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Passenger Acceptability of Teleoperation in Railways

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Abstract: In this survey-based study, passenger awareness and acceptability of potential teleoperation services in the railway domain were analyzed. The literature on the important factors for the acceptability of automated transport was reviewed. These factors were adapted to teleoperation in the railway domain. An online survey was conducted for obtaining passengers' views on automated rail transport and the remote control of trains. A choice-based conjoint analysis was conducted to obtain user preferences regarding a potential teleoperation service. Overall, the teleoperation system and its capabilities received positive feedback. While increased resilience and reliability of rail services were identified as potential opportunities for higher acceptance, safety and security concerns of prospective passengers were highlighted as influencing factors.

Keywords: railways; remote operation; acceptability; conjoint analysis; passengers; teleoperation

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1. Introduction

The growth in rail passengers and freight traffic demand is resulting in the need for improvements in existing railway operations. Automation systems such as those enabling Automatic Train Operation (ATO) are considered as a solution to this challenge. Driverless metros are already being implemented in various cities around the world. However, mainline passengers and freight operations bring different challenges due to being more prone to external disturbances. Remote control of trains can be a potential application to increase the resilience of railway operations. Remote operation (or teleoperation) allows for supervising and controlling automated trains and intervening remotely in case of disruptions. In the event of a failure, a remote operator can interact with the system remotely, communicate with other stakeholders—technical and human—and drive the train remotely.

Before developing and implementing such systems, the requirements and preferences of prospective users must be analyzed to avoid developing systems which are not acceptable. Acceptability and acceptance can be distinguished. The former refers to the potential judgement on acceptance before using the technology and the latter describes the judgement after using it [1]. Since teleoperation is currently not an alternative transport option in the railway domain, acceptability is the focus of the presented study.

The paper is structured as follows. Previous research on the acceptance of automated transport and the determinants of public acceptance are discussed on the basis of a literature review in Section 2. Section 3 describes the methodology of the analysis. In Section 4, the survey results of public opinion about automated rail transport and teleoperation are presented. Subsequently, the results of a choice-based conjoint analysis, which enable us to investigate future passengers' preferences for the identified attributes, are presented. Finally, the most important findings are discussed in Section 5 and concluding remarks are made in Section 6.

2. Previous Research

A considerable amount of research has been conducted on the acceptance of automated vehicles or automated transport systems. Most of these studies are concerned with driverless cars and road-bound public transport vehicles and shuttles. There are few studies in the area of autonomous rail transport, with research contributions for teleoperation being particularly sparse. In the railway domain there are several studies and demonstrations on teleoperation. These studies have investigated the use of different data transmission technologies [2], the interaction between the operator and assistance systems [3,4], the operational design of the teleoperation system [5,6], and safety and security risk analyses [7]. A pilot site in the Drive2theFuture project investigates user acceptance of teleoperation from the operator's perspective [8]. To our knowledge, there are no studies that investigate teleoperation in railways from the consumer perspective.

Considering rapidly increasing numbers of driverless systems, high awareness and acceptance levels of such systems are often reported in the literature. Various studies recorded high levels of interest in owning Level 4 Autonomous Vehicles (AV) [9], high levels of willingness to use autonomous public transport in the future [10], and high acceptance of unattended trains [11]. The latter study reported that autonomous rail-bound means of transport are preferred to autonomous non-rail-bound means of transport [10]. However, there are several important concerns and challenges regarding the safety and security of autonomous rail transport [12]. Besides several technical challenges, acceptance of unattended rail operation on the part of passengers is critical.

Another study identified several acceptance factors in two levels [13], micro-level and meso-level. Micro-level factors are individual difference factors such as sociodemographic factors, and meso-level factors are related to the exposure of individuals to AVs, domain-specific system evaluation, and social influence and moral aspects. Trust in automation technologies is a strong predictor of AV adoption [14]. Perceived risk is closely related to trust, safety, and security, and thus would affect people's acceptance of AVs [15]. A 2019 study reported that the presence and responsibilities of an onboard employee influence transit users' initial willingness to ride in driverless buses [16]. A passenger survey showed that the majority of respondents would prefer to see a driver or a driver cabin in a driverless train to help users adapt to new systems [17]. Service quality factors such as travel time, waiting time, and travel cost are important factors for the acceptance of automated transport services [18]. Prior experience with automated transport systems positively affects user acceptance [10] and feedback on security and safety [19]. Current technology awareness was shown to increase the interest in AV adoption and willingness-to-pay [9]. A wider list of determinants behind the acceptance of automated vehicles can be seen in the review of Becker and Axhause, 2017 [20].

Since teleoperation in railways is not yet an alternative within the transport sector, passenger choices cannot be observed yet. Therefore, stated choice-based analysis can be conducted to obtain user preferences regarding transportation services. Choice-based conjoint (CBC) analyses are widely used in many areas including transportation [21]. Alternatives within teleoperation can be defined by various attributes and the respective levels. Conclusions can be drawn about the importance of the individual attributes by systematically varying these factors in a repeated set of choices.

Maas, 2021 conducted a CBC analysis on various combinations of mobility services in Dresden by using attributes such as type of public transport passes and extent of use [22]. In another study, choice-based conjoint analysis was performed to understand travelers' preferences concerning a ridepooling system [23]. According to these results, fare was the most important service attribute, especially for younger participants. Consumer preferences for teleoperated robotaxis were investigated using choice-based conjoint analysis [24]. That analysis revealed that price was the most important attribute, followed by the possibility of intervention, pilot, and interior monitoring. Some of the attributes used in this study were adapted to rail transport and applied in the present study.

3. Materials and Methods

An online survey was created for the data collection with the use of identified factors that have the potential to influence passenger opinion. The survey was prepared in English and German. Survey questions aimed to encompass these factors for the driverless trains and teleoperation in railways.

The first part of the survey was concerned with autonomous rail transport in general. The respondents were queried regarding their views on the quality attributes of rail transport. Information regarding technology awareness and prior experience with automated vehicles was also collected. Questions on attitude and preference regarding driverless trains and automated operations were asked. The second part of the questionnaire included questions regarding teleoperation in railways. Factors that are important for the implementation of teleoperation were assessed by the participants. At the end of the questionnaire, sets of options were included for the choice-based analysis.

The respondents were informed about the proposed teleoperation system prior to the survey questions. The teleoperation service defined in the study was limited to the use case of a fallback system for driverless trains. According to this use case, railway operation runs in fully automated mode in regular operation. In cases of a system disruption where the train cannot continue the journey by itself, an operator in a remote-control center can intervene. Some examples of remote operator tasks are failure diagnosis, manual driving, and communication with passengers. For the choice-based questions, a scenario was defined for the purpose of informing the respondents about the operational situation. The scenario included a train journey with a duration of around two hours. A journey with the IC train between Berlin and Dresden was used as a reference.

Based on a literature review, five relevant attributes of the operational concept of teleoperation systems were determined (Table 1). For each attribute, two or more levels were identified. Several assumptions were employed when determining the attribute levels. Respondents were informed that part of the journey would be condicted by a remote driver. Assuming that the teleoperation takes place in cases of emergency for our scenario, the maximum duration between the stations in the reference ride was 30 min. Therefore, 30 min. was selected as the attribute level of duration. For the ticket price attribute, the reference price for the time of the study design (25 €) and a 32% reduced price were considered. Price reduction was assumed to be the result of potential lower costs in higher automation levels, an expectation in line with the literature. However, the accurate estimation of a potential reduction is outside the scope of this analysis. For the study design, a D-optimal factorial design with 12 choice profiles was used with the help of XLSTAT software version 2022.3.1 [25].

Table 1. CBC attributes and attribute levels.

Attributes	Levels
Remote driver	Human Driver A.I. under human supervision A.I.
Surveillance	Always During remote control Only after passenger activation
Communication	On-board announcements Interactive communication device Steward on-board
Ticket price	€25 €17
Remotely driven duration	>30 min <30 min

Each choice set included three answers: the two options and one none-of-these option. Figure 1 shows an example of a choice set.

(1) Please select your preferred option.

Category	Option 1	Option 2
Remote driver	Artificial Intelligence	Human driver
Surveillance	During remote control	During remote control
Communication	Steward on board	Interactive screen/button
Ticket price	17.00 €	17.00 €
Remotely driven duration	>30 min	>30 min

○ Option 1 ○ Option 2 ○ None of these

Figure 1. An example of a choice set.

4. Results

One-hundred-eighty-six people completed the online survey (Appendix A). Young people (<34) and people with higher education (77% with a bachelor's degree or higher) are overrepresented. This is mainly due to the method of data collection. The reach of the survey was limited to online survey users who speak English or German. The majority of responses came from Germany (61%), while 22% came from other EU-countries and 17% from the rest of the world. 96% of the respondents had a high-income country of residence, while only 8 respondents were in a low- or middle-income country according to the World Bank classification [26].

Twenty-two percent of all the respondents think they are early adopters of technology products, while 13% consider themselves among the last. Awareness of automated transport technology was relatively high. Ninety-four percent of all the respondents had heard of automated vehicles (AV), and 43% of those had personal experiences with AVs. These were mostly with driverless urban rail systems. However, only 56% had heard of teleoperated vehicles prior to this survey. Descriptive statistics are given in Appendix B.

4.1. Automated Trains

The Figure 2 below shows the distribution of responses regarding the importance of several aspects in rail transport. All factors were considered important by the respondents, but reliability and safety received the highest proportion of positive answers. The least crucial factors were sustainability and comfort.

Attitudes towards driverless trains were rated positively by the majority. Sixty-five percent of the respondents support the implementation of driverless trains. In order to analyze the effect of prior experience with AV and awareness of teleoperation technology, the responses to the attitude towards driverless trains were compared between the two groups. The group labeled "AV-experienced" has respondents with prior experience with an automated vehicle or system and those who had heard of teleoperation technology prior to the survey. The distribution of answers is given in Figure 3 below. In total, 71% of this group have a positive attitude, while this value for the other group is 63%. More importantly, the AV-experienced group has three times more respondents that strongly support the implementation of driverless trains.

Another question inquired about passengers' views on the importance of rail personnel for rail operations. Figure 4 shows that around half of the respondents think that train drivers are not crucial for the operation of rail services. This is in line with the results of the support for driverless trains. However, the presence of an onboard staff is highly preferred. The respondents still prefer GoA-3 systems (53%) over GoA-4 systems (13%).

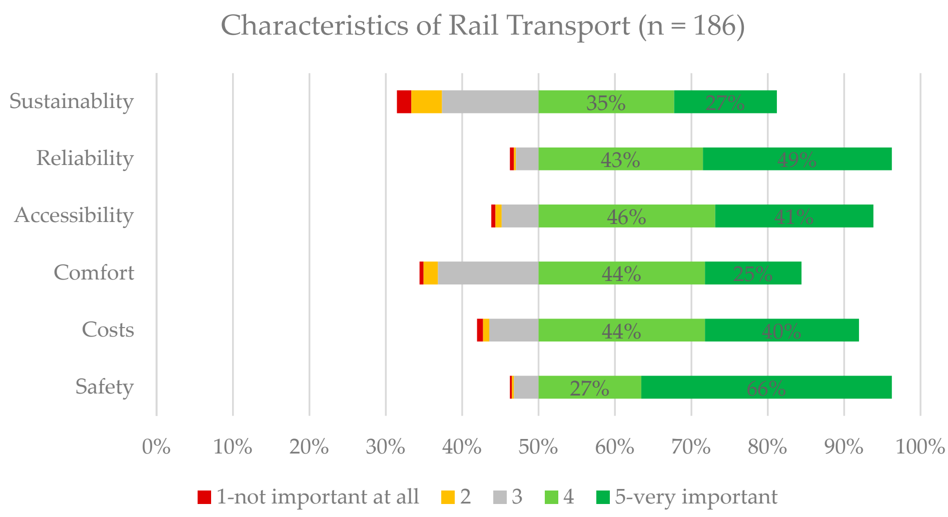

Figure 2. Important aspects of rail transport.

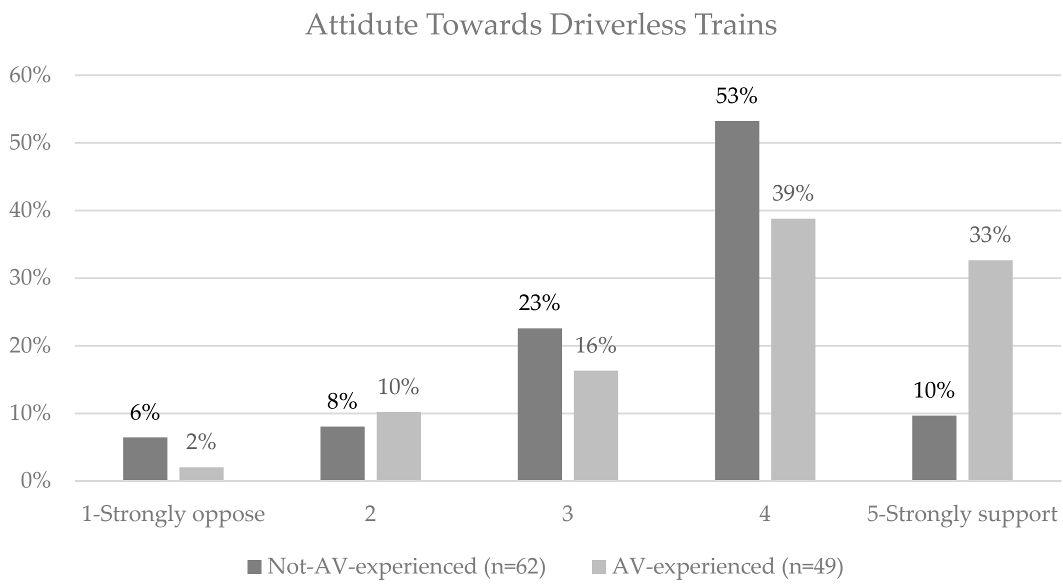

Figure 3. General opinion towards driverless trains.

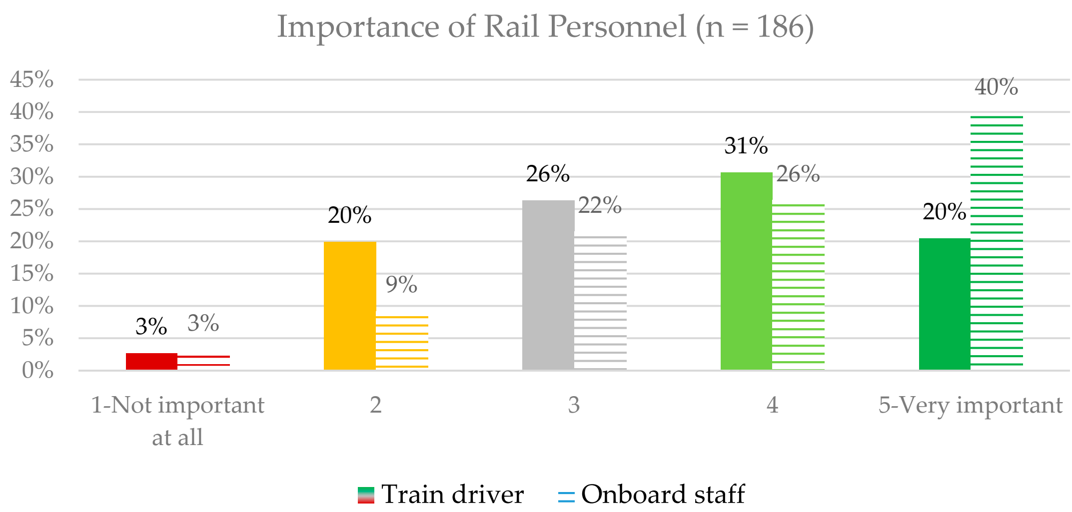

Figure 4. Importance of rail personnel for rail operations.

4.2. Teleoperation

The importance of the factors regarding the implementation of teleoperated trains was evaluated by the respondents. Potential aspects of teleoperation were determined with reference to the frequently discussed benefits of railway automation in the literature. These benefits include, among others, operational efficiency, cost savings, and stability of the schedule [27]. Therefore, this survey question aims to explore the importance of aspects that can influence respondents' preferences for future systems. Whether or how teleoperation can achieve these goals is outside of the scope of this study.

Reduced delays caused by disruptions are rated highest in terms of importance, while lower ticket prices seemed to be the least important determinant in choosing this railway system as the preferred option (Figure 5).

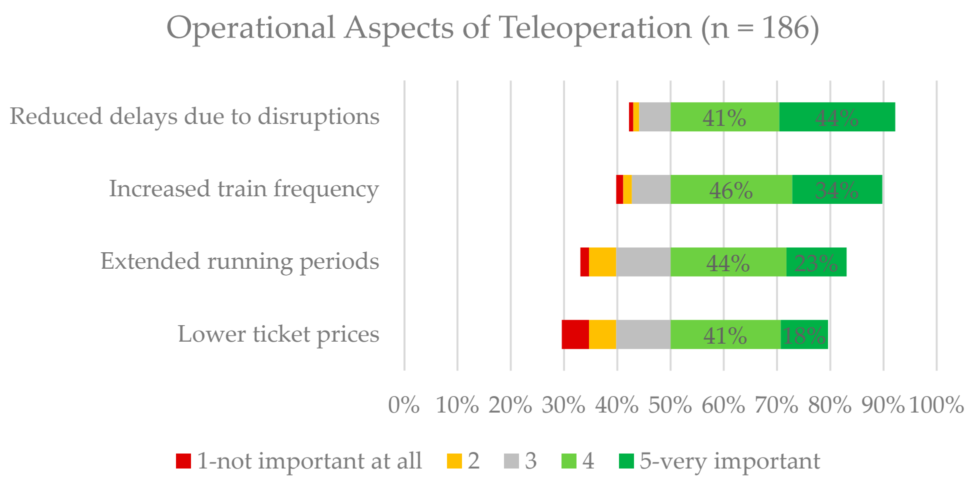

Figure 5. Factors that would influence passengers for considering teleoperation as preferred option.

The aspects of teleoperation were analyzed with regard to the age of the respondents (Figure 6). Two age groups were defined for probing the effect of age on importance rates: a younger group under 25 years ($n = 74$), and an older group over 35 years ($n = 50$). The age group of 25–35 was excluded in order to consider extreme ends of the age spectrum within the dataset. Younger respondents attribute higher importance to lower ticket prices for the implementation of teleoperation (H statistic = 6.5867, (1, $n = 122$), $p = 0.01027$). Even though the importance of reduced delays is rated highest by both groups, this seems much higher for younger people (H statistic = 5.081, (1, $n = 122$), $p = 0.02419$).

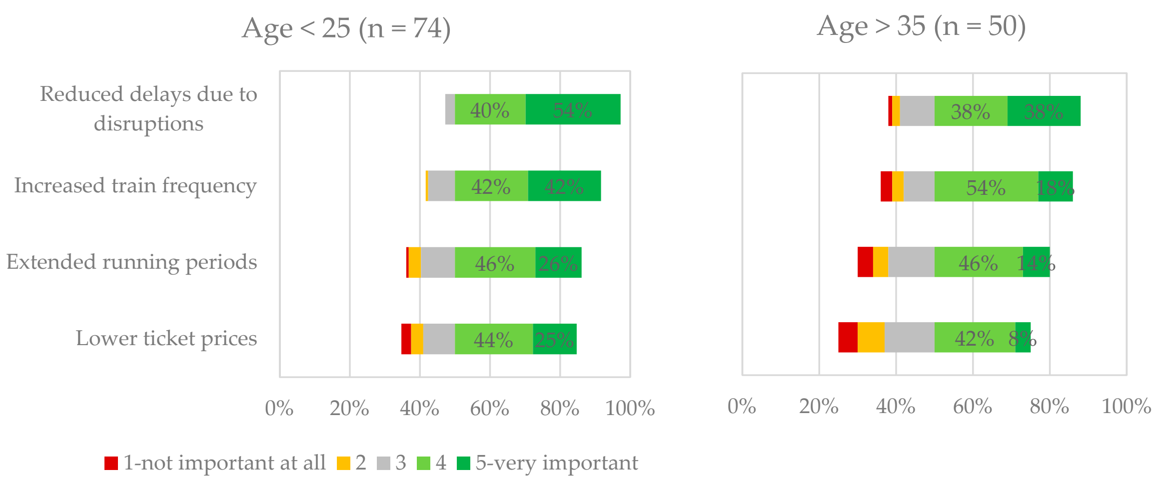

Figure 6. Importance of the Operational Aspects of Teleoperation per age.

Acceptable safety levels were inquired with comparison to the safety perception of the current systems. The respondents were divided into two country classes, Germany and others, in order to compare the public opinion in Germany with the rest of the respondents. Figure 7 shows the answers of the respondents from Germany and from other countries. The respondents in Germany have lower safety requirements, with 34% thinking it is acceptable to have the same level of safety as the trains of today. Nevertheless, 43% expect fewer accidents from new systems. On the other hand, 39% of the respondents in the other category expect much fewer accidents (i.e., reduction by half or more) from driverless vehicles with a teleoperation fallback. The Kruskal–Wallis test (KW) showed that the difference between the groups was statistically significant ($\chi^2(2) = 6.984$, $n = 186$, $p = 0.008$).

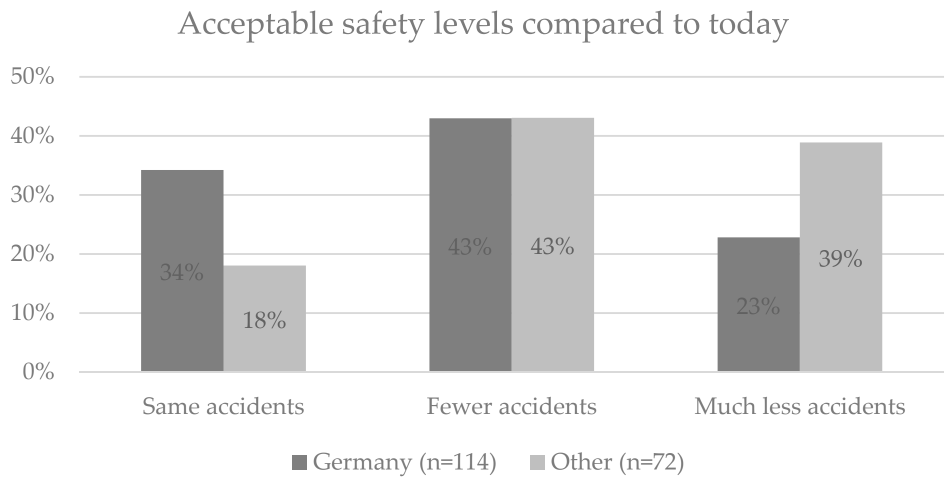

Figure 7. Acceptable levels of safety for driverless vehicles with remote operation as fallback system.

The last question of the first part of the survey collected responses to statements on several aspects of teleoperation. Figure 8 below shows the distribution of answers. Statement 4 has the most equally distributed responses compared to the other statements. Thirty-three percent of respondents are unsure about the state of the technology for safe teleoperation, and 30% think the current state of technology would not be sufficient. The majority of the respondents (68%) think that the use of a remote operator for fallback level is a good idea. However, only half of the respondents think teleoperation can reduce delays caused by disturbances. The threat of cybersecurity is another aspect that people mostly agree on.

Country-wise comparison resulted in significant differences only for statements 4 and 6. The Kruskal–Wallis H test indicated that there is a significant difference across country of residence at 95% confidence level for statement 4 (H = 9.035, n = 114-72, p = 0.0027) and statement 6 (H = 5.97, n = 114-72, p = 0.0145). Parallel to the results of the acceptable level of safety, responses to statement 6 indicate a higher trust of the automated system in Germany compared to the other group (Figure 9). These statements did not differ significantly between younger and older age groups.

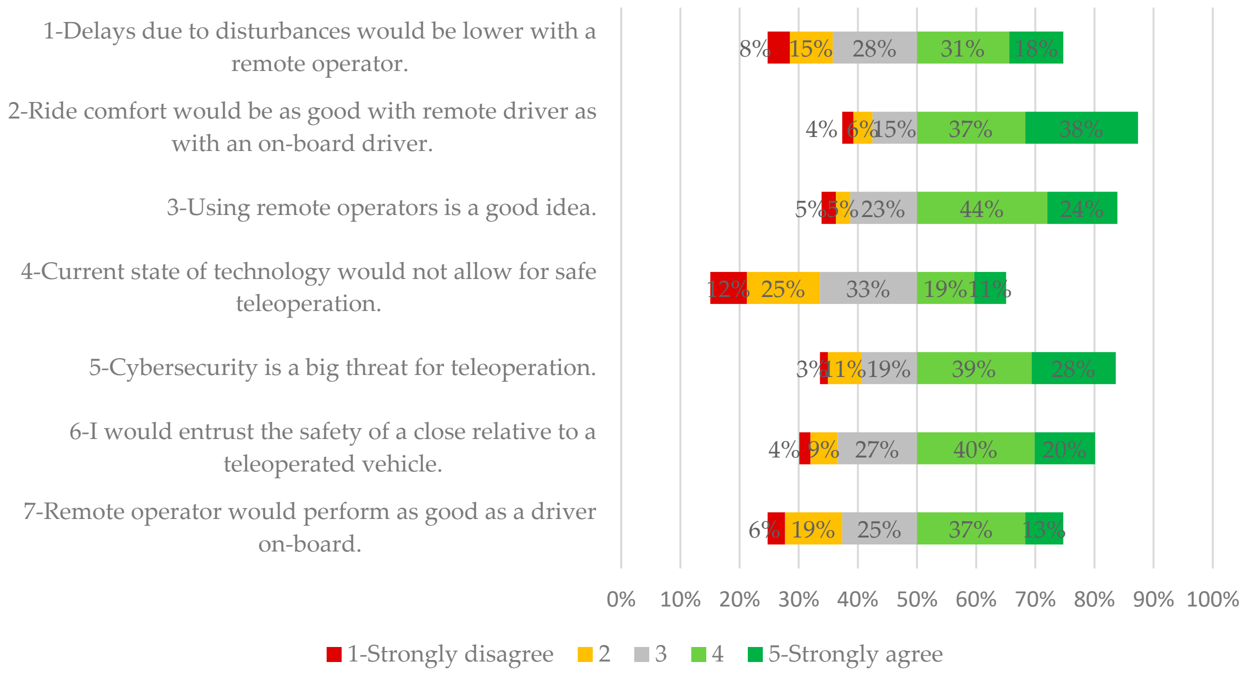

Figure 8. Passenger statements on teleoperation in railways.

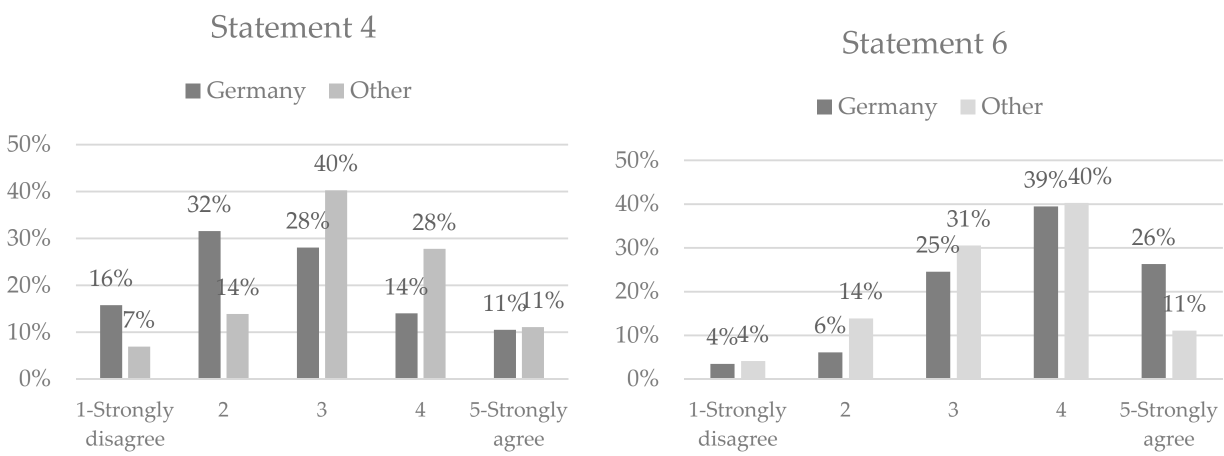

Figure 9. Statements on technology capability (**left**) and trust in the system (**right**).

4.3. Choice-Based Conjoint Analysis

The table below (Table 2) shows the utilities of the attribute levels. For most of the attributes, the signs and relative magnitudes of the parameter values are reasonable. For example, the higher ticket price attribute has a negative and lower utility. However, contrary to expectations, the longer duration of the remote driving option received higher utility value in the respective attribute. In the attribute of remote driver types, the level of automated remote driving received the highest utility value (0.682). The highest utility within the surveillance type is the level of surveillance during teleoperation rather than continuous surveillance. According to the choice analysis, a communication system consisting of an interactive interface is preferable to the presence of a steward on board. The attribute level none-of-these indicates the high utility of an alternative that is not captured by the analysis.

Table 2. Aggregated utilities of CBC attribute levels.

Attribute	Levels	Utility	Std. Dev.
Remote driver	A.I.	0.682	0.077
	A.I. under human supervision	−0.477	0.100
	Human driver	−0.205	0.079
Surveillance	Always	−0.320	0.107
	During remote control	0.606	0.105
	Only after passenger activation	−0.286	0.098
Communication	Interactive device	0.242	0.085
	Onboard announcements	0.089	0.077
	Steward onboard	−0.332	0.060
Ticket price	€17	0.147	0.028
	€25	−0.147	0.028
Remotely driven duration	<30 min	−0.305	0.050
	>30 min	0.305	0.050
None-of-these	-	−1.520	0.084

The results of the relative importance of the attributes are given in Figure 10. The type of remote driver had the highest relative importance on the overall judgement of the teleoperation services (32.5%). The ticket price attribute had the lowest relative importance (8.2%). The type of surveillance (26%) for remote operations was rated more important than the type of communication channels (16.1%). The differences between the two age groups in terms of attribute importance are given in Figure 11 below.

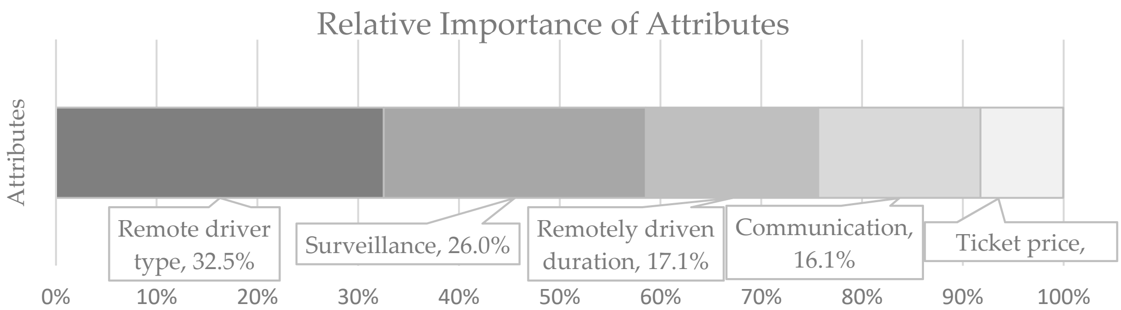

Figure 10. Relative importance of attributes.

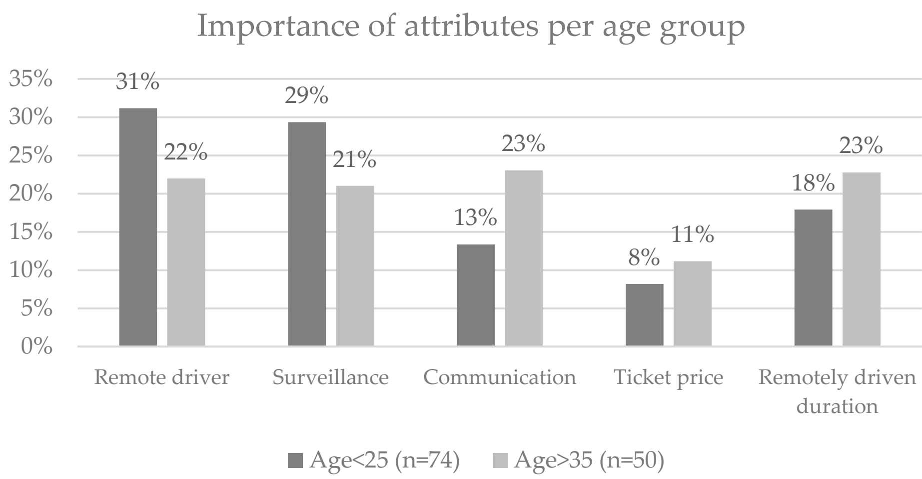

Figure 11. Relative importance of attributes for younger and older groups.

5. Discussion

Support for the implementation of highly automated rail transport is high among respondents, as often seen in the existing research literature. This is especially true for those who have previous experience with automated vehicles. Even though driverless operation is supported by many, the presence of onboard personnel is highly preferred. This preference is also in line with previous research. Factors such as personal security in automated vehicles as well as the need for assistance for disabled individuals might have played a role in this result. Additionally, the GoA-3 operation is preferred over the GoA-4 operation. This highlights the importance of human intervention from the passengers' perspective. Teleoperation with human operators as a fallback layer has the potential to increase the acceptance of this system, especially in the transition period.

Respondents rated reliability and safety highest among the identified service quality aspects of rail transport. This is important, as remote operation has the potential to increase operational reliability by fast recovery after disruptions. Reduction of delays due to disruptions is considered as the most important factor to justify implementation of teleoperation, especially among young passengers. Ticket price was considered more important by younger passengers.

The importance of safety was observed in multiple indicators. The majority of respondents demand increased safety levels from automated rail transport and remote fallback operation. The survey results revealed that trust in the system is an important factor to be addressed. Trust in the system and in acceptable safety levels showed differences between Germany and the other countries. This indicates that local differences in safety perception must be taken into consideration for the implementation of these systems. Additionally, passengers with prior experience with an automated vehicle are more supportive of the implementation of driverless trains. Cybersecurity is one of the common concerns regarding teleoperation.

The type of remote driver and the surveillance of the operation are very important according to the CBC analysis. Continuous surveillance of the vehicle during remote control is preferred by respondents. Perceived risk and potential threats to personal security might have played a role in this rating. Even though the respondents reported that onboard staff are still crucial, choice analysis suggests that, given the choice, passengers would instead prefer an automated and interactive communication channel.

It should be noted that the number of respondents (186) and the representation of the whole population through the sample (in terms of age, education level, etc.) impose limitations for this study.

6. Conclusions

Even though the teleoperation service for railways is currently not available to the public, a few trends can be identified by analyzing the study results. Overall, the teleoperation system and its capabilities received positive feedback. The results of this questionnaire and choice-based conjoint analysis reveal several aspects that are important for the acceptability of teleoperation. Future implementation plans should address perceived safety, security, and trust concerns. Demographic aspects such as age, country of residence, technology awareness, and prior experience with AVs could influence the acceptance of these systems. Teleoperation as a fallback system provides an opportunity for increasing the resilience and reliability of rail systems, as agreed by most of the respondents.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Detailed profile of survey respondents.

Respondent Profile	#
Education level	
Min Bachelor's	144
Less than Bachelor's	42
Gender	
Male	100
Female	81
Other	5
Heard of AVs	
Yes	174
No	12
Experience with AVs	
Yes	80
No	106
Heard of Teleoperation	
Yes	104
No	82
When it comes to trying new technologies, I am . . .	
Among the first	40
In the middle	121
Among the last	25
Age	
under 18	4
18–24	68
25–34	64
35–44	24
45–64	26

Table A2. Transport mode choice.

Transport Mode Choice	Commuting	Business Travel	Leisure/Social	Errands	Vacation
Passenger car/motorcycle	29%	20%	29%	33%	28%
Public transport	23%	20%	17%	12%	12%
Taxi	4%	8%	4%	2%	4%

Table A2. *Cont.*

Transport Mode Choice	Commuting	Business Travel	Leisure/Social	Errands	Vacation
Bicycle/walking	32%	5%	36%	46%	10%
Airplane	1%	19%	4%	1%	34%
Ship	1%	2%	3%	0%	8%
Sharing services	1%	2%	6%	3%	2%
I don't take such trips	8%	24%	1%	2%	2%

Appendix B

Table A3. Descriptive statistics.

					Quantiles		
Items	**Mean**	**Median**	**SD**	**CI**	**25%**	**50%**	**75%**
Important aspects of rail transport							
Safety	4.56	5	0.687	0.099	4	5	5
Costs	4.19	4	0.839	0.121	4	4	5
Comfort	3.88	4	0.866	0.124	3	4	4.75
Accessibility	4.25	4	0.780	0.112	4	4	5
Reliability	4.39	4	0.720	0.103	4	4	5
Sustainability	3.74	4	1.059	0.152	3	4	5
Attitude towards driverless trains	3.67	4	1.063	0.153	3	4	4
Importance of rail personnel							
Train driver	3.46	4	1.106	0.159	3	4	4
On-board staff	3.90	4	1.125	0.162	3	4	5
Operational aspects of teleoperation							
Reduced delays due to disruptions	4.23	4	0.859	0.123	4	4	5
Increased train frequency	4.05	4	0.926	0.133	4	4	5
Extended running periods	3.72	4	1.028	0.148	3	4	4
Lower ticket prices	3.46	4	1.195	0.172	3	4	4
Acceptable safety levels (3-point-scale)	2.01	2	0.757	0.109	1	2	3
Passenger statements							
1-I believe the delays due to disturbances would be lower with a remote operator	3.38	3	1.162	0.167	3	3	4
2-I believe ride comfort would be as good with a remote driver as with an on-board driver	3.99	4	1.065	0.153	3.25	4	5
3-I think that using remote operators is a good idea	3.77	4	1.022	0.147	3	4	4
4-I believe the current state of technology would not allow for safe teleoperation	2.91	3	1.169	0.168	2	3	4
5-I believe cybersecurity is a big threat for teleoperation	3.79	4	1.062	0.153	3	4	5

Table A3. *Cont.*

Items	Mean	Median	SD	CI	Quantiles		
					25%	50%	75%
6-I would entrust the safety of a close relative to a teleoperated vehicle	3.64	4	1.026	0.147	3	4	4
7-I believe the remote operator would perform as well as a driver on-board	3.31	3	1.105	0.159	2.25	3	4

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