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Reliability of Travel Time: Challenges Posed by a Multimodal Transport Participation

Monika Wanjek [1], Georg Hauger [1]

[1] Technische Universität Wien, Augasse 2-6, Vienna

monika.wanjek@tuwien.ac.at

Abstract. Travel time reliability represents an essential component in individual decision making processes for transport participants, particularly regarding mode choices. As criteria that describe the quality of both transportation systems and transportation modes, travel time reliability is already frequently compiled, analysed and quoted as an argument. Currently, travel time reliability is solely mentioned on monomodal trips, while it has remained unconsidered on multimodal transport participation. Given the fact that multimodality gained significantly in importance, it is crucial to discuss how travel time reliability could be determined on multimodal trips. This paper points out the challenges that occur for applying travel time reliability on multimodal transport participation. Therefore, examples will be given within this paper. In order to illustrate theoretical ideas, trips and influencing factors that could be expected within the everyday transport behaviour of commuters in a (sub)urban area will be described.

1. Introduction

Travel time is defined as the period of time that is needed to travel from one location to another. Changes in the value of travel times – that can be noticed due to an observation – form the basis to estimate travel time reliability. Within the individual decision making process of transport participants, both travel time value and travel time reliability are essential components. While travel time values are often a decisive criterion for route and mode choices, travel time reliability is more than ever perceived as a quality factor to describe transport modes and transport systems.

2. Theoretical background

2.1. Travel Time

Time is not a simple concept and in contrast to the opinion of most people, the concept of time is still intensively discussed between physicists and not yet clarified. However, within this paper, time is used in the manner of everyday life and measured by clocks. In the following, current debates of philosophers and physicists, so as challenges that are triggered by these debates remain unconsidered. Whereas, disparities resulting from time measured by clocks and time being subjectively perceived (challenges pointed out by perception psychology and neuroscience) can be assumed to be relevant, particularly within individual decision making processes of transport participants. Thus, relevant discussions and challenges will be outlined.

Travel time is defined as the period of time that is needed to travel from one location to another covering the entire door-to-door-distance. Therefore, it is used to describe trips that are characterised by a predefined start and destination as well as transport modes. Travel times are frequently used in comparative analyses in order to evaluate transport modes or transport systems. This is not only the objective of transport planners and transport companies. Even transport participants intuitively use their experiences regarding travel time (and travel time reliability) for their route and mode choice.

2.2. Variability of Travel Time

Due to practical experience gained from participating in transport-related and longitudinal studies that observe trips and their travel times (exemplarily made by [1], [2], [3]), a broad consensus exists regarding the fact that travel times can be even within simple trips both very robust and highly variable. Therefore, discussions regarding acceptable values of delay or acceptable delay-ratios (e.g. delay in relation to the minimal travel time) are decisive components of assessment methods.

In order to illustrate the variability of travel times even on simple trips, let us suppose a short walk. One fact that causes different travel time values results from the fitness of the transport participant. Although the fitness varies every day depending on health-conditions or fatigue, it can be assumed that the influence on changes in travel time is marginal. However, the circumstances along a trip route (e.g volume of traffic, density of crossroads, conditions at a crossroad, the use of the road environment) can be assumed to be of great importance. In case the trip route is characterised by a pedestrian crossing with traffic lights, an arrival at the pedestrian crossing while traffic lights are green results in smallest possible travel time values (e.g. 3 minutes). Whereas, in those cases where traffic lights turn into red immediately before the transport participant arrives at the pedestrian crossing, waiting times (e.g. 1 minute) and consequently longer travel times (e.g. 4 minutes) can be expected. Thus, the extra time (delay) in that example is about 30% of the minimal travel time.

In addition to that, travel time values also vary depending on the time of day (e.g. during peak hours), the day of the week (e.g. during working days) and over months (e.g. during holiday season). Therefore, both the range of travel time values and the values of delays depend on various disruptions (e.g. caused by demonstrations) that can be expected once in a while. In order to plan trips, transport participants have to deal with this range of travel time values. This leads transport participants to complex decision processes under consideration of risk assessments, changes regarding the time of departure (or arrival), route or transport mode. Particularly, commuters are faced with the variability of travel times and the challenge to anticipate travel times for specific routes. Thus, travel time reliability is a highly relevant quality criterion that describes transport modes and transport systems and is of decisive importance for individual route and mode choices of transport participants.

2.3. Reliability of Travel Time

In order to define reliability of travel time, it is crucial to distinguish between the expected travel time (pre-trip) and the actual travel time (on-trip) that is finally determined at the destination. In the following, the deviation of pre-trip travel time and on-trip travel time is used to define reliability of travel time. Thus, delays and early arrivals are results of a deviation from (expected) pre-trip and on-trip travel times with different mathematical operators.

Especially in the context of public transport, punctuality is used synonymously with reliability, although this is a fuzzy use of its concept. In order to determine punctuality, the deviation from pre-trip and on-trip travel times has to be compared with a time schedule plan [4]. In addition, punctuality solely considers the number of public transport journeys (e.g. instead of the share of punctual journeys) that did not arrive on time at the predefined destination and the value of delays remain unconsidered [4]. Consequently, using the concept of punctuality is only appropriate in the context of scheduled transport modes or services.

3. Practical experiences

3.1. Mono- and Multimodal Transport Participation

In order to understand how people participate in transport, it is necessary to describe their behavior precisely. In doing so, the concept of trips that is defined as travels with a specific purpose is used and parameters (e.g. number of trips per day, transport mode for specific trips, modal split) which can be compiled and quantified are developed on that basis. Due to the adverbs, mono- and multimodal transport participation can be specified regarding the number of transport modes that are used (one transport mode is monomodal; more than one transport mode is multimodal). This classification is depicted in figure 1. Thereby, multimodality can occur on a trip due to using more than one transport modes in a row (e.g. using the bus from origin to get to the underground and using the underground to get to the destination). Whereas, the term of multimodality can also be used for describing the multimodal transport behaviour over a period of time (e.g. using the bus on Mondays, the bicycle on Tuesdays and so on) [5].

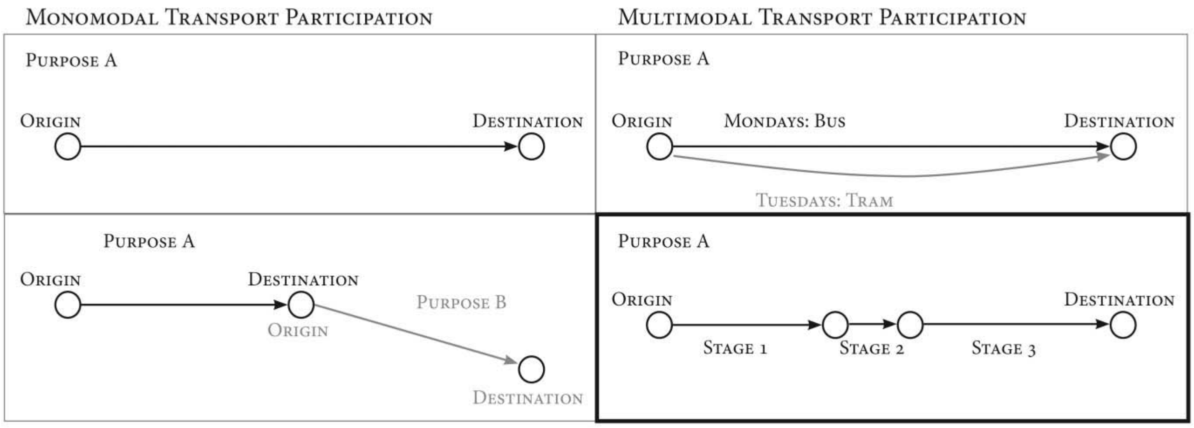

Figure 1. Classification of mono- and multimodal trips.

An outstanding characteristic of multimodal trips is given by its structure. Particularly because more than one transport mode is needed for a multimodal trip, it has to consist of stages (defined as those components that are assigned with a specific transport mode). These stages represent the smallest possible units within a travel. In addition to that, it is of importance that in this manner trips are characterised by the respect of all stages and thus represent travels from door-to-door. This also leads to the fact that herein changing the transport mode is also defined as an independent stage of a trip. Consequently, figure 1 illustrates multimodal trips consisting of at least three stages.

3.2. Current Indicators for Travel Time Reliability

Especially trips of commuters in (sub)urban areas are suggest to be characterised more often by a multimodal than a monomodal transport participation. In addition, considering multimodality gained a lot of importance among transport systems over the last years. This is why it seems to be crucial to take up the concept of multimodality for assessing travel time reliability.

Studies so far that took travel time reliability into consideration, concentrated mainly on precisely defined and therewith limited system boundaries. Numerous studies addressing travel time reliability of motorised individual transport (e.g. [6], [7], [8], [9], [10], [11]) and public transport (e.g. [12], [13]) have already worked out a large range of aspects in detail. Additionally, even aspects of a transportation system (e.g. [4], [14], [15], [16], [17]) have already been made a subject of the travel time reliability discussion. However, aspects of multimodal transport participation remained rare and concentrated on optimising web-based routing systems for public transport (e.g. [18], [19]) or on a description of influences on a multimodal transport behaviour and system (e.g. [20], [21]). However, a method that outlines a way to assess travel time reliability on multimodal trips is still missing. One reason for this could be that an application based on analogies is hardly possible [16]. Furthermore, the consideration of travel time reliability in the context of multimodal transport participation poses significantly more challenges than it does for monomodal transport participation.

In order to determine travel time reliability, a various number of indicators were developed and tested (see table1). Due to the fact that these indicators were developed out of a precisely defined perspective, their application is aligned with the view of a specific actor (e.g. a transport companies, planners) and according to that their informative value is limited. Nevertheless, to evaluate currently developed indicators three approaches have to be distinguished [13]:

- Mean-Variance-Model (MVM),
- Mean-Lateness-Approach (MLA) and
- Scheduling-Model (SM).

Table 1. Overview of Current Indicators for Travel Time Reliability.

No.	Indicator Calculation	Indicator name	Resource/s	Approach Allocation
#1	$\sigma^2 = \sum_{1=i}^{n}(\frac{x_i - \bar{x}}{n-1})$	Variance	[4]	MVM
#2	$\sigma = \sqrt{\sigma^2}$	Standard Deviation	[13]	MVM
#3	$v = \frac{\sigma}{E}$	Coefficient of Variation	[2]	MVM
#4	$\mathrm{IQR} = \mathrm{Q}_{0,75} - \mathrm{Q}_{0,25}$	Interquartile Range	[13]	MVM
#5	$\tilde{x}_P = \begin{cases} \frac{x_{n*P} + x_{n*P+1}}{2} \end{cases}$	90-/ 95-Percentil; Planned Travel Time	[7]	MVM
#6	$PI = \frac{\tilde{x}_{0,95} - \bar{x}}{\bar{x}}$	Puffer Index	[7]	MVM
#7	$TTI = \frac{TT_{PP}}{TT_{FF}}$	Travel Time Index	[7]	MVM
#8	$PTTI = \frac{\tilde{x}_{0,95}}{TTI} = \frac{\tilde{x}_{0,95}}{\frac{TT_{PP}}{TT_{FF}}}$	Planned Travel Time Index	[7]	MVM
#9	$MI = \frac{\overline{TT_{0,8} - \bar{x}}}{\bar{x}}$	Misery Index	[22]	MVM
#10	$SD = TT_{observed} - TT_{scheduled}$	Schedule Delay	[4]	MLA
#11	$DT_{Scheduled} = E(TT) + \tau$	Scheduled Departure Time	[23]	MLA
#12	$A_{OT} = \frac{T_{OT}}{T}$	On-Time Arrivals	[4]	MLA; SM
#13	$DP = \frac{DP_o\ (Veh * D)}{DP_P\ (Veh * D)}$	Driving Performance	[24]	-
#14	$\widetilde{x_{Ac}} = \widetilde{x_{ZGH}} + \widetilde{x_{AGH}}$	Accessibility of Public Transport Stops	[3]	-

Note: MVM - Mean-Variance-Model | MLA - Mean-Lateness-Approach | SM - Scheduling-Model.

Thereby, two general motivations are assigned with the use of these three approaches. Firstly, the Mean-Variance-Model serves to describe frequencies and probability distributions. Thus, statistical methods are used to compile the variability of travel time reliability (e.g. median, 90-percentil, standard deviation, spread of a distribution, probability of occurrence). Secondly, the Mean-Lateness-Approach is used to describe the appearance and the value of delays, while the Scheduling-Model additionally serves to describe the appearance and the value of early arrivals. [4] Thereby, indicators like On-Time Arrivals, Schedule Delay etc. have been used in literature. Whereas, the Mean-Variance-Model can be applied for all trips and transport modes, the Mean-Lateness-Approach and the Scheduling-Approach require the existence of a pre-trip travel time (which might originate from a routing system, a timetable etc.) in order to compare actual (on-trip) and planned (pre-trip) travel times.

It is clear that current indicators for travel time reliability are appropriate to describe the performance of a multimodal trip as long as it does not take respective stages into account. In order to use these indicators, a trip including his origin and destination has to be predefined even before data are collected. Although travel times for respective stages can be added-up, this is not appropriate for the variability of travel times [4]. Al-Deek and Emam assumed that little reduction in reliability of a link hardly reduces the reliability of the whole system [6]. However, this might be appropriate for individual transport participation, but it can be assumed that this does not adopt on multimodal transport participation that includes collective transport services. Considering the combination of different transport modes additional sources of errors are assumed to occur.

3.3. Influences on Travel Time Reliability on Multimodal Transport Participation

Beside statistical analysis that are used to compile indicators, influence factors on travel time and therewith travel time reliability have to be considered in order to deduce limitations of current approaches and furthermore challenges stemming from travel time reliability and posed by a multimodal transport participation. Although most factors that influence travel times in individual motorised or public transport do not significantly differ on mono- or multimodal trips, there have to be considered a few additional ones. In order to draw up a scope of influence factors figure 2 and figure 3 depict them and thereby distinguish between individual (e.g. using a car, a bike) and collective (e.g. using a bus, a train) transport participation.

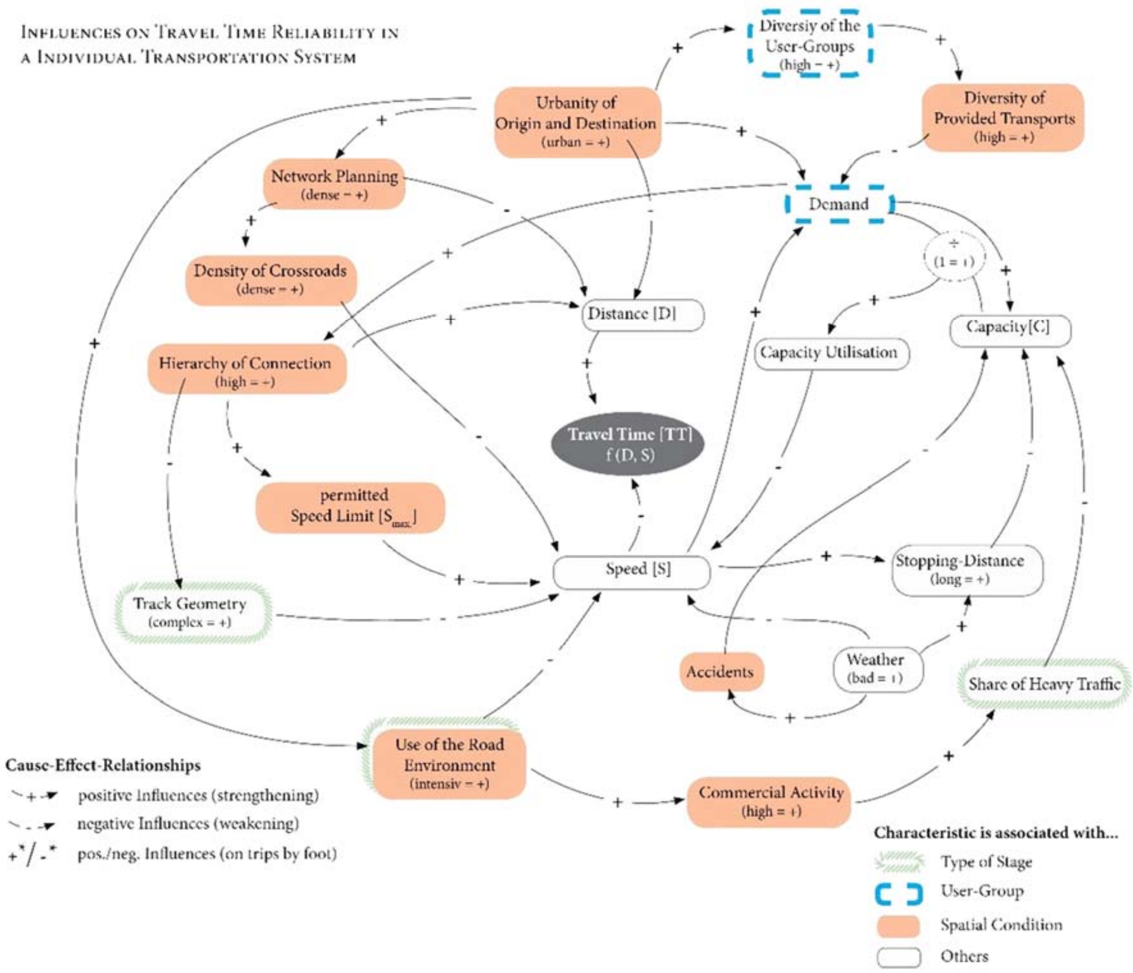

Figure 2. Influence Factors on Travel Time Reliability on Individual Transport Participation.

In general travel times are a product of distance and speed. Factors that influence either the distance that has to be overcome or the speed that could be achieved are various and can be clustered into factors depending on (1) the spatial conditions (e.g. rural, urban), (2) the type of stage (e.g. route for changing transport mode within a small walking distance, distance overcome with a high-level transport mode), (3) the user-group that is taken into account (e.g. seniors, participants with a season ticket for public transport) and (4) others. One of these influences can be illustrated by using the density of stops in public transport. While a high density of stops in public transport does not causally influence the distance of the trip (distance between origin and destination), it does influence the speed that could be achieved with the vehicle that overcomes the way. Thereby the density of stops in public transport is significantly associated with spatial conditions, as for example the use of the surrounding area (e.g. place of residence).

In addition to that, internal and external influence factors could be distinguished in order to gauge whether they are assessable for infrastructure, and transport providers, or transport participants. This distinction is reasonable in order to monitor and consequently improve travel time reliability within both a transport mode and a transport system. Furthermore, the influence factors (see figure 2 and figure 3) are also characterised by an inherent reliability and availability which depend themselves on various factors. Giving an example, the availability of a public transport service depends on the time of day (e.g. 12 a.m. vs. 12 p.m.) and the day of week (e.g. Monday vs. Sunday). Regarding factors that influence the reliability, for example of changing a transport mode, the type of the respective stage (e.g. public transport stop that is used by one or more than one lines) and the spatial condition (urban vs. rural) can be mentioned.

However, for the sake of completeness it has to be indicated that herein captive riders and influences induced by the costs of a transport service remained unconsidered.

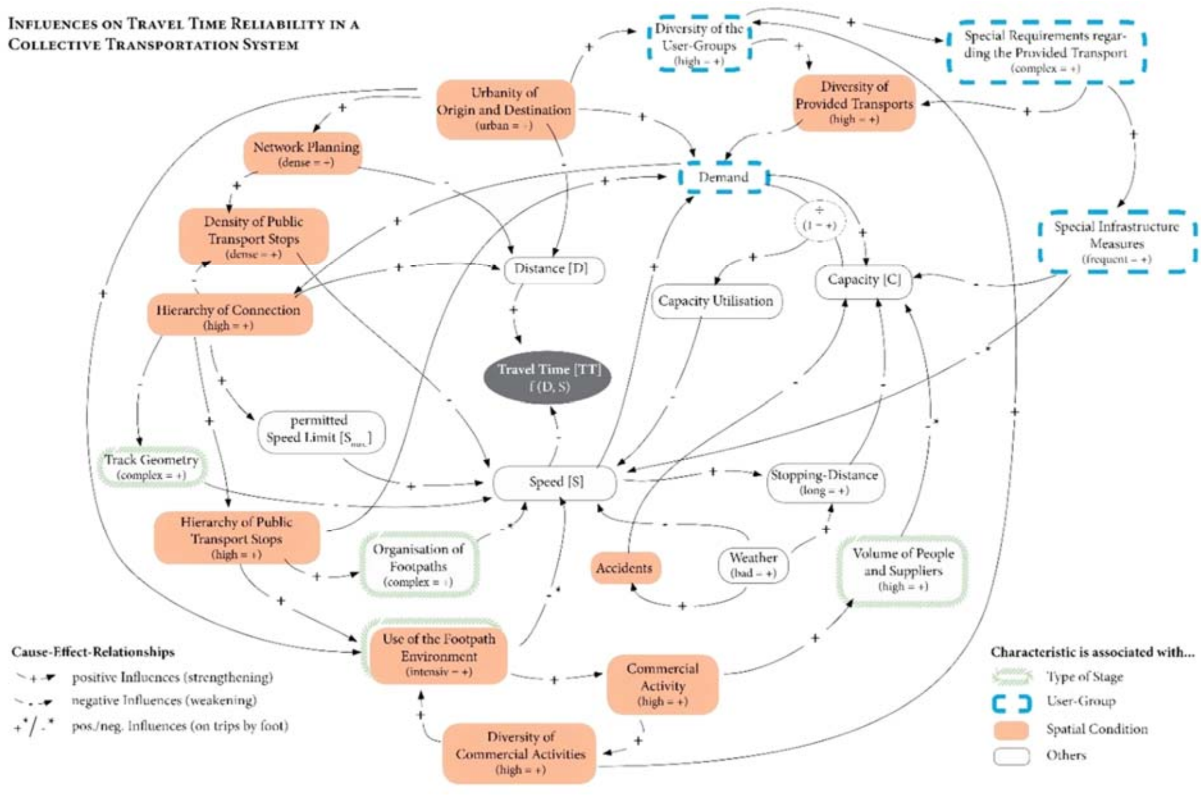

Figure 3. Influence Factors on Travel Time Reliability on Collective Transport Participation.

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4. Discussion

This paper derives challenges that result from the objective of considering travel time reliability on multimodal transport participation. In order to cluster these challenges, three types are pointed out.

4.1. Challenges stemming from Inherent Limitations of Indicators

Indicators always come along with inherent limitations stemming from the chosen method and the calculation components that are used to form the indicator. As a measurement that should give a brief overview of relevant factors or criteria, indicators are products based on an analysis of a data set. Thus, it is of importance to be aware of the loss of information which is an inherent characteristic of an indicator.

In addition, indicators allow a scope for interpretation that can be simply illustrated by the indicator #12 On-Time Arrivals (see table 1). This indicator compares the number of those trips that were on-time with regard to all trips. If 10 out of 100 trips were on-time, the indicator will be 0.1. In order to enhance the indicator up to the value of 0.2, there are two possibilities: 1) enlarge the number of on-time arrivals up to 20 or 2) reduce the number of all trips down to 50. Thus, by using the indicator, it is impossible to predict the reasons behind a change of his value.

Furthermore, it is necessary to know that within a data set, statistical outliers have to be expected all the time. Additionally, indicators always react on outliners differently depending on the way they are formed. This reaction is named robustness and represents an important characteristic of an indicator.

4.2. Challenges stemming from Data Collection and Indicator Application

Given the fact that statistical analyses mostly use historical data predictions on future performance developments are difficult (future is not the continuation of the past). Although the reasons for limitations to anticipate future travel time reliabilities are various, this paper lists a few of them that could be imagined: change of network conditions (e.g. a transport service occurs additionally or is given up), change of demand or change of social expectations (e.g. travel times are not any longer lost times, because wearable technologies help people to use that time for numerous purpose).

The study results and indicators that were compiled in table 1 and pointed out in this paper have been developed within precisely defined and limited system of boundaries. Thus, these indicators are characterised by a limited application that has to be checked with regard to the respective purpose of application. Thereby, it is reasonable to distinguish between limited applications that originate from complexity, spatial, cultural, and legal issues. Especially for capturing multimodal transport participation in a model where structure and scope of data collection is of great importance (complexity). Thereby, mostly both are missing, accurate and consistent data that cover the respective transport network entirely and adequate budgets to compile the missing data [7]. The more complex is the transport participation (e.g. using individual or collective transport modes in a row) or transport system (e.g. historically grown road structure with different types of roads) that should be modelled, the more complex are the required data (e.g. travel times per stages instead of origin-destination relation). In addition, limitations from spatial, cultural, and legal issues are expected to influence human behaviour (e.g. the dispersion of residential areas influence the value of travel time), social acceptance (social norms and user-groups influences the acceptance delays or the value of travel times) and the relevance of travel time reliability in a society (e.g. compliance agreements regarding punctuality influence decisions and investments of transport companies).

It has already been noted that some operators of transport infrastructure were worried about a negative image that might occur induced by the implementation of an indicator for travel time reliability [7]. Thereby these operators are especially worried about events that cause disruptions on the entire transport system and which are neither manageable nor predictable by them. Indicators that are applied for multimodal transport participation might be characterised by the same worries, particularly because the reliability of the stage changing transport mode remained unconsidered by transport service providers and infrastructure operators till now.

4.3. Challenges stemming from Human Particularities

This paper suggests that human particularities cause numerous challenges that show up for applying travel time reliability on multimodal transport participation. Especially if the transport participation has to be described and understood psychological issues are of great importance. Thereby, theories that try to explain human behaviour within a decision-making process and human perception with regard to time are the most important aspects herein.

The theory of ‘homo economicus’ is a method to explain human decisions. Thereby it has frequently been criticised as a too idealised picture [e.g. 25]. However, it is clear that people do not necessarily have access to extensive information about all relevant facts within their transportation choices. In addition, it is also clear that people do not always act logically. Nevertheless, as a basis, the theory of homo oeconomicus could be assumed firstly, while those observed phenomena where the theory lacks should be used to clarify (e.g. add-up some influence factors) or to deviate from the theory (e.g. find a better theory or describe observations). The paper suggests that this approach particularly gains importance in the context of multimodal transport participation induced by the increasing complexity regarding motivations within route and mode choices. Whereas multimodal transport participation is already characterised by the need of changing transport modes, the tendency to an increasing influence of those factors that represents qualitative criteria (e.g. comfort, preference to or advantage of a specific line or route) could be assumed.

Due to the application of the prospect theory on transport participation, a few studies already claimed a risk-averse behaviour when the average travel time along the alternative route is shorter than the certain travel time at the main route and a risk-seeking behaviour when it is vice versa (e.g. [26] [27]). This might be an interesting theory in order to describe the role of travel time reliability in multimodal transport participation.

Beside these two theories that addresses human particularities within decision making processes, differences in the subjective perception of time and the passage of time that is measured with a clock pose challenges even if travel time reliability is frequently compiled and monitored by transport providers. Almost everybody has already experienced a stressful or dangerous situation, where time seems to slow down. This assumes that perception of time is not a constant experience. Some studies suggest that there is a difference in the perception of time between depressive and healthy people (e.g. [28], [29]) or young and elderly people (e.g. [30]). Exemplarily, it was found out that the perception of time expends in depressive people [29]. This phenomenon applies for the perception of already bygone experiences, but also for present ones. Additionally, it is assumed that the perception of time depends not only on physical processes, but also on the emotional state of people. The reason for this could be found in the way neuronal processes for cognition and emotion work. Cognition and emotions are not processed in different parts of our brain (e.g. [31]). This might be an explanation, why the emotional state of people influences the perception of time. Thus, it is questionable (1) what role possible differences that might occur between the results of an adopted indicator for travel time reliability and subjective perceptions would play within the individual decision making processes of transportation participants and (2) if there are differences between a mono- and multimodal transport participation.

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