Acceptability of Autonomous Trains in Europe: Citizens' expectations and determinants for usage.

Simone Borsci, Sarah Kusumastuti, Julia Lo, Tom Kolkman

Abstract

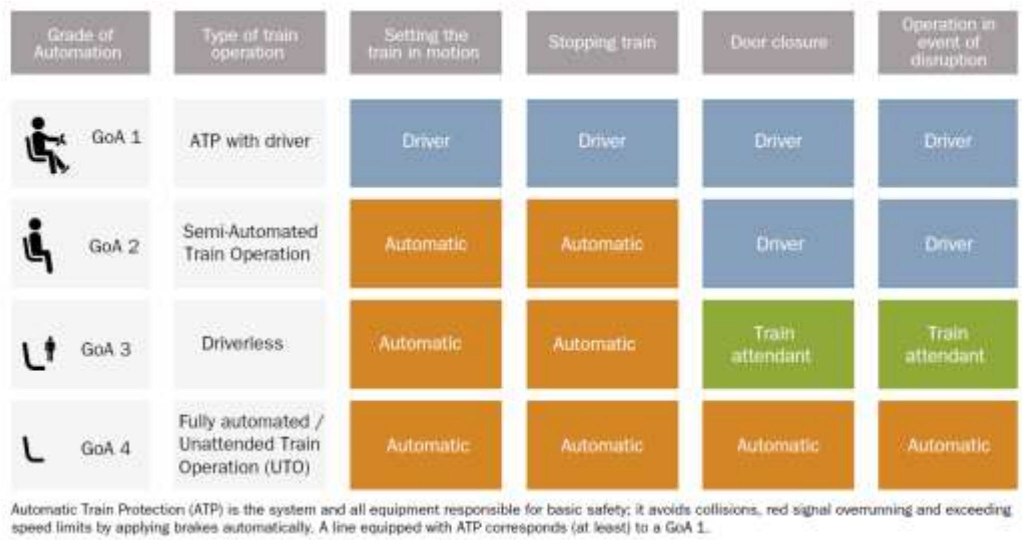
Background: Autonomous Train Operation (ATO) promises improvements in capacity, reliability, and efficiency for European railways. However, successful deployment depends on public acceptance. Building on previous single-country research with varying methodologies, the present study attempted to map the transnational European acceptability of automated rail services. **Methods**: A multilingual online survey was administered to 519 European residents across 23 countries from May to September 2025. The survey assessed demographics, commuting behavior, service quality expectations, attitudes toward automation, and preferences regarding Grade of Automation (GoA) levels. Exploratory factor analysis identified latent constructs related to automation attitudes. Model selection approach was used to identify predictors of five outcome variables: driver preference, GoA preference, deployment support, intention to use, and unemployment concerns. **Results**: Respondents preferred intermediate automation (GoA2: 36%; GoA3: 47%) over full automation (GoA4: 7%). Support for ATO was the strongest predictor of intention to use (OR = 17.72) and GoA preference (OR = 6.32). General fear of autonomous trains substantially reduced intention to use (OR = 0.30). Operator presence is an importance aspect for people to support ATO deployment (OR = 0.60). Nevertheless, acceptance of remote communication tools as an alternative to operator presence, also, increased support towards ATO (OR = 1.44). Cybersecurity concerns were present in the cohort, but participants awearnes of such issues were associated with a positive intention to use autonomous trains (OR = 1.32). Regional differences emerged, with for instance Northern Europeans showing higher deployment support but lower GoA preferences compared to Southern Europeans. **Conclusions**: European citizens show some moderate openness toward autonomous trains, preferring intermediate automation with maintained human oversight. Deployment strategies should emphasize reliability, transparent cybersecurity communication, and quality remote assistance while addressing regional variations and demographic differences in accessibility needs.

1. Introduction

Autonomous Train Operation (ATO) represents one of the most significant developments in rail transport infrastructure, promising substantial improvements in capacity, reliability, and operational efficiency. The railway sector occupies a unique position in the landscape of autonomous transportation: unlike private autonomous vehicles, autonomous trains operate within established public transport systems where passengers must trust not only the technology but also the institutional frameworks governing its implementation. Applying autonomous operations in mainline rail systems presents distinct challenges including longer journey distances, more heterogeneous passenger populations, and operational contexts that vary from high-speed intercity routes to regional services passing through rural communities.

The European Union is investing on a more integrated rail systems across Europe with the ultimate goal of establishing a Single European Railway Area (SERA) that overhauls and harmonises technical standard and infrastructure of railways across Europe through the Europe's Rail Joint Undertaking initiative (Europe's Rail, n.d.). A component of the initiative is accelerating the adoption of ATO in order to increase capacity, efficiency, and sustainability (Litvina, 2019).

Ultimately, the transformation of the rail infrastructure promised by ATO depends on whether citizens will accept, trust, and choose to use autonomous trains. Above manual train operations that is designated as level 0, there are 4 grades of rail automation recognised by the International Association of Public Transport (2016). A representation of the Grade of Automation (GoA) levels is shown in figure 1. As levels of automation become higher, more tasks are delegated to automated systems. The highest GoA level (4) does not require any staff to be present.



Grade of Automation	Type of train operation	Setting the train in motion	Stopping train	Door closure	Operation in event of disruption
GoA 1	ATP with driver	Driver	Driver	Driver	Driver
GoA 2	Semi-Automated Train Operation	Automatic	Automatic	Driver	Driver
GoA 3	Driverless	Automatic	Automatic	Train attendant	Train attendant
GoA 4	Fully automated / Unattended Train Operation (UTO)	Automatic	Automatic	Automatic	Automatic

Automatic Train Protection (ATP) is the system and all equipment responsible for basic safety; it avoids collisions, red signal overrunning and exceeding speed limits by applying brakes automatically. A line equipped with ATP corresponds (at least) to a GoA 1.

Figure 1. Description of Grade of Automation levels in railway operations

Currently, driverless trains (GoA 3 and 4) have seen usage in contexts such as people movers in airports or urban/metro rail, operating in cities across the world from Copenhagen Metro to Mexico City's Aerotrén to Tokyo's Yurikamome Line. Driverless ATO concepts for heavy rail has been less common and often still in trial stages, mainly in the context of freight such as the Rio Tinto iron ore train in Australia (Smith, 2017) and Betuweroute across the Netherlands and Germany (ProRail, 2025). Thus, there is likely a gap in the public perception and understanding of autonomous trains, specifically in the context of passenger rail.

Previous work on passenger research

A key aspect of successfully implementing and deploying autonomous train operations is understanding the expectations of both current passengers and the broader public, including those who use rail services infrequently or not at all (Morast et al., 2023). In fact, the ATO technological shift should not be only oriented at current users but also attempt to consider the needs and expectation of non-users and occasional users that represent a substantial portion of potential future passengers. Expectations towards ATO may differ markedly among citizens based on whether if they are commuters or not as well as their context (Morast et al., 2023; Pakusch & Bossauer, 2017; Fraszczak & Mulley, 2017). Understanding people's expectations, needs, and attitudes toward automation is crucial for developing user-centered solutions. It enables industry leaders to anticipate adoption barriers and supports policymakers in crafting regulatory frameworks and communication strategies that facilitate a smooth transition toward automated rail operations (Arzer et al., 2024; Lemonnier et al., 2023).

In line with previous studies (Cogan et al., 2022; Pakusch & Bossauer, 2017; Lemonnier et al. 2023)), the current work aims to establish the aspects that affect acceptability of ATO, by asking participants to assess their expectation towards the implementation of ATO. Acceptability can be considered an early stage evaluation of the wider construct in the acceptance of technology (Davis, 1989), in which potential future users and stakeholders are expected to express their judgment before they can actually use the technology, based on their current knowledge and their expectations (Pigeon et al., 2021; Schade & Slag, 2003). Identifying factors shaping public acceptability (i.e., acceptance at early stage in the development process) allows stakeholders to proactively address concerns and tailor their service offerings to different user groups' needs. Ultimately, this allows stakeholders to maximize the potential societal benefits of autonomous train technology.

Previous research investigated the passenger acceptability of automated rail employing various methodological approaches, including surveys (Morast et al., 2023; Cogan et al., 2022; Pakusch & Bossauer, 2017; Fraszczak & Mulley, 2017), semi-structured interviews (Lemonnier et al., 2023), focus groups combined with creative problem-solving sessions (Arzer et al., 2024), and Q-methodology for attitude clustering (Detjen et al., 2021). Despite the wide methodological heterogeneity, a range of aspects seems to be consistently identified when investigating passenger expectations of autonomous train technology. For example, the presence of rail personnel on automated trains has emerged as a strong predictor of acceptability in multiple studies. Lemonnier et al. (2023) found GoA3 trains, which have onboard staff, was significantly more likely to be acceptable than fully unattended GoA4 trains. Qualitative interviews revealed that participants associated the absence of onboard staff with feelings of abandonment and vulnerability, especially in emergency situations and with regard to personal safety and medical incidents. This finding was corroborated by Arzer et al. (2024), whose focus groups identified the presence of staff as a key determinant of passenger comfort and perceived safety. The presence of "staff on board" were consistently ranked among the top solutions across all focus groups sessions. Additionally, Fraszczyk and Mulley (2017) found that more than 60% of their participants preferred to maintain a driver's cabin as a visible safety backup in fully autonomous train designs, even when it would serve no practical purpose. Similarly, Cogan et al. (2022) found that, although 65% of respondents supported the implementation of driverless trains, the presence of onboard staff was highly preferred.

Trust in technology, remote communication, and supervision systems is also a critical factor influencing acceptability. Lemonnier et al. (2023) found that, when considering GoA4 scenarios, participants expressed considerable mistrust toward remote communication tools and train supervisors due to the fear that operators would be less engaged, or busy managing multiple trains or unable to fully understand the situation from a distance. Similarly, Arzer et al. (2024) found that participants assessing higher grades of automation expressed concerns about technical failures such as software bugs, sensor malfunctions, and cyberattacks, as well as uncertainty about the system's decision-making capabilities and emergency response in the absence of onboard staff. Detjen et al. (2021) identified various attitudes toward autonomous public transportation, emphasizing that acceptability is not uniform and targeted communication strategies may be necessary. Furthermore, Cogan et al. (2022) reported that cybersecurity concerns were widely shared among public transport passengers especially in relation with highest grade of automation.

Across multiple studies, service quality and expected improvements have emerged as potential facilitators of acceptability. Cogan et al. (2022) identified reduced delays due to disruptions as the most important operational factor for boosting potential acceptance, along with increased train frequency, extended operating hours, and lower ticket prices. Fraszczyk et al. (2015) and Fraszczyk and Mulley (2017) found that safety, price, extended running periods, and increased train frequency were the two most important priorities for passengers. Pakusch and Bossauer (2017) suggested that improved train punctuality is also key to acceptability of ATO based on the expectation that autonomous operations would minimize disruptions.

Commuting behaviour and experience with automation emerged as aspects that might affect expectations and, therefore acceptability, regarding ATO. Morast et al. (2023) found that occasional commuters tend to express a higher intention to accept high automation grades than daily users. Fraszczyk and Mulley (2017) reported that users were in general more positive toward driverless trains than non-users. Pakusch and Bossauer (2017) similarly found that 88% of individuals with prior autonomous transportation experience expressed intention to use autonomous public transport in the future, compared to people without experience with automation. Cogan et al. (2022) found that respondents with any autonomous vehicle experience were three times more likely to strongly support driverless trains than those without such experience, demonstrating the importance of familiarity in shaping acceptability. In general, knowledge and awareness of autonomous train and autonomous technology also influence acceptability. Lemonnier et al. (2023) found that participants had limited knowledge of autonomous trains and frequently relied on comparisons with automated metro systems they were familiar with.

Concerns about employment also seem to impact potential acceptance. Lemonnier et al. (2023) found that job loss was the most frequently mentioned concern in their interviews. Participants reported being aware that automation would likely reduce railway employment, even if some jobs evolved into supervisory roles. Similarly, Arzer et al. (2024) documented participants' concerns about the effects of ATO on employment. These recent insights differ from those reported in 2015 by Fraszczyk et al. regarding unattended trains. In that study, the public was less concerned about the effects on operators because it was expected that operators could be requalified for other positions within the railway system.

Demographic differences seem to affect acceptability, despite such aspects are inconsistent across studies. For instance, Morast et al. (2023) found significant effects of age, with the 25-39 age group showing the highest level of acceptability towards automation and participants aged 60 and older showing the lowest acceptability. Cogan et al. (2022) found that younger respondents attributed higher importance to service factors such as reduced delays and lower ticket prices. However, Pakusch and Bossauer (2017) found no significant influence of age on overall intention to use autonomous transport. Pakusch and Bossauer (2017) found that while overall intention did not differ significantly, male respondents rated willingness to use specific autonomous transport modes systematically higher than female participants. Lemonnier et al. (2023) observed that women were more likely than men to expect the autonomous trains to be useful.

Important gaps remain in understanding attitudes toward autonomous trains, particularly across diverse transnational contexts. Existing research has been conducted within single-country settings or in contexts with relatively harmonized rail infrastructure, including Australia (Fraszczyk & Mulley, 2017), France (Lemonnier et al., 2023), Germany (Morast et al., 2023; Cogan et al., 2022), the Netherlands (Arzer et al., 2024), and the United States (Detjen et al., 2021). The generalizability of these findings to the European context may be limited, given that infrastructural harmonization and cross-border interoperability remain ongoing processes and the quality and characteristics of rail services vary substantially across member states. Methodological heterogeneity across existing studies further constrains generalizability. Sample sizes have ranged considerably, from 30 participants in qualitative interview studies (Lemonnier et al., 2023) to 530 respondents in online surveys (Morast et al., 2023), with corresponding differences in the depth and breadth of insights obtained. Recruitment and compensation strategies have also varied: some studies recruited voluntary participants without compensation (Morast et al., 2023; Lemonnier et al., 2023), while others provided monetary incentives through paid online panels (Fraszczyk & Mulley, 2017;Detjen et al., 2021). Arzer et al. (2024) offered refreshments to focus group participants. However, several studies did not report compensation details (Cogan et al., 2022; Fraszczyk et al., 2015; Pakusch & Bossauer, 2017), limiting the ability to assess potential selection or response biases across the literature. These methodological inconsistencies, combined with the predominance of single-country studies regarding contexts with unified infrastructures, provided an opportunity for cross-national research to better understand citizens' expectations regarding the deployment of autonomous trains across the heterogeneous European rail landscape. This multinational perspective may inform, confirm, or provide new insights for local and European decision-makers regarding the development of ATO in different European regions.

The present work attempted to address such methodological inconsistencies through a large-scale, multilingual survey to map acceptability of European citizens toward autonomous train operations. The study attempted to: i) identify factors that may affect future passengers' intention of usage and tendency to support or oppose the diffusion of autonomous trains across European countries; ii) establish lessons learned from this study and potential insights from policy and decision makers to promote acceptability towards autonomous rail in Europe.

2. Methods

The data collation was performed from May to September 2025. Ethics approval was obtained from the Ethical board of the University of Twente [ID 251406, 251702].

2.1. Participants

A total of 638 participants were involved in the study. An initial sample of 165 valid responses were obtained from the 221 participants who voluntarily took part in the study that was advertised on social media. Participants who did not complete correctly the survey were excluded. To enlarge the sample an additional 471 participants were recruited by Panel Service (Prolific Inc.), 381 valid answers were obtained, each participant was paid 1.5 Euro as compensation for filling in the survey. Additionally, 29 participants were excluded from the 546 obtained by the data collection phase, based on statistical analysis of interquartile ranges, i.e. too long or too little time to complete the survey. A final sample of 519 European residents was included in the study.

2.2. Material

A survey was designed in five Languages (English, Dutch, German, Italian, Spanish) based on insights from previous studies. With five main sections (see Appendix 1 for the items list and the associated Likert scale):

i) **Demographics**. This contains items regarding individual characteristics (i.e., age, sex, nationality of residence) experience with autonomous transport systems, area of living, modality and frequency of commuting with a particular focus in train usage (Morast et al., 2023; Cogan et al., 2022; Pakusch & Bossauer, 2017).
ii) **Current and future expectations regarding service quality.** This section contains items about current quality of rail service experience and expectation of improvements due to automation (Appendix 1, TH2 and TH3). Items were inspired by previous studies (Cogan et al., 2022; Fraszczyk et al., 2015; Fraszczyk & Mulley, 2017; Pakusch & Bossauer, 2017) and presented in a 5-point Likert Scale to assess importance e.g., 1 = Not important at all; 5 = Extremely important.
iii) **Expected Changes and future needs for communication and security**. This section contains items from previous studies (Lemonnier et al., 2023; Arzer et al., 2024) to assess expected changes in the service due to train automation. Items were presented in a 5-point Likert Scale to assess importance. And also items concerning acceptability of not having operators on board, need for communication, fear of usage and communication, and cybersecurity were adapted from previous studies (Detjen et al, 2021; Morast et al. 2023). Items were presented in a 5-point Likert Scale (e.g., 1 = Strongly disagree; 5 = Strongly agree) to assess importance of the aspects presented in the items, or to assess the agreement with statements concerning for instance fears and cybersickness.
iv) **Preference and intention of usage.** This section asked respondents to declare their preferences about having or not a human driver (Autonomous driven, Human drives, or Any type of train), their preferred Grade of Automation level (Lemonnier et al., 2023), as well as to declare their agreement towards two statements regarding their attitude and usage of autonomous trains and to declare their intention to support or oppose to the diffusion of autonomous trains. See Appendix

A for insights about the types of scales. These items were connected to previous studies (Fraszczyk & Muller 2017; Fraszczyk, et al. 2015).

While the survey collected multiple variables as described above, in the present study we consider preferences (Autonomous or human driven train, and GoA) and intention of usage and support as our main outcome variables, with all other measured variables serving as potential predictors. A pilot study of the survey was performed on 20 participants to gather feedback and improve wordings and flow of the survey.

2.3. Data Analysis

Statistical analyses were performed using R software (version 4.5). Interquartile ranges were used to identify outliers in terms of completion time i.e., participants were excluded if their completion time fell below 5 minutes or exceeded 50 minutes. Descriptive statistics were used to characterize the overall sample responses. Answers to the items of section ii were utilized separately to explore quality of service and expectations e.g., accessibility or ticket price etc. Scree plot and exploratory factor analysis with oblimin rotation (using psych package) was conducted on items from sections iii to identify latent constructs related to e.g., automation acceptability, and security concerns. Scores were computed as mean scores of constituent items.

Identified aspects were used model selection using genetic algorithms (glmulti package) was used to identify optimal predictor combinations for the participants answers to the last (iv) survey section about preference and intention of usage, that asked about: i) preference for autonomous vs. human drivers, ii) acceptable grade of automation, and iii) intention of use, fear of unemployment due to automation and support towards train automation. Candidate predictors included demographics, travel frequencies with multiple means, service quality expectations (sections ii), and the four factor scores from factor analysis. A quality check was performed to explore differences due to recruitment methods and the fit indexes of the selected models. Moreover, as the country of residence of the respondents was used as one of the potential predictors fit indexes were used to decide the best strategies of grouping countries. Regarding the recruitments we compared answers of volunteers or participants who received a compensation (panel sample) the questions of sections iv by a logistic regression. If systematic differences were detected, recruitment method was included as a factor in the selection model. The quality of the models were characterized using the McFadden's R (McFadden, 1987) to indicate the fit; with values range from 0 to less than 1, with a common rule of thumb suggesting that a range of 0.2 to 0.4 indicates a very good model fit. The Corrected Akaike Information Criterion (AICc, Hurvitch & Tsai, 1993) was used in model selection; with lower values indicating better model fit while accounting for sample size and number of factors. The Bayesian Information Criterion (BIC, Schwarz, 1978) was used to characterize the amount of complexity in the model. The model selection was performed with the variable of country of residence grouped in multiple modalities to check the stability of the model. As glmulti process of model selection is automated and it might not account for model selection uncertainty, the output may be anti-conservative and p-values are inappropriate to report. Therefore, odd ratio was reported to present and discuss the results.

3. Results

3.1. Overview of the respondents' characteristics

The average age of the participants was 37 years old (SD:12, min:19 max:81) and 61.3% of the participants to the survey were male. About 37% of the participants declared experience with one or more autonomous systems, e.g. a tram, train or car. Overall summaries can be found in Table 1.

Table 1. Summarises the main demographic aspects collected from the survey.

Area of Living	Frequency (%)
Urban	58.2
Sub urban	26
Rural	15.2
not say	0.6
Propensity to take risks	
Average risk takers	65.3
High risk takers	13.9
Low risk takers	20.8
Connection with the Rail Service	
Not working in rail	70.6
family or friends work in rail	22.7
I work in rail	6.7
Frequency of using train*	
Every day of the week	6.6
3-4 days/week	6.9
1-2 days/week	11.8
1-3 times/month	30.8
Less than once a month	33.7
Not used in the last 12mo	10.2

We received answers from people living in 23 European countries: Italy, Polan, Spain, Netherlands, Portugal, Germany, Greece, France, Ireland, Sweden, Belgium, Finland, Slovenia, Austria, Norway, Croatia, Czech Republic, Estonia, Slovakia, Switzerland, Denmark, Serbia, United Kingdom.

Figure 1 offers a depicture of the top 10 countries in which the respondents are living and using trains (for a full overview see Appendix 2). Distribution in European regions of participants is reported in Table 2.

Figure 1. Top ten residential countries of the participants.

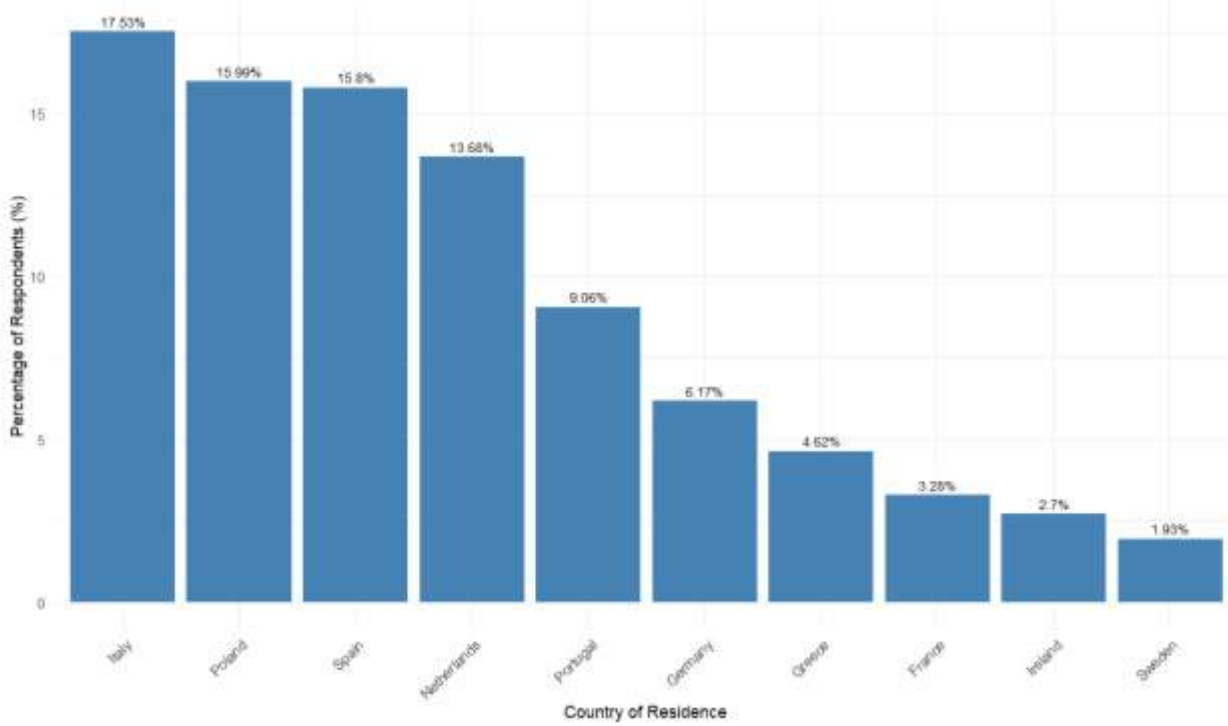
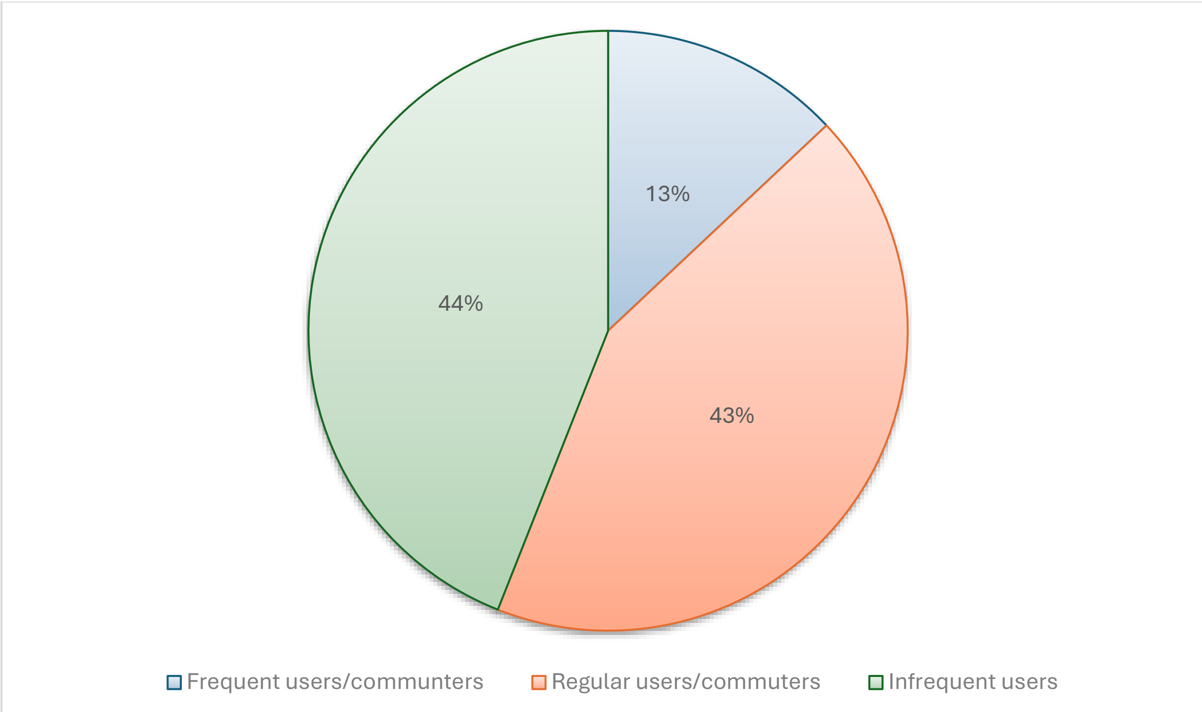


Table 2. Distribution in European Regions

Region	Participants (%, n)
Western Europe (France, Belgium, Netherlands, Germany, Austria, Switzerland)	25.8% (134)
Eastern Europe (Poland, Czech Republic, Slovakia)	17.7% (92)
Northen Europe (Norway, Sweden, Finland, Denmark, Estonia, United Kingdom, Ireland)	7.7% (40)
Southern Europe (Italy, Spain, Portugal, Greece, Slovenia, Croatia, Serbia)	48.8% (253)

Figure 2 summarizes the usage of trains declared by respondents, with about 13% of frequent users who are commuting at least 3 to 4 days a week by train. We considered regular users those (about 43%) who declared to use trains at least 1 to 3 time a month, while the remain 44% of the users were considered infrequent or rare users.

Figure 2. Frequency of usage of the trains declared by participants.



3.2. Key quality aspects, and expectations and needs of the respondents

Respondents consider reliability and safety the most important aspects for a good rail service, followed by cost, passengers' comfort, and accessibility, while sustainability is the last concern for our cohort (See Table 3). When it comes to the future, respondents expect service to operate for more hours per day and with more frequent trains, with reduced prices and improved safety for operators. Again, the last concern for the respondents was energy saving at the infrastructural level.

Table 3. Importance of quality aspects and expected service changes. Scale: 1 = Not important at all; 2 = Slightly important; 3 = Moderately important; 4 = Very important; 5 = Extremely important

Importance of aspects **To judge quality of current service**	**Rating** **M (SD)**
Safety	4.5 (0.74)
Reliability Importance	4.58 (0.6)
Sustainability Importance	3.42 (1.07)
Accessibility Importance	3.7 (1.03)
Comfort Importance	3.91 (0.78)
Cost Importance	4.24 (0.79)
Regarding expected service changes with ATO	**M (SD)**
Reduced Price Importance	4.1 (0.88)
Operational hours Importance	4.16 (0.82)
Train Frequency Importance	4.15 (0.77)
Reduced Operator Risk Importance	3.86 (1.02)
Energy Saving Importance	3.55 (1.06)

Section iii of the survey investigate aspects such as acceptability of not having operators on board, need for communication, fear of usage and communication, and cybersecurity. The items (See Appendix 1, items from 4.1 to 6.7) were explored to identify hidden association and constructs. The factorial analysis identified four aspects (see Table 4) that were investigated from the survey: (F1) General Fear of Autonomous Trains, (F2) Operator Presence i.e., accessibility and closeness of support and information, (F3) Means to compensate for absence of Operators i.e., Remote/alternative access to support because of lack of operator, and (F4) Cybersecurity Concerns.

Table 4. Factor loading of the items of the third section of the survey.

Items	**Factors**			
	F1	F2	F3	F4
TH4_1	-0.03	**0.83**	-0.05	0.02
TH4_2	0.01	**0.79**	-0.01	-0.02
TH4_3	0.05	0.13	**0.61**	0.00
TH4_4	0.14	**0.48***	0.27	-0.05
TH5_1	0.02	**0.57**	0.04	0.09
TH5_2	-0.07	-0.05	**0.69**	0.03
TH5_3	0.01	-0.05	**0.61**	0.02
TH5_4	-0.04	-0.02	**0.52**	-0.05
TH6_1	**0.63**	-0.01	0.09	-0.02
TH6_2	**0.30***	0.13	0.12	0.09
TH6_3	**0.83**	-0.03	0.00	0.07
TH6_4	**-0.76**	-0.01	0.05	0.04
TH6_5	**-0.53**	-0.07	0.10	0.04
TH6_6	-0.02	0.01	0.05	**0.76**
TH6_7	0.01	0.00	-0.02	**1.00**

*We retained the highest loading per item

When asked about potential fears, opportunities, and concerns related to unattended ATO, it appears that cybersecurity is the leading concern of the respondents, with expressing some concerns regarding fears of cyberattacks (F4, M=3.55, SD=1.15). Regarding perceived safety, respondents show cautious attitudes: there is moderate agreement that it is safe to use unattended trains (TH6_4, M=3.23, SD=1.12) while opinions about ATO's ability to reduce accident risk remain near neutral (TH6_3, M=2.96, SD=1.01). Respondents show a neutral attitude, with a slight tendency to disagreement, with the statement that unattended trains are dangerous (TH6_3, M=2.9, SD=1.01). There is some disagreement that trains will move unexpectedly before passengers are seated (TH6_1, M=2.59, SD=1.25) but respondents moderately agree that school-age children should be accompanied by adults when using driverless public transportation (TH6_2, M=3.42 SD=1.24) reflecting ongoing safety concerns for vulnerable passengers. Overall, attitudes indicate cautious potential acceptance of ATO with a quite neutral, and probably uncertain, opinion regarding the aspects connected to (F1) passenger overall fear towards ATO (See Table 5).

Table 5. Attitudes toward automated train operations. Scale: 1 = Strongly Disagree; 2 = Disagree; 3 = Neither agree nor disagree; 4 = Agree; 5 = Strongly Agree

Factors	Items	Rating	Factor
		M (SD)	**M (SD)**
1	TH6_1 I am afraid that, without a human driver, the vehicle could start moving before I sit down	2.59 (1.25)	3 (1.17)
1	TH6_2 I think school-age children should be accompanied by adults when using driverless public transportation.	3.42 (1.24)	
1	TH6_3 I believe that using unattended rail vehicles is dangerous	2.9 (1.2)	
1	TH6_4 I would feel safe while using unattended rail vehicles	3.23 (1.12)	
1	TH6_5 Using unattended rail vehicles decreases the accident risk	2.96 (1.01)	
4	TH6_6 I have concerns about cyberattacks in general	3.57 (1.15)	3.55 (1.15)
4	TH6_7 I have concerns about cyberattacks in automated transport in general.	3.53 (1.15)	

Regarding Factors 2 and 3, as reported in Table 6, respondents place high importance on both clear information provision and the availability of human operators. During normal operations, respondents consider it very important to have an attendant capable of taking over driving, either on board the train (TH4_1, M=3.95; SD=1.02) or in the driver's cab (TH4_2, M=3.89; M=1.11). They also highly value information provided through rail personnel (TH5_1, M=3.88, SD=0.98). Overall, the presence on board of operators is rated as important (F2, M=3.81, SD=1.04).

Concurrently there is a moderate agreement on the importance of the aspects associated with the means to compensate for absence of operators (F3, M=3.5, SD=1). In general, having access to information by displays could be acceptable as an alternative to information provided by operators (TH5_2, M=3.95, SD=0.87), this is acceptable also in emergency situations (TH4_3, M= 3.84, SD=0.93). this is Digital communication with remote operators via phones and apps is also moderately acceptable (TH5_3, M= 3.45, SD=1.07), whereas interaction with robots on board is considerably rated as the less acceptable option (TH5_3, M=2.77, SD:1.15).

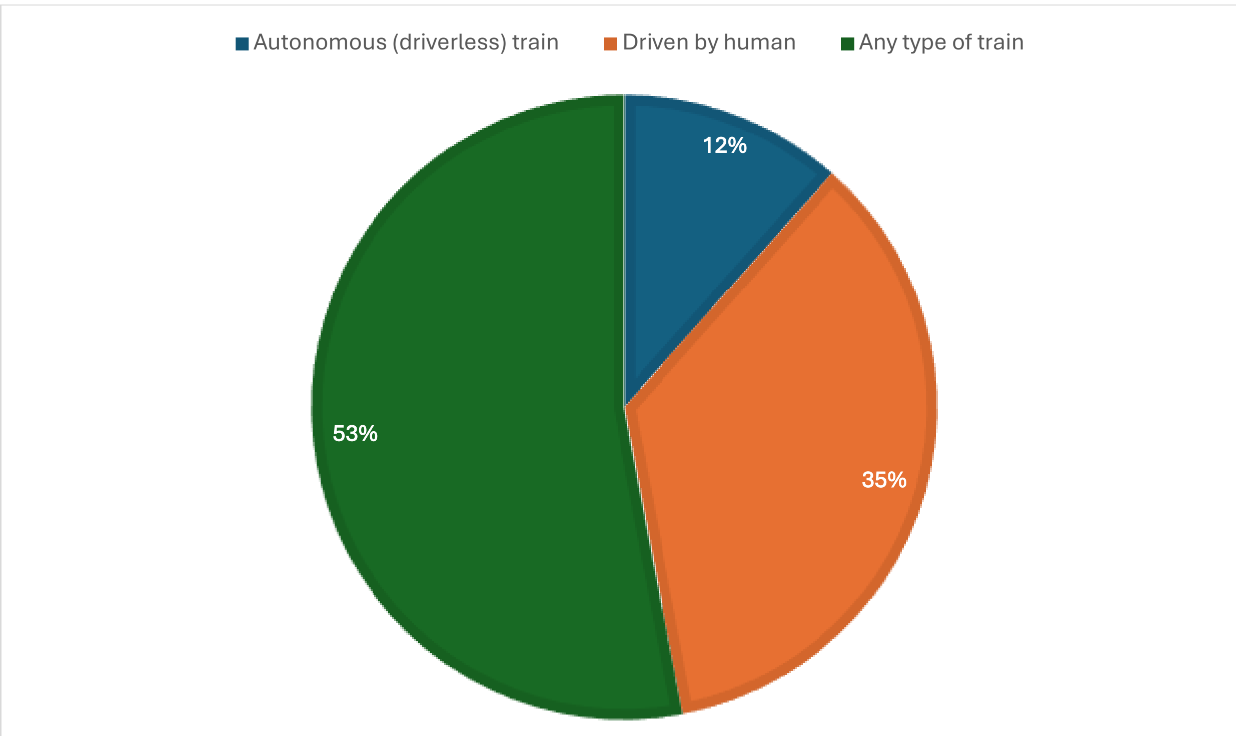
Table 6. Importance of information and operator presence. Scale: 1 = Not important at all; 2 = Slightly important; 3 = Moderately important; 4 = Very important; 5 = Extremely important

Factors	Items	Rating	Factor Rating
		M (SD)	
2	TH4_1 Presence in the train of an attendant who is able to drive the train if needed	3.95 (1.02)	3.81 (1.04)
2	TH4_2 Presence in the driver cab of an attendant who is able to drive the train if needed	3.89 (1.11)	
2	TH4_4 Having available, accessible and comprehensible information about the status of the train when necessary thanks to the presence of rail personnel	3.5 (1.05)	
2	TH5_1 Receive information and communication by rail personnel on board to talk to and provide assistance	3.88 (0.98)	

3	TH4_3 Having available, accessible and comprehensible information about the status of the train when necessary, by interactive screens	3.84 (0.93)	3.5 (1)
3	TH5_2 Receive information and communication by interactive systems and displays	3.95 (0.87)	
3	TH5_3 Receive information and communicate digitally by phones and Apps with remote operators	3.45 (1.07)	
3	TH5_4 Receive information and communicate with robots on board of the train	2.77 (1.15)	

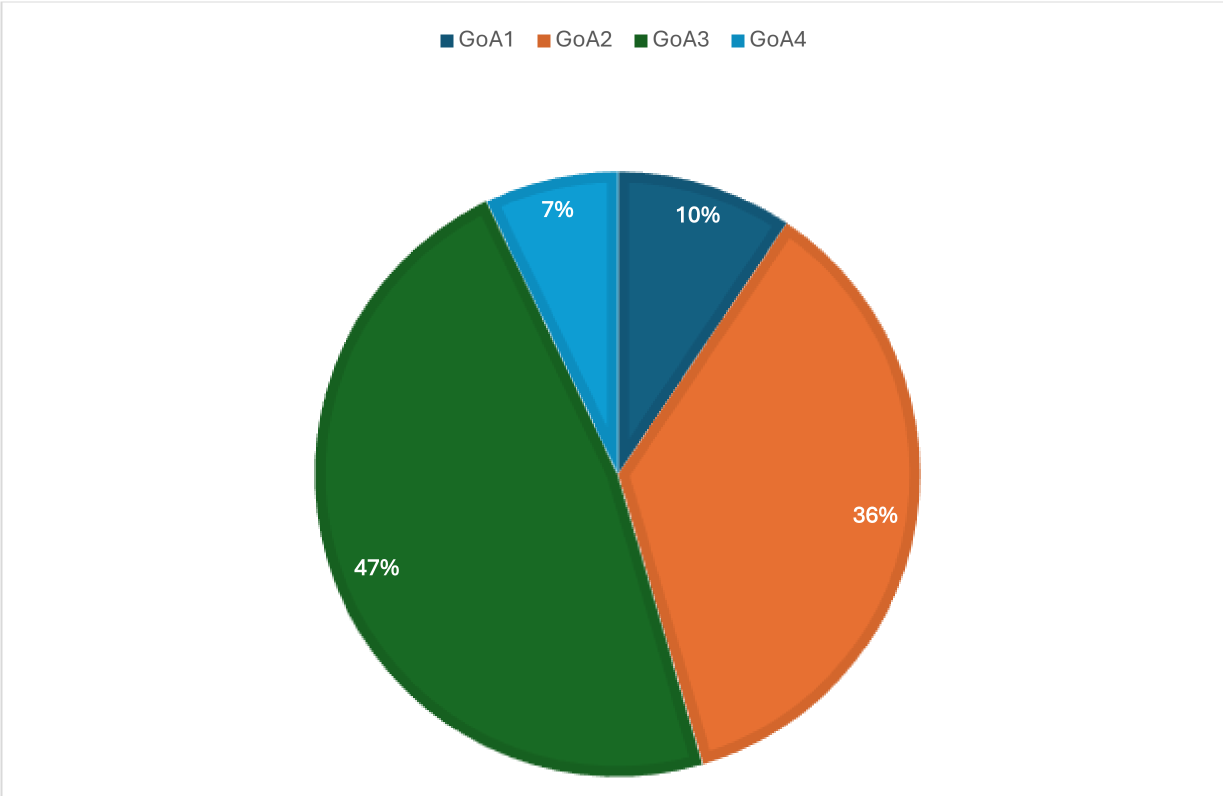
When asked which trains they would prefer to ride (See Figure 3), 35% of respondents said that they would like to have trains driven by humans, only 12% answered that Autonomous driverless trains are their preferred option and about 53% declared that they do not have a preference and both options are fine.

Figure 3. Preference, in percentage, towards autonomous drive, human drive or any type of train (autonomous or human drive) declared by participants.



As summarized in Figure 4, after reading the description of the different GoA levels (Selipa, 2024) respondents suggested that if they would have the possibility to decide the level of autonomy of trains, they would go 36% GoA level 2, and 47% GoA Level 3. Only 7% of respondents opted for GoA level 4, and concurrently only 10% opted for GoA Level 1.

Figure 4. Preference, kin percentage, of GoA levels.



Respondents moderately agree that overall, they would use regularly (intention to use) autonomous trains (M=3.5, SD=1.04), and also express overall moderate disagreement that ATO will produce unemployment see Table 7.

Table 7. Declared intention to use autonomous trains and belief that ATO will bring to unemployment

Agreement	Rating M (SD)
Once I will have access to driverless train system, I predict that I would use them regularly	3.5 (1.04)
I believe that implementations of driverless trains contribute to increase of operators' unemployment	2.48 (1.19)

When asked to express their support or opposition to the deployment of autonomous trains (on a 5 – point Likert scale, from 1 – Strongly oppose, 3 – Not oppose nor support, and 5 - Strongly Support) respondents on average support moderately the implementation of driverless train (M: 3.56, SD: 1.05).

3.3. Quality check: Participants' compensation and model fit.

A logistic regression was conducted to examine whether responses to the main outcome variables differed between panel sample – i.e., compensated participants, n = 381 – and volunteers' sample i.e., not compensated participants, n = 138. The overall model was significant, $\chi^2(5) = 46.07$, $p < .001$, indicating that response patterns differed by recruitment method. Volunteers were significantly more likely to report higher scores on ALP2 (OR = 1.47, 95% CI [1.06, 2.04], $p = .021$) and significantly lower scores on FC1_1 (OR = 0.70, 95% CI [0.56, 0.88], $p = .003$) and FC1_2 (OR = 0.70, 95% CI [0.58, 0.83], $p < .001$). No significant differences were observed for ALP1 or FC2_1. Given these differences, the fact that the respondents were compensated or not was retained as a candidate predictor in subsequent model selection analyses.

We conducted an exploratory investigation of the factors influencing respondents' answers to items in the preference and intention of use section of the survey using model selection procedures. As the sample of respondents was skewed towards Southern European countries, the model was run with the variable country grouped based on the UN geo-scheme (Table 2), or with the countries dichotomized in Southers and Non-Southern European. The selection model analysis revealed substantial variation in predictive power across the five outcome variables, but quite some stability when comparing the modality of grouping country of residence (See Table 8). Overall, we opted for the model using the UN geoscheme. This approach balances parsimony with the ability to explore regional differences across Europe, and comparison with alternative specifications (binary country variable) confirmed that model fit remained stable.
The model for preference between automated and human drivers achieved the strongest predictive performance ($R^2 = 0.479$), explaining nearly half the variance and indicating that the selected predictors effectively capture the factors underlying this preference. Support for autonomous train deployment showed moderate predictive success ($R^2 = 0.329$), suggesting that the identified predictors explain approximately one-third of the variance in deployment support. The automation grade model achieved similar moderate performance ($R^2 = 0.263$), while intention to use autonomous trains showed somewhat weaker predictive power ($R^2 = 0.235$). The model for unemployment concerns due to automation performed poorly ($R^2 = 0.082$), with the highest AICc (1244.1) and BIC (1312.4) values, indicating that the survey items included in the analysis only marginally predict concerns about job displacement due to automation.

Table 8. Results of the model selection analysis

Dichotomous model (south vs non-south)	**Fit (McFadden's R^2)**	**AICc**	**BIC**
Preference for autonomous or human driven trains	0.479	542.5	720.3
Automation grade	0.260	774.9	846.7
Support in the deployment of autonomous train	0.326	898.5	997.9
Intention of use autonomous trains	0.236	1009.4	1122.3
Unemployment due to automation deployment	0.081	1243.9	1308.2
Grouping based on UN geoscheme			
Preference for autonomous or human driven trains	0.479	542.5	720.3
Automation grade	0.263	775.3	855.3
Support in the deployment of autonomous train	0.329	896.5	999.8
Intention of use autonomous trains	0.235	1011.4	1122.3
Unemployment due to automation deployment	0.082	1244.1	1312.4

3.4. Main predictors

3.4.1. Potential predictors of preference towards automated or human driver

The analysis was performed using as reference the participants who are indifferent if the train is driven by human or automated i.e., those who answer, "any type of train (autonomous or human)". Results are presented in Table 9.

Preference for autonomous driven trains. Support for autonomous trains (FC2_1) emerged as a strong predictor exhibiting a complex, non-linear relationship with preference for autonomous train operation. The linear contrast was strongly positive (OR = 28.42, 95% CI: 7.15–112.97), and the cubic contrast was also clearly positive (OR = 13.16, 95% CI: 2.98–58.19), indicating that increasing support for automation is associated with markedly higher odds of preferring autonomous trains, particularly at moderate to high levels of support. However, this positive effect saturates and reverses at the extreme end of the scale, as reflected in the negative fourth-order term (OR = 0.05, 95% CI: 0.01–0.33), suggesting that at very high levels of expressed support, the likelihood of exclusively preferring autonomous operation may actually decline. Beliefs about unemployment impact of ATO (FC1_2) showed a negative cubic trend (OR = 0.22, 95% CI: 0.08–0.59), suggesting that at the highest levels of perceived unemployment risk, the probability of preferring driverless trains decreases. High-risk participants showed higher odds of preferring autonomous trains compared to the average risk-takers (OR = 3.74, 95% CI: 1.46–9.59), indicating that individuals with greater risk tolerance are more likely to favour automation. Participants responding through unpaid channels showed reduced odds of preferring autonomous operation (OR = 0.24, 95% CI: 0.09–0.66) compared to panel respondents. Less frequent use of trains for commuting (TH1_5) was associated with preference for autonomous driven trains (OR = 0.63, 95% CI: 0.43–0.91), suggesting that individuals who rarely use trains are more open to driverless operation. Conversely, frequent car use for commuting (TH1_7) was associated with higher preference for autonomous trains (OR = 1.43, 95% CI: 1.11–1.82). Placing high value on service accessibility (TH2_4) also negatively affected preference for driverless trains (OR = 0.56, 95% CI: 0.36–0.85).

Preference for human driven trains. The preference in terms of GoA (ALP2) exhibited very strong negative associations (See Table 9) across all polynomial terms. The higher is the GoA level acceptable for participants the lower the preference for human drivers. The overall support regarding the deployment of automation (FC2_1) showed a complex pattern (Table 9) that suggests heterogeneity of opinions: the strongly negative linear term (OR < 0.01) combined with a strongly positive quadratic term (OR = 1721.43, 95% CI: 450.97–6571.01) and negative cubic term (OR = 0.02, 95% CI: 0.01–0.06) indicates that some respondents strongly support automation and yet still prefer a human driver, whereas others with similar levels of support of automation do not prefer human drivers. Belief that driverless trains contribute to increased operator unemployment (FC1_2) was associated with lower odds of preferring a human driver (OR = 0.19, 95% CI: 0.05–0.72), suggesting that respondents who acknowledged potential job displacement were nonetheless less inclined to favour human drivers. Male respondents were less likely than female respondents to prefer a human driver (OR = 0.44, 95% CI: 0.22–0.85). Frequent car use as a driver (TH1_7, OR = 1.33, 95% CI: 1.11–1.61) was associated with higher preference for human drivers versus any type of driver. Similarly, frequent use of taxi or ride-hailing services (TH1_10, OR = 1.60, 95% CI: 1.10–2.33) was also associated with higher preference for human drivers. The perceived importance of reducing risks for human operators in future transport (TH3_4, OR = 0.65, 95% CI: 0.46–0.92) was associated with lower preference for human drivers. Finally, fear of autonomous trains (Factor 1) emerged as a strong positive predictor of preferring human drivers (OR = 4.26, 95% CI: 2.48–7.34).

Table 9. Regression coefficients for preference for automated versus human drivers

	Variable	B	SE	OR	95% CI
Autonomous driven	Support ATO:				
	FC2_1.L	3.35	0.70	28.42	7.15, 112.97
	FC2_1.C	2.58	0.76	13.16	2.98, 58.19
	FC2_1^4	-3.03	0.98	0.05	0.01, 0.33
	Unemployment due to ATO				
	FC1_2.C	-1.53	0.51	0.22	0.08, 0.59
	High risk[a]	1.32	0.48	3.74	1.46, 9.59
	Unpaid response[b]	-1.42	0.51	0.24	0.09, 0.66

	TH1_5 – frequency of train commuting*	-0.47	0.19	0.63	1.10, 2.31
	TH1_7 – frequency of car commuting*	0.35	0.12	1.43	0.55, 0.90
	TH2_4 – accessibility	-0.59	0.22	0.56	0.36, 0.85
Human Driven	GoA level preference				
	ALP2.L	-12.34	0.59	<0.01	0.00, 0.00
	ALP2.Q	-5.82	0.58	<0.01	0.00, 0.01
	ALP2.C	-3.45	0.28	0.03	0.02, 0.06
	Support ATO:				
	FC2_1.L	-14.11	0.64	<0.01	0.00, 0.00
	FC2_1.Q	7.45	0.68	1721.43	450.97, 6571.01
	FC2_1.C	-3.78	0.52	0.02	0.01, 0.06
	Unemployment due to ATO				
	FC1_2.L	-1.64	0.67	0.19	0.05, 0.72
	Male[c]	-0.83	0.34	0.44	0.22, 0.85
	TH1_7 – frequency of car commuting*	0.29	0.09	1.33	0.62, 0.90
	TH1_10 – frequency of ride-hailing*	0.47	0.20	1.6	0.43, 0.91
	TH3_4 – risk of operator	-0.44	0.18	0.65	0.46, 0.92
	Factor 1 – Fear of ATO	1.45	0.28	4.26	2.48, 7.34

Note. B = unstandardized coefficient; SE = standard error; OR = odds ratio; CI = confidence interval. From the list Sex (other) was excluded because of extreme and unclear indexes.
* TH1_ questions were inverted to make positive the direction of the frequency of usage
a. Reference: Average risk-taker participant
b. Reference: Panel response
c. Reference: Female

3.4.2. GoA preference

Table 10 suggests that when participants are asked which Grade of Automation (GoA) they would prefer, participants who preferred human drivers (ALP1) were substantially less likely to select higher levels of automation (OR = 0.30, 95% CI: 0.17, 0.52), corresponding to an approximate 70% reduction in the odds of preferring higher GoA compared with respondents who were indifferent about whether the driver is human. General support for autonomous trains, as captured by the linear component of FC2_1, emerged as a strong positive predictor of preference for higher GoA (OR = 6.32, 95% CI: 2.55, 15.63), indicating that individuals who are more supportive of autonomous train deployment are markedly more likely to endorse higher automation levels. Regional differences pointed in a consistent direction when Southern Europe served as the reference category: respondents from Western Europe (OR = 0.54, 95% CI: 0.32, 0.92) and Northern Europe (OR = 0.31, 95% CI: 0.14, 0.69) were significantly less likely to favor higher GoA levels, whereas other regions did not show clear differences. Commuting behavior was also associated with automation preferences. More frequent car use (TH1_7) was linked to higher odds of preferring higher GoA levels (OR = 1.19, 95% CI: 1.08, 1.32), suggesting that individuals who rely more heavily on private car travel might be more inclined to endorse higher levels of train automation deployment. Similarly, more frequent use of taxi or ride-hailing services (TH1_10) was associated with increased odds of selecting higher GoA levels (OR = 1.32, 95% CI: 1.04, 1.64)Participants who place greater importance on accessibility in their current rail experience have lower odds of preferring higher automation levels (TH2_4, OR = 0.80, 95% CI: 0.65, 0.99). Data also suggest that higher scores on general fear of autonomous trains (Factor 1; OR = 0.65, 95% CI: 0.48, 0.88), stronger preferences for the presence of operators (Factor 2; OR = 0.59, 95% CI: 0.44, 0.80), and greater concern about cybersecurity (Factor 4; OR = 0.80, 95% CI: 0.65, 0.98) were each associated with reduced odds of selecting higher GoA levels.

Table 10. Regression coefficients for preference towards Grade of Automation levels

Variable	B	SE	OR	95% CI
ALP1 Human driven	-1.21	0.29	0.30	0.17, 0.52
FC2_1.L Support towards automation of trains	1.84	0.46	6.32	2.55, 15.6
Western Europe[a]	-0.61	0.27	0.54	0.32, 0.92
Northern Europe[a]	-1.16	0.40	0.31	0.14, 0.69
TH1_7* – frequency of car commuting	0.18	0.05	1.19	0.76, 0.93
TH1_10* – frequency of ride-hailing	0.27	0.12	1.32	0.61, 0.96
TH2_4 – Accessibility	-0.22	0.11	0.80	0.65, 0.99
Factor 1 – Fear of ATO	-0.44	0.16	0.65	0.48, 0.88
Factor 2 – Operator Presence	-0.53	0.15	0.59	0.44, 0.80
Factor 4 – Cybersecurity	-0.22	0.10	0.80	0.65, 0.98

Note. B = unstandardized coefficient; SE = standard error; OR = odds ratio; CI = confidence interval.
* TH1_ questions were inverted to make positive the direction of the frequency of usage
a. Reference: Southern Europe participants

3.4.3. Predictors of support in the deployment of autonomous train

When asked about their support for the deployment of autonomous trains (FC2_1), participants who preferred automatically driven trains showed substantially higher support (ALP1 - Autonomous driven, OR = 3.82, 95% CI: 1.84, 7.93), corresponding to almost a fourfold increase in the odds of expressing stronger support compared with those who were indifferent. In contrast, respondents who preferred human drivers were markedly less supportive regarding ATO deployment (ALP1 - Human Driver, OR = 0.17, 95% CI: 0.10, 0.29) resulting in an 83% reduction in the odds of support. Preference for higher GoA (ALP2, linear term) was positively associated with support (OR = 5.41, 95% CI: 2.28, 12.83), indicating that respondents favouring higher GoA levels (e.g., GoA 3–4) were more than five times as likely to endorse stronger support for ATO deployment than those preferring lower GoA. Intentions to use autonomous trains regularly (FC1_1) emerged as particularly strong predictors of support. The linear component showed a very large positive association (OR = 17.52, 95% CI: 7.33, 41.86), suggesting that each unit increase in usage intention was associated with roughly a 17-fold increase in the odds of expressing higher support. The cubic component was also positively related to support (OR = 2.08, 95% CI: 1.22, 3.54), indicating a non-linear pattern in which the association between intention and support becomes even stronger at higher levels of intended use.

Concerns about employment effects of automation were inversely related to support. Beliefs that autonomous and driverless trains would increase operators' unemployment (FC1_2) were negatively associated with support, both for the linear term (OR = 0.34, 95% CI: 0.18, 0.64) and the quadratic term (OR = 0.46, 95% CI: 0.25, 0.85). In this sense, participants who were more worried about job losses showed substantially lower odds of supporting autonomous trains.

Compared with respondents from Southern Europe (reference category), participants from Northern Europe expressed higher support for autonomous train deployment (OR = 3.36, 95% CI: 1.51, 7.48), whereas no clear associations were observed for other regions. Moreover, respondents who prioritize reliable service are more likely to endorse autonomous train deployment (TH2_2, OR = 1.84, 95% CI: 1.33, 2.53). Conversely, people who assign higher importance to ticket cost are less inclined to support autonomy (TH2_6, OR = 0.72, 95% CI: 0.53, 0.97). In fact, clearly having a reduced ticket cost is considered one of the most important aspects to endorse ATO (TH3_1, OR = 1.32, 95% CI: 1.00, 1.73). Preferences regarding the presence of human operators on trains played a central role. Respondents who strongly valued the immediate onboard presence of operators and staff assistance were less likely to support autonomous trains (Factor 2, OR = 0.60, 95% CI: 0.44, 0.81), whereas those who were more comfortable with reduced onboard presence and remote assistance showed higher support (Factor 3, OR = 1.44, 95% CI: 1.05, 1.96).

Table 11. Predictors of support for the deployment of autonomous trains

Variable	B	SE	OR	95% CI
ALP1 – Autonomous driven	1.34	0.37	3.82	1.84, 7.93
ALP1 – Human driven	-1.77	0.28	0.17	0.10, 0.29
ALP2.L – GoA level preference	1.69	0.44	5.41	2.28, 12.83
Intention of use				
FC1_1.L	2.86	0.44	17.52	7.33, 41.86
FC1_1.C	0.73	0.27	2.08	1.22, 3.54
Unemployment due to ATO				
FC1_2.L	-1.08	0.32	0.34	0.18, 0.64
FC1_2.Q	-0.78	0.32	0.46	0.25, 0.85
Northern Europe[a]	1.21	0.41	3.36	1.51, 7.48
TH2_2 – Reliability	0.61	0.16	1.84	1.33, 2.53
TH2_6 – Cost of tickets	-0.33	0.15	0.72	0.53, 0.97
TH3_1 – Reduced ticket price	0.28	0.14	1.32	1.00, 1.73
Factor 2 – Operator Presence	-0.52	0.16	0.60	0.44, 0.81
Factor 3 – Compensate absence	0.36	0.16	1.44	1.05, 1.96

Note. B = unstandardized coefficient; SE = standard error; OR = odds ratio; CI = confidence interval.
a Reference: Southern Europe participant

3.4.4. Predictors of the intention of use autonomous trains

When asked about their intention to use autonomous trains regularly (Table 12), the declared support for autonomous train operation emerged as the strongest positive predictor (FC2_1 linear, OR = 17.72, 95% CI: 7.31, 42.97), indicating that each unit increase in support was associated with roughly a 17 times increase in the odds of reporting higher intention to use. In contrast, participants who preferred human drivers (ALP1 – Human Driver) reported lower intention to use autonomous trains (OR = 0.57, 95% CI: 0.34, 0.96), corresponding to about a 43% reduction in the odds of higher intention compared with those who were indifferent about the type of driver.

Employment status and place of residence were also related to intention. Respondents working in the rail sector showed lower intention to use autonomous trains (OR = 0.29, 95% CI: 0.10, 0.90), indicating about a 70% reduction in the odds of higher intention relative to those not employed in rail. By contrast, participants living in suburban (OR = 1.84, 95% CI: 1.03, 3.28) and urban areas (OR = 1.96, 95% CI: 1.16, 3.32) reported higher intention than those in rural areas. Respondents aged 56–65 also displayed a higher intention to use autonomous trains (OR = 5.91, 95% CI: 2.14, 16.33) compared with the reference age group, indicating more than a fivefold increase in the odds of higher intention. Participants responding through unpaid channels showed reduced odds of intending to use autonomous trains (OR = 0.53, 95% CI: 0.32, 0.87) compared to panel respondents. Commuting behaviour was associated with intention in several ways. More frequent use of trains (TH1_2; OR = 1.31, 95% CI: 1.04, 1.64), metro (TH1_5; OR = 1.28, 95% CI: 1.10, 1.49), and travelling as a car passenger or via car sharing (TH1_8; OR = 1.27, 95% CI: 1.09, 1.49) were each positively related to intention, suggesting that individuals accustomed to these modes are more open to autonomous trains. In contrast, more frequent ferry use (TH1_6) was associated with reduced intention (OR = 0.62, 95% CI: 0.45, 0.85), predicting a modest but significant decrease in the odds of intending to use autonomous trains. Beliefs about environmental benefits also played a substantial role. Participants who believed that autonomous trains would be more sustainable and reduce energy consumption compared with human driven trains (TH3_5) reported higher intention (OR = 1.43, 95% CI: 1.18, 1.73), corresponding to a 43% increase in the odds of higher intention per unit increase in this belief.

General fear of autonomous trains (Factor 1) was very strongly and negatively associated with intention (OR = 0.30, 95% CI: 0.22, 0.41), implying roughly a 70% reduction in the odds of intending to use autonomous trains for each unit increase in fear; this represents the most substantial psychological barrier identified in the model. Conversely, and counterintuitively, concern about cybersecurity (Factor 4) was positively associated with intention (OR = 1.32, 95% CI: 1.09, 1.59), suggesting that respondents who are more alert to cybersecurity issues nonetheless report higher intention to use autonomous trains.

Table 12. Predictors of intention to use autonomous trains

Variable	B	SE	OR	95% CI
ALP1 - Human driver	-0.55	0.26	0.57	0.34, 0.96
FC2_1.L – Support for ATO	2.87	0.45	17.72	7.31, 42.97
Work Rail (I work in rail)[a]	-1.22	0.57	0.29	0.10, 0.90
Sub Urban area[b]	0.61	0.30	1.84	1.03, 3.28
Urban area[b]	0.67	0.27	1.96	1.16, 3.32
Unpaid response[c]	-0.64	0.26	0.53	0.32, 0.87
Age 56-65[d]	1.78	0.52	5.91	2.14, 16.33
TH1_2 – commute by train*	0.27	0.12	1.31	1.04, 1.64
TH1_5 – commute by metro*	0.24	0.08	1.28	1.10, 1.49
TH1_6 – commute by ferry*	-0.48	0.16	0.62	0.45, 0.85
TH1_8 – commute as car passenger*	0.24	0.08	1.27	1.09, 1.49
TH3_5 – Energy recovery and sustainability	0.36	0.10	1.43	1.18, 1.73
Factor 1 – Fear of ATO	-1.20	0.16	0.30	0.22, 0.41
Factor 4 – Cybersecurity	0.27	0.10	1.32	1.09, 1.59

Note. B = unstandardized coefficient; SE = standard error; OR = odds ratio; CI = confidence interval.
* TH1_ variables were reverse-coded so that higher values indicate more frequent usage
a. Reference: not working in rail
b. Reference: Rural area
c. Reference: Panel response
d. Reference: age 36-45

3.4.5. Predictors of concerns regarding unemployment due to automation deployment

Participants who preferred human drivers (ALP1 - Human Driver) reported lower unemployment concerns (OR = 0.58, 95% CI: 0.36, 0.95). Support for autonomous trains was strongly and negatively associated with concerns about operator unemployment. The linear component of support was a substantial negative predictor (FC2_1.L, OR = 0.09, 95% CI: 0.04, 0.24), indicating that each unit increase in support corresponded to roughly a 90% reduction in the odds of expressing higher unemployment concern. Participants responding through unpaid channels also showed reduced odds of expressing unemployment concerns (OR = 0.56, 95% CI: 0.36, 0.87) compared to panel respondents.

By contrast, several attitudinal variables were positively associated with unemployment concerns. Participants who rated reliability as an important feature of train services were more likely to believe that autonomous trains would increase unemployment (TH2_2, OR = 1.60, 95% CI: 1.21, 2.11). Similarly, those who expected automation to reduce ticket costs reported higher unemployment concerns (TH3_1, OR = 1.26, 95% CI: 1.04, 1.54). General fear of autonomous trains (Factor 1) also predicted stronger unemployment concerns (OR = 1.55, 95% CI: 1.19, 2.03), indicating that the more the fear of ATO the more the concerns of job loss due to ATO.

Table 13. Predictors of unemployment concerns about autonomous trains

Variable	B	SE	OR	95% CI
ALP1 – Human Driver	-0.54	0.25	0.58	0.36, 0.95
FC2_1.L – Support for ATO	-2.35	0.46	0.09	0.04, 0.24
Unpaid response[a]	-0.58	0.22	0.56	0.36, 0.87
TH2_2 – Reliability	0.47	0.14	1.60	1.21, 2.11
TH3_1 – Reduced ticket price	0.23	0.10	1.26	1.04, 1.54
Factor 1 – Fear of ATO	0.44	0.14	1.55	1.19, 2.03

Note. B = unstandardized coefficient; SE = standard error; OR = odds ratio; CI = confidence interval.
a. Reference: Panel response

4. Discussion

The present work provides comprehensive insights into European citizens' attitudes toward autonomous train operations, revealing a landscape of moderate acceptability with considerable variability. The results suggest that citizens' expectations toward future ATO services cannot be reduced to a binary outcome, as respondents' opinions exist on a continuum influenced by multiple aspects. This complexity is well represented by several non-linear, multifaceted relationships identified in the models. Looking at the overall results and considering the fit of our models, we capture with an acceptable (but moderate) power the predictors when it comes to preferences for driver type and GoA, support, and intention. Moreover, we only minimally captured the predictors that lead people to believe that ATO will result in increased operator unemployment (McFadden's $R^2 = 0.082$). We utilized such analysis to map the relationship among the potential predictors and to extrapolate key insights.
Overall, approximately 53% of respondents express moderate intention to use autonomous trains regularly (M = 3.5, SD = 1.04), suggesting neither strong enthusiasm nor rejection but rather a cautious openness to the technology. While 58.5% of respondents tend to support the deployment of ATO, a similar proportion (58.7%) believe that ATO will lead to increased operator unemployment—a tension that decision-makers must address. While only 12% of participants declared it acceptable to ride in fully autonomous systems, the majority (53%) expressed indifference between human-driven and autonomous options. Moreover, respondents clearly showed a preference for intermediate automation levels (GoA2: 36%, GoA3: 47%) over full automation (GoA4: 7%), aligning with previous research (Lemonnier et al., 2023; Fraszczyk & Mulley, 2017; Arzer et al., 2024) and with the so called "ironies of automation" (Bainbridge, 1983; Endsley, 2023). These ironies describe the paradox whereby increased automation creates new human factors challenges rather than eliminating them, such as the fact that passengers appear to accept automation in principle while still expecting meaningful human oversight.

Having operators on board ready to take control is a predictor of support toward ATO. Respondents valued both immediate on-board staff (Factor 2, M = 3.81) and expressed moderate acceptability of remote alternatives (Factor 3, M = 3.5). However, those who strongly valued immediate on-board operator presence were less likely to support autonomous trains (Factor 2, OR = 0.59–0.60), whereas those who were comfortable with reliable and accessible remote assistance showed higher support (Factor 3, OR = 1.44). In this sense, it is important to enable passengers to understand when an how operators are going to be onboard, and with which functions, and help passengers to form appropriate mental model regarding how to receive adequate assistance remotely when operators are not on board. Such aspects are particularly relevant for female respondents and those with disabilities, who rated operator presence as significantly more important. In fact, perceptions of accessibility and safety are not uniform across the population. The variation in preferences, combined with the finding that male respondents were less likely than female respondents to prefer human drivers (OR = 0.44), suggests that deployment strategies must consider diverse user needs. These findings are consistent with previous studies documenting gender differences in automation acceptability (Fraszczyk et al., 2015; Fraszczyk & Mulley, 2017). There is certainly no one-size-fits-all solution regarding the presence of operators on board, as context seems to play a major role. For instance, operators are not always necessary, but passengers may feel safer when they are present, particularly when trains are running in certain areas, at specific times of day, or when people with special needs are on board.

Regional variations in attitudes also emerged, with Northern European respondents showing higher support for deployment (OR = 3.36 compared to Southern Europeans) yet lower preference for high GoA levels (OR = 0.31). Western Europeans similarly showed reduced preference for higher GoA (OR = 0.54). This paradoxical pattern might suggest that contextual factors—potentially including existing rail infrastructure quality, cultural attitudes toward technology, or prior exposure to automated systems—moderate citizens' expectations toward future ATO services in multifaceted ways. The heterogeneity across European regions suggests that cross-border interoperability, technological and technical alignment must be accompanied by regionally tailored communication and deployment strategies. In our sample, citizens are on average more concerned with cybersecurity aspects (M = 3.55, SD = 1.15) than expressing general fear toward ATO implementation safety (M = 3.0, SD = 1.17). This might suggest that technical assurances and communication about train control and general safety may be less effective than addressing broader anxieties about digital vulnerability in connected transportation infrastructure. Nevertheless, our data also suggest that while it is important to address general concerns about cybersecurity, citizens with high awareness regarding such risks are also the ones who are showing a positive intention to use autonomous trains (OR = 1.32). In line with Everett Rogers' (2003) classification of diffusion of innovation these citizens might be consider early adopters that would like to use of the technology despite the risks. To transform such people in adopters transparency about limitations, investments and protocols to cover potential issues can paradoxically increase trust and encourage adoption.

General fear of autonomous trains emerged as the strongest barrier to the intention of use (OR = 0.30), representing roughly a 70% reduction in the odds of intending to use autonomous trains for each unit increase in fear. This finding aligns with the broader automation literature suggesting that unfamiliarity and uncertainty drive negative attitudes more than specific technical concerns (Endsley, 2023; Bainbridge, 1983). Autonomy in transport systems remains an emerging concept for citizens who, in many cases, have never experienced autonomous systems – 63% of our sample declared no experience with such systems. Nevertheless, unlike previous studies (Pakusch et al., 2017; Cogan et al., 2022) where prior experience was an important factor for supporting ATO, the experience of our cohort did not emerge as a predictor of support or intention to use the ATO service.
Participant age plays a complex role. Consistent with previous studies (Cogan et al., 2022; Morast et al., 2023), age influenced certain attitudes. However, participants between 56 and 65 years showed both significantly higher fear that trains would move unexpectedly before sitting, but also the highest declared intention to use ATO trains (OR = 5.91). This pattern may reflect a cohort effect whereby older experienced passengers recognize both the potential benefits and risks of automation.
Surprisingly data suggest that rail industry workers showed lower intention to use autonomous trains (OR = 0.29) despite potentially higher acceptability of advanced GoA levels. This may reflect insider knowledge about implementation challenges, occupational identity concerns, or more critical evaluation based on professional experience. Regardless of the underlying mechanism, this group represents potential opinion leaders whose concerns merit particular attention in deployment planning - a finding consistent with the

broader philosophy of participatory design of technological transition (Peet et al., 2025). Employment concerns represent an important consideration for public acceptance. Participants who rated reliability as important were more likely to believe autonomous trains would increase unemployment (OR = 1.60), as were those expecting ticket cost reductions (OR = 1.26). General fear of ATO also predicted stronger unemployment concerns (OR = 1.55). However, the low explanatory power of our unemployment concerns model ($R^2 = 0.082$) suggests that beliefs about automation's employment effects may be driven by factors outside our measured variables, potentially including broader economic attitudes, media exposure, or political orientation.

The recruitment method differences identified in our quality check warrant attention. Volunteers showed different response patterns compared to compensated participants on several key outcomes, including preferences for driverless trains, their intention to use them, and their concerns about unemployment. This finding has important implications for interpreting the broader literature, in which compensation strategies are often unreported.

4.2. Potential insights for decision-makers

4.1. Limitations and future work

To our knowledge, this study presents the largest multilingual survey on the acceptability of train automation in Europe. However, the cross-sectional, exploratory design of this study precludes causal inference. The findings regarding expectations may not reflect actual usage patterns when autonomous trains become available and people experience ATO services in the real world. Longitudinal research tracking respondents throughout the deployment process would provide stronger evidence of behavioral prediction. Despite limited effects on the identification of predictors, it should be highlighted that in the present work the Central and Northern European perspectives are underrepresented compared to the Southern European one. This limits the generalizability of the results, and future studies should aim to include larger and more balanced populations across European regions. Finally, our model for predicting unemployment showed poor performance ($R^2 = 0.082$), suggesting that beliefs about the employment effects of automation are driven by factors outside of our measured variables. Future research should explore additional predictors, including political orientation, economic attitudes, and media and social media consumption patterns.

Conclusion and recommendations

This study reveals that European citizens are cautiously open to autonomous train operations, with a clear preference for intermediate automation levels (GoA2–3) that balance technological advancement with human oversight. The strongest barriers to adoption are general fear of autonomous trains and concerns about cybersecurity, while regional variations highlight the need for tailored deployment strategies.

Our data can be used to draw six high-level insights and recommendations for the decision-makers in Europe, including policy makers and management of rail services:

1. ***Frame train automation around reliability, safety, and sustainability****:* Passengers prioritize reliability and safety as the most important aspects of rail service, with sustainability ranking lowest when assessing current quality. However, energy saving and sustainability, along with cost reductions, emerged as key predictors for support of ATO and intention to use autonomous trains. Improved punctuality, reduced delays, and the ability to run trains at closer intervals are priorities for passengers, but these benefits must be accompanied by assurances of reliability, safety, and energy efficiency. Cost reductions in commuting are highly valued. Decision-makers should frame and communicate automation initiatives around these priorities to maximize acceptability.

2. ***Prioritize communicated intermediate automation and regional deployment strategies**:* Survey data show that 83% of respondents prefer intermediate automation levels (GoA2–3), while only 7% accept full automation (GoA4). These results suggest that phased implementation strategies aligned with Europe's staged approach to ATO specification development will be more readily accepted than abrupt transitions to fully unattended operations. Technical demonstrations alone may not overcome resistance. Regional variations further complicate acceptance. Southern Europeans show higher GoA preferences, while Northern Europeans exhibit higher support for deployment but lower GoA preferences. Western Europeans display the lowest preference for higher automation levels. These contextual factors suggest that demonstrations and trials tailored to specific regions are essential to address cultural resistance and build trust. Infrastructure managers should plan for extended periods of intermediate automation while preparing for a gradual transition to higher automation levels.
3. ***Invest in remote communication and onboard safety***: Acceptance of compensatory measures for operator absence positively predicts both deployment support (OR = 1.44) and should be a high-leverage intervention point. Passengers are willing to accept reduced onboard staffing if high-quality alternatives are available. However, women and passengers with disabilities rated operator presence as significantly more important, highlighting demographic variations in accessibility and safety perceptions. Safety must be guaranteed even when onboard personnel are reduced, especially during peak hours or late-night travel. Robot-based communication was rated least acceptable (M = 2.77), indicating that technology solutions must feel human-mediated. Investments in trained remote staff, high-quality communication interfaces, and visible onboard safety systems are critical to generating public acceptance.
4. ***Address cybersecurity concerns through transparency and information about investments***: Cybersecurity emerged as the predominant concern among respondents. Rather than merely attempting to minimise cyber risks from a technical standpoint, decision-makers must communicate transparently about security investments, incident response protocols and the advantages of standardised, interoperable systems. The positive correlation between cybersecurity concerns and the intention to adopt suggests that security-conscious citizens may become early adopters and advocates if they are adequately informed. To avoid giving citizens the impression that problems are being underestimated, decision-makers should prioritise transparency and proactive communication.
5. **Engage rail industry workers as ambassadors**: Rail workers showed higher acceptance of advanced GoA levels but significantly lower intentions to use autonomous trains (OR = 0.29), likely due to complex attitudes shaped by professional knowledge and occupational identity. This group represents potential opinion leaders whose credible endorsement could shift public attitudes, but only if their concerns about implementation, safety, and workforce transition are genuinely addressed. Proactive workforce transition planning, retraining programs, and meaningful involvement in deployment planning can transform potential resistance into advocacy. Decision-makers should engage rail workers as ambassadors by addressing their concerns and involving them in strategic planning.
6. **Link price reductions with workforce protection**: Economic factors strongly influence acceptance of autonomous train deployment. Expectations of price reductions predict support (OR = 1.26–1.32), while unemployment concerns reduce support. Rail operators and policymakers should make credible commitments that automation will bring advantages to passengers through, for instance, reduced fares, but also to workers through retraining and transition support. These commitments might address legitimate concerns that ATO will bring advantages to companies letting citizens and human operators to deal with the consequences.

The path toward autonomous train operations in Europe requires more than technical innovation and standardization. The successful deployment of ATO depends on understanding and addressing the multifaceted expectations of different passenger groups, maintaining meaningful human involvement during the transition period, and fostering trust by transparently communicating about capabilities and limitations. Widespread public acceptance will require investment in stakeholder engagement, regional adaptation, and progressive, step-by-step introduction of intermediate automation levels toward a fully automated future that promises to enhance the capacity, reliability, and sustainability of European rail.

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Appendix 1 Survey

Demographic Section (from D5 Showed after the other sections below)

D1 Which is your nationality
D1_1 In which country do you currently reside?
D2 Please indicate your age in numbers (e.g. 21).
D3 As you choose to answer the questionnaire in English, we want to know what is your English proficiency level
D4 You are...

Male (1)
Female (2)
Non-binary / third gender (3)
Prefer not to say (4)

D4_1 Please answer the following: When I use a train, I usually suffer from accessibility problems, e.g. problems getting on and off the train, mobility problems on the train, etc.

Yes (1)
No (2)
Prefer not to say (3)

D5 Do you work or do you know someone (i.e.., family members or close friends) who works in the railway sectors?

Yes, I work for the railway sector (1)
Yes, I know someone who is working in the railway sector (2)
No (3)

D6 Which of the following statements best describes the area where you currently live?

I live in quite rural area i.e., a countryside village etc. (1)
I live in quite in a suburban i.e., a city with a low density population (2)
I live in quite in an urban area (3)
Prefer not to say (4)

D7 How willing are you to take risks, in general? From 0 to 10
D8 I experienced in the past or I am currently using (select the ones that apply)

Autonomous trains or metro (1)
Autonomous cars (2)
other autonomous systems (specify) (3)
None of above (4)

D9 (Optional) Please let us know if something was missing in the present survey in terms of topics, or if something was problematic/unclear in the survey. Your feedback are important to us

TH1 In the past 12 months, how often have you used the following travel methods? Please check the appropriate box for each method listed.
(5 or more days per week (1) 3-4 days per week (2) 1-2 days per week (3) 1-3 times per month (4) Less than once per month (5) Not used in the last twelve months (6))
Airplane (1) Train (2) Bus (3) Metro (4) Light Rail\Trams (5) Ferry (6) Car as driver (7) Car as passenger (8) Motorcycle (9) ride-hailing e.g., Taxi (10) Cycling (11) Walking (12)

Section 2. Current and future expectations regarding service quality.

TH2 Thinking about your current experience with rail transportation, please indicate how important the following aspects are to you in assessing service quality
(1 - Not at all important; 5 - Extremely important)
Safety (1) Reliability (2) Sustainability (3) Accessibility (4) Comfort (5) Cost of tickets (6)
TH3 Imagine that future trains are going to be autonomous (i.e., driverless). Rate the importance of the following changes, resulting from moving from the current train service to driverless train operation? (1 - Not at all important; 5 - Extremely important)
Reduced ticket price (1) Extended running periods - trains available for a larger part of the day and night (2) Increased train frequency (3) Reduced risks for human operators (4) Energy recovery and sustainability (5) To show you are paying attention, please select '5 - extremely important' just for this statement (6)

Section 3 Expected Changes and future needs for communication and security.

TH4 Imagine that future trains are going to be autonomous (i.e., driverless). Please indicate how important the following aspects are to you in order to decide to use future trains (1 - Not at all important; 5 - Extremely important)
Presence in the train of an attendant who is able to drive the train if needed (1)
Presence in the driver cab of an attendant who is able to drive the train if needed (2)
Having available, accessible and comprehensible information about the status of the train when necessary by interactive screens (3)
Having available, accessible and comprehensible information about the status of the train when necessary thanks to the presence of rail personnel (4)

TH5 Imagine that future trains are going to be autonomous (i.e., driverless). In case of emergency, for each statement below, rate how important is going to be for you to have that option available
(1 - Not at all important; 5 - Extremely important)
Receive information and communication by rail personnel on board to talk to and provide assistance (1)
Receive information and communication by interactive systems and displays (2)
Receive information and communicate digitally by phones and Apps with remote operators (3)
Receive information and communicate with robots on board of the train (4)
To show you are paying attention, please select '5 - extremely important' just for this statement (5)

TH6 Thinking about trust, safety and security of electronic data (cybersecurity) of future autonomous (i.e. driverless) trains, please indicate how much you agree or disagree with each of the following statements
(Strongly disagree (1) -Strongly agree (5))
I am afraid that, without a human driver, the vehicle could start moving before I sit down. (1)
I think school-age children should be accompanied by adults when using driverless public transportation. (2)
I believe that using unattended rail vehicles is dangerous (3)
I would feel safe while using unattended rail vehicles (4)
Using unattended rail vehicles decreases the accident risk (5)
I have concerns about cyberattacks in general (6)
I have concerns about cyberattacks in automated transport in general. (7)

Section 4. Preference and intention of usage.

ALP1 Would you prefer to use trains with human drivers or driverless (i.e., Autonomous trains)?

Autonomous (driverless) Train (1)
Driver Train (2)
Any Train (3)

ALP2 There are different levels of automation (GoA) of trains. From GoA 0 (trains manually driven) to GoA 4 (fully automated). In Europe most of the trains are currently between GoA 1 and 2, some metros of big cities can be close to GoA4. **Imagine you can decide the level of automation for the train that you are travelling on, what level of automation would you feel most comfortable with when traveling by train?**

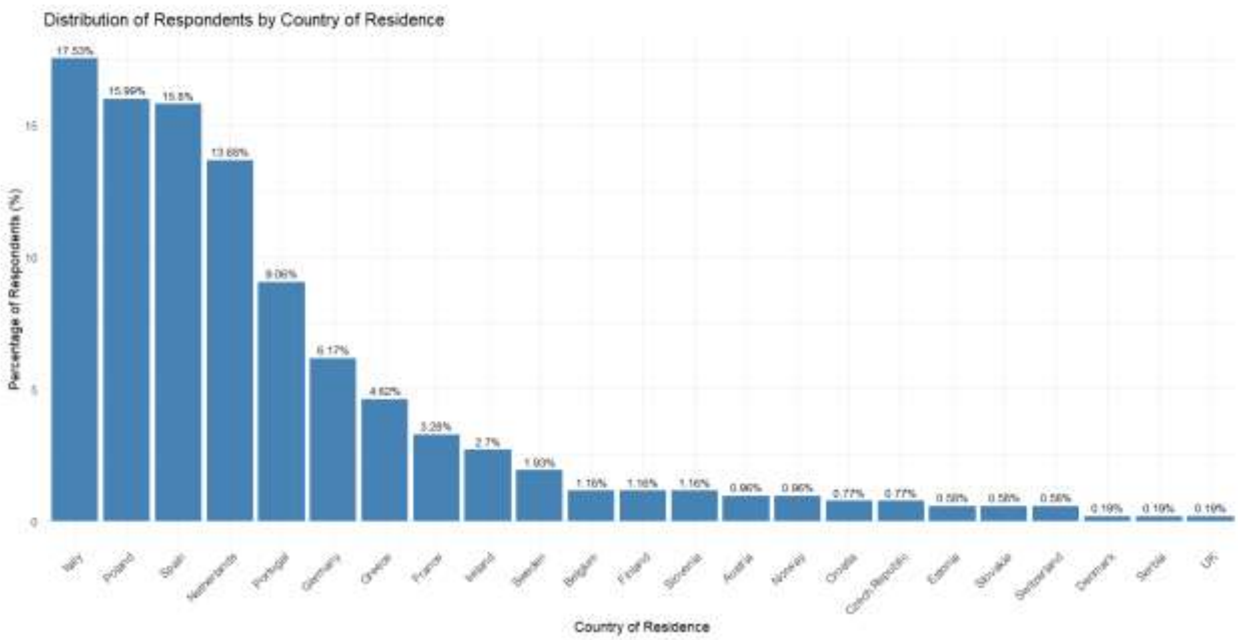
GoA 1: The train is driven manually but protected by automatic train protection (ATP). This GoA can also include providing advisory information to assist manual driving. (1)
GoA 2: The train is driven automatically, stopping is automated but a driver in the cab is required to start the automatic driving of the train, the driver can operate the doors (although this can also be done automatically), the driver is still in the cab to check that the track ahead is clear, and to carry out other manual functions. The driver can also take over in emergency or degraded situations. (2)
GoA 3: The train is operated automatically, including automatic departure, but a train attendant has some operational tasks, e.g. operating the train doors (although this can also be done automatically) and can assume control in case of emergency or degraded situations. (3)
GoA 4: Unattended train operation. All functions of train operation are automatic with no staff on-board to assume control in case of emergencies or degraded situations. (4)

FC1 Please indicate your level of agreement with the following statement about your intention in the future to use automated trains.
(Strongly disagree (1) -Strongly agree (5))
Once I will have access to driverless train system, I predict that I would use them regularly (1)
I believe that implementations of driverless trains contribute to increase of operators unemployment (2)

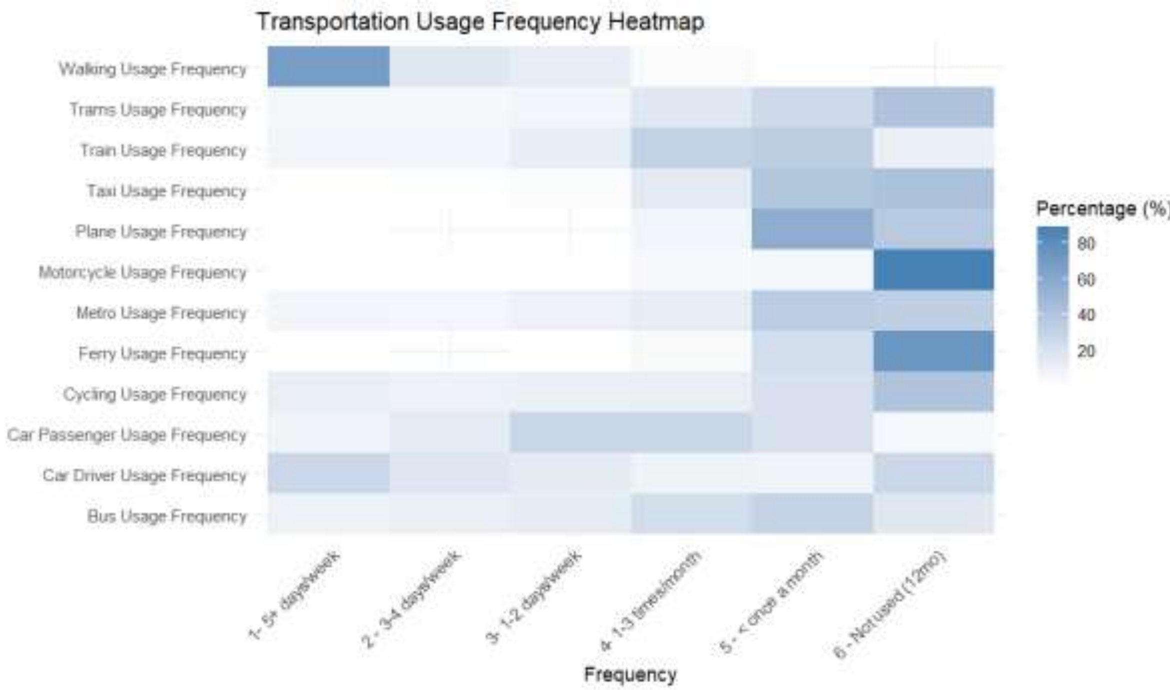
FC2 In general when it comes to the deployment of driverless trains I...
Strongly oppose it (1) - Strongly support it (5)

Appendix 2. Additional visualization of Demographics data

a. Distributions of Respondents per Country of Residence



b. Transportation type usage for commuting: Heatmap



Transportation Usage Frequency Heatmap
Walking Usage Frequency
Trams Usage Frequency
Train Usage Frequency
Taxi Usage Frequency
Plane Usage Frequency
Motorcycle Usage Frequency
Metro Usage Frequency
Ferry Usage Frequency
Cycling Usage Frequency
Car Passenger Usage Frequency
Car Driver Usage Frequency
Bus Usage Frequency
1- 5+ days/week
2 - 3-4 days/week
3- 1-2 days/week
4- 1-3 times/month
5 - < once a month
6 - Not used (12mo)
Frequency
Percentage (%)
80
60
40
20