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Assessing the effects of traffic information to passengers: a literature review

Abderrahman Ait-Ali[a,b,*], Anders Peterson[a]

[a]Linköping University, Luntgatan 2, 602 47 Norrköping, Sweden
[b]Swedish National Road and Transport Research Institute (VTI), Malvinas v 6, 114 28 Stockholm, Sweden

Abstract

The use of information systems in the rail sector has recently accelerated thanks to increasing innovations in digitalization and information technology in different transport sectors. Thus, investments in systems such as traffic information can bring substantial social value to the users, particularly during traffic disruptions. Investments in an efficient sustainable and scalable traffic information system could be an important complement to infrastructure investments and maintenance activities. In this context, we review existing research on traffic information systems, their different effects and more importantly, the assessment of their social value. We focus on the case of disruptions in railway passenger traffic although many discussions are about more general transport situations. The reviewed literature reveals several studies on the valuation of traffic information to passengers under different travel situations. However, we conclude that such valuations are rarely used in the context of cost-benefit analysis for planning investments for traffic information systems.

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Keywords: Literature review; Traffic information; Train passengers; Traffic disruptions;

1. Introduction

Railway punctuality is an important question, often followed with large interest from both media and politicians. Delays are causing problems for travellers and can be expensive in terms of socio-economic costs, both directly as they occur and indirectly in terms of reliability for railway transport systems (Landex, 2012). Traffic information

* Corresponding author. Tel.: +46 (0) 85 55 36781
E-mail address: abderrahman.ait.ali@liu.se

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cannot increase punctuality but has the potential to lower the costs of delays. This study is a literature review on the effects of traffic information to passengers and their assessments.

In this introductory section, we first present some background information and motivation. Thereafter, the aim and scope of the work are mentioned. Finally, we briefly describe the adopted methodology and structure of the review paper.

1.1. Background and motivation

New developments in information and communication technologies (ICTs) allowed for increasing innovations and applications of these technologies in different sectors such as transportation. They have been particularly used in different transportation systems such as road, air, maritime as well as in railways (Giannopoulos, 2004).

Providing traffic information to passengers, at any time and/or any location, is a promising application of ICTs in transportation (van Essen, Thomas, van Berkum, & Chorus, 2016), and in public transport and railways in particular (Giannopoulos, 2004). Unlike traffic information, which is mainly aimed at traffic operators and companies, traveller's information is often referred to, in the literature, as advanced traveller information service or ATIS for short (Chorus, Molin, & Van Wee, 2006). Such services describe all systems that acquire information, analyse it, and then present it to individual travellers. Hence, ATIS allow the provision of travel information for the whole network without considerable additional costs, i.e., scalable with low marginal costs.

In addition to its scalability, several studies indicate the potential of ATIS to reduce the costs that are related to delays, crowding, travel uncertainty and discomfort (Samuelsson, Klareld, & Hellmer, 2016). According to certain cost-benefit guidelines (Trafikverket, 2020a), travel time uncertainties increase travel costs by up to 350% while travel discomfort can increase the experienced travel time by up to 150%. These costs can become more substantial with increasing demand and disruptions. However, by making both passengers' and operators' awareness of current travel conditions, travel demand management allows for a more effective alleviation of overcrowding thanks to passengers making more informed choices (Drabicki, Kucharski, Cats, & Szarata, 2021). Thus, providing information about the current traffic, even if disruptions are not yet ceased, may benefit the whole system by helping stakeholders to make better choices, e.g., passengers taking alternative routes.

Although the potential is high, there is still a need for research to improve the quality and use of traffic information, especially during disruptions (Samuelsson et al., 2016). For instance, in comparison with research on the costs and benefits of traditional infrastructure investments (e.g., new railway lines, tunnels) and their maintenance, knowledge about the benefits of investments related to traffic information is still shallow. Moreover, with continuous changes in populations (e.g., train passengers) and their habits/needs (e.g., use of ICTs), there is a need for updated knowledge about their use of traffic information. In this context, we review, analyse, and discuss the existing studies about traveller information and the assessment of their benefits. By understanding the effects of traffic information to passengers, it is possible to increase the efficiency and benefits of such services and thus improve the travel experience and the transport system quality (Skoglund, 2018).

1.2. Aim and scope

This literature review aims to identify potential directions for research and improvements by reviewing the existing use, and studies on the effects, and value/benefits of ATIS. Furthermore, such a review can reveal the existing gap(s) between research and practice. However, with the continuous progress and fast changes in the ICT field and its ATIS applications (Skoglund, 2018), even this recent research review may soon be outdated.

It is important to distinguish between information about traffic and traffic information directed to passengers, often called travel or travellers' information. The former, aimed at railway undertakings (e.g., train operators and companies), is beyond the scope of this review. Throughout the review, both terms are used interchangeably to refer to the information directed to passengers.

Even if the focus is on train passengers in disrupted traffic in large cities, research on other transport scenarios is also included when relevant to the discussions. Moreover, although also important, this review does not include other important types of traffic information, e.g., passengers with a disability, freight traffic, directions at stations, ticket booking and emergencies, which are also outside the scope of this review.

1.3. Methodology and structure

To review the existing literature on the value of traffic information for train passengers in case of disruptions, we mainly use *Google Scholar* to search for relevant studies using specific keywords (e.g., travel/traffic information; train passengers; traffic disruptions). First, we focus on the general characteristics of travel information in practice, i.e., channels, users, content, processes, and quality. Thereafter, we review the studies about their effects, specifically on passengers. As a final step, we look at the different existing assessment methods and measures. Fig. 1 provides an overview of the steps in this review methodology.

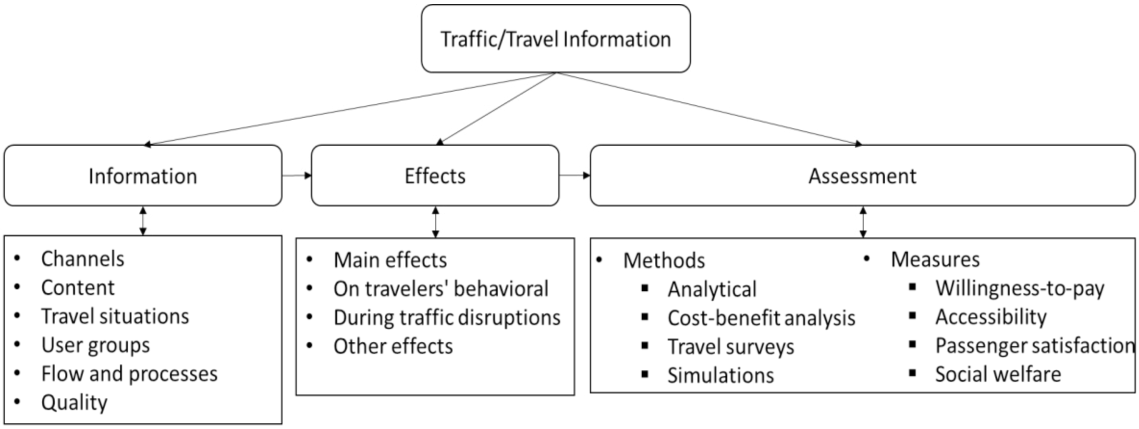

Fig. 1. Overview of the main steps in the review methodology.

The review is structured as follows: Section 2 introduces the main terminology that is related to travel information by reviewing the use of such information. Section 3 reviews some of the main references in the literature, e.g., articles, reports, and official legal documents, and focuses on (the assessment of) the effects of traffic information to passengers. The main conclusions are given in section 4 which concludes the paper.

2. Traffic Information to Passengers

In this section, we present and discuss important constituents of travel information. We introduce the main dimensions and discuss existing processes and certain quality aspects.

Traffic information can be seen as a complex system where processes depend on different constituents with various characteristics (Trafikverket, 2020b). As illustrated in Fig. 2, some important dimensions can define how travel information is formed and communicated, i.e., traffic situation, information/content, channels, and the users.

An important element in this system is the travel/traffic situation which can be characterized by major disruptions. For instance, such a situation can trigger a process that affects other important constituents, e.g., content, channels, and users.

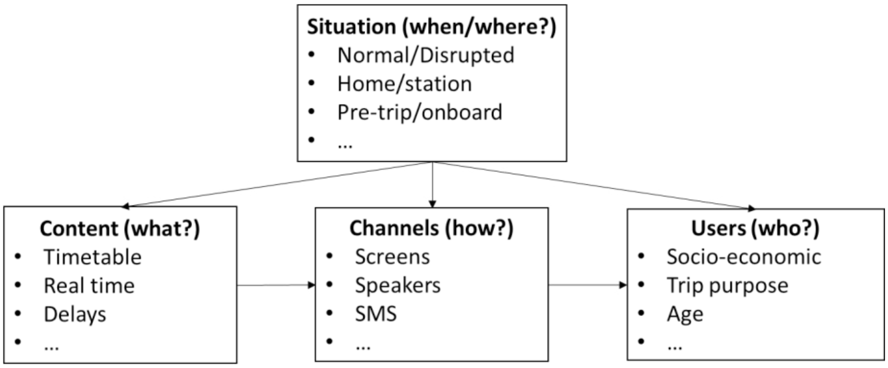

Fig. 2. Main reviewed constituents and characteristics of travel information.

2.1. *Travel situations*

An important consideration for travel information is the travel situation in which it is communicated, i.e., when and where passengers receive information, see Table 1 for a few examples. In a British report by GfK (2011) about the needs of passengers for travel information during unplanned disruptions, the authors distinguish between different travel phases, i.e., pre-trip, at station/platform and onboard information.

Pre-trip information is mainly available up until the trip starts, e.g., before leaving home to the origin station. In case of disruptions, it is, therefore, most beneficial to get the information at this phase to prepare for alternative plans. According to the GfK (2011) report, few people proactively looked for information at this phase but stated that Short Message Service (SMS) information about the estimated delay is highly desirable. The benefits of such information often decrease as soon as the traveller has started the trip and can become irrelevant upon arrival at the departure station/platform.

Information at stations or platforms can be communicated by members of the staff which is usually more beneficial than using automated and/or digital tools such as visual displays via screens and audio announcements through speakers (GfK, 2011).

Several other determinants of travel situations exist, see Table 1 for some examples of typical real-life scenarios. As presented in the table, another important dimension of the travel situation is whether the traffic is normal according to schedule or delayed due to a disruption. The need for information during all the phases can vary depending on this other dimension. This aspect will be further discussed later.

Table 1. Examples of typical travel situations affecting the need for travel information.

Determinant of travel situation	Examples of corresponding scenarios
State of traffic	normal, disrupted, cancelled
Trip purpose	leisure, commuting, business
Travel phase (location of the traveller)	pre-trip (at home/on way to station), at station/platform, onboard
Travel mode	bus (local/regional), car, train (commuter/intercity)
Trip weather	normal, extreme cold/warm
Time of travel	night/day, working day/holiday

2.2. *Information content*

There are several existing examples of information content which are commonly used and communicated. These can be distinguished by different characteristics, e.g., static/real-time (Holmberg, Reutherborg, Kåbjörn, & Fogelberg, 1988), qualitative/quantitative (van Essen et al., 2016), descriptive/prescriptive (Ben-Elia & Avineri, 2015), by locations and/or transport situations (GfK, 2011).

It is also possible to distinguish between passive and active travel information. Unlike passive information (e.g., via SMS, push notifications in the phones or speakers at stations), to get active information, one must actively look for it (e.g., screens at the station, information on homepages/apps).

Static information does not change in principle over time and space, e.g., timetables or scheduled departures/arrivals. Dynamic or real-time information is however variable in time depending on the traffic conditions, e.g., delays (Holmberg et al., 1988). For instance, real-time departures/arrivals/travel time, seats/crowding and real-time vehicle location (Watkins, Ferris, Borning, Rutherford, & Layton, 2011), are often used to benefit transit passengers in general (Brakewood & Watkins, 2019) or train passengers in particular (Ekroth & Ahlander, 2016). Maps, showing real-time public transport service, are also another example of dynamic travel information which is preferred by passengers to be used to look for line details, plan a trip, find destinations and give information about disruptions and propose alternative trip routes (Dahlman, Lindström, Stave, Lidestam, & Hjort, 2020).

The relevant information content may also differ depending on the location. At smaller stations/stops, one can find the timetable and sometimes real-time information (Dziekan & Kottenhoff, 2007). At larger transfer stations or hubs, other types of information become relevant such as track number, connections and walking distances/times to the platform (Thorselius & Hiselius, 2011). For instance, Thurfjell and Sund (2009) state that certain information is found to be more desirable at (Swedish) train stations, e.g., planned arrival/departure times/tracks, delay estimation and cause (if more than 5 minutes), transfer stations and connections, name of the operator and transport service. Similar results are found at British train stations where information about the estimated delay, its cause or suggested alternative routes are all relevant and even desirable by passengers in case of traffic disruptions causing delays (GfK, 2011). In the case of large transfer hubs, integrated multimodal travel information is desirable. In particular, such information allow passengers to transfer between vehicles and/or modes (Grotenhuis, Wiegmans, & Rietveld, 2007).

In the rail sector, minimal information content is often required and specified in the national network statement. For instance, Trafikverket (2022b) considers a list of basic (and supplementary) information that is required to be communicated to travellers in order of priority. See Appendix B for the full list of information content and the corresponding characteristics.

New types/forms of information emerge with new innovative solutions using large existing datasets, e.g., historical, real-time, or both, to infer relevant travel information. For instance, artificial intelligence (AI) methods have been used in Germany and United States for real-time estimation of delays (Trafikverket, 2020b). In Sweden, an app prototype has been developed to warn people of trains crossing (un)protected level crossing using, e.g., traffic information (Trafikverket, 2022a). Another more commonly used type is the crowdsourcing-based traffic information which allows users to share real-time data about accidents and crowding (and radars for road traffic) to name a few examples (Steinfeld, Zimmerman, Tomasic, Yoo, & Aziz, 2011).

2.3. Communication channels

Channels are important elements in information processes during traffic disruptions (Zetterberg, 2010). These can either be stationary (signage at stations/stops) or mobile personal devices (Ghahramani & Brakewood, 2016). With increasing innovation in information technology, multiple channels have been used to communicate information to passengers, e.g., SMS, e-mail, RSS feeds, social media but also mobile applications, Radio, TV, and websites. These can be characterized by the audience, message and cost (Zetterberg, 2010).

A study by Zetterberg (2010) focused on the use of traffic information in Sweden to reach out to passengers in the case of traffic disruptions. The author explores the use of different communication channels such as SMS, e-mail, RSS, social media (Facebook and Twitter) but also mobile applications. The study finds that SMS best meet the requirements of society and the passengers whereas e-mail and RSS are good complements/alternatives. Moreover, social media should be used as two-way channels whereas mobile applications are suitable for reaching travellers along their way.

Some channels such as subscriptions to information, push notifications and ticket-related information are necessary to provide passengers with real-time information (Ekroth & Ahlander, 2016). Few experiments have been conducted to understand the passengers' preferences for channels under the trips. One such experiment was done in Dublin by Caulfield and Mahony (2007) who examined, using stated preference, four stages, namely pre-trip to destination, at-stop, onboard, and pre-trip to the origin, and channels such as mobile phones, Internet, and paper-based.

In some transport markets, there are several private operators providing services including traffic information to their customers (Hallin & Fehrm, 2016). In such cases, travellers can get traffic information by consulting the different channels that are used by these operators, e.g., their websites or mobile applications.

Different channels fall within the responsibilities of different stakeholders. For instance, screens and speakers at large stations are taken care of by the infrastructure manager, e.g., Trafikverket in Sweden. In a deregulated market with several train operators, these have their channels, e.g., apps and homepages. By using different application programming interfaces APIs and sources of traffic information, third-party mobile app developers can create tools that add to the existing channels, e.g., 1409.se for rail traffic information in Sweden. Table 2 gives an overview summary of the main important characteristics of some communication channels.

Table 2. Important characteristics of communication channels for travel information.

Channel	Responsible(s)	Reception media	Example of content
SMS	operator, (e.g., train company)	GSM phone	Information about tickets, deviations
e-mail	operator (e.g., train company)	mail client (e.g., smartphones, computers)	Information about tickets, deviations
Mobile apps	operator, agency or third-party	smartphones/tablets	Ticket, real-time information
RSS	operator or third-party	computers or smartphones	Notifications of disruption/delays
Social media	operator or agency	smartphones/tablets	Notifications of disruption/delays
Web	operator, agency or third-party	computers or smartphones	Real-time information
Screens/speakers	Infrastructure manager	(eyes)/(ears)	Departure times/platforms, disruptions

In addition to the various characteristics that are presented in the table, such information channels have different (dis-)advantages (ELTIS, 2010). For instance, mobile apps are suitable for personalized and interactive real-time information but require phone and internet access and may exclude some user groups. Social media channels can further allow for more information (user-generated/crowdsourcing) but may be unreliable, irrelevant, or redundant.

2.4. *User groups*

There are several user groups of the railway system that can benefit from traffic information, but we focus here on individual passengers. Other types also exist such as freight customers and train operators. The infrastructure manager is often responsible to communicate traffic information to these users.

Passengers can further be split into different user groups depending on, e.g., gender, age, and socio-economic characteristics. In their review of the role of traffic information, van Essen et al. (2016) state that the Dutch government considers five types of passenger groups, i.e., accepters, deliberates, conscious, competitors and enjoyers. These groups are based on the attitude of the user towards mobility which allows for certain customizations (van Essen et al., 2016). A similar US study investigated who are the main users of ATIS (Lappin, 2000). Based on survey data, the author identified the following groups: control seekers, web-heads pre-trip info seekers, mellow techies, and others. These groups have different demands for information via different channels.

The most efficient channels and content for traffic information differ between the user groups. For instance, with the same information, the difference in the need and expectations may arise depending on user group parameters such as age/generation (Ekroth & Ahlander, 2016). A clear example of such a difference is the case of passengers with disabilities and the elderly (Waara, 2009).

2.5. *Flow and processes*

Before being received by the end-users, or train passengers in our case, the flow of information follows a particular process depending on the traffic situation. In Fig. 3, Berglund et al. (2020) illustrate a general process for traffic information during disruptions. A certain traffic situation/event can trigger communication (orally by phone calls) between the traffic leader in the control centre and the train driver, informants can thereafter communicate with the train operators and passengers using different channels. This process is centred around the infrastructure manager responsible for, among others, traffic planning and hence sending out the corresponding traffic information. This is often done according to detailed processes, for instance in the national network statement, e.g., the rules for the announcement of travel information (e.g., when/what) at stations (speakers/screens) and on their homepage. The document also indicates the requirements for the different train operators when it comes to providing important information to be used in the announcements.

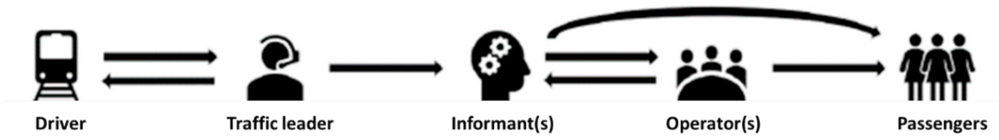

Fig. 3. General process between railway stakeholders of traffic information flow to passengers.

Railway markets around Europe have undergone major changes and reforms (Ait-Ali & Eliasson, 2021), but the processes for managing travel information have not followed (Hallin & Fehrm, 2016). In an attempt to develop a more adapted process, Hallin and Fehrm (2016) proposed an improved process to manage traffic information in case of train disruptions. After studying the needs and requirements of the different actors in the markets, the authors recommend creating a portal where different stakeholders can send and/or receive information about traffic, delays, and disruptions. In a more general context, Clegg, Orme, Owen, and Albores (2018) presented a concept for the gamification of the travel information process to improve a train-operating company's customer service during disruptions.

To decrease the effect of some potential disruptive scenarios in practice, stakeholders such as railway infrastructure managers use traffic information when preparing action plans for certain predictable scenarios, e.g., disruptions scenarios in specific sections of the network, see for instance the network statement by Trafikverket (2020c). Such action plans include the use of traffic information to minimize the negative effects of such disruption on both passengers and freight customers. Such plans are prepared in collaboration with different railway stakeholders, e.g., railway undertakings and organizations.

An important element in improving the current process is data standardization, e.g., format for sending/receiving/storing/retrieving traffic information. Some already exist such as the GTFS (General Transit Feed Specification) from private actors which became a *de facto* global standard for static and real-time information (GTFS RT), or European interface standard SIRI for exchanging real-time information. There are, however, increasing attempts toward a unified data framework, e.g., for real-time public transport using crowd-sourced passenger-contributed data (Lau & Ismail, 2015).

2.6. *Quality*

Access to good quality travel information is shown to be one of the (physical) quality attributes in passenger transport, alongside travel time, accessibility and ticket prices (Karlsson, Friman, Olsson, & SAMOT, 2011). In practice, travel information is assessed using various quality criteria which attempt to capture, among others, how good the information content, the communication and the reception of the information is. For instance, van Essen et al. (2016) find that the timing and the level of personalization of travel information are important for its quality. Moreover, Chorus, Molin, et al. (2006) state that the next generation of travel information will be characterized by being mobile, dynamic, multimodal, and personalized. However, Dewar et al. (2000) consider that the effectiveness of traffic information systems for travellers will depend on, among others, an understanding of changing user population and their requirements, the existence of cost-effective technologies, system designs and human interactions and testing strategies.

In the case of real-time information to passengers, Giannopoulos (2004) lists several quality characteristics such as personalised/customized travel information, real-time route changes and suggestions of alternative routes, information on intermodal transport and optimized connections/interchanges, and congestion-minimizing travel recommendations. Similarly, Balcombe et al. (2004) state that British rail passengers rate relevancy and accuracy as important key requirements for quality travel information.

To characterize the quality of the communicated travel information, Berglund et al. (2020) studied different measures for information on delayed train services. Some measures are developed and used by the Swedish Transportation Administration. These are as follows: foresight (how early information about a delay is announced, currently the only measure used by traffic informants), precision (how correct the estimated delay is), and the number of information updates (how many times the delay is updated). In many cases in practice, the usefulness of travel information is determined using customer satisfaction surveys where passengers are asked about the quality of the provided information. Berglund et al. (2020) state that passengers are more satisfied when information is precise with few updates of the announcements and includes a reason for the delay in case of disruptions.

3. Effects and Their Assessments

This section describes some of the main effects of using travel information including in case of traffic disruptions. Existing methods and measures for assessing these effects are also briefly presented. The section is concluded with a summary and some discussions.

3.1. *Effects of traffic information to passengers*

Several research studies show that traffic information has several effects on transport users such as passengers and hence on the transport system. The following is a review of the main effects that are studied in the existing literature.

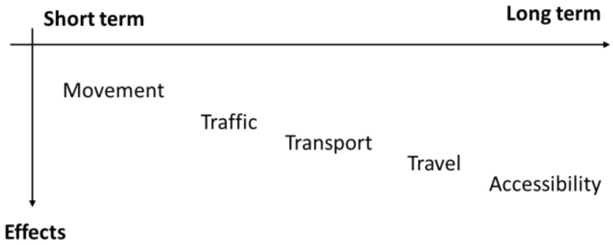

Fig. 4. Long and short-term effects of traffic information (Skoglund, 2018).

In a review of existing research, Skoglund (2018) presents some major effects within the research area of Human Factors, an area studying the interaction between humans and systems. The author distinguishes between the long-term and short-term effects as illustrated in Fig. 4. In another review of the use (and effects) of advanced traveller information services (ATIS for short), Chorus, Molin, et al. (2006) present and describe the use of ATIS by travellers for individual decision-making as illustrated in Fig. 5.

From a behavioural perspective, Ben-Elia and Avineri (2015) distinguish between the effects on individual travel behaviour and on the network level which involves collective behaviours. The authors conclude that information seems to assist individual travellers in coping with uncertainty, e.g., by affecting the path choice of certain passengers (Cats, Koutsopoulos, Burghout, & Toledo, 2011). However, the subsequent impacts relating to collective behaviour on networks remain unclear. A similar distinction is made by Planath (2003) who separates the effect of improved travel information on public transport (PT) passengers on the one hand and society on the other hand.

According to a study focusing on dynamic at-stop PT real-time information, Dziekan and Kottenhoff (2007) find that the main effects on passengers are reduced waiting time and travel time uncertainty. Subsequent research studies focused on the effects on travellers' waiting time (Watkins et al., 2011), its uncertainty (Cats & Gkioulou, 2017), and some others on their travel comfort such as crowding, e.g., (Drabicki et al., 2021).

With a focus on real-time arrival information for public transit, Ferris, Watkins, and Borning (2010) find that such information leads to strongly increased overall satisfaction with public transit, decreased waiting time, increased transit trips per week and increased feelings of safety. Another study by Watkins et al. (2011) looks at the benefits of travel information in terms of waiting times. It states that providing real-time information is a cheap way to reduce the cost of travel unreliability for passengers.

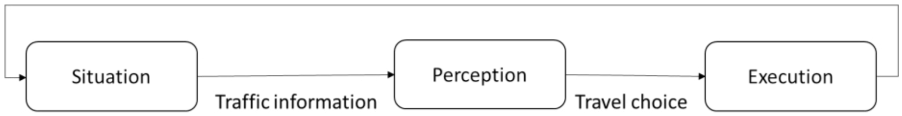

Fig. 5. Use of traffic information for travellers' decision-making, inspired by Chorus, Molin, et al. (2006).

To illustrate that traffic information to passengers has wide and varied scope, Giannopoulos (2004) mentions that such information can also be used for, e.g., more effective individual planning/execution of trips, demand management (reduce travel at peak hours and/or induce travel at non-peak to a specific destination, vehicle sharing), improve connections/interchanges and increased passenger satisfaction. This can increase, in the long run, the attractiveness and thus the modal split of public transport (Ekroth & Ahlander, 2016).

3.1.1. *Traffic disruptions*

In addition to studies looking at the effect of travel information in normal and general traffic situations, some studies have focused on effects during disrupted travel scenarios. For instance, Kattan, de Barros, and Saleemi (2013) study the effects of advanced traveller information in the case of prolonged and large-scale network disruptions. The authors find a substantial shift towards PT thanks to pre-trip information. However, a such shift is affected by path, trip purpose and departure time. Closely related, van Essen et al. (2016) find that real-time information in case of disruptions is widely expected to improve travel conditions since such information can help shift the network effects from user equilibrium towards the optimum state at the network level. These effects have been shown in several case study from Norway (Killi & Samstad, 2002), Spain (Monzon, Hernandez, & Cascajo, 2013), and Sweden (Cats & Gkioulou, 2017).

Information to passengers during traffic disruptions has also several applications. Earlier research by Giannopoulos (2004) reviews these applications in several transport modes including rail and distinguished between their use for the operation and management of networks on the one hand and that of guidance to the users on the other (including for freight services).

In a comprehensive research focusing on road congestion (resulting from disruptions) and drivers' travel choices, Peer (2013) studied the economics of trip schedules, travel time variability and traffic information. The author, through various studies, attempts to understand how travel time information affects travellers' choices in the presence (or not) of recurrent or non-recurrent congestion/disruptions. The results show that travel information can reduce the high costs of traffic uncertainties. Although focused on car drivers, such results can also be relevant to PT travellers such as train passengers.

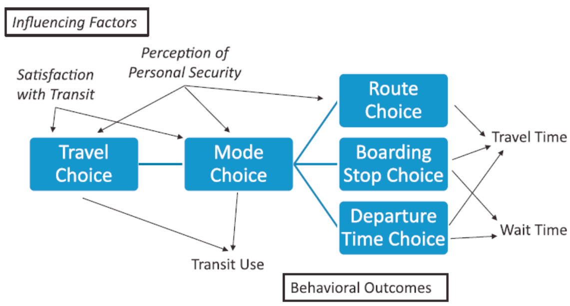

Fig. 6. Effects of real-time information on passengers (Brakewood & Watkins, 2019).

3.1.2. *Travellers' behaviour*

Several studies of the effects of travel information have focused on travellers' behaviour. An extensive review by Ben-Elia and Avineri (2015) of the recent theoretical developments in behavioural and cognitive sciences. According to the authors, certain types of information can be distinguished by their behavioural effects on travellers. The authors distinguish between the following types of information:

- **Experiential**: retained in memory and gained by learning reinforced from the feedback of past experiences.
- **Descriptive**: information describing the prevailing travel conditions such as current or predicted travel times. It can be provided either before departure (pre-trip) or once on the move, and can be based on historic and or real-time estimates.
- **Prescriptive:** suggestion, guidance, or a recommended alternative (e.g., the quickest path in real-time from A to B).

In their study of the impact of travel information, Brakewood and Watkins (2019) state that such information may influence travellers' decisions that relate to, e.g., travel, mode and route choice as well as boarding stop and departure time. The same authors reviewed the existing literature on the impacts on, among others, waiting and travel time, transit (mode choice), satisfaction and perceived security. An illustration of these effects is summarized in Fig. 6 by the same authors.

Other studies look at specific practical cases. For instance, Bai and Kattan (2014) investigate riders' behavioural responses to en-route real-time information on light rail transit (LRT) in Calgary, Canada. The authors designed a survey and collected riders' responses in several hypothetical scenarios. The results indicate that behavioural responses to real-time LRT information are strongly influenced by various socioeconomic attributes (e.g., age, gender, and the number of cars per household), experience with traffic information systems (familiarity and perceived accuracy), and experience with transit and the LRT system (primary mode of transportation, frequency of use, and familiarity) as well as the trip purposes, travel time, and weather conditions.

There are, however, some studies which have not found enough evidence for such effects on travellers' behaviour. For instance, Skoglund (2018) states that although travellers' experience can be shown to be affected by access to real-time information, e.g., less stress, shorter perceived waiting time at stops, and easier choice of alternative safer routes, it is however more difficult to show that these effects are caused by these information systems alone.

3.1.3. Additional effects

Besides the effects on travellers during disruptions, travel information has been shown to have additional long and short-term effects. In a Swedish study, Janhäll, Genell, and Jägerbrand (2013) and Janhäll and Carlson (2017) have both shown that such information allows for efficient traffic management which in turn leads to substantial environmental benefits. Brakewood and Watkins (2019) mention further effects, i.e., comfort at stations (walking speed), walking distances to access transit stops, transfers between modes, and in some cases even health benefits in terms of increased walking activities when using transit (Ferris et al., 2010).

An efficient information system can induce additional transport demand, e.g., from car users (Redman, Friman, Gärling, & Hartig, 2013), and thus increase the number of travellers using the PT system (Zito, Amato, Amoroso, & Berrittella, 2011). Furthermore, Hallin and Fehrm (2016) show that traffic information may also affect operators as well, e.g., the numerous railway undertakings after market reforms.

However, if the system is not well designed, it can lead to opposite effects. For instance, users can be repelled by a large amount of information, also called information overload (Johansson & Arvidsson, 2003). Consequently, individuals may skip some information on certain attributes to reduce cognitive effort. This can further lead to increased travellers dissatisfaction, especially in case of traffic disruptions (Frid & Grehn, 2016).

3.2. Methods for effect assessment

Besides studies aiming at assessing the quality of travel information (Berglund et al., 2020) and their usability characteristics (Janhäll & Carlson, 2017), several studies focus on assessing the effects of using such information systems. Various methods have been developed using, e.g., analytical approaches, travel surveys, simulations, or cost-benefit analysis (CBA). The following is a brief description of each of these methods or approaches including some relevant research examples. Appendix C presents some examples of research studies using various methods.

3.2.1. Analytical approaches

Based on certain assumptions, some effects can be modelled using analytical expressions. For instance, Malchow, Kanafani, and Varaiya (1996) present several analytical formulations on the economics of travel information. Although focused on road traffic, the authors use several economic concepts by formulating the demands and supplies of traffic information as well as their costs and benefits to study the societal value of such information. Another study by Arentze and Timmermans (2005) attempt to formulate the expected information gain, under conditions of uncertainty (e.g., traffic disruptions), based on Bayesian modelling of mental maps and the travel utility function of the different trip choice alternatives.

3.2.2. Travel surveys

In Sweden, Trafikverket (2016) recommends the use of certain guidelines (locally called ASEK) for evaluating the costs and benefits of transport investments. The recommended values are mainly based on stated/revealed preference (SP/RP) surveys of passengers in different traffic scenarios (Killi & Samstad, 2002). These studies can be used to estimate very useful values, e.g., waiting and travel time valuations, or even the willingness-to-pay (WTP) for travel information (Zito et al., 2011). For instance, a compilation of these valuations for information, among others, in large transfer stations in Sweden is reported by Thorselius and Hiselius (2011). A similar compilation focusing on the British public transport has been published earlier by Balcombe et al. (2004) including, among others, the valuations of attributes such as pre-trip/at home information, at the bus stops/interchanges, information accuracy.

3.2.3. Simulations

Simulation-based methods are also found in the literature aiming to assess the value of travel information. For instance, Chorus, Arentze, Molin, Timmermans, and Van Wee (2006) simulate the utility value of different knowledge and reliability levels to evaluate the perceived value of travel information. A similar approach was used by Cats and Gkioulou (2017) to assess the impact of travel information on the uncertainty of the waiting time of public transport passengers. In some studies, simulations are combined with economic assessment, see the study with a focus on car drivers by Levinson (2003). Another more recent approach is gamification which can also be used to assess the effectiveness of passenger information/customer service during disruptions scenarios (Clegg et al., 2018).

3.2.4. Cost-benefit analysis

Cost-benefit analysis (CBA) is an approach that is often used by infrastructure managers to assess transport infrastructure investment projects, see the EU guidelines (Sartori et al., 2014). CBA-based models use valuations from travel surveys and can also be applied to assess investments other than infrastructural such as traffic information during disturbances. For instance, Trafikverket developed a CBA model (called Wikibana -SEK) to estimate the costs for delays caused by disturbances in the railway traffic flow for both passenger and freight trains (Westin & Westin, 2018). Another example from Norway is by Odeck, Hagen, and Fearnley (2010) who include the traffic information-related costs and benefits in their economic appraisal of a universal design in transport.

3.3. Assessment measures

In addition to the different theoretical approaches that are used in assessing the effects of travel information, the literature includes measures to quantify such assessments. We briefly describe some of the commonly used measures in this section. Appendix C presents an overview of some research studies using various measures.

3.3.1. Willingness-to-pay

One typical measure that is used in the valuation of different travel attributes (e.g., travel and waiting times) is willingness-to-pay (WTP). In the case of travel information, several studies have estimated how much travellers are willing to pay for information about the traffic in different travel situations. For instance, Arentze and Timmermans

(2005) define the perceived value of information as an element of the utility function. The authors illustrate how such value is derived from trip alternatives in the acquired travel information.

Based on a similar utilitarian perspective, Chorus, Arentze, et al. (2006) considers that the willingness to pay for information can be framed as a cost-benefit trade-off from a passenger point of view. In this case, the costs account for the effort to acquire the information, e.g., monetary expenses, whereas the benefits correspond to the pay-off from choosing the best alternative. For instance, Dziekan and Kottenhoff (2007) summarized earlier research in the UK and estimates the willingness to pay for real-time information systems at stops/stations to be about 5-20% of the ticket price. An overview of some existing examples of valuations is presented in Table 3.

Table 3. Examples of valuations of passengers' WTP for travel information.

Reference	Travel information	Assessment
(Wardman, 2001)	Real-time information via screens at British bus stations	1.2 SEK per trip
(Fearnley & Killi, 2006)	Real-time information via speakers at Norwegian bus stops during disruptions	2.37 NOK per trip
(Dziekan & Kottenhoff, 2007)	Real-time information via screens at Swedish bus stations	5-20% of the price ticket

3.3.2. *Accessibility*

Effects of travel information can also be assessed via measures of travel accessibility such as reliability, punctuality, and congestion. More particularly, variations in travel time (including waiting and transfers) and congestion, as well as delays, are all relevant measures. Some of these measures are linked together, for instance, Tseng, Knockaert, and Verhoef (2013) and Peer (2013) show, in the case of road traffic, that travel time variability is positively correlated with delays.

To study the impact of such information in terms of perceived and actual waiting time, Watkins et al. (2011) use a real-time information app for bus services in the US. The authors find that informed passengers have their typical waiting time reduced by around 30%. Table 4 presents a few more examples of accessibility-based valuations.

Table 4. Examples of accessibility valuations of travel information to passengers.

Reference	Travel information	Assessment
(Prather Persson, 1998)	Real-time information at Swedish long-distance train stations	3 min (speakers), 6 min of travel time (screens)
(Wardman, 2001)	Real-time information via screens at British bus stations	1.4 min of travel time
(Watkins et al., 2011)	Real-time information via a phone app for bus services in the US	30% reduction in average waiting time

In a closely related study focusing on passengers waiting at a Dutch train station, Van Hagen, Galetzka, and Ptuyn (2007) observe how they perceived their waiting time. The results show that the waiting experience can be made more pleasant by introducing elements to the station environment to prevent stress and irritation such as real-time information. In this context, the waiting experience is said to be directed waiting for the delayed trip (Kellermann, 2017).

3.3.3. *Passenger satisfaction*

An important measure of the effects of travel information is the level of satisfaction of passengers with the travel experience, this is usually captured using the so-called passenger satisfaction index. In a US study of providing real-time travel information for bus passengers, Ferris et al. (2010) find that between 48% to 92% of the users reported being at least somewhat more satisfied with their travel experience.

Unlike studies looking at the effect of information on passenger satisfaction, a recent experiment in Malaysian rail transport by Rezapour and Ferraro (2021) focused on the effect of delays on perceived satisfaction with/without travel information. The study results further highlight the importance of more accurate real-time information in reducing the negative feelings from transport delays and hence passenger satisfaction in case of traffic disruptions.

3.3.4. Social welfare

Providing travel information, e.g., real-time information for passengers, has several benefits. For instance, such information lead to behavioural changes that reduce waiting and travel time for informed passengers which in turn leads to wider societal benefits (Brakewood & Watkins, 2019).

An important social value of travel information is the reduction in travel and discomfort costs due to less crowding both inside and outside transport vehicles. For instance, Pritchard (2018) shows how information about crowding can contribute to benefit both rail passengers and train operators. Closely related, a review by Drabicki et al. (2021) focused on the benefits for public transport passengers.

At the network level, travel information can provide benefits when it comes to reducing vulnerable links and improving the robustness of the transport system. With a focus on public transport networks, Cats and Jenelius (2014) assessed the value of real-time information during disruptions. Using a dynamic and stochastic vulnerability analysis, the authors find that such information reduces the costs of disruptions but, in some cases, they do not due to, e.g., secondary spill-over effects.

3.4. Summary and discussions

Traffic information to passengers has multiple and various effects on both travellers and the transportation system. The existing literature about these effects can be categorized in different ways, e.g., short (movement) vs. long-term effects (Skoglund, 2018), or individual vs. collective network behaviour (Ben-Elia & Avineri, 2015). Some other important effects have also been researched in the literature, e.g., induced demand (Zito et al., 2011) and environmental aspects (Janhäll & Carlson, 2017). Table 5 presents some of the main reviewed research, the type of travel information that is studied as well as the effects that are found.

Table 5. Examples of studied effects of travel information.

Reference	Travel information	Effect(s)
(Dziekan & Kottenhoff, 2007)	Real-time information at bus stops	Reduced waiting time and travel time uncertainty
(Ferris et al., 2010)	Real-time information about arrivals in PT	increased overall satisfaction with travel experience and PT, health benefits
(Watkins et al., 2011)	Real-time information on a mobile app for buses	Reduced perceived and actual wait time of transit riders, and the cost of travel unreliability

Although different channels are studied such as mobile apps and screens/speakers at stations, most of the investigated effects are from real-time information which is useful in the case of disruptions and delays. Moreover, earlier studies focused on content such as departure/arrival times, whereas recent studies included additional content such as crowding level which was especially important during the Covid-19 pandemic.

The summary in Table 5 also indicates that most of the effects of (real-time) travel information are reflected in improved accessibility measures such as congestion, travel and waiting time as well as their uncertainties. However, additional effects are also important to highlight, e.g., network effects, ridership, and passenger satisfaction.

The reviewed research includes effect assessments with or without traffic disruptions. Different assessment methods and measures have been used. For instance, quantitative assessments are often expressed in terms of WTP (see Table 3) and/or corresponding improvements in accessibility such as travel or waiting time (see Table 4).

These studies provide quantitative evaluations of traffic information to passengers under various travel conditions such as channels and/or modes. However, most of the reviewed studies are using empirical analysis based on data from stated preference (SP) travel surveys. Table 6 presents some of the reviewed SP-based valuation research from different countries focusing on various channels and modes.

Table 6. Examples of SP-based studies assessing the effects of real-time travel information at stations/stops.

Reference	Channel	Mode (country)
(Wardman, 2001)	Screens	Bus (Britain)
(Fearnley & Killi, 2006)	Speakers	Bus (Norway)
(Dziekan & Kottenhoff, 2007)	Screens	Bus (Sweden)

Few studies have used other methods, e.g., simulations, or analytical approaches, for assessing the value of traffic information to passengers. Moreover, based on the reviewed literature, such valuations are rarely considered in the context of cost-benefit analysis, for example, for more efficient planning of investments in traffic information systems and their deployment strategies.

4. Conclusions

In this literature study, we reviewed existing works about the use of travel information as well as the existing research literature on their effects and assessment of their value. We find many studies on the use of such information treating one or more constituents that characterize traffic information systems, e.g., travel situation (when/where?), information content (what?), communication channels (how?) and user groups (who?). Depending on if the traffic is disrupted or not, different channels are often used in practice to create a specific flow of information based on specific processes. The quality of such travel information processes has been assessed in several research studies using different perspectives/metrics, e.g., multimodality, effectiveness, and precision.

Even if understanding the impacts of travel information may allow for more appropriate planning of transport services as well as more efficient prioritization in infrastructure investments, research and applications are still lacking in certain directions, especially during traffic disruptions and in mass transit transport services such as railways. For instance, the review indicates that assessment methods such as cost-benefit analysis are rarely used as a decision tool to help plan for more efficient travel information systems. Measuring the impacts of such infrastructure investments from a social welfare perspective, especially during traffic disruptions, can be a promising direction for future research.

Current policies, especially within the rail sector, aim to improve the quality and accessibility of travel information, e.g., through initiatives such as EU regulations, national campaigns, use of new digital channels and technologies. There is therefore a growing recognition in the sector of the importance of such information for improving the passenger experience and for enhancing transport efficiency and sustainability. Thus, further research trends may also include, among others, evaluating the impact of different information channels, developing adaptive and more personalized systems using artificial intelligence and big data.

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Appendix A. Acronyms and abbreviations

- ASEK: Analysis methods and values for socio-economic calculation (Swedish: *Analysmetod och samhällsekonomiska kalkylvärden)*
- API: Application Programming Interface
- ATIS: Advanced Traveller Information Services
- CBA: Cost-Benefit Analysis

- ICT: Information and Communication Technology
- PT: Public Transport
- RP: Revealed Preference
- RSS: Really Simple Syndication
- SMS: Short Message Service
- SP: Stated Preference
- WTP: Willingness to pay

Appendix B. Traffic information to passengers in Swedish railways

Based on the Swedish railway network statement by Trafikverket (2022b), the list of basic information to train passengers is provided in Table 7 alongside the corresponding main characteristics.

Table 7. Basic travel information in Swedish railways and their main characteristics (Trafikverket, 2022b)..

		Main characteristics (X if yes)			
Prio.	Information content	Dynamic	Prescriptive	Quantitative	Active
1	Train number				
2	Start and final station				
3	Intermediate stations				
4	Operator name				
5	Arrival/departure times			X	
6	Arrival or departure platform at stations		X		
7	Estimated arrival/departure times for delayed trains	X		X	X
8	Cause for delay	X			X
9	Aggregated info with cause and forecast of a disruption event	X		X	X
10	Booking, other information, information on train formation, deviation, service, and product information	X	X		X
11	Instructions in the event of traffic disruption (e.g., replacement traffic)	X	X		X

In addition to the basic list, the supplementary information includes:

- Booking, other information, information on train formation, deviation, service, and product information
- Instructions in the event of traffic disruption (e.g., replacement traffic).

Appendix C. Methods and measures for assessing the effects of travel information

Table 8. Existing methods and measures for the valuation of travel information.

Reference (chronologically)	Measure	Method
(Malchow et al., 1996)	Demand and supply of traffic information	Analytical economics and CBA
(Killi & Samstad, 2002)	Passengers' valuation of traffic information during work trips	SP and RP surveys
(Levinson, 2003)	Value of ATIS for drivers' route choice during road congestion	Simulation and economic modelling
(Arentze & Timmermans, 2005)	Information gain under traffic disruption uncertainty	Bayesian modelling and utility function
(Chorus, Arentze, et al., 2006)	Perceived value of traffic information and its reliability	Simulation and utility function

(Ferris et al., 2010)	Bus passengers' satisfaction and real-time information	SP survey using an app
(Zito et al., 2011)	PT passengers' willingness to pay for ATIS	SP surveys and Monte Carlo simulations (uncertainty)
(Watkins et al., 2011)	Value of real-time travel information in terms of perceived and actual waiting time	SP survey using an app
(Cats & Gkioulou, 2017)	Waiting time uncertainty for PT passengers	Agent-based simulation
(Pritchard, 2018)	Benefits of crowding information to train passengers and operators	SP surveys
(Clegg et al., 2018).	Effectiveness of travel information during disruptions	Gamification (small-scale real-world game/experiment)
(Westin & Westin, 2018)	Cost of train traffic delays due to disruptions	CBA model (Wikibana-SEK)
(Rezapour & Ferraro, 2021)	Perceived satisfaction with travel information and delays	SP survey

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