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Dynamic Passenger Guidance in Rail Transport - Decision-Making Behaviour of Passengers

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Abstract

High capacity utilisations and short-term incidents in the public passenger rail transport can cause delays and thus affect the journey of the passengers concerned. Influencing passenger flows in such situations, e.g. by tailored information, may help to avoid overcrowded trains and further delays. This paper shows the possibility of determining the decision-making behaviour of passengers in incident situations based on relevant influencing factors. By application of regression analyses based on collected data, the decision-making behaviour can be determined. Thus, passenger flows can be modelled, and the effects on other sections of the rail network can be estimated. Using the decision-making behaviour, suitable measures can be selected in case of incidents to be able to realise targeted guiding of passengers or passenger flows. The impact of incidents can be reduced by consistent implementation of a Dynamic Passenger Guidance, and passengers can be guided efficiently. Dynamic Passenger Guidance in Rail Transport is to be regarded as dynamic traffic management, which refers to the railway operation and represents the optimal control of the current traffic for the appropriate transport of all passengers in the case of an incident.

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Keywords: Dynamic passenger guidance; decision-making behaviour; passenger flows; regression analyses, logit model; degree of compliance; rail transport

1. Introduction

In recent years, there is an increasing trend in the total number of rail transport passengers in Germany. As shown by the Statistisches Bundesamt (2018), long-distance rail transport reached the peak of 142 million passengers in 2017 (2.3% more than in 2016), and local public rail transport (excluding trams) reached 2 692 million passengers (2.4% more than in 2016). Overall, the number of passengers in public transport in Germany in 2017 is about 11 509 million (without air transport), with a share in the model split of about 15%. The high number of passengers is

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already leading to significant loss of comfort and capacity utilisation during peak traffic hours. Since the rail infrastructure is used to capacity on the majority of the routes and further expansion is hardly possible due to the low availability of space, alternative solutions are required to meet the demand.

Besides, disruptions in the operation can cause deviations from the timetable, additional loss of comfort for the passengers and capacity utilisation problems. Delays of individual train connections or even train cancellations affect the planned journey of the passengers. In order to keep the satisfaction of passengers and to ensure efficient operation in the case of an incident, measures are required. These measures should not only lead back to the planned operation, but also provide the best possible opportunities for the passengers directly concerned to continue their journey. According to Boltze and Tuan (2016), these traffic management measures should influence both supply and demand to optimise their negative and positive effects.

Dynamic Passenger Guidance in Rail Transport represents the optimal control of the current traffic for the appropriate transport of all passengers in the case of an incident. Through the targeted implementation of demand-influencing measures, passenger flows can be steered efficiently in the rail network. Comparable with the traffic management in road traffic, passengers can be informed in case of expected or occurring incidents and be influenced to change their itinerary choice. The effectiveness of chosen measures depends on the acceptance of passengers concerning the alternative connectivity, additionally given incentives and the provision of information. The most critical factor for optimal control, however, is the knowledge on the decision-making behaviour of passengers.

The decision-making behaviour of passengers concerning the itinerary choice in public transport has rarely been investigated so far. To be able to make a statement about the acceptance of measures, the influencing factors, as well as their effect on the decision-making behaviour, must be known. It should be noted that each passenger's behaviour is influenced by individual factors, such as mobility restrictions or comfort requirements, which results in a high level of complexity in determining decision-making behaviour.

This paper presents a modelling of the decision-making behaviour of passengers in rail transport in two different incident cases based on the conducted passenger survey. Influencing factors can be identified by using the survey data and their effects are estimated by regression analyses. Section 1 gives a brief introduction to the topic. Section 2 sets out the procedure up to modelling. Section 3 provides a more detailed description of the term "acceptance" and provides an overview of the relevant influencing factors on decision-making behaviour. The performance of the regression analyses and its results are listed in Section 4 and 5. Section 6 summarises the major findings and conclusions.

This paper shows the results of the project "Fundamentals of acceptance of measures" by Boltze and Gillich (2017), which was carried out in cooperation with Deutsche Bahn AG as part of the innovation alliance AG Connected Mobility.

Nomenclature

BLR	binary logistic regression
c^2	Chi-Square test of independence
df	degree of freedom
f	regression coefficient
IS	Information System
N	sample size
p	probability value
X	respective characteristic of an influencing factor
X^2	test value

2. Methodology

A proven method for predicting the behaviour of passengers in decision-making situations is the use of a discrete choice model. It is assumed that the passengers individually assess the different decision-making options in order to be able to make the selection about the overall benefit (utility maximisation). The assessment is based on the different properties (attributes) of the decision-making options, such as comfort requirements. Regression analyses offer the possibility to simulate the decision-making process by converting the attributes into regression coefficients and by determining the overall benefit through the utility function. In this manner, very complex decision-making processes can be simulated, but a sufficiently large sample is required to determine the regression coefficients.

To be able to describe and estimate the decision-making behaviour via regression analyses, the influencing factors are required to be identified. Therefore a tripartite questionnaire was designed. The first part of questionnaire was used to gather the individual influencing factors, and the second part included incident-related influencing factors. With the help of the recording of hypothetical incident scenarios in the third part, a correlation between the influencing factors and the decision-making behaviour could be established. The hypothetical incident scenarios were included train cancellation as well as an incident due to capacity utilisation problems. By a hypothetic incident situation, the participants had to indicate whether they would continue their planned journey or follow the recommended option for action. The third part was varied concerning the further investigation by modifying the travel time and the number of additional transfers if the option for action was followed. Overall, the passenger survey was conducted with six different versions.

In the run-up to the passenger survey, the developed questionnaire was validated through field tests. The passenger survey was carried out in the means of transport and on the platforms. A sample size of 503 data records was obtained. A uniform distribution (between 14.5% and 19.3%) of the different versions of the questionnaires was considered to obtain a sufficient data basis for the regression analyses. The evaluation was then carried out using the statistical software IBM SPSS in version 24.

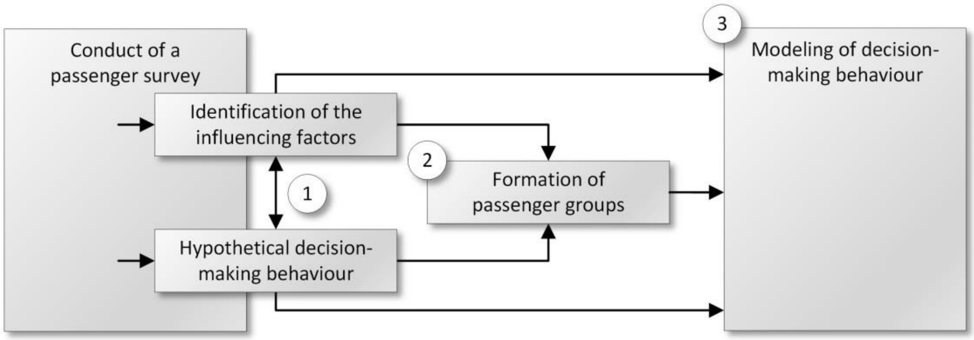

Fig. 1. Steps of the investigation.

The evaluation of the questionnaire data for the determination and modelling of the decision-making behaviour was done in several steps and is shown in Fig. 1. In the first step, the dependencies between the investigated influencing factors and the decision-making behaviour of the respective incident situation were shown. Since the influencing factors were mainly in the form of nominal (categorical) variables and a sufficiently large sample size was available, the Chi-Square test of independence was used to determine a significant relationship. In the next step, a subdivision of the passengers into stereotypical passenger groups was made that premised on the detected significant influencing factors. The division of passengers ensures the development of a user-manageable simulation model since a large number of internal factors of influence are stored within the passenger group.

The final evaluation step was to set up a function to assess the decision-making behaviour of the passengers. Since the decision-making behaviour was queried within the hypothetical incident scenario with two characteristics (acceptance or rejection of the option for action), a binary logistic regression could be used. The identified influencing factors were included as independent variables in the logistic regression analyses. The result of the logistic regression analyses reflects a function that quantifies the probability of acceptance of an option for action depending on the influencing factors. The regression coefficients were used to determine the direction of action and weighting of an influencing factor. A logistic regression analyses was carried out both with the classification of the groups of passengers and without them, to show the overall accuracy, which was achieved by the passenger survey.

Finally, a model for practical application was generated based on the results of regression analyses. For the simulation model, the influencing factors resulting from the classification of passenger groups were used. In addition to the input of train connections and the number of passengers, the model can also be used to set the passenger groups and other incentives for action so that the distribution of the passenger flow in case of an incident can be shown.

3. Acceptance and influencing factors for route selection in public passenger transport

3.1. Acceptance by passengers

For the determination and modelling of the decision-making behaviour of passengers, interdependency relations between the influencing factors and the acceptance is a mandatory prerequisite. For this reason, a brief insight into the term "acceptance" in the context of the dynamic influence of passengers in railway operations is given at this point.

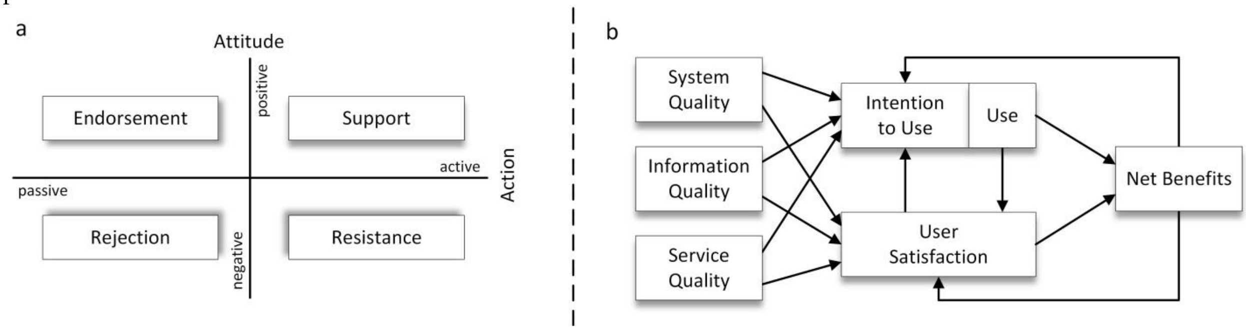

Fig. 2. (a) Forms of acceptance by Schweizer-Ries et al. (2008); (b) DeLone and McLean (2003) updated IS success model.

According to Lucke (1995), the acceptance is an individual size which cannot be enforced. Therefore, measures or the options for action resulting out of them for the passengers must be tailored to the needs of the passengers to be able to influence them in a targeted manner. Here, a distinction is made between the attitude dimension and the action dimension of a passenger. According to Schäfer and Keppler (2013), it is not enough to conclude from the passenger's positive (negative) attitude to his action. Acceptance thus differentiates both in attitude and in action, so that endorsement or rejection results from a passive action and support or even resistance due to an active action. It should be noted that an efficient and targeted influence and guidance always depends on the support (compliance) of the passengers. Without sufficient compliance, demand-influencing measures will not achieve the desired impact.

Fig. 2 (a) shows the described forms of acceptance. The interdependency between the selected measures and the acceptance can be demonstrated using the extended Information System (IS) success model by DeLone and McLean (2003) in Fig. 2 (b). For this, the terminology out of table 1 is used. The Dynamic Passenger Guidance reflects, from the perspective of the passengers, an information system that outputs an alternative option for action in an incident situation based on the requirements of the passengers. The IS success model represents the influence of the information system on the acceptance. The interdependency between information system and *User Satisfaction* is shown. Likewise, the *Net Benefits* and the experience of passengers out of active action (*Use*) have an impact on *User Satisfaction*.

User Satisfaction is directly related to *Intention to Use*. A faulty or incomplete information transfer to the passengers has an adverse effect on compliance with the option for action. On the other hand, it can be deduced that a successful Dynamic Passenger Guidance can cause higher *User Satisfaction* and thus to an increase in the acceptance of the passengers. The *System Quality*, *Information Quality* and *Service Quality* can be used as superordinate terms of the system-relevant influencing factors on the decision-making behaviour.

A large number of factors thus influences the decision-making behaviour for route selection. This also includes factors that are not related to the passenger but are caused by the information system or the incident from the outside. An overview of these influencing factors is given in the next part.

Table 1. IS success model constructs with regard to decision-making behaviour of passengers based on Petter and McLean (2009).

Construct	Description
System Quality	Performance of the IS in terms of reliability, convenience, ease of use, functionality, and other system metrics
Information Quality	Characteristics of the output offered by the IS, such as accuracy, timeliness, and completeness
Service Quality	Support of users by the IS department, often measured by the responsiveness, reliability, and empathy of the support organization. In this case: Also the service personnel in the means of transport, on the platform or in service stations
Intention to Use	Expected future consumption of an IS or its output
Use	Consumption of an IS or its output described in terms of actual or self-reported. In this case: Acceptance of the (individual) option for action
User Satisfaction	Approval or likeability of an IS and its output. In this case: User satisfaction concerning information and quality of the operation in railway operations
Net Benefits	The effect an IS has on an individual, group, organization, industry, society, etc., which is often measured in terms of organizational performance, perceived usefulness, and affect on work practices. In this case: Net benefits result from lower capacity utilisation and shorter waiting times, shorter transportation times and optimised incident management

3.2. Influencing factors

Internal and external influencing factors determine the decision-making behaviour of passengers. Internal influencing factors relate to the individual characteristics of the passengers, such as age, mobility impairments, and personal preferences. In contrast, the external influencing factors reflect system-related or incident-related "interventions" and "conditions" of the environment as well as from the information system. The extent to which the external influencing factors are considered in the evaluation of options for action depends on the individual characteristics of the passenger. Therefore, all influencing factors must be considered in interaction.

One way of positively influencing the acceptance of measures in emergency situations is via the so-called incentives for action. Incentives for action may be offered in addition to a recommended option for action to increase the degree of compliance. These include, for example, a temporary upgrade of the travel ticket (upgrade 1st class), the issue of vouchers (free coffee) or the permission to use a faster connection to compensate travel time losses. The effects of incentives on decision-making behaviour were analysed within the project.

The influencing factors are listed in table 2. The characterisation of the internal influencing factors in demographic and socioeconomic, psychographic, situational and behavioural factors is defined based on Knapp (1998). Since the internal influencing factors are largely unknown, a categorisation of the passengers in passenger groups offers itself. In this case, the passenger groups should be considered as an internal influencing factor.

Table 2. Influencing factors on route selection of passengers in incident situations.

Category	Subcategory	Influencing factors
Internal	Demographic	gender, age, household size, marital status, mobility impairments, car availability, possession of driver's license
	Socio-economic	income, employment, willingness to pay
	Psychographic	perception, preferences, emotions, expectations, attitudes, experience
	Situational	purpose of travel, level of information, frequency of use
	Behavioural	flexibility, receptivity of information, comfort requirements
External	Supply-related and time-related	travel time, transport time, transfer time, waiting time, duration from destination station to final destination, duration from starting point to departure station, traffic time, weather conditions, number of affected passengers, capacity, equipment
	Incident-related	travel time loss, gain of travel time, delay, number of additional transfers, incentives for action
	System-related	time of provision of information, information quality, system quality, service quality

4. Examination

4.1. Analyses of influencing factors and passenger groups

The passenger groups were formed based on the results of the passenger survey with a sample size N of 503 participants. According to Krejcie and Morgan (1970), a minimum sample size of 400 respondents was sought for the application of the Chi-Square test of independence, since in public rail transport a large population size has to be assumed. According to Green (1991) and Wilson VanVoorhis and Morgan (2007), the sample size is also suitable for the application of a regression analyses. However, the accuracy of the regression results also depends on the number of independent variables.

By using the Chi-Square test of independence, significant relationships between the queried internal influencing factors and the hypothetical decision-making behaviour in the case of an incident were determined. These relationships can be used to delineate the passenger groups. The results of the investigations are shown in table 3. A probability value of $p \leq 0.05$ is to be interpreted as a significant relationship.

The investigation of the independencies between the influencing factors and the decision-making behaviour showed a multiplicity of significant relationships. However, it should be noted that individual influencing factors correlate with each other (multicollinearity). Thus, for example, relationships between the purpose of travel and age, the purpose of travel and frequency of use as well as the frequency of use and ticket can be shown.

Due to the highly significant relationship between the purpose of travel and the decision-making behaviour, a classification of the passengers in groups was carried out according to this influencing factor. This influencing factor also offers the advantage of a comprehensible classification. The purpose of travel was queried based on the study of mobility in Germany according to infas and DLR (2008) within the passenger survey.

Table 3. Results of Chi-Square test of independence with: $c^2(df,N)= X^2,p$.

Influence factor	Asymptotic significance (two-sided) – train cancellation	Asymptotic significance (two-sided) – capacity utilisation problem	Parameter
Gender	c^2(1, N=497) = 1.173, p=0.279	c^2(1, N=496) = 0.027, p=0.870	Dichotomous
Age	c^2(6, N=495) = 15.698, p=0.015	c^2(6, N=494) = 24.811, p=0.000	Categorical
Purpose of travel	c^2(6, N=495) = 20.932, p=0.002	c^2(6, N=494) = 24.843, p=0.000	Categorical
Itinerary	c^2(1, N=497) = 0.119, p=0.730	c^2(1, N=496) = 1.928, p=0.165	Dichotomous
Frequency of use	c^2(4, N=497) = 25.341, p=0.000	c^2(4, N=496) = 23.768, p=0.000	Categorical
Flexibility: time	c^2(4, N=497) = 6.444, p=0.168	c^2(4, N=496) = 7.267, p=0.122	Categorical
Flexibility: route	c^2(4, N=497) = 3.026, p=0.553	c^2(4, N=496) = 1.784, p=0.775	Categorical
Mobility impairments	c^2(7, N=487) = 29.214, p=0.000	c^2(7, N=486) = 12.146, p=0.096	Categorical
Smartphone app	c^2(1, N=495) = 11.737, p=0.001	c^2(1, N=494) = 4.010, p=0.045	Dichotomous
Local knowledge	c^2(4, N=491) = 19.791, p=0.001	c^2(4, N=490) = 7.594, p=0.108	Categorical
Comfort: seat	c^2(4, N=496) = 3.792, p=0.435	c^2(4, N=495) = 18.678, p=0.001	Categorical
Comfort: storage space	c^2(4, N=496) = 16.483, p=0.002	c^2(4, N=495) = 6.587, p=0.159	Categorical
Comfort: capacity utilisation	c^2(4, N=496) = 1.278, p=0.865	c^2(4, N=495) = 14.710, p=0.005	Categorical
Comfort: air-condition	c^2(4, N=496) = 5.594, p=0.232	c^2(4, N=495) = 4.076, p=0.396	Categorical
Ticket (grouped)	c^2(1, N=470) = 11.708, p=0.001	c^2(1, N=469) = 23.114, p=0.000	Dichotomous

By using additional subdivisions according to the frequency of use, the local knowledge and the age groups, the passenger groups were set up according to table 4. The division was made successively taking into account the accuracy of the simulation model. The differentiation between business passengers according to local knowledge is optional. However, the analyses showed that business passengers' decision-making behaviour differs significantly depending on the extent of local knowledge.

Table 4. Definition of passenger groups.

Frequency of use	Purpose of travel	local knowledge	Age group	Passenger group
≤ 12 days a year	-	-	-	inexperienced passengers
> 12 days a year	School	-	-	pupils
	Education	-	-	education passengers
	Business trip	increased	-	business passengers (urban)
		low	-	business passengers (rural)
	Work	-	-	business commuters
	Sightseeing	-	-	tourists
	Leisure	-	≤ 28 years	power passengers
		-	> 28 years	leisure passengers
	Shopping/Running errands	-	-	occasional passengers

Passengers who travel for leisure have been further subdivided concerning age. In this regard, it could be stated in the analyses that especially persons up to the age of 28 have a clear activity pattern and want to reach their destination flexible and quickly. The proportion of passengers with a season ticket is particularly higher among power passengers.

Furthermore, the analyses showed that stereotypical behaviour is to be found among all passengers who use public transport only a few days a year. To illustrate this behaviour, the group of passengers of inexperienced passengers was developed, which is not delimited by the purpose of travel but only by the frequency of use.

The mobility impairments are recorded separately. In addition to the impairments on walking, sight and hearing, mobility impairments also include the carrying of luggage, pushchairs and bicycles as well as infants.

4.2. Regression analyses to determine decision-making behaviour

By using a BLR, the decision-making behaviour of passengers can be described by a function. The utility function *V* includes the weighted influencing factors (regression coefficients *f*) and the respective characteristic *X* of these influencing factors. The general utility function is shown in equation 1.

$$V = f_{konst} + \sum f_i * X_i \quad (1)$$

The probability of accepting the option for action *P (Y = 1)* ultimately results from the utility of the utility function according to equation 2.

$$P(Y = 1) = \frac{e^V}{1 + e^V} \quad (2)$$

Because the passenger groups are categorical variables, they are transformed into dummy variables, which are shown in table 5.

Table 5. Definition of the dummy variables of the passenger groups.

Passenger group	Passenger group: dummy variables								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
education passengers	1	0	0	0	0	0	0	0	0
pupils	0	1	0	0	0	0	0	0	0
occasional passengers	0	0	1	0	0	0	0	0	0
power passengers	0	0	0	1	0	0	0	0	0
leisure passengers	0	0	0	0	1	0	0	0	0
tourists	0	0	0	0	0	1	0	0	0
business commuters	0	0	0	0	0	0	1	0	0
business passengers (urban)	0	0	0	0	0	0	0	1	0
business passengers (rural)	0	0	0	0	0	0	0	0	1
inexperienced passengers	0	0	0	0	0	0	0	0	0

Table 6 shows the determined regression coefficients of the utility function V_1 for application of situation 1 (train cancellation) and V_2 for application of situation 2 (utilisation problem). The gain of travel time or travel time loss results from the new time of arrival by accepting the proposed alternative connection, whereby additional transfers may be required. The passenger groups, as well as the mobility impairments, are included separately in the utility function. Other external influencing factors are the current weather, capacity utilisation (only for situation 1), time of provision of information (only for situation 2) and additional incentives for action, such as seat guarantee, upgrade to 1st class and vouchers.

The regression coefficient *f* determines the direction of action and weighting of an influencing factor. As shown in table 6, adding additional incentives leads to an increased probability of acceptance. On the other hand, the mobility impairments mainly have a negative impact on the probability of acceptance. Passengers travelling with infants tolerate a later arrival time as well as additional transfers to travel as comfortably as possible in the case of capacity utilisation problems. Additional transfers on the alternative train connection have an adverse effect on the probability of acceptance depending on the number of transfers. With a value of 0.810, the time of provision of information, which was queried only in the incident situation 2, has a high impact on the acceptance. By sharing information with passengers at an early stage, load peaks can be reduced, because passengers can use an alternative train connection.

By way of illustration, the following scenario is used. A leisure passenger is on his way home. Arrived at the station, he realises that his planned train connection is cancelled. The next regular train connection would take 60 minutes, according to the schedule. As an option for action, the passenger is given an alternative train connection. By using this connection, the passenger can reach his destination 20 minutes earlier, but a further transfer has to be made. The weather conditions have no negative impacts on the transfer. The probability of acceptance *P(Y = 1)* results from using equations 1 and 2:

$$V_1 = 0.952 + 0.030 * 20 - 0.685 * 1 + 0.078 * 1 + 0.208 * 1 = 1.153$$

$$P(Y = 1) = \frac{e^{1.153}}{1 + e^{1.153}} = 0.7601 = 76.01\ \%$$

If two additional transfers are to be made on the alternative train connection, the probability of acceptance is reduced to:

$$V_1 = 0.952 + 0.030 * 20 - 0.685 * 2 + 0.078 * 1 + 0.208 * 1 = 0.468$$

$$P(Y = 1) = \frac{e^{0.468}}{1 + e^{0.468}} = 0.6149 = 61.49\ \%$$

If the passenger also carries luggage with him, then there is a probability of acceptance of the alternative train connection option of:

$$V_1 = 0.952 + 0.030 * 20 - 0.685 * 2 + 0.078 * 1 + 0.208 * 1 - 0.897 * 1 = -0.429$$

$$P(Y = 1) = \frac{e^{-0.429}}{1 + e^{-0.429}} = 0.3943 = 39.43\ \%$$

Table 6. Regression coefficients *f* and *p-values* for determining decision-making behaviour.

Influence factors	Situation 1 (train cancellation)		Situation 2 (capacity utilisation problem)	
	f	*p-value*	*f*	*p-value*
Constant	0.952	.000	0.319	.003
Situative parameters				
Gain of travel time (1/min)	0.030	.000	-	-
Loss of travel time (1/min)	-	-	-0.003	.041
Additional transfers (1/transfer)	-0.685	.000	-0.358	.000
(good) Weather conditions	0.208	.000	0.068	.044
(low) Utilisation	0.117	.004	-	-
(early) Provision of information	-	-	0.810	.000
Incentives for action				
Seat guarantee	0.357	.000	0.254	.000
Upgrade to first class	0.298	.000	0.321	.000
Voucher (e.g. free coffee)	0.145	.000	0.152	.000
Passenger groups (dummy variables)				
Passenger groups (1)	0.699	.000	-0.461	.000
Passenger groups (2)	0.941	.000	-0.848	.000
Passenger groups (3)	0.037	.677	-0.239	.004
Passenger groups (4)	0.573	.000	-0.425	.000
Passenger groups (5)	0.078	.281	0.534	.000
Passenger groups (6)	1.016	.000	0.145	.351
Passenger groups (7)	0.450	.000	-0.743	.000
Passenger groups (8)	0.676	.000	0.868	.000
Passenger groups (9)	1.235	.000	0.254	.076
Mobility impairments				
Carriage of bicycles	-0.070	.422	-0.405	.000
Luggage	-0.897	.000	-0.112	.029
Infant(s)	-0.402	.006	0.960	.000
Pushchair	-2.136	.000	-0.594	.001
Impairments on walking	-0.110	.927	0.046	.689
Impairments on sight	-1.559	.000	-1.136	.000
Impairments on hearing	0.730	.002	1.163	.000

The decision-making behaviour of the surveyed passengers was predicted by the determined regression coefficients according to table 6 and compared with the surveys on the hypothetical decision-making behaviour. The datasets of the passenger survey were multiplied by the number of possible combinations 2^5 to determine the decision-making behaviour so that ultimately 16,096 data records were used for the analyses. The increase was necessary because the decision-making behaviour was also queried depending on the influence factors weather conditions, utilisation / provision of information and the incentives for action. It was considered whether the influence factors alone or only in combination lead to the acceptance of the option for action. The possible combinations are listed in table 7 in part. In this way, based on these possible combinations the decision-making behaviour could be determined. Thus, it was able to determine that passengers will only accept the alternative train connection if a seating guarantee and an upgrade to first class are offered as an incentive for action (exemplified in bold in table 7).

Table 7. Combination possibilities of the additionally requested influencing factors.

Combination possibility	Weather conditions [good; bad]	Utilisation [high; low]	Seat guarantee [no; yes]	Upgrade to first class [no; yes]	Voucher (e.g. free coffee) [no; yes]
1	good	high	no	no	yes
2	good	high	no	no	no
3	good	high	no	yes	yes
4	good	high	no	yes	no
5	good	high	yes	no	yes
6	good	high	yes	no	no
7	**good**	**high**	**yes**	**yes**	**yes**
8	**good**	**high**	**yes**	**yes**	**no**
…	…	…	…	…	…
$2^5 = 32$	**bad**	**low**	**yes**	**yes**	**no**

The total percentage of correct assignments is 77.7% (situation 1) and 63.6% (situation 2). The comparison is given in table 8. A huge inaccuracy could be pointed out concerning the prognosis of the rejection of the option for action in case of cancellations. The decision-making behaviour of individual passengers in these incident situations is contrary and can only be predicted to a limited extent with the influencing factors stored.

Table 8. Forecasted decision-making behaviour with passenger groups.

	Situation 1 (train cancellation)			Situation 2 (capacity utilisation problem)		
	|--------Prognosis----------|		Percentage of the correct assignment	|--------- Prognosis ---------|		Percentage of the correct assignment
Survey	Rejection	Acceptance		Rejection	Acceptance	
Rejection	460	3061	13.1 %	4145	3061	57.5 %
Acceptance	403	11596	96.6 %	2570	5712	69.0 %
		Total percentage:	77.7 %		Total percentage:	63.6 %

An improvement in the accuracy of the predicted decision-making behaviour results in consideration of all relevant influencing factors, without the formation of groups of passengers. The results are shown in table 9. From the results, it can be deduced that a comprehensive gathering of influencing factors, for example with the help of a corresponding smartphone app may have positive effect on decision making process.

Table 9. Forecasted decision-making behaviour without passenger groups.

	Situation 1 (train cancellation)			Situation 2 (capacity utilisation problem)		
	|--------- Prognosis ---------|		Percentage of the correct assignment	|--------- Prognosis ---------|		Percentage of the correct assignment
Survey	Rejection	Acceptance		Rejection	Acceptance	
Rejection	1131	2223	33.7 %	4522	2351	65.8 %
Acceptance	546	10980	95.3 %	2094	5881	73.7 %
		Total percentage:	81.4 %		Total percentage:	70.1 %

As no tracing of the necessary influencing factors of the passengers takes place in the current railway operation, the results of the regression analyses according to table 6 were used in the further course.

5. Findings

5.1. Decision-making behaviour of passengers

Based on the conducted examinations, the decision-making behaviour of passengers can be estimated in the case of an incident. According to incident situation the investigated groups of passengers have different probabilities of acceptance. The probability of acceptance is shown graphically for each passenger group depending on a gain of travel time or a loss of travel time in Fig. 3 and Fig. 4. In addition to the influencing factors from the passenger group, the data in Fig. 3 and Fig. 4 are based on the number of transfers (2 transfers), the mobility impairments (no mobility impairments), the incentives for action (no incentives for action) and the weather conditions (good weather conditions). Except for the gain of travel time for situation 1 in Fig. 3 and the travel time losses for situation 2 in Fig. 4 all influencing factors remain constant. Situation 1 shows a degressive curve, the curve progression in situation 2 is regressive. This difference between these situations can be justified by the regression coefficients, since the influence of the time factor in situation 1 is 10 times higher than in situation 2.

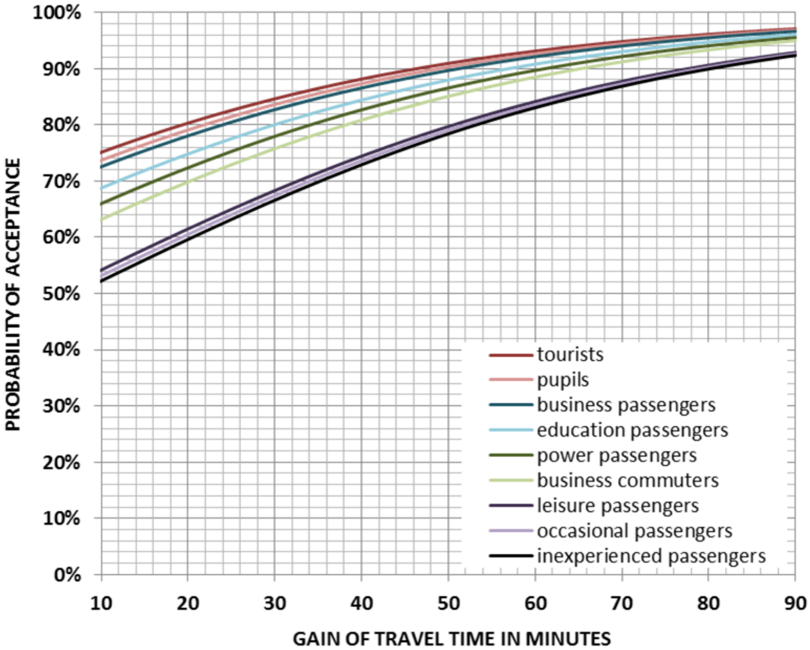

Fig. 3. Probability of acceptance of passenger groups for incident situation 1.

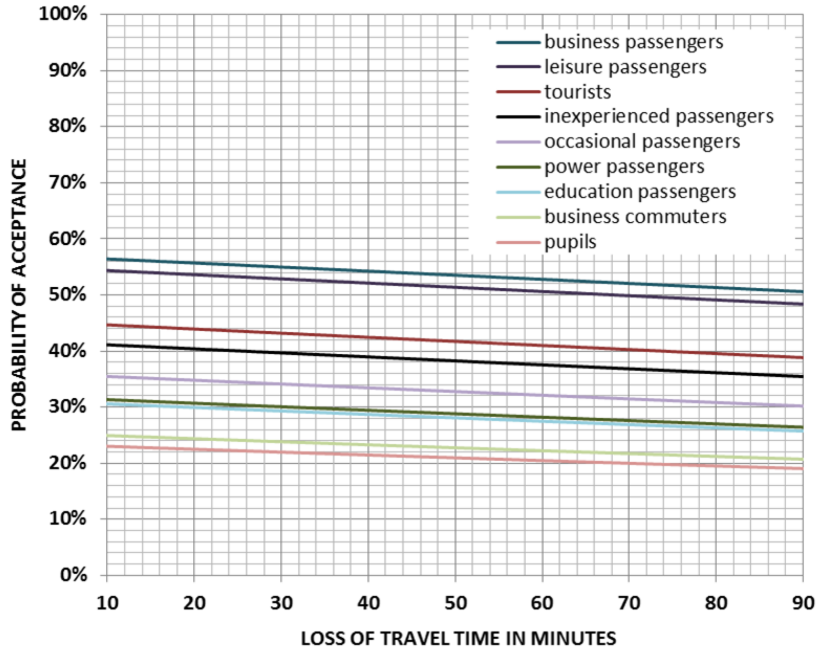

Fig. 4. Probability of acceptance of passenger groups for incident situation 2.

In Fig. 5 and Fig. 6, the change in the probability of acceptance of the passenger group business commuters is illustrated by varying the number of transfers and defining luggage as a mobility impairment. As the number of transfers increases, the probability of acceptance of the proposed alternative train connection decreases.

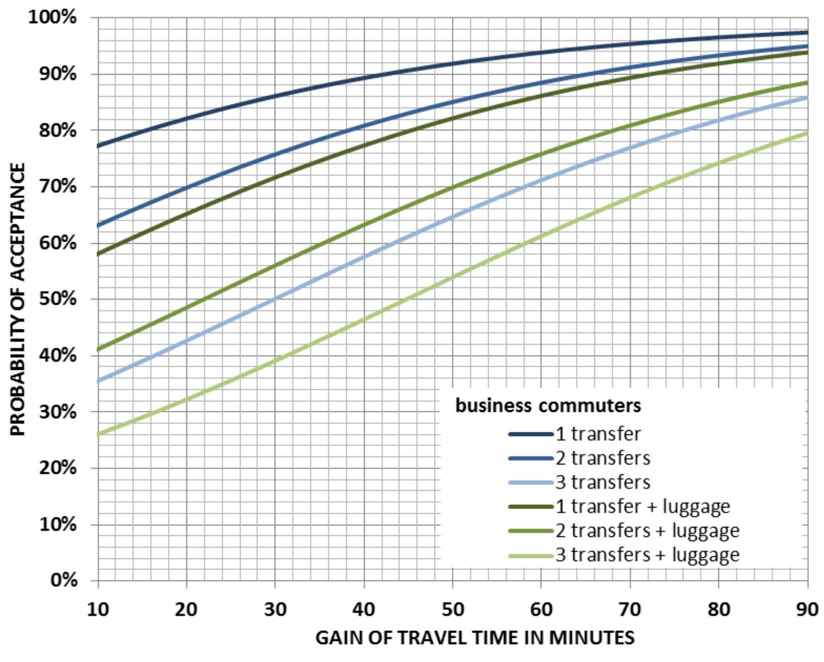

Fig. 5. Probability of acceptance of business commuters for incident situation 1.

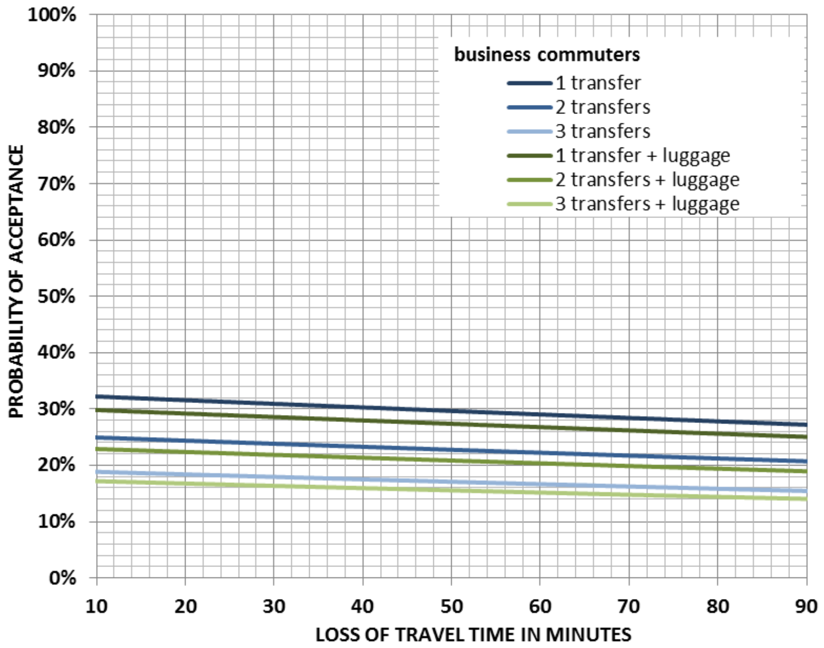

Fig. 6. Probability of acceptance of business commuters for incident situation 2.

To be able to direct passenger flows in a targeted and efficient manner for incident situations, the influencing factors on the decision-making behaviour must be known in detail. Passenger groups of inexperienced passengers, occasional passengers and leisure passengers are only partially influenced by train cancellations compared to the other passenger groups and remain with a higher probability on the platform to use the next regular train connection. On the other hand, these passenger groups and business passengers are more likely to focus on a later alternative train connection in the case of capacity utilisation problems. The reason for this behaviour can be found in the reduced time pressure and increased comfort requirements.

Since capacity utilisation problems occur especially during peak hours and since at this time of the day mostly passenger groups with increased time pressure (pupils, education passengers, business commuters) are travelling, measures will be accepted to a limited extent. However, additional incentives for action can be used to reduce peaks in demand. Even by an early provision of information to the passengers leads to an increase in the probability of acceptance.

The success of the Dynamic Passenger Guidance in Rail Transport depends on the information about the current passenger flows. An important factor is the knowledge about the composition of the passenger flow as well as other influencing factors, such as mobility impairments. A continual survey can already record essential characteristics. By using automated data-collecting systems (e.g. by using an appropriate smartphone app), passengers can be guided efficiently in the case of incidents and the negative impacts can be reduced in the future.

5.2. Guidance of passenger flows

The effects of an incident can trigger other incidents in other parts of the rail network. This property is referred to as displacement and must be taken into account when guiding passenger flows. Knowledge of decision-making behaviour can also be used to counteract the displacement effects by modifying measures to the degree of compliance. Fig. 7 and Fig. 8 show the effects in the form of the sum of waiting time and the sum of transportation time of passengers depending on the degree of compliance for a hypothetical case of a train cancellation.

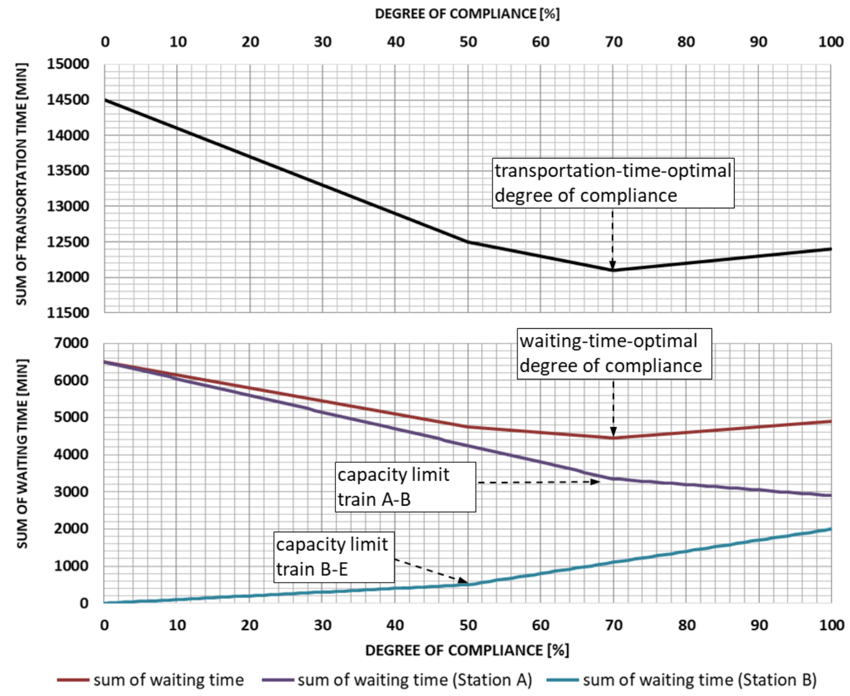

Fig. 7. Degree of compliance: waiting-time-optimal = transportation-time-optimal.

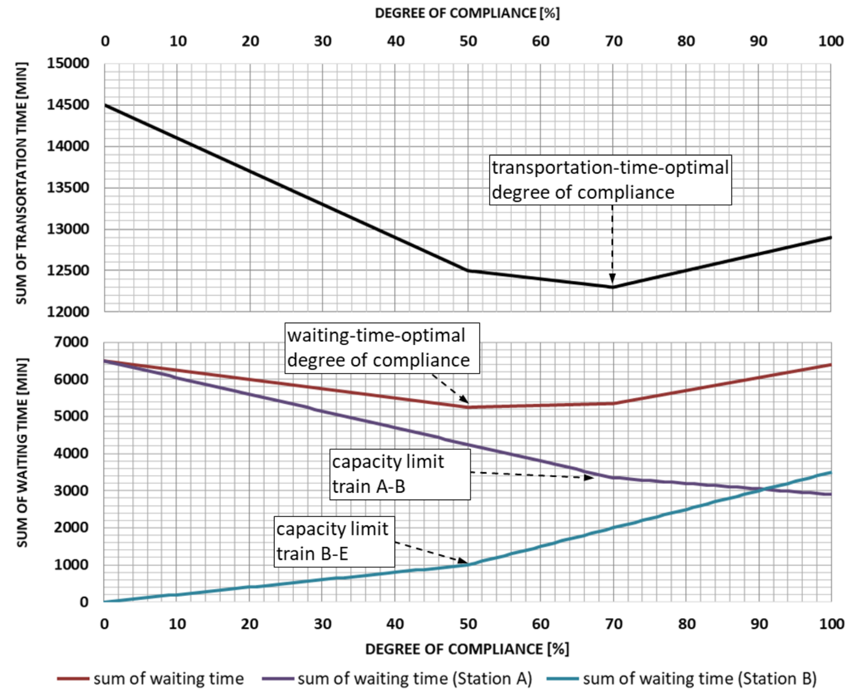

Fig. 8. Degree of compliance: waiting-time-optimal < transportation-time-optimal.

Assuming that all passengers wait for the next regular connection of the planned itinerary this results in high waiting and transportation times (no compliance). As compliance increases, the impact of the incident can be reduced for all passengers. However, the benefits of guiding passenger flows to an alternative connection are dependent on the existing capacities. The emergence of utilisation problems on the alternative connection (displacement effect) generate further waiting and transportation times. A high degree of compliance is therefore not necessarily the best solution.

Decision-making behaviour can already measure the impact of the measures during the selection of measures. For this purpose, suitable target values have to be defined, such as a minimum of waiting time, a minimum of transportation time or a minimum duration of the incident. The desired degree of compliance ultimately results from the defined target value, so that, for example, a waiting-time-optimal degree of compliance or a transportation-time-optimal degree of compliance can be achieved. As shown in Fig. 7 and Fig. 8, a balance between these targets may be required.

6. Conclusion

The decision-making behaviour of passengers was analysed in this project to ensure efficient handling of passenger flows in public passenger rail transport, even in incident situations. A regression analyses function was used to determine the probability of acceptance. The necessary influencing factors were previously obtained via passenger survey. The accuracy of the results depends on the number of influencing factors. However, as the influencing factors of passengers are not fully known, they have been grouped into stereotypical passenger groups, whereby the function can be used for further field trials. Any existing mobility impairments, as well as the impact on travel time and the number of transfers, are relevant to decision-making behaviour. Incentives for action can be used to increase acceptance and thus to increase the probability of acceptance. An early provision of information also has a positive effect on the acceptance of measures.

The probability of acceptance of the individual passengers or the individual groups of passengers is different. Passengers who commute to work or travel to their training facility are less flexible and prefer the faster train connection if they need to reach their destination in time. Possible comfort losses are accepted. In contrast, passengers who travel for leisure or pursue personal activities have a higher need for comfort. The passenger groups of inexperienced passengers, occasional passengers and leisure passengers can be accordingly more easily influenced in case of capacity utilisation problems to reduce peaks in demand.

The simulation models that are established in this project based on the regression coefficients allow forecasting passenger flows in case of an incident even before the implementation of measures. Since influencing factors are not entirely known, further assumptions have to be made, for example concerning the composition of the passenger flow. Forecasting decision-making behaviour can achieve a targeted and efficient implementation of Dynamic Passenger Guidance in Rail Transport. Passengers can be specifically influenced and can be guided accordingly. The desired target values, such as a minimum transportation time of the passengers or a minimum duration of the incident, are to be determined in advance and the measures are to be selected based on the effects of the target values. The implementation of a consistent Dynamic Passenger Guidance in Rail Transport is ultimately ensured.

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