within the BCA as part of the operational costs (and benefits will occur, if operational costs can be reduced by improved infrastructure, e.g. locks).

## 4. INTERNATIONAL LITERATURE RESEARCH ON RELIABILITY STUDIES

### 4.1. Overview

An analysis of international studies dealing with the topic of reliability reveals a large concentration of reliability studies especially in Europe and the US. Some of the studies are taken from respondents' answers (see chapter 2), others are the result of extensive literature research. However, no claim to completeness is made here, but an attempt to provide an overview of the geographical distribution of the different reliability studies and their focuses.

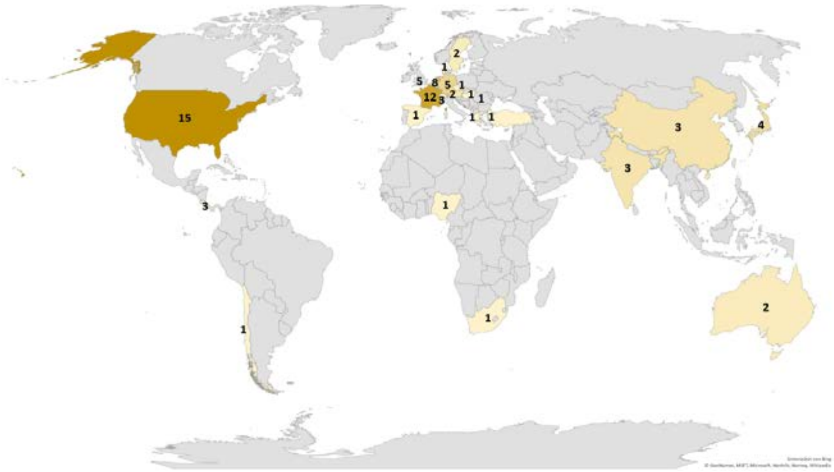


*Figure 5: Geographical distribution of studies on reliability and their amount*

Figure 5 synthesizes the countries where, in the opinion of the authors, relevant studies on the topic have been implemented today or in recent years. The numbers illustrate the amount of studies that were founded or considered in more detail. A total of 77 studies from 22 countries were examined more deeply. The time span of the analysed literature is from 2002 to 2017.

Figure 6 shows the key topics that are associated to the term reliability in the literature studied in this review. The quality of public transport plays a predominant role, followed by the value of travel time or value of reliability. In addition, attempts are being made to include reliability measurements in transport infrastructure assessment guidelines and to improve forecasting the reliability of travel time.

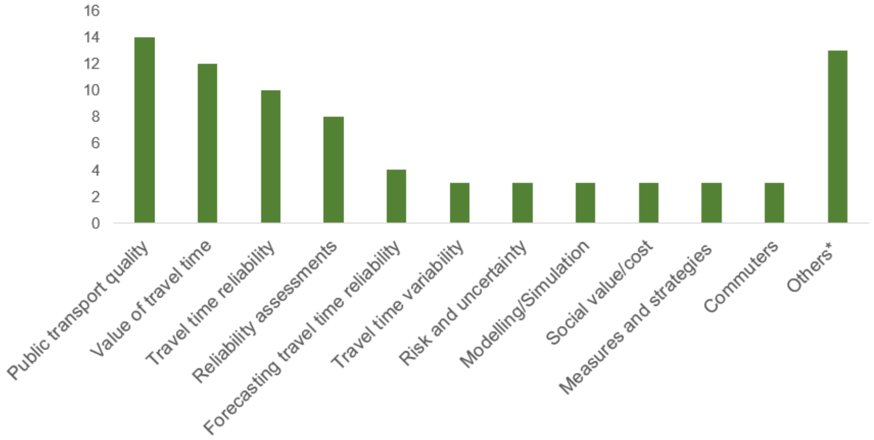


*Figure 6: Frequency of main topics in the reliability studies*

*Road network, Information, Monitoring Resilience, Maintenance, Congestion

It is also interesting to see which countries are dealing with the identified main topics. Table 1 demonstrates that the geographical distribution of specific topics is very heterogeneous; except for forecasting travel time reliability, which seems to be explored in Europe and the US only.

*Table 1: Geographical distribution of the most frequently occurring topics within the examined reliability studies*

| **Topic** | **Public transport quality** | **Value of travel time** | **Travel time reliability** | **Reliability assessment** | **Forecasting travel time reliability** |
|---|---|---|---|---|---|
| **Country** | Nigeria, Czech Republic, Chile, China, Costa Rica, France, Netherlands, Switzerland, Turkey | Denmark, France, Great Britain, Germany, Japan, Netherlands, Spain, USA | Australia, Costa Rica, France, Great Britain, Japan, USA | Chile, England, France, Germany, Greece, USA | Hungary, Netherlands, Sweden, USA |

## 4.2. Values of (travel time) Reliability (VoR)

To integrate the benefit of increasing travel time reliability into BCA, it is necessary to monetize this benefit component by using a reference value, which is understood as value of reliability (VoR)*. Following a common understanding, it measures the willingness to pay for reductions in the day-to-day variability of travel times facing a particular type of trip (7). Some countries have official values of travel time (VoT), but in general there are no official values of reliability, which is due to the disagreement generated by its determination. Possible methods use different measures, data sources, and calculation methods (8). It can be said that the estimation of VoR is similarly complex to the estimation of the VoT. There

* Equivalent: Value of Travel Time Reliability (VTTR)

are numerous studies that attempt to determine the VoR using a variety of survey methods as well as estimation methods, and the results for the values vary depending on the method and the way the data is prepared. In addition, differences between trip attributes, modes, socio-demographic characteristics as well as gender are found, further clarifying or complicating the problem of determining VoR.

It is not even agreed whether the VoR should be higher, equal to or lower than the VoT. For example, in the FTIP 2030 it is proposed that the VoR should be 70% of the value of the VoT. In the study by Sadabadi et al. (9) it is stated that depending on different investigations, the VoR accounts for between 60 and 100% of the VoT and the Maryland State Highway Administration in the US considers a reliability ratio (RR) of 0.75.

In contrast, according to a study by Jin, Hossan and Asgari (10) that compares various studies on reliability, the VoR is usually 0.55 to 3.22 times the VoT. Another study from Li, Hensher and Rose (11) estimated a higher mean VoR than the mean VoT and explained it with the argument that "on-time arrival (…) incurs more utility than the reduction in mean travel times" (ibid.) The results would be in line with many previous empirical studies.

It can be highlighted that both, the valuation of reliability and the inclusion of reliability in transport forecasting models are challenging. "As a result, the benefits of projects and policies that reduce travel time variability are likely to be underestimated" (Kouwenhoven et al. (7)). But science is fundamentally in agreement that "Cost Benefit Analysis should include valuations of the impact on travel time variability as an additional issue in order to improve the results of project evaluation" (12).

Table 2 below illustrates how different the VoRs have been estimated in different countries and studies. It must be made clear at this point that comparability is not possible because the source of the data, the method of estimating and determining the results is very heterogeneous. In addition, for a direct and possible comparison, one would normally have to cite, in addition to the listed values, price level and purchasing power of the countries under consideration.

*Table 2: Comparison of VoT and VoR Estimations*

| Study | Date Collection periods | Mode trip and purpose | Location | VoT | VoR |
|---|---|---|---|---|---|
| Asensio and Matas (2006)* | n/a | Car<br>Commute | Spain/<br>Barcelona | 14.20€/h | 22.40-51.10€/h (valuation of delay time)<br>6.70-8.90€/h for fixed start time only<br>(valuation of early arrival time) |
| Li, Hensher, Rose (2008)† | 2008 | Car<br>Commute | Australia/<br>Sydney | 28.28$AUD/h (2008) | 40.39 $Aud/h<br>(2008) |
| Uchida (2014)‡ | n/a | Car | Japan | 40 [JPY/min] | 20 [JPY/unit variance] |

* Asensio, J./ Matas, A. (2006) **(12)**

† Li, Z., Hensher, D.A. and Rose, J. (2010) **(10)**

‡ Uchida, K. (2014) **(18)**

| | | | | | |
|---|---|---|---|---|---|
| Kouwenhoven, M, De Jong, GC, Koster, P et al. (2014)* | 2011 | Car Commute | Netherlands | 9.25€/h (2010) | 3.75€/h (2010) |
| Lazor et al. (2017)† | n/a | Car Commute | Czech | 3.32CZK/h | 3.93 CZK/min.SD |
| Small et al. (2005)‡ | 1999/2000 | Car Commute | US/Los Angeles | 21.46$/h | 19.56$/h |

In summary, it should be emphasized once again that the VoR measurement approach differs from study to study in almost all aspects, from the concept, the data source to the depiction of reliability in different scenarios. The VoR estimates therefore show large differences between the studies.

## 4.3. Case studies incorporating reliability

The following case studies from Nigeria, Australia and France demonstrate the great variety of strategies for dealing with reliability in transport planning and science.

*Abuja – Keffi road corridor (Nigeria)*

The purpose of this study (13) was to identify events influencing traffic flow and causing congestion to help commuters to plan well their journey. They determined the travel time reliability along Abuja – Keffi corridor using the 95th percentile method and developed a variety of reliability measures, such as; planning time, planning time index, and buffer index. Following this approach, the mentioned indicators were defined as:

- travel time index = actual travel time / travel time at free flow speed
- planning time index = travel time needed for arriving on time (within the 95th percentile) / travel time at free flow speed
- buffer time index = planning time index – travel time index or
- buffer time index = (buffer) time to be allowed to arrive on time (within the 95th percentile) / travel time at free flow speed.

Video coverage helped to collect the travel times of vehicles for the weekday and weekend during rush hour and off-peak hours. There were also a few roadside interviews to gather the travellers' view on the daily journeys. It turned out that travellers can hardly predict how long it takes to get to work. It seems to be even more difficult for travellers to plan their work trip, as most offices resume work at 8:00 am and the stretch of road between 7:00 am and 9:00 am is always over capacity. Among other things, this is due to the growth of the urban population and equally high motorization growth as well as a concentration of activities in the city centre. In addition, complex safety and security issues arise because roads and infrastructures have not been developed at the same pace as urban traffic.

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* Kouwenhoven, M., De Jong, G.C., Koster, P. et al. (2014). **(11)**

† Lazor, M., Šimeček, M., Klímová (2017) **(19)**

‡ Small, K. A., Clifford, W., Jia Y. (2005) **(17)**

The results of the measuring period are the following: The index value for planning times is 1.65 compared to the index value of 1.25 for the travel times during the rush hour (7:00 to 9:00) (Figure 7). This means, that for a trip that takes 15 minutes in light traffic, a traveller should plan a total of 25 minutes to ensure a punctual arrival in 95 percent of all trips.

The study work was able to identify traffic jams and their causes, to estimate travel times, and to determine the variability of average travel times. It found that (with a strong tendency increasing) travel times on average become more variable (i.e. unreliable) and unpredictable but public transport companies cannot benefit from the commuters' problems, as long as they use the same overcrowded roads for their bus services. Thanks to the results of the study, the interaction between travel needs, traffic flows, congestion, travel time variability, and individual planning options can be better understood by both commuters and government agencies responsible for planning road networks in Nigeria.


*Figure 7: Reliability measures compared to average congestion measures, Source: Ibitoye et al. (2015)*

### *Bus line 709 at the Gold Coast (Queensland, Australia)*

In this study (14), a model was developed to evaluate the calculated punctuality and reliability of bus services (bus line 709) provided by TransLink in Queensland, Australia. The bus travel time is very sensitive to small disturbances, such as a delay in getting in or out, which leads to unpunctuality of the bus. The bus travel time on a route can be divided into dwell time and driving time. The former describes the time when passengers board and get off at bus stops including the opening and closing of the doors, and the latter is the time when buses really travel from one stop to another. Both components show variability. The travel time usually fluctuates at an expected time specified in the timetable.

In Queensland, more than 80% of passengers use a "go card" (electronic ticket). The average entry time for this passenger category is about 3 seconds. By contrast, paper ticket buyers need at least 10 seconds per passenger to board. For those passengers who charge their tickets in the TransLink buses, a duration of at least 30 seconds is scheduled. In addition to ticket selling in buses, there are a variety of other payment and charging alternatives online and offline.

The passengers were divided into four category types: p1 - travel card users (tapping in), p2 - travel card users (topping up onboard), p3 - passengers with disabilities, p4 - single paper ticket users. The average boarding times were measured for 150 different passengers and a percentage distribution was calculated. The dwell time is determined by the boarding and alighting times at all bus stops as well as the time for doors opening and closing (2 seconds). The boarding time per passenger is represented by random variables where p1 = 42s, p2 = 3s, p3 = 30s and p4 = 20s.

The driving time from one stop to another usually varies with a given time. It was assumed that the driving times of different intervals follow a normal distribution. The mean values are the given times from the timetable of the bus line 709 and the variances are assumed for this exercise to be a proportion of the mean values. In view of their characteristics, discrete random variables were used to represent dwell times.

Beside the impacts of the four categories, variability in dwell time can also be a result of variations in the number of passengers at all. To evaluate the impact of onboard travel card top-up, in this study it is assumed that the number of passengers is known and remains unchanged. However, the punctualities at various stops are not the same. In this regard, a proper weighting system needs to be proposed for evaluating the reliability for a particular bus line. Here, a higher weight is given for bus stops with more boarding and alighting passengers.

A bus is considered on time if it arrives within 3 minutes of the scheduled time. Calculations have shown that the reliability of the bus line under today's ticket offer is 0.65 and the bus line reliability without onboard top-up is 0.81. This means, the reliability of the bus line under investigation would increase by about 15% if on-board charging for "go cards" (electronic tickets) was not offered by TransLink. It was found that not providing this method of charging would be detrimental to the user but would result in improved bus line reliability.

*Managed lanes in the Greater Paris Area (France)*

This paper (15) presents results from the field test experience of the dynamic use of hard shoulder (HSR) on the A4-A86 motorway in eastern Paris. In addition to the reliability assessment, the paper focuses on further possible reliability indicators. Results reveal a positive effect on travel time reliability by dynamic use of HSR.

Managed lane operations refer to several strategies for recurring congestion control by increasing the road capacity or adjusting its configuration to the demand level. Typically, the increase in capacity is achieved by redefining the transverse profile within the roadway limits. Several technical alternatives are possible, such as the reduction of lane width and the temporary or permanent use of the hard shoulder as a running lane. France has a well-known example of hard-shoulder running schemes: a section of the motorway in the east of Paris.

In addition to conventional benefit indicators the authors present different measures to integrate reliability into the impact assessment of dynamic use of the hard shoulder. Based on different percentiles (TTx) they define among others:

- the width indicator $\lambda^{var}$ [-]

$$\lambda^{\mathrm{var}} = \frac{TT_{90} - TT_{10}}{TT_{50}}$$

The wider (or more skewed) the travel time distribution the less reliable travel times are. Large values of $\lambda^{var}$ in turn indicate that the width of the travel time distribution is large relative to its median value.

- the buffer index BI [-]

$$BI = \frac{TT_{95} - M}{M}$$

The buffer time (BT) is defined as the difference between the 95th percentile (TT 95) and the average travel time (M). The buffer time appears to relate particularly well to the way in which travellers make their decisions, because it describes the extra time a user must add to the average travel time to arrive on time 95% of the time. The buffer index (BI) is then defined as ratio between buffer time (BT) and average travel time (M).

The hard shoulder running (HSR) experiment was launched in July 2005 on a four-lane 2.3 km long weaving section between two urban motorways (A4 and A86) in the east of Paris, which is highly congested, almost 10 hours a day. It gives drivers access – at peak times – to an additional lane on the hard shoulder where traffic is normally prohibited. The opening and closure of this lane are activated from the traffic control centre according to the value of the occupancy measured upstream of the common trunk section.

To determine the impact of HSR on reliability, data were analysed for three years (2000-2002) before the device was introduced and one year later (2006). To calculate the travel times, three induction loops were used in the east (two on the weaving section and one downstream) and four induction loops in the west. The analysis shows the unreliability decreases between 2002 and 2006 when HSR is open, according to the indicator planning time (PT) (the 95th percentile) and buffer time. PT decreases when HSR is open, due to the reduction of congestion. On the contrary PT is stationary when HSR is closed (daylight). BT decreases when HSR is open, due to the decrease of the 95th percentile, although the average travel time decreases as well. $\lambda^{var}$ measures the width of travel time distribution effectively, indicating both reliability and congestion, and showing decreasing values for the HSR during daylight and night.

## 5. CONCLUSION

Our paper shows that many of the more than 120 nations, which are members of PIARC, are dealing with the topic “reliability of transport systems”. For a world-wide operating organization like PIARC it is always challenging to draw the whole picture of an interesting issue, meaning that status quo and results must be collected from all member states and consolidated into a comprehensive report.

Our contribution goes in this laborious task regarding the worldwide discussion on reliable transport systems. We do not claim to draw the complete picture but try to give a deeper insight into the ongoing debate, conducted by scientists, transport planners, politicians, and the public. Obviously, we cannot go further into the details of the mathematical problems of describing and forecasting reliability, but we can sustain a better common understanding of reliability with the results of our survey, some theoretical considerations, selected approaches to determine the value of (improved) reliability and three case studies at the end of the text.

The main finding is that there is still a great deal of disagreement about reliability in transport systems, from definition, through measurement, to calculation and interpretation of results. However, there is a consensus that reliability in BCAs should be considered to get accurate and correct results, avoiding underestimation of possible benefits. The task of research is therefore to continue discussing methods for measuring and forecasting reliability and for estimating adequate values of reliability at national level (also in relation to VoT). And again: the latter effort is the prerequisite to integrate reliability in assessment procedures like BCA.

On the one hand, people allow a certain amount of time to get to their destinations but are averse to unexpected additional travel times. Reliability is fundamental for a society which is more and more “scheduled”. On the other hand, reliability is an ideal measurement for the quality of transport systems and can be used as a benefit component within appraisal procedures indicating which projects are worth to be realized. We hope for further exchange as reliability will be one of the prominent topics in the next years and acknowledge the intensive support of our survey by PIARC’s office in Brussels.

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