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Transfer Resistance in Long-Distance Rail: Evidence from an On-Board Passenger Survey and Operational Data

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Abstract

Transfer behaviour is a key determinant of the attractiveness of public transport, yet it has been quantified less thoroughly than the elasticities of journey time and fare—particularly in long-distance travel, where the competitiveness of rail determines its potential for modal shift and thus for reducing emissions. This study quantifies transfer resistance in long-distance rail using an on-board survey conducted in 2016 on three major Austrian routes (1009 questionnaires distributed, 903 valid), supplemented by sales data from a long-distance rail operator and an analysis of five tram lines linked into direct, transfer-free through services. Around 53% of respondents travelled without transferring, around 97% transferred no more than twice, and fewer than 2% transferred three times; the decline follows a multiplicative pattern. Among direct travellers, the stated cumulative willingness to accept additional transfers falls from around 44% for one to 4% for two additional transfers; around 51% of all respondents would look for an alternative at two or fewer additional transfers. An additional transfer requires, on average, a journey time saving of around 17% or a fare reduction of around 30%; as journey duration increases, the relative requirement falls from 33% to 10%, while the directly stated absolute requirement rises from around 12 to 37 min. Travel context (journey duration, purpose, frequency, luggage) is associated with transfer behaviour, whereas no association with age, gender or occupation was detectable. Transfers should therefore be modelled as a distinct, non-linear and context-segmented barrier.

Keywords: transfer penalty; transfer resistance; long-distance rail; passenger survey; mode choice; travel demand modelling; modal shift; public transport planning

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1. Introduction

1.1. Problem Statement and Sustainability Context

Rail transport is regarded as the backbone of low-emission mobility. The European Commission's Sustainable and Smart Mobility Strategy aims to double high-speed rail traffic by 2030 compared with 2015 and to triple it by 2050, and to make scheduled collective travel on routes under 500 km carbon-neutral by 2030 [1]. In long-distance travel, routes of this length correspond to a journey time of approximately two to five hours—precisely the range in which rail competes with cars and short-haul flights and in which the choice of transport mode is decided. Achieving these targets therefore depends less

on the technical capabilities of the systems than on the conditions under which travellers actually choose a rail connection. In this context, transferring is not merely a matter of convenience but a quantifiable access barrier: it plays a decisive role in determining whether an available connection is perceived as a viable alternative. A robust quantification of transfer resistance in long-distance travel is therefore a prerequisite for a realistic assessment of the modal shift potential.

Shifting travel demand to rail requires rail connections to be competitive not only in terms of journey time and fare but across the entire travel chain. In long-distance travel in particular, necessary transfers can significantly impair the attractiveness of a connection, as they involve additional walking distances, waiting times, the risk of missed connections and increased organisational effort. A key factor in the attractiveness and competitiveness of public transport is therefore the structure of the travel chains offered and, in particular, the number of transfers required [2].

1.2. Transfers as a Barrier to Travel: State of the Art

Integrated transport networks theoretically enable high spatial accessibility, but user acceptance is largely determined by the quality of the transfer processes. In the literature, this effect is described as the 'transfer penalty', i.e., an additional, subjectively perceived burden that goes beyond the objective journey time and cost components [2–4]. Accounting for it is highly relevant for user-oriented planning and realistic travel demand modelling, as public transport travel chains regularly involve several routes or modes [5,6].

The magnitude of the transfer penalty varies considerably between user groups and with infrastructural and operational conditions; the most important influencing factors include age and gender, mobility impairments, luggage, weather conditions and infrastructure quality [7,8]. Quantitatively, the transfer penalty is usually expressed as additional perceived journey time, which significantly exceeds the actual duration of a transfer: for Madrid's multimodal network, the pure transfer penalty corresponds to 15.2 to 17.7 min of in-vehicle travel time [4]. Travellers therefore often prefer longer direct connections to faster connections involving a transfer [4], although transfers between rail-based systems generate less resistance than transfers between bus and rail [5]. The design of the interchange also has a direct impact: same-platform transfers without a change of level are rated significantly more positively than transfers involving stairs and long walking distances [9].

Non-linear effects have been documented with regard to the number of transfers. For Madrid's multimodal network, the pure transfer penalty amounts to 15.2 equivalent in-vehicle minutes for one transfer and 17.7 min for two transfers [4]. While journeys involving one transfer are rated as satisfactory as direct connections, the odds of a satisfactory journey decrease by 32% when there are two or more transfers [10]. For inter-urban rail in Great Britain, the interchange penalties recommended for demand forecasting increase with journey length, from 19 min for journeys of 30 miles to 65 min for journeys of 200 miles, and an analysis of ticket sales data indicates that interchange should be given even greater weight [11]. For network and timetable planning, this implies that the number of necessary transfers should be minimised and connections consistently coordinated [10].

Significant differences are evident between user groups. Older travellers are more sensitive to transfers, which is attributed to physical barriers, uncertainty during the journey and wayfinding demands [7]; qualitative studies cite a lack of accessibility, complex journey planning and insufficient information as major hurdles [12,13]. For women, safety aspects such as lighting and natural surveillance in particular influence their willingness to use connections involving transfers [6,14]. People with reduced mobility are particularly affected by transfer barriers [15]; accessibility along the travel chain is enshrined in law [16], but barriers to its implementation remain [15].

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Situational conditions also play a role: extreme weather reduces the use of connections involving transfers, as transfers often involve waiting outdoors [8,17,18]. The location of the transfer within the travel chain is also relevant; transfers close to the destination are perceived as less burdensome than those at the start of the journey [19]. A transfer is therefore not merely a technical model parameter but a multidimensional factor comprising infrastructural, organisational and psychological components.

In modelling, transfers are predominantly represented in discrete choice models based on random utility theory [20], which increasingly incorporate not only journey time and cost but also the number of transfers, transfer time, infrastructure quality and user characteristics [4,20]; transfer-friendly infrastructure, information and coordinated operations are regarded as effective levers for increasing the competitiveness of public transport [21]. The disutility of a transfer depends not only on the transfer itself but also on the distribution of time across the stages of the trip and on the headway of the connecting service [22]. However, the available evidence stems predominantly from urban and regional networks. For long-distance and intercity travel, more recent studies show that direct rail connections to the destination and short first and last miles increase the probability of choosing rail for long-distance holiday trips to Austria [23], and that, in intercity road–rail intermodal travel, travellers are risk-averse and the reliability of a transfer option weighs heavily in mode choice [24]. Owing to shorter journey times, more frequent services and lower proportions of passengers with luggage, the urban findings cannot be readily transferred to long-distance rail, for which an empirical quantification of the acceptance and compensation thresholds for additional transfers, based on the journeys actually being made, has so far been lacking.

1.3. Research Gap

Despite extensive research into individual influencing factors, there is no consistent quantification of transfer resistance in long-distance travel in the form of behaviour-based metrics. Existing studies are predominantly based on stated-preference surveys or simulations in local and regional networks, while analyses that link the actual travel chains of long-distance passengers with operational demand data are rare. Three questions therefore remain unanswered: how many transfers are actually accepted in long-distance travel, what compensation is required for an additional transfer, and which characteristics differentiate the level of resistance.

1.4. Objectives, Scope and Research Questions

The study deliberately focuses on long-distance rail; this scope is the core of the work and not a consequence of data availability. In long-distance travel, conditions differ systematically from those in urban networks: journey times extend to several hours, service frequencies are lower, a missed connection leads to waiting times in the order of an hourly headway, and the proportion of passengers travelling with luggage is high. The survey was therefore carried out on board long-distance trains on three main lines; passengers were surveyed only while on board, so that the information on transfers, journey duration, luggage and purpose of travel refers to the journey actually being made rather than to a journey recalled from memory; the questions on willingness to transfer also refer to this specific journey. Local, commuter and urban transport are expressly excluded from the derived metrics; urban operational data are used solely as an independent benchmark for assessing the effect of a transfer-free route.

The aim of this study is to empirically quantify transfer resistance in long-distance rail and to translate it into metrics that can be applied directly in transport models and service planning. Specifically, three research questions are addressed: (1) How are the actual transfers distributed along the travel chain, and where does the practical acceptance

threshold lie? (2) What compensation in terms of journey time or fare do passengers require for an additional transfer, and how does this vary with journey duration? (3) Which characteristics—socio-demographic or journey-related—influence transfer resistance, and can the metrics derived from the survey be verified against independent operational data? The results provide key metrics for assessing the modal shift potential between road, air and rail, thereby contributing to the evaluation of sustainable transport service concepts.

2. Materials and Methods

2.1. Study Design and Data Sources

The study combines a standardised passenger survey on long-distance services with supplementary operational data from two transport operators. The theoretical framework is based on a structured literature review of transfer resistance and its contextual factors in public transport.

2.2. Passenger Survey: Data Collection and Questionnaire

The empirical data are based on a standardised passenger survey conducted on board long-distance trains. A total of 1009 questionnaires were distributed, of which 903 were deemed suitable for analysis following a plausibility check, corresponding to 89.5% of the questionnaires distributed. Questionnaires containing incomplete or obviously contradictory information were excluded. As the number of questionnaires actually returned was not recorded separately, no response rate in the strict sense can be reported.

The sample comprises passengers from different age groups, with varying frequencies of use and purposes of travel. The questionnaire was divided into four sections. The first section covered the current journey (transfers on the access leg from the origin to the departure station, on the rail leg and on the egress leg from the destination station to the final destination; journey duration; purpose of travel; luggage carried; frequency of use) as well as—separately for these three legs—the willingness to make additional transfers under otherwise unchanged conditions regarding time, cost and comfort (no/yes, one more/yes, two more). Only changes within a leg were counted as transfers; the change from the access mode onto the first train and from the last train onto the egress mode was not counted (Figure 1a). Journey duration was recorded in ten categories ranging from under 10 min to over 5 h and grouped into five categories for the analysis. The second section covered the conditions for an additional transfer (nine attributes; for journey time and fare with open-ended specification of the minimum reduction in minutes or euros) as well as thresholds for fare (+1 to +20%), journey time (+2 to +60 min) and number of transfers (+1 to +3 transfers), each with the option 'I would not choose an alternative'. The third section assessed the perception of the individual sub-processes of a transfer using five-point scales modelled on the Austrian school grading system, with verbally defined endpoints (perceived disruption caused by six sub-processes and by a single and by frequent transfers: 1 = no problem to 5 = very disruptive; importance of six framework conditions: 1 = very important to 5 = not important). The fourth section comprised general statistical information, the departure, destination and transfer stations for validating the journey data, and a free-text field for further comments. Closed-ended questions were predominantly used. The complete questionnaire is provided as Questionnaire S1 in the Supplementary Materials.

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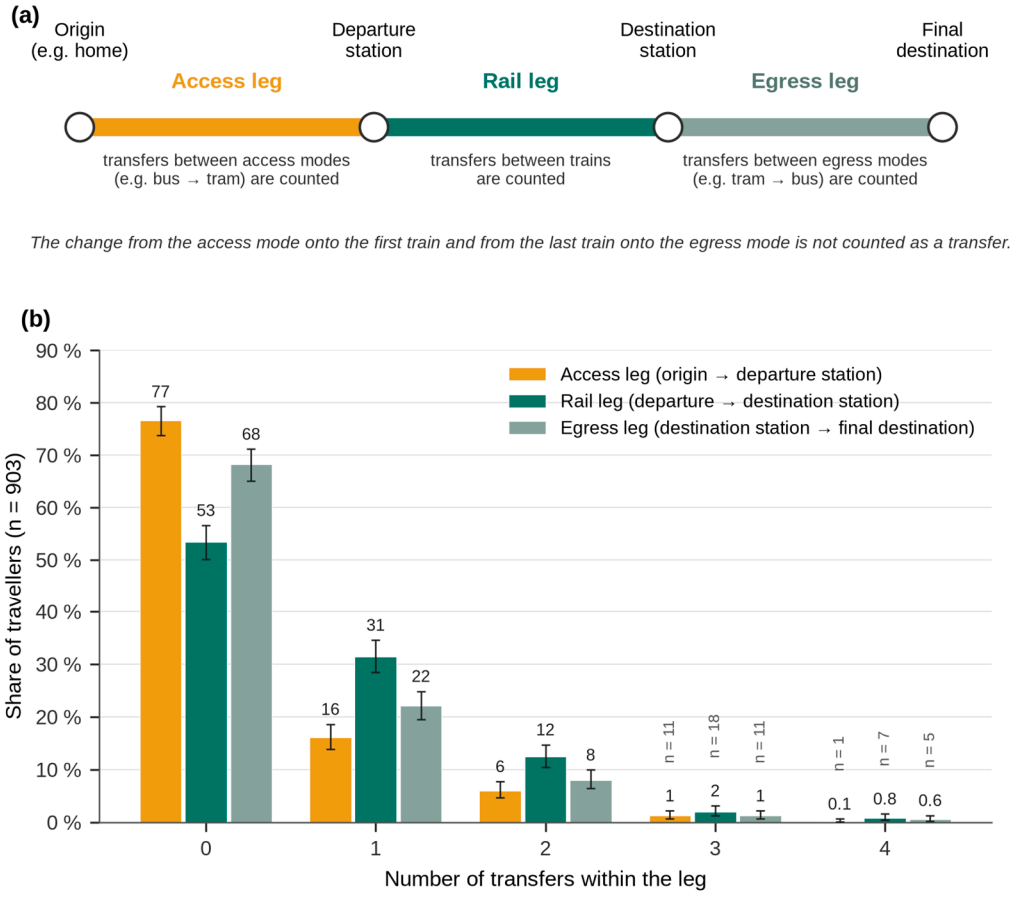


Figure 1. Transfers along the travel chain: (**a**) definition of the access leg, rail leg and egress leg (colours as in panel (**b**)); (**b**) number of transfers per leg with 95% confidence intervals; $n = 903$. Four transfers: access leg $n = 1$ (0.1%), rail leg $n = 7$ (0.8%), egress leg $n = 5$ (0.6%).

The survey was conducted from 27 to 29 June 2016 as part of a diploma thesis at St. Pölten University of Applied Sciences; it was not commissioned by the railway operator but was carried out with its permission on the following lines:

- Western Railway (Westbahn): Vienna–Linz–Vienna;
- Southern Railway (Südbahn): Vienna–Klagenfurt–Vienna;
- Tauern Railway (Tauernbahn): Salzburg–Bischofshofen–Salzburg.

The timing of the survey, shortly before the main holiday season, affects the composition of the sample and must be taken into account when interpreting the results; compared with the annual average, it results in a higher proportion of travellers under 20 years of age and in higher proportions of leisure travel and luggage.

To assess generalisability, a distinction must be made between level values and structural findings. Level values, such as the proportion of direct travellers, the distribution of travel purposes or the fare-related compensation values, are specific to the time and network. The survey was conducted almost five years after the open-access operator WESTbahn had entered the market on the Western Railway in 2011, a period in which ÖBB fares on the Vienna–Salzburg route fell by around 20 to 25% [25]; this competitive situation is therefore already reflected in the data. Since then, however, fares and ticket products have changed further—for example, through the nationwide KlimaTicket introduced in October 2021 [26]—and the COVID-19 pandemic has changed the teleworking behaviour and travel patterns of many train travellers [27]. These developments may have shifted the level values and, in particular, the findings by travel frequency (Section 4.6). The key findings of this study, by contrast, are structural: the acceptance threshold of two transfers,

the pattern of the decline in demand with an increasing number of transfers, the less-than-proportional decrease in the relative compensation requirement with journey duration, and the dominance of journey-related contextual variables over socio-demographic characteristics. Three observations support, but do not prove, this structural interpretation: the findings are corroborated by two independent operational data sources that are not part of the survey; the derived values are of the same order of magnitude as reference values reported internationally over more than two decades [3,4,20], although these values stem from other contexts and methods, so that the agreement indicates plausibility rather than mechanistic equivalence; and the underlying mechanisms—uncertainty about connections, orientation effort and luggage handling—are linked to the topology and sequence of the transfer process rather than to the level of demand. The reported level values should therefore be interpreted as point-in-time data, whereas the structural parameters are considered transferable as working hypotheses that require replication with recent data.

Respondents were recruited as a convenience sample during the respective train journey. Passengers were invited to participate voluntarily after a brief explanation of the study. Consent was given verbally; participation was anonymous, no names or contact details were recorded, and age was recorded only in age groups. No questionnaires were distributed to children under the age of 14; under Austrian law, persons aged 14 and over are considered mature minors (Section 21(2) of the Austrian Civil Code, ABGB).

Of the 903 valid questionnaires, 46.8% were collected on the Western Railway, 31.6% on the Southern Railway and 21.6% on the Tauern Railway. These figures describe the distribution of the valid questionnaires across the three lines studied and do not represent line-specific response rates.

2.3. Supplementary Operational Data

To contextualise the survey results, supplementary datasets from transport operators were used. Of the four companies approached, two provided data: sales data from a long-distance operator on the distribution of transfers per journey sold, and passenger data from an urban transport operator relating to a service reorganisation in which tram lines that previously terminated in the city centre were linked into through services requiring no transfers. In addition, the companies were asked about their modelling and assignment approaches in order to ensure comparability in the treatment of transfers.

2.4. Operationalisation of Transfer Resistance

Transfer resistance was operationalised using several descriptive indicators: the number of transfers during the current journey, the willingness to accept additional transfers, the required reductions in journey time and fare, the subjective assessment of individual phases of the transfer process, and the aforementioned conditions for accepting an additional transfer. Willingness was analysed both in relation to the existing number of transfers and in relation to journey duration, frequency of use and luggage. The required relative journey time saving and the required fare reduction serve as compensation variables; as time and price reductions were stated openly in minutes and euros, respectively, absolute compensation values per transfer are available in addition to relative ones.

Socio-demographic characteristics such as age, gender and occupation were compared with journey-related contextual characteristics. The analyses serve to identify descriptive differences within the sample; associations were tested using χ^2 tests of independence (Section 2.5); no causal analyses were performed. The fitted trend functions describe the observed patterns descriptively and do not represent a causal demand model. To put the orders of magnitude into context, two independent operational data sources

were finally consulted; this comparison serves methodological triangulation and does not demonstrate a causal relationship between the datasets.

2.5. Data Analysis Procedures

The completed questionnaires were checked for completeness and plausibility prior to data entry; forms that were obviously incorrect or inadequately completed were excluded. Digitisation and data preparation were carried out in Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA), with supplementary analyses conducted in IBM SPSS Statistics (version 23; IBM Corp., Armonk, NY, USA); the test statistics, confidence intervals and the willingness and threshold values (Section 3.4) were calculated from the individual records using Python (version 3.14; Python Software Foundation, Wilmington, DE, USA) with SciPy (version 1.18). The analysis was descriptive, based on absolute and relative frequencies, proportions, means and cross-tabulations, differentiated by age group, gender, occupational category, journey duration, frequency of use, purpose of travel and luggage carried. Willingness and threshold values were derived directly from the response distributions. The linear trend function was fitted by least squares to the five proportion values of the transfer classes, whereas the exponential function was fitted non-linearly; both coefficients of determination refer to the untransformed proportion values and are therefore comparable. With five data points, they serve a descriptive purpose rather than model validation. For the cross-tabulations of actual transfers and willingness to transfer by journey duration, existing number of transfers, travel context and socio-demographic characteristics, χ^2 tests of independence were calculated together with Cramér's V; sparsely populated transfer classes were merged into 'two or more transfers' for this purpose, and missing data were excluded. As χ^2 tests become significant even for very small associations in a sample of this size, Cramér's V with its 95% confidence interval (based on the non-central χ^2 distribution) is treated as the primary measure; Table S2 in the Supplementary Materials lists all tests together with the minimum detectable effect at a power of 0.80 and $\alpha = 0.05$, which amounts to $V \approx 0.08$ to 0.10 for the tests reported here. Age trends in ordinal ratings were examined using Spearman's rank correlation coefficient (ϱ). Proportions are reported with 95% confidence intervals (Wilson score method); for the total sample, the half-width is at most 3.3 percentage points (direct travellers: 53.4%, 95% CI 50.1–56.6%), whereas for subgroups, the intervals are correspondingly wider. Group sizes and confidence intervals for the proportions of transfers per journey leg, of transfers by journey duration and of willingness to transfer (by existing transfers, journey duration and luggage) are listed in Table S1 in the Supplementary Materials.

The number of valid responses varies between analyses, as not all respondents answered all questions. The respective sample size is therefore reported in the relevant figures and tables.

3. Results

3.1. Transfers Along the Door-to-Door Travel Chain

In order to assess transfer resistance not only for the rail journey itself but for the entire travel chain, transfers on the access leg (from the origin to the departure station), on the rail leg (from the departure station to the destination station) and on the egress leg (from the destination station to the final destination) must be considered separately (Figure 1a).

Figure 1b shows the number of transfers along the entire travel chain, broken down by access leg, rail leg and egress leg. The rail leg is defined as the trip from the departure station to the destination station, including any intermediate stations. A direct connection requires no transfer, whereas an indirect connection consists of at least two legs. A transfer

is counted only within a leg; the change from the access mode onto the first train and from the last train onto the egress mode is part of every rail journey and is therefore not counted. Zero transfers on the access leg thus means that the departure station was reached with a single mode, for example, on foot, by car or with one public transport vehicle.

Most transfers occur on the rail leg itself, whereas a much stronger predominance of transfer-free trips is evident for the access leg (76.6%) and the egress leg (68.2%) (Figure 1b). Travellers rarely undertake rail journeys involving more than two transfers; with three transfers, the proportion falls below 2%. The classes with three and four transfers are sparsely populated (rail leg: $n = 18$ and $n = 7$); their proportions are therefore subject to wide relative confidence intervals (Table S1).

The decline in the proportion with an increasing number of transfers follows a multiplicative rather than an additive pattern. An exponential function fitted non-linearly to the proportions of the transfer classes (0 to 4 transfers during the rail journey) yields $y = 54.91 \cdot e^{(-0.720 \cdot x)}$ with a coefficient of determination of $R^2 = 0.975$; a linear fit of the same values, $y = 46.93 - 13.47 \cdot x$, achieves only $R^2 = 0.908$ and yields a negative proportion for four transfers. On average, around half of the demand of the preceding transfer class remains with each additional transfer (factor $e^{(-0.720)} \approx 0.49$). The empirical ratios of successive classes decrease from 0.59 (zero to one transfer) via 0.39 (one to two) to 0.16 (two to three transfers), meaning that the exponential function also overestimates the proportions from three transfers onwards. A constant penalty per transfer, as is common in transport models, therefore underestimates the effect of the second and every subsequent transfer.

3.2. Sample Structure and Travel Context

In the following, the structural data from the survey are linked to transfer behaviour. All analyses relate to the current rail journey, meaning that the observed behaviour should be interpreted within the specific context of journey time, number of transfers and fare.

3.2.1. Socio-Demographic Structure

Figure 2 shows the age and gender distribution of the valid responses. Women account for around 55% of the sample and men for 45%; women aged 20 to 25 form the largest single group. The high proportion of travellers under 20 years of age, compared with other studies, is attributable to the timing of the survey—shortly before the main holiday season—and the school trips that typically take place during these weeks. Representativeness cannot be inferred from the stability of a distribution alone but requires comparison with a known population.

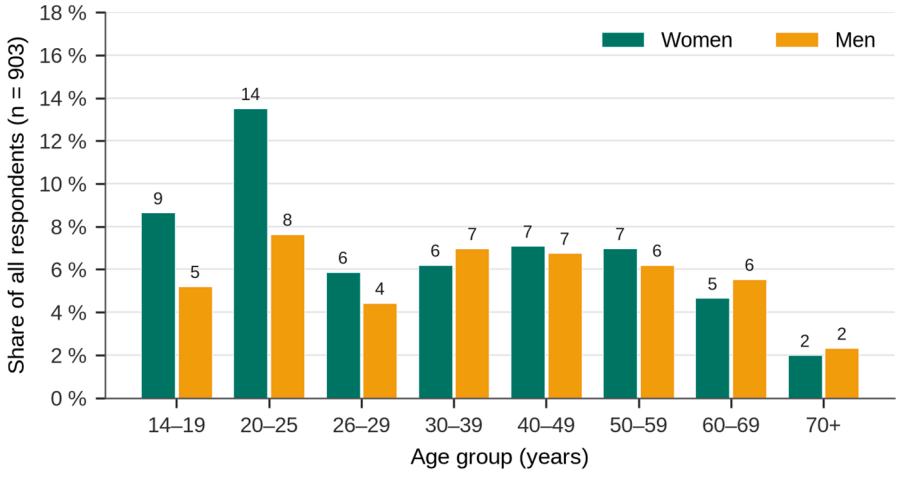


Figure 2. Gender and age distribution; $n = 903$.

The age and gender distribution shows descriptive similarities with the comparative study on time-use advantages of rail compared with air and car travel [28]. This correspondence allows a rough assessment of the sample structure but does not prove its representativeness. As both studies exclusively cover actual rail travellers, comparable self-selection of participants cannot be ruled out.

Across all age and gender groups, the number of transfers during the current rail journey remains approximately constant (Figure S1 in the Supplementary Materials). No association between age or gender and the choice between a direct and an indirect connection was detectable in this sample (age: $\chi^2(14) = 15.9$, $p = 0.32$, Cramér's V = 0.09, 95% CI 0–0.10; gender: $\chi^2(2) = 4.1$, $p = 0.13$, V = 0.07, 95% CI 0–0.13; Table S2). With $n = 903$, an association of V ≈ 0.10 would have been detected with a power of 80%; weaker associations cannot be ruled out, but the upper confidence limits exclude more than weak associations. No specific target group for transfer behaviour can therefore be identified.

Occupational structure does not differentiate transfer behaviour either. More than a third of respondents are civil servants and white-collar employees (37.65%), a fifth are students (20.38%), while apprentices and blue-collar workers are scarcely represented (Figure S2 in the Supplementary Materials)—a consequence of the survey being conducted on long-distance services and of the fact that many manual trades require workers to carry tools, which favours car use. The descriptive analysis reveals no clear differences in transfer frequency between occupational categories (Figure S3 in the Supplementary Materials), and no association was detectable in the χ^2 test ($\chi^2(14) = 13.7$, $p = 0.47$, V = 0.09, 95% CI 0–0.09). Likewise, no association between willingness to transfer and age, gender or occupation was detectable (all $p > 0.3$; V ≤ 0.09, upper 95% confidence limits ≤ 0.10; Table S2).

3.2.2. Travel Context: Luggage, Travel Frequency, Purpose of Travel and Journey Duration

The inconvenience caused by a transfer depends largely on whether luggage is carried. Travellers who travel by train daily or several times a week predominantly carry no luggage or only hand luggage; the vast majority of those who travel less often than several times a month carry one or more pieces of luggage (Figure S4 in the Supplementary Materials).

In the sample, there is a positive association between carrying luggage and the frequency of transfers ($\chi^2(2) = 20.7$, $p < 0.001$, Cramér's V = 0.15, 95% CI 0.08–0.21; Figure S5 in the Supplementary Materials), which seems implausible at first glance, as travellers with luggage would be expected to prefer direct connections. This association is mediated by journey duration: as journey duration increases, both the number of transfers required (Figure 3) and the proportion of travellers with luggage (Section 3.4.3) rise.

At the same time, purpose of travel, travel frequency and journey duration are interrelated. As described in the literature, from a journey duration of around two to three hours, mode choice shifts in favour of public transport, particularly for journeys involving an overnight stay and for holiday travel [29,30]. The longer the journey, the more likely it is that transfers are required, the less frequently the route is travelled and the more frequently luggage is carried.

No greater willingness to transfer among travellers with luggage can be inferred from this association; the figures merely show that, within the sample, travellers with luggage were more frequently affected by transfers. Luggage increases the physical and organisational effort involved in transferring and thus represents an additional barrier [31].

As travel frequency decreases, the proportion of direct travellers falls from 60.9% among those travelling daily or almost daily to 50.5% among very infrequent travellers,

while the proportion with exactly one transfer remains almost constant across all frequency categories at 30 to 31.7% (Figure S6 in the Supplementary Materials); no association is detectable ($\chi^2(8) = 6.6$, $p = 0.58$, V = 0.06, 95% CI 0–0.08). In contrast, travel frequency is significantly, albeit weakly, associated with willingness to transfer: 77% of daily travellers are not willing to make any additional transfer, compared with around 53% of occasional travellers ($\chi^2(8) = 26.5$, $p < 0.001$, Cramér's V = 0.12, 95% CI 0.05–0.15). Multiple transfers occur predominantly among occasional travellers; daily travellers transfer at most twice.

The purpose of travel varies considerably with age (Figure S7 in the Supplementary Materials): the proportion of business trips is highest among 30–39-year-olds at around 31% and among 40–49-year-olds at around 28%, whereas among 60–69-year-olds around 84% and among those over 70 around 89% of trips are for private occasions, day trips and overnight stays. As journey duration increases, the purposes 'to work' and 'to/from education' decrease, while trips involving an overnight stay increase (Figure S8 in the Supplementary Materials). The results describe the distribution within the sample; a general influence of age on the purpose of travel cannot be inferred from them.

Transfer behaviour differs significantly but only slightly by purpose of travel ($\chi^2(10) = 41.0$, $p < 0.001$, Cramér's V = 0.15, 95% CI 0.08–0.18; Figure S9 in the Supplementary Materials); the difference in the proportion of direct journeys between private purposes and work or education purposes is around 10 percentage points. Transfers are most common for journeys involving an overnight stay: around 28% of these travellers transfer once, 25% transfer several times, and only around 47% are able to use a direct connection.

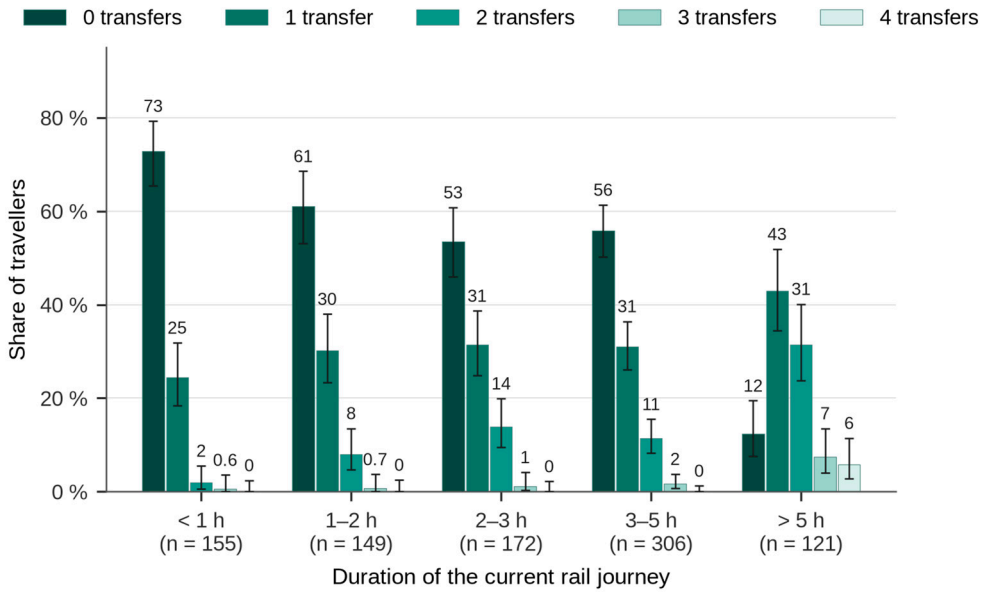


Figure 3. Number of transfers by journey duration, with 95% confidence intervals; $n = 903$.

As journey duration increases, the need to transfer rises markedly (Figure 3; Table S3 in the Supplementary Materials). For journeys under one hour, only around 27% of travellers need to transfer once or more; for journeys over five hours, only 12.4% can use a direct connection, and 13.2% have to transfer more than twice, of whom 5.8% transfer four times. For journey durations between one and five hours, the proportions remain largely constant, with an average of around 57% travelling without a transfer, 31% with one transfer and 12% with more than one transfer. Across all categories, the proportion of direct travellers thus falls from 72.9% to 12.4% ($\chi^2(8) = 149.1$, $p < 0.001$, Cramér's V = 0.29, 95% CI 0.23–0.33; transfer categories 0, 1 and ≥2).

3.3. Value of an Additional Transfer

The aim of the following section is to quantify the value of an additional transfer in terms of the required relative journey time saving and relative fare reduction, depending on journey duration, travel frequency and luggage carried.

The time saving is defined as the percentage reduction in journey time relative to the original journey duration. As journey duration was recorded in intervals, the required time saving—stated as an open-ended figure in minutes—was related to the midpoint of the respective interval; for a journey duration of two to three hours (midpoint 150 min), a required saving of 30 min thus corresponds to 20%. Similarly, the fare reduction is defined relative to the original fare and was calculated from the price reduction stated in euros, based on the midpoint of the respective ticket price category.

3.3.1. Value of an Additional Transfer by Journey Duration

Figure 4 shows the value of an additional transfer as a function of the current journey duration.

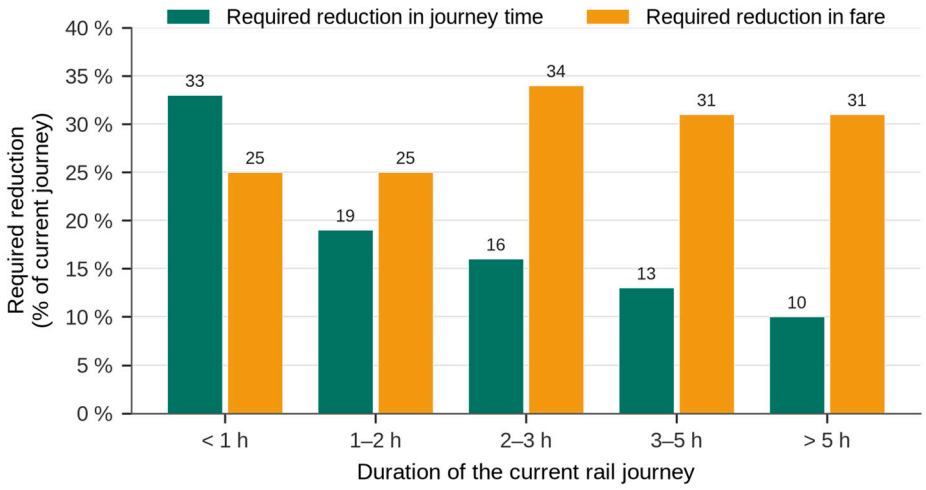


Figure 4. Value of an additional transfer in terms of the required reduction in journey time and fare (in %) by current journey duration; $n = 316$ (relative values from the original analysis; directly stated minutes in Table S4).

As journey duration increases, the required relative time saving decreases from 33% for journeys under one hour, via 19% (one to two hours) and 16% (two to three hours), to 13% (three to five hours) and 10% (over five hours). The primary absolute measure is the minimum time saving stated directly in minutes ($n = 500$): on average 12 min for journeys under one hour ($n = 87$), 17 min for one to two hours ($n = 89$), 23 min for two to three hours ($n = 93$), 32 min for three to five hours ($n = 165$) and 37 min for journeys exceeding five hours ($n = 66$) (Table S4 in the Supplementary Materials). As a plausibility check, the relative savings can be converted back to minutes using the class midpoints of 30, 90, 150 and 240 min, which yields approximately 10, 17, 24 and 31 min. The two sets differ slightly because they are based on different subsamples ($n = 500$ and $n = 316$) and because the back-calculation assumes that each journey lasts exactly as long as the class midpoint; for the open-ended class over five hours, no back-calculation is possible. Only the directly stated values are used in the following. The relative time saving therefore decreases less than proportionally with journey duration, while the absolute time saving increases; for long-distance journeys of two to five hours, it amounts to around 23 to 32 min. Across all journey duration categories, this results in an average relative time saving of around 17%. The

figures were derived directly from the distribution of responses and should be understood as sample-based compensation values.

The required fare reduction shows a much flatter trend across the journey duration categories: the extreme values differ by around 9 percentage points, and the mean is 29.3%. For journeys under two hours, the required reduction is slightly below this average at around 25%; for journeys of two hours or more, it is slightly above at 31 to 34%, meaning that, overall, the required fare reduction per additional transfer can be considered approximately constant.

3.3.2. Value of an Additional Transfer by Travel Frequency

Figure 5 shows the required relative journey time saving and fare reduction as a function of travel frequency.

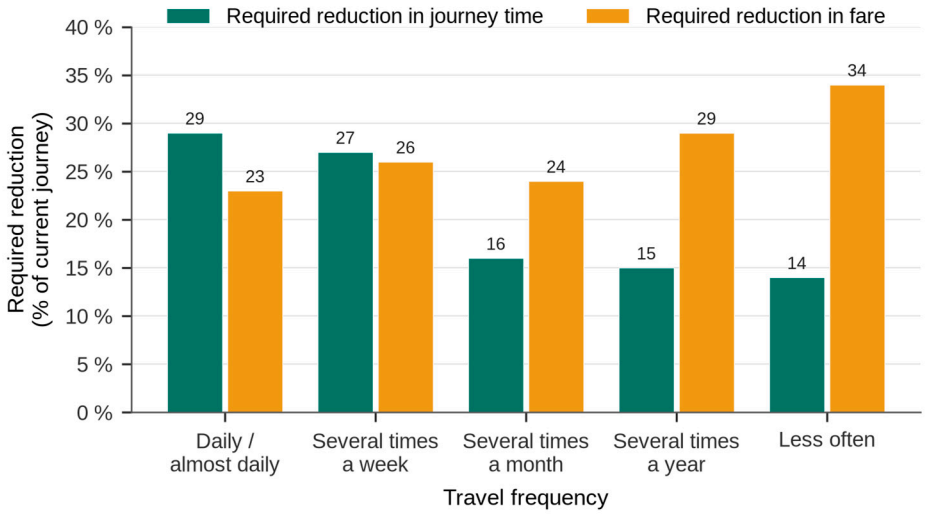


Figure 5. Value of an additional transfer (in %) by current travel frequency; $n = 316$.

Frequent travellers—those travelling daily or several times a week—place roughly equal weight on time and fare compensation, whereas infrequent travellers respond much more strongly to fare reductions and less to journey time savings.

No distinct pattern emerges for luggage; the values follow the combination of journey duration and travel frequency (Figure S10 in the Supplementary Materials). An average journey time saving of around 17% and an average fare reduction of around 30% can therefore be used as compensation values for an additional transfer.

3.4. Willingness to Transfer

The aim of the willingness analysis is to determine the willingness to make an additional transfer under subjectively perceived ideal conditions and to derive a threshold value from it. Using this willingness threshold, the transfer elasticity determined from actual transfers is adjusted upwards or downwards according to the given parameters (journey duration, luggage, existing transfers).

3.4.1. Willingness to Make Additional Transfers by Number of Existing Transfers

Figure 6 shows the willingness to make an additional transfer depending on the number of transfers already made during the current journey, with time, cost and comfort remaining unchanged in each case.

Of the travellers currently using a direct connection, 39.4% would be willing to make exactly one additional transfer, and a further 4.1% would be willing to make two. As it can be assumed that travellers who accept two additional transfers would also accept one,

the cumulative willingness is 43.6% (95% CI 39.2–48.0%), rounded to approximately 44% in the following; accordingly, around 56% of direct travellers are not prepared to make any additional transfer. This stated cumulative willingness (around 44% for one and 4% for two additional transfers) is the primary willingness measure of this study; it must be distinguished from the threshold-based measures and the theoretical willingness threshold introduced below. Where one transfer is already required, the cumulative willingness is at the same level (45.4%); where two or three transfers are already required, it falls to around 33% (Table S5 in the Supplementary Materials). The association between the number of existing transfers and willingness is significant but very weak ($\chi^2(4) = 10.5$, $p = 0.033$, Cramér's V = 0.08, 95% CI 0–0.11; transfer categories 0, 1 and ≥2).

Across all respondents ($n = 903$), 57.6% are not willing to accept additional transfers and 42.4% are willing, namely 37.0% to accept one and 5.4% to accept two additional transfers. The pattern thus corresponds to the distribution of the number of transfers actually made.

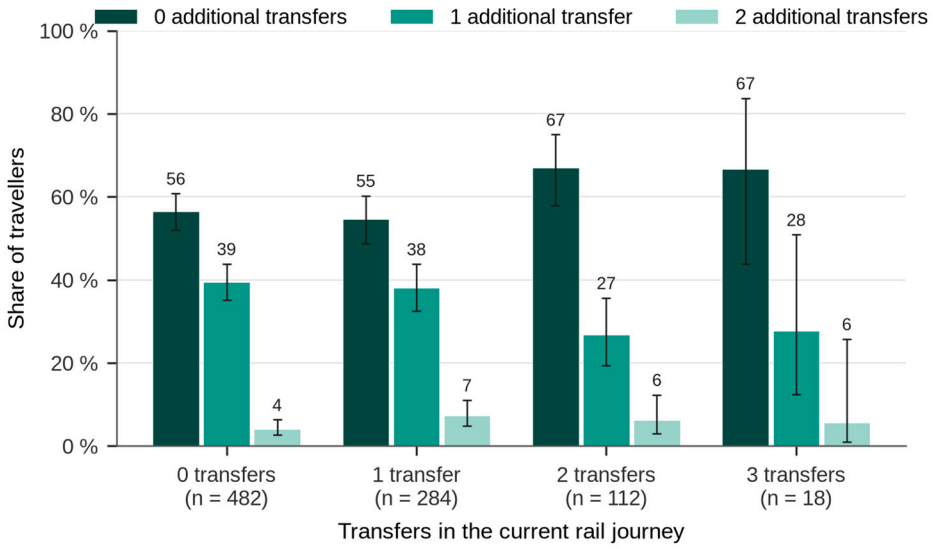


Figure 6. Willingness to accept additional transfers by number of existing transfers, with 95% confidence intervals; $n = 896$ (travellers with four transfers, $n = 7$, excluded owing to the small group size).

A threshold value is the point at which, once reached or exceeded, passengers would look for an alternative to their current rail connection, such as car or bus. In Table 1, 'threshold for +1 transfer' denotes the proportion of respondents who would accept one additional transfer and would only look for an alternative at +2 or +3 transfers; 'threshold for +2 transfers' denotes the proportion who would only look for an alternative at +3 transfers. Respondents who would already look for an alternative at +1 transfer are included in neither column; passengers who would remain with rail despite deteriorating conditions are shown as 'no alternative'. The two threshold columns thus represent a threshold-based acceptance of one and two additional transfers that can be compared with the stated willingness.

Table 1 compares the willingness and threshold values with the number of transfers actually made. All proportions are given with 95% confidence intervals; the last column shows the theoretical willingness threshold, i.e., the arithmetic mean of the stated cumulative willingness and the threshold-based acceptance for the same number of additional transfers.

Table 1. Willingness and threshold values by number of actual transfers (in %, 95% confidence intervals in brackets).

Transfers in the Current Rail Journey	*n*	Actual Transfers (Share of All)	Willingness +1 Transfer (Cumulative, Incl. +2)	Willingness +2 Transfers	Threshold for +1 Transfer [1]	Threshold for +2 Transfers [1]	No Alternative	Theoretical Willingness Threshold +1/+2 [2]
0 transfers	482	53.4 (50.1–56.6)	43.6 (39.2–48.0)	4.1 (2.7–6.3)	51.0 (46.6–55.5)	13.1 (10.4–16.4)	34.4 (30.3–38.8)	47.3/8.6
1 transfer	284	31.5 (28.5–34.6)	45.4 (39.7–51.2)	7.4 (4.9–11.0)	47.5 (41.8–53.3)	13.4 (9.9–17.8)	34.2 (28.9–39.8)	46.5/10.4
2 transfers	112	12.4 (10.4–14.7)	33.0 (25.0–42.2)	6.2 (3.1–12.3)	51.8 (42.6–60.8)	22.3 (15.6–30.9)	37.5 (29.1–46.7)	42.4/14.3
3 transfers	18	2.0 (1.3–3.1)	33.3 (16.3–56.3)	5.6 (1.0–25.8)	33.3 (16.3–56.3)	11.1 (3.1–32.8)	44.4 (24.6–66.3)	33.3/8.3
Mean [3]	–	–	38.8	5.8	45.9	15.0	37.6	42.4/10.4

Values in %, 95% confidence intervals (Wilson) in brackets; recalculated from the individual records. [1] Threshold for +1 transfer: proportion of respondents who would only look for an alternative at +2 or +3 additional transfers; threshold for +2 transfers: proportion who would only do so at +3 additional transfers. [2] Arithmetic mean of the stated willingness and the threshold-based acceptance for +1 and +2 transfers (columns 4 and 6, and 5 and 7), calculated from unrounded values. [3] Unweighted mean across the four transfer classes. Travellers with four transfers (n = 7) are excluded owing to the small group size.

Willingness and threshold-based values are of the same order of magnitude (Figure S11 in the Supplementary Materials): for direct travellers and travellers with one transfer, they differ by 0 to 9 percentage points; for travellers with two transfers, by 16 to 19 percentage points. This indicates broad, but not exact, consistency between the two question formats.

Figure 7 summarises the trend across the number of transfers: with each transfer already made, the willingness to make further transfers tends to decrease. Three measures must be distinguished. (i) The stated cumulative willingness of direct travellers is 43.6% (around 44%) for one and 4.1% (around 4%) for two additional transfers. (ii) The threshold-based acceptance, i.e., the proportion who would accept the additional transfer(s) before looking for an alternative, is 51.0% and 13.1%, respectively (Table 1). (iii) The theoretical willingness threshold is the arithmetic mean of (i) and (ii) for the same number of additional transfers, calculated from the unrounded values; it amounts to around 47% and 9%, respectively, and is shown in Figure 7. Regardless of the measure, acceptance drops to between a quarter and a tenth from the first to the second additional transfer. Unless stated otherwise, the stated cumulative willingness of around 44% and 4%, respectively, is used for direct travellers in the following.

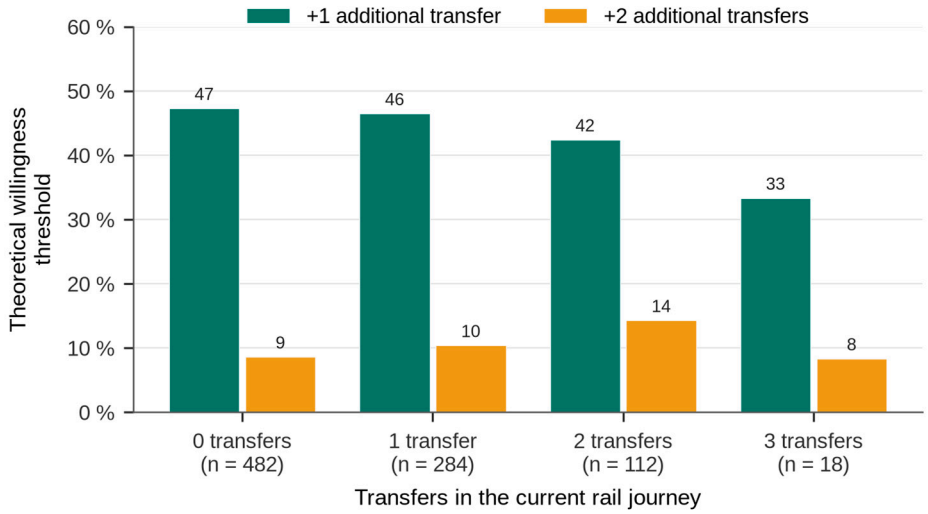


Figure 7. Theoretical willingness threshold per transfer (mean of the stated cumulative willingness and the threshold-based acceptance; last column of Table 1); $n = 896$.

3.4.2. Willingness to Transfer by Journey Duration

Figure 8 shows the willingness to make an additional transfer depending on journey duration, again under otherwise unchanged conditions.

As journey duration increases, the willingness to make an additional transfer rises; transfer resistance therefore decreases with journey duration. For journeys under one hour, the willingness is around 30%, meaning that around 70% of these travellers are not willing to make any additional transfer (Table S6 in the Supplementary Materials); in the threshold question, around 43% of them would accept one additional transfer before looking for an alternative to rail (Table 2).

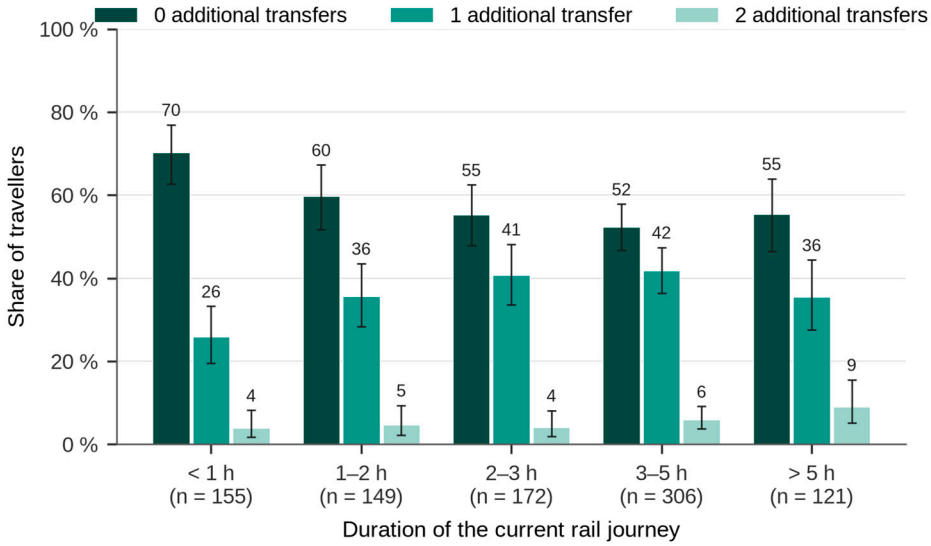


Figure 8. Willingness to transfer by current journey duration, with 95% confidence intervals; $n = 903$.

Table 2 compares the willingness and threshold values for each journey duration category, with 95% confidence intervals; the threshold columns are defined as in Table 1, and the mean values are calculated unweighted across the five categories.

Table 2. Willingness and threshold values by journey duration (in %, 95% confidence intervals in brackets).

Journey Duration	*n*	Willingness +1 Transfer (Cumulative, Incl. +2)	Willingness +2 Transfers	Threshold for +1 Transfer [1]	Threshold for +2 Transfers [1]	No Alternative	Theoretical Willingness Threshold +1/+2 [2]
<1 h	155	29.7 (23.0–37.3)	3.9 (1.8–8.2)	43.2 (35.7–51.1)	10.3 (6.5–16.1)	38.7 (31.4–46.6)	36.5/7.1
1–2 h	149	40.3 (32.7–48.3)	4.7 (2.3–9.4)	49.0 (41.1–56.9)	14.1 (9.4–20.6)	34.2 (27.1–42.2)	44.6/9.4
2–3 h	172	44.8 (37.5–52.2)	4.1 (2.0–8.2)	55.2 (47.8–62.5)	14.5 (10.0–20.6)	31.4 (24.9–38.7)	50.0/9.3
3–5 h	306	47.7 (42.2–53.3)	5.9 (3.8–9.1)	52.3 (46.7–57.8)	12.7 (9.5–16.9)	33.7 (28.6–39.1)	50.0/9.3
>5 h	121	44.6 (36.1–53.5)	9.1 (5.2–15.5)	44.6 (36.1–53.5)	24.8 (18.0–33.2)	38.0 (29.9–46.9)	44.6/16.9
Mean [3]	–	41.4	5.5	48.9	15.3	35.2	45.1/10.4

Values in %, 95% confidence intervals (Wilson) in brackets; recalculated from the individual records. [1] Definitions as in Table 1. [2] Arithmetic mean of the stated willingness and the threshold-based acceptance for +1 and +2 transfers (columns 3 and 5, and 4 and 6), calculated from unrounded values. [3] Unweighted mean across the five duration classes.

The willingness and threshold values shown in Table 2 for each journey duration class are at the same level as the values based on existing transfers, which suggests consistency in the order of magnitude.

The mean of the stated willingness and the corresponding threshold-based acceptance yields the theoretical willingness threshold for each journey duration class (last column of Table 2; Figure 9; individual values in Figure S12 in the Supplementary Materials).

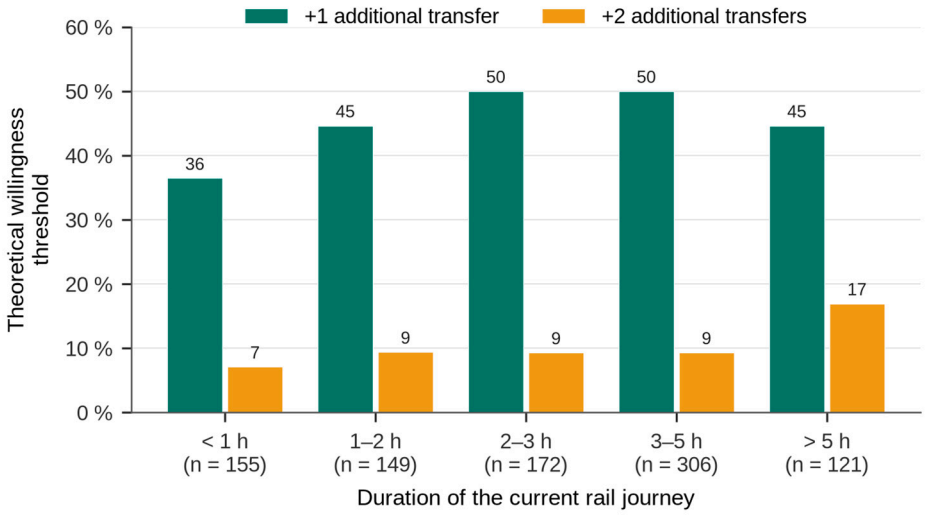


Figure 9. Theoretical willingness threshold by journey duration, derived from Table 2; *n* = 903.

As journey duration increases, the stated cumulative willingness to make one additional transfer rises from 29.7% (under one hour) to 47.7% (three to five hours), and the theoretical willingness threshold from around 36% to 50% (Figure 9); for journeys lasting over five hours, the willingness to make two additional transfers also rises (stated: 9.1% compared with 3.9 to 5.9%; theoretical threshold: around 17% compared with 7 to 9%).

The confidence intervals of adjacent duration classes overlap (Table 2); the association between journey duration and willingness to transfer is statistically significant but weak ($\chi^2(8) = 18.7$, $p = 0.016$, Cramér's V = 0.10, 95% CI 0.02–0.13).

3.4.3. Willingness to Transfer by Luggage

Figure 10 shows the luggage carried by journey duration category. As journey duration increases, the proportion of travellers with luggage rises markedly: for journeys under two hours, 83.2% carry no luggage or only hand luggage; for journeys over three hours, 77.3% carry one or more pieces of luggage. Willingness to transfer on journeys under two hours is therefore predominantly determined by travellers without luggage, whereas on journeys over three hours it is determined by travellers with luggage. In between lies a neutral zone in which around 55% carry no luggage or only hand luggage and around 45% carry one or more pieces of luggage.

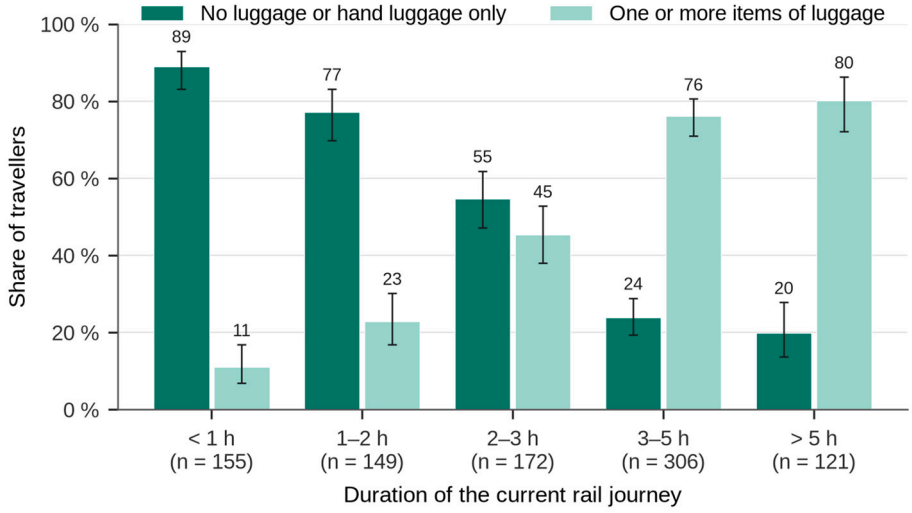


Figure 10. Luggage by journey duration, with 95% confidence intervals; $n = 903$.

Figure 11 shows that the willingness to accept additional transfers varies with journey duration and luggage. Among travellers without luggage or with hand luggage only, the proportion willing to make at least one additional transfer increases with journey duration (from 28% to 62%). For travellers with one or more larger pieces of luggage, however, this trend is not apparent; their willingness tends to decrease from 59% (one to two hours) to 40% (over five hours). As several subgroups are small (e.g., $n = 17$ travellers with luggage on journeys under one hour and $n = 24$ travellers without luggage on journeys over five hours), the confidence intervals are wide and partly overlap (Figure 11; Table S1).

This result differs from the general relationship between the number of existing transfers and willingness to transfer shown in Figure 6. One possible explanation is the additional physical and organisational effort involved in transferring with luggage [31]. Particularly on longer journeys, luggage can therefore constitute a barrier in its own right. The results should be understood as a descriptive indication of an interaction between journey duration and luggage; an independent causal influence cannot be inferred from them.

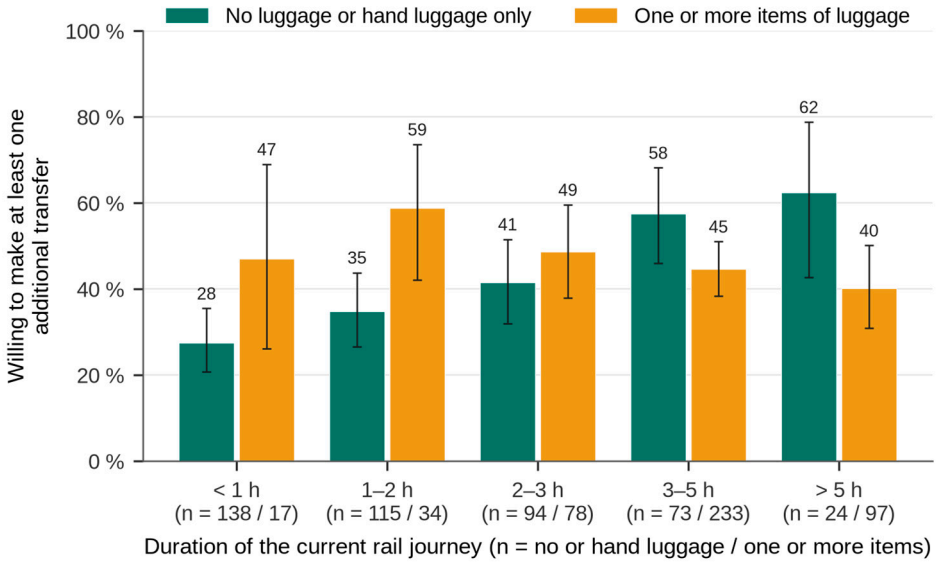


Figure 11. Proportion of travellers willing to make at least one additional transfer by luggage and journey duration, with 95% confidence intervals; n = 903 (group sizes in the axis labels; full distribution in Table S1).

3.4.4. Combination of Threshold Parameters

Figure 12 shows the threshold values for the three key parameters—fare, journey time and number of transfers—at which travellers would choose an alternative to their current rail journey. Travellers who would remain with rail despite a substantial deterioration in conditions were able to select 'I would not choose an alternative'; bus and car are the main alternatives considered. As it can be assumed that passengers who would switch to another mode even in the event of a minor deterioration would also do so in the event of a more substantial one, the proportions must be cumulated to estimate the passenger loss. The increases in journey time are shown in the increments offered in the questionnaire (+2 to +60 min).

For all three parameters, the largest proportion is accounted for by 'I would not choose an alternative'. With regard to fare, 52% of respondents would continue to use the train for their current journey despite a massive price increase. The situation is similar for journey time: 41% of respondents would continue to travel by train even if the journey time were extended due to operational circumstances.

For the parameter 'additional transfers', this loyalty is less pronounced at 35% (34.8%). Two additional transfers (+2 transfers) represent a significant barrier: 35.2% of respondents would seek an alternative to their current rail connection at exactly this step. Cumulating the steps yields the stated passenger loss: 15.5% (95% CI 13.3–18.0%) for one, 50.7% (47.5–54.0%) for up to two and 65.2% (62.1–68.3%) for up to three additional transfers (n = 903). This cumulation assumes monotonic preferences, i.e., that a respondent who would look for an alternative at a given deterioration would also do so at any greater one. The single-choice format of the question presupposes this assumption and does not allow non-monotonic responses to be identified. In reality, reverse effects are conceivable: travellers who have already completed part of a journey may continue despite further transfers (sunk-cost effect), and captive travellers may accept additional transfers because they have no other choice; the latter are captured at least in part by the option 'no alternative'. The cumulative values should therefore be interpreted as an upper estimate of the stated switching potential, not as a forecast of demand losses.

Minor deteriorations, by contrast, trigger only limited passenger losses: for fare increases of up to 2%, around 7% of respondents would choose an alternative, and for journey time increases of up to 10 min, around 7% would do so.

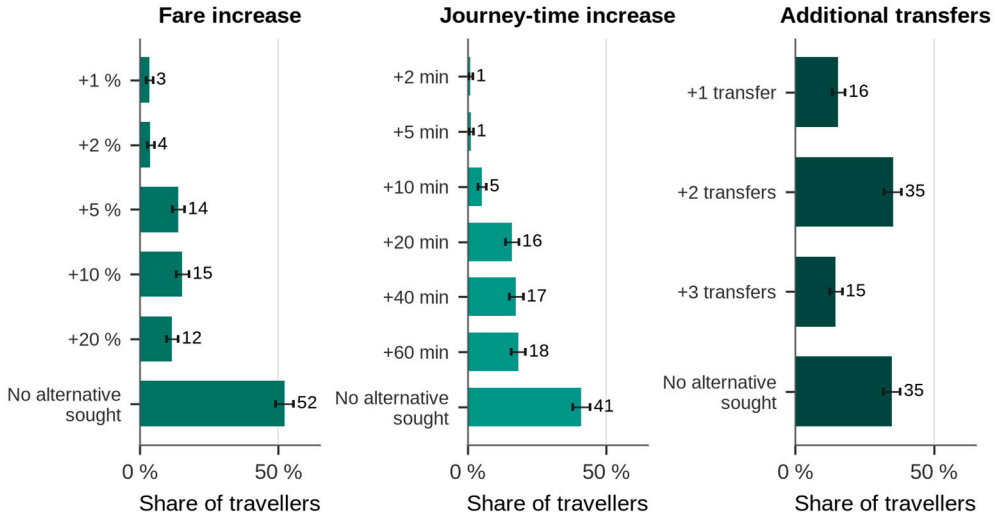


Figure 12. Threshold parameters at which an alternative connection would be sought (proportion per response step with 95% confidence intervals; journey time in the increments of the questionnaire); $n = 903$.

The eight most frequent combinations of switching thresholds—excluding 'no alternative' for all three parameters—cover around 32% of the 691 respondents who indicated at least one threshold (Figure S13 in the Supplementary Materials, recalculated from the individual records with the journey time thresholds in minutes); in seven of these eight combinations, the threshold of two additional transfers is cited, and in the eighth, three additional transfers, which underlines the significance of the number of transfers as a reason for switching. Around 23% of all respondents (212 of 903) selected 'no alternative' for all three parameters.

Of these 23%, around 32% do not have a car available and 10% only rarely; for 42% of this group, the car is therefore not an option, meaning that they are likely to be more dependent on rail than the remaining 58%.

3.5. Perceptions of and Prerequisites for Transfers

The following section presents the subjective perception of the sub-processes involved in a transfer and derives the prerequisites for accepting an additional transfer.

The level of disruption was rated on a school grading scale from 1 (no problem) to 5 (very disruptive). As around 97% of passengers transfer no more than twice, multiple transfers are defined as two transfers per rail journey. Contrary to expectations, there are no notable differences in ratings between travellers with and without luggage (Figure S14 in the Supplementary Materials): a single transfer is perceived on average as only slightly disruptive (1.85), whereas frequent transfers are perceived as rather disruptive (3.75). Connections involving two transfers should therefore already be regarded as unsatisfactory.

3.5.1. Importance of Framework Conditions and Perceived Disruption of the Sub-Processes

Figure 13 shows how important six framework conditions relating to transfers are to travellers (1 = very important to 5 = not important), broken down by age group. The aver-

age across all six conditions is 1.79; all framework conditions are therefore rated as important. The most important are guaranteed connections (1.27) and good information in advance and in the event of delays (1.38), followed by an unchanged total journey time (1.49) and short walking distances between platforms (1.69). Convenient and step-free boarding and alighting (2.26) and a good luggage handling service (2.63) are, on average, rated as the least important.

With increasing age, all six conditions gain in importance (Spearman's ϱ between −0.11 and −0.30, $p < 0.01$ in each case). The strongest age-related trends are observed for luggage handling (from 3.0 among 14- to 19-year-olds to 1.7 among those over 70; ϱ = −0.30), short transfer distances (from 2.0 to 1.2; ϱ = −0.23) and step-free boarding and alighting (from 2.3 to 1.5; ϱ = −0.21). Older travellers therefore attach significantly greater importance to physical transfer barriers than younger travellers.

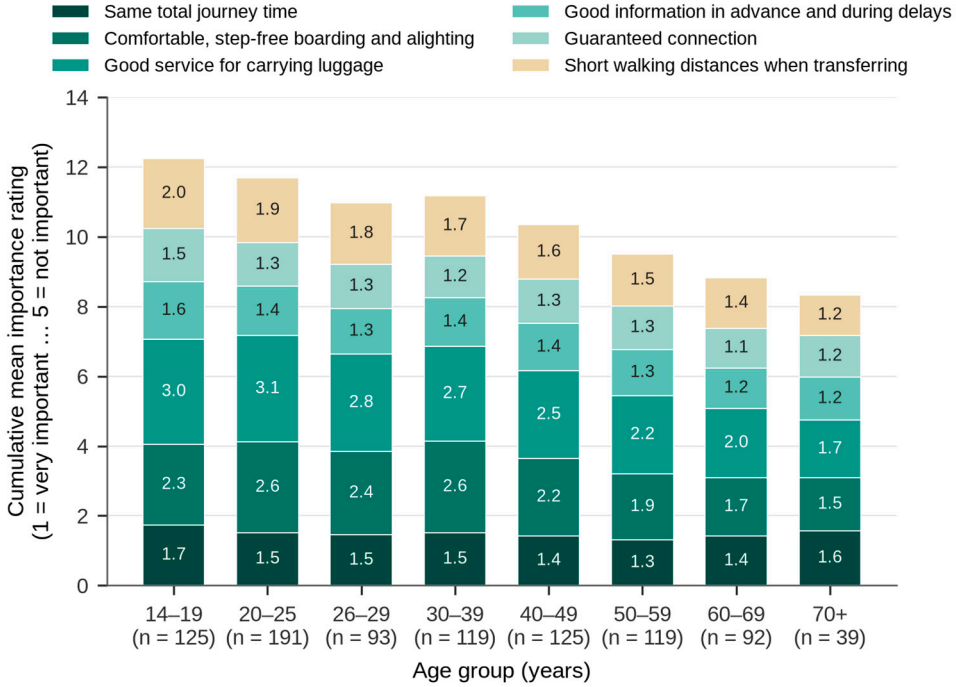


Figure 13. Importance of transfer conditions by age group (1 = very important to 5 = not important); n = 883–892 per condition.

Regarding the perceived disruption of the individual phases of a transfer (1 = no problem to 5 = very disruptive; Figure S15 in the Supplementary Materials), alighting (1.82) and boarding the connecting train (1.94) are perceived as the least disruptive, stowing luggage (2.27) and walking to the platform of the connecting train (2.37) as moderately disruptive, and the waiting time at the station (2.77) and finding a seat on the connecting train (2.91) as the most disruptive.

Passengers with a seat reservation (26%) rate the six phases on average around 11% less favourably than passengers without a reservation (2.53 compared with 2.28). This is likely to be due to journey duration: seat reservations are concentrated on journeys lasting over three hours (42 to 44% compared with 5 to 7% for journeys under two hours) and on passengers with luggage (37% compared with 16%). It cannot be concluded from this that seat reservations have a relieving effect.

3.5.2. Conditions for an Additional Transfer

Figure 14 shows the prioritisation of possible influencing factors for accepting an additional transfer.

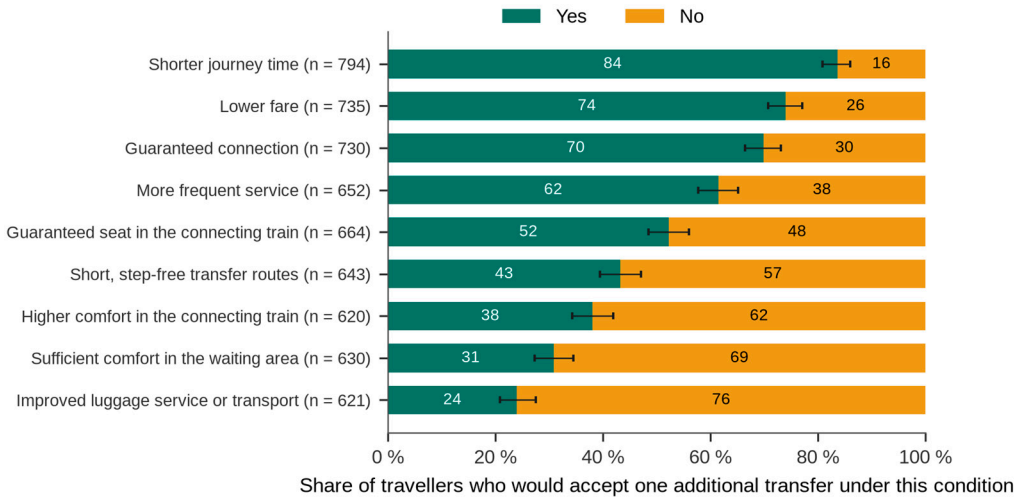


Figure 14. Prioritisation of influencing factors for an additional transfer; proportions of valid 'yes'/'no' responses per attribute with 95% confidence intervals; n = 620–794.

The motivational factors are presented individually and not in relation to one another; an actual shift in passenger numbers cannot be inferred from them.

The traditional factors journey time (84%) and fare (74%), as well as operational conditions such as guaranteed connections (70%) and service frequency (62%), are given the highest priority. Comfort factors such as a guaranteed seat, the layout of the station and the general level of comfort on the connecting train and at the station therefore have a lower potential to motivate passengers to make an additional transfer. Viewed in isolation, an improved luggage service or improved luggage transport also shows little potential for prompting an additional transfer during the journey.

This prioritisation is consistent with the importance ratings: on average, the luggage service is rated as the least important factor (2.63; Figure 13) and, considered in isolation, also shows little potential to motivate passengers. In combination with other attributes, however, it remains relevant, as around 10% of all combinations mentioned include it as a necessary improvement; for older travellers, it is also significantly more important than average.

To realistically assess the effect of an additional transfer, multiple motivational factors acting in parallel must be taken into account, as is known from the literature on mode choice [4].

In total, around 200 different combinations were mentioned. The 15 most frequent combinations (nine individual motives and six combined motives) account for around 30% of respondents who are in principle willing to transfer (Figure S16 in the Supplementary Materials); the remaining 70% are distributed across combinations that are very similar in content.

The parameters act predominantly in combination: just under 3.6% of all respondents would be motivated to make an additional transfer by a single improvement, half of them by a shorter journey time alone, whereas around 10% would only be willing to transfer if all parameters were optimised simultaneously.

Around 5% of all passengers would already be motivated to make one more transfer by a shorter journey time combined with a reduced fare. Journey time and fare are included in just under 90% of all combinations, which again underlines the importance of these two parameters.

3.5.3. Further Comments on Transfers

Table 3 summarises the free-text comments on transfers. A total of 96 comments on this topic were made; around 10% of respondents thus provided an individual opinion.

Table 3. Comments on transfers; *n* = 96 comments, percentages based on 85 thematically categorised mentions.

Summarised Comments from the Questionnaire	Share
Guaranteed connection reliability in the event of delays (including for people with physical disabilities)	27.06%
Improved information on board trains and on platforms, particularly in the event of delays	17.65%
Connecting train on the same platform	14.12%
Accessible and convenient boarding and alighting	11.76%
Optimised waiting times	9.41%
Improved luggage service	7.06%
Improved comfort on board	5.88%
More frequent services/higher frequency	4.71%
Transfer perceived as a welcome change	2.35%

Around 27% of comments relate to guaranteed connections in the event of delays for all passenger groups, and around 18% to improved information. Approximately 19% relate to accessible boarding and alighting or an improved luggage service.

3.6. Operational Data Versus Survey Results

The following section compares the survey results with data from transport operators. Of the four companies approached, two provided data; the reluctance of the others is likely to be linked to competition in the liberalised rail sector.

3.6.1. DB Data Versus Survey Results

Figure 15 compares the actual number of transfers recorded by DB Vertrieb GmbH on the German network for January to December 2015 with the results of the passenger survey; the corresponding figures are shown in Table S7 in the Supplementary Materials. The DB data cover long-distance and regional services; the survey data refer exclusively to transfers on the rail leg and do not include transfers on the access and egress legs.

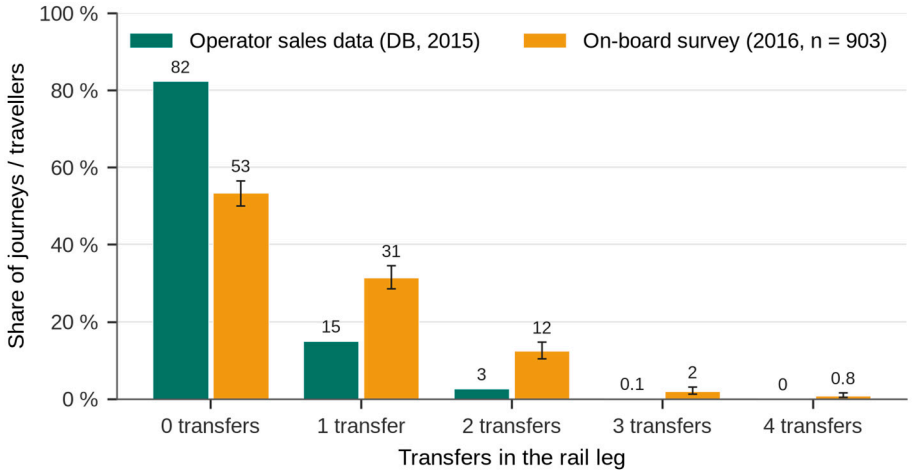


Figure 15. Operational data versus survey results; survey *n* = 903 (with 95% confidence intervals), DB sales data 2015.

The DB data are dominated by connections without transfers: more than 80% of passengers use a direct connection, around 15% transfer once and fewer than 5% transfer

more than once. In both data sources, connections involving more than two transfers are rarely used, which independently supports the threshold of two transfers derived in Sections 3.1 and 3.4.

3.6.2. Wiener Linien Data Versus Survey Results

The Wiener Linien data relate to a network reorganisation in which tram lines that previously ran from the districts to the city centre were linked, and the resulting passenger numbers were compared with those before the change. Linking the lines made it possible to eliminate the previously necessary turnaround times at the terminus. Furthermore, as part of this adjustment, the road network was optimised in terms of traffic signal phasing and junctions, ensuring a continuous traffic flow for both private and public transport [32].

Wiener Linien linked the former Ring lines 1 and 2 with tram lines 65, J and N to form new direct through services requiring no transfers; lines 65, J and N were fully integrated into lines 1 and 2 and ceased to exist as separate designations (Figure S17 in the Supplementary Materials). In addition, lines 71 and D were extended, while their designations remained unchanged [33].

Passenger and operational data for the Wiener Linien tram network for 2001 to 2024 are summarised in Table S8 in the Supplementary Materials [34,35]. Up to and including 2011, passenger numbers were estimated on the basis of seat-kilometres rather than actual passenger counts, resulting in a jump from 193.8 to 295.1 million passengers between 2011 and 2012. Within the methodologically consistent time series from 2012 onwards, passenger numbers outside the pandemic years 2020 to 2023 range between 291.8 and 305.8 million and thus remain at a constant level; the slumps in 2020 (186.1 million) and 2021 (200.6 million) are pandemic-related and had been almost entirely recovered by 2024.

The time series reveals an association between the number of lines, network length and passenger numbers, while the overall level of tram ridership remains constant within methodologically comparable periods.

Table 4 shows the change in passenger numbers resulting from the new line routing. To protect trade secrets, the figures have been multiplied by a constant factor; consequently, only relative values can be derived.

Table 4. Passenger numbers following the rerouting of Ring lines 1 and 2 (anonymised) [36].

Line	2007–2008	2012–2013	Change
Newly linked lines 1 and 2	**95,076**	**148,666**	**+56.4%**
Line 1	31,123	71,115	+128.5%
Line 2	63,953	77,551	+21.3%
Extended lines 71 and D	**129,458**	**128,882**	**−0.4%**
Line 71	59,408	64,472	+8.5%
Line D	70,050	64,410	−8.1%
Total	**224,534**	**277,548**	**+23.6%**

Passengers (persons), anonymised using a constant factor; change from 2007–2008 to 2012–2013. Rows in bold show the subtotals for each line group and the total.

Table 4 shows that the rerouting of the affected lines was accompanied by a 23.6% increase in passenger numbers, which is entirely attributable to the newly linked lines 1 and 2 (+56.4%), while the extended lines 71 and D remained virtually unchanged (−0.4%); seating capacity across the entire network also remained virtually unchanged over the same period, at 87,555 seats (2007) and 89,060 seats (2012) (Table S8). A network-wide comparison of passenger numbers is not possible due to the methodological break in 2011/2012.

It should also be noted that the growth forecast by the Austrian Institute for Spatial Planning (ÖIR)—as reported in the annual report of Wiener Stadtwerke (+700,000 passengers per financial year on the optimised lines [32])—corresponds to the observed growth to within a few percentage points.

The observed increase of 23.6% can only be compared with the survey results in terms of order of magnitude. For journeys of less than one hour—typical of tram travel—only around 30% of respondents are prepared to make an additional transfer (Figure 8); an increase of around 25–30% when one transfer is eliminated is consistent with this high level of transfer resistance. However, a quantitative extrapolation is not possible, as the long-distance survey and the urban network reorganisation differ in terms of trip length, service frequency and the proportion of passengers carrying luggage.

4. Discussion

4.1. Transfers as an Independent Barrier to Travel

The results suggest that transfers should be modelled not merely as a component of journey time but as an independent barrier to travel. Evidence for this comes from the pattern of the decline in demand: the distribution of actual transfers on rail journeys follows a multiplicative rather than an additive pattern ($y = 54.91 \cdot e^{(-0.720 \cdot x)}$; $R^2 = 0.975$ compared with $R^2 = 0.908$ for the linear fit). If the resistance per transfer were constant, one would, in simplified terms, expect a constant ratio of successive transfer categories. What is observed, however, is a decreasing ratio (0.59, 0.39, 0.16): with each additional transfer, an additional barrier arises—plausibly explained by uncertainty about connections, the effort required for wayfinding and luggage handling, all of which must be dealt with anew at each transfer. As the observed distribution also reflects the network's service structure, this finding should be interpreted as an indication rather than conclusive evidence (Section 4.6).

The willingness analysis is consistent with this: the stated willingness of direct travellers drops sharply from the first to the second additional transfer (Section 3.4.1). Resistance therefore does not increase additively but escalates. In the threshold question, 15.5% of respondents would look for an alternative at one, 50.7% at up to two and 65.2% at up to three additional transfers (Section 3.4.4), whereas around 52% would not choose an alternative even in the event of a fare increase of 20% and around 41% would not do so even if journey times were extended by 60 min. These proportions cannot be used to rank the three parameters by effectiveness, as the response scales are not commensurable: one or two additional transfers, a fare increase of up to 20% and a journey time increase of up to 60 min represent deteriorations of different magnitude. What can be stated is that, within the ranges offered, the proportion of respondents who would not look for an alternative is lowest for transfers (35%, compared with 41% for journey time and 52% for fare)—a finding that does not support the common modelling practice of applying flat-rate transfer penalties.

4.2. The Two-Transfer Threshold and Its Support from Operational Data

Across all levels of analysis, the same threshold emerges (Sections 3.1 and 3.4): rail journeys with more than two transfers are rare, and in seven of the eight most frequent threshold combinations for switching to an alternative, the threshold of two additional transfers is cited. Subjective assessments also align with this threshold: a single transfer is rated as only slightly disruptive, whereas multiple transfers—defined as two or more—are rated as rather disruptive, regardless of whether passengers are carrying luggage.

Crucially, this threshold appears not only in the survey but also in independent operational data. In the sales data for the German network provided by DB Vertrieb, over

80% of passengers use a direct connection, around 15% transfer once and fewer than 5% transfer more than once. Thus, revealed-preference data from a different network support the same structure as the on-board survey, albeit at a different level. The difference between 53% and 80% direct travellers is to be expected, as the DB data cover long-distance and regional services together, and regional services systematically comprise shorter trips with fewer transfers; the survey for this study, by contrast, was conducted predominantly on long-distance services. The consistent structure, together with an explainable difference in level, indicates that the derived threshold values are transferable.

4.3. Quantification of Transfer Resistance and Comparison with the International Literature

The key quantitative contribution of this study is the determination of the compensation required for an additional transfer. Across all journey duration categories, this results in a required relative time saving of around 17% of the total journey time and a required fare reduction of 29.3% on average. The structure of these values is noteworthy: the required relative time saving decreases from 33% to 10% with increasing journey duration, but less than proportionally, so that the absolute compensation requirement—measured directly in minutes—rises from around 12 min for journeys under one hour to around 23 to 32 min for journeys of two to five hours, and to 37 min for longer journeys. Transfer resistance therefore behaves neither as a fixed time penalty nor as a proportional penalty but increases degressively with journey duration. For long-distance travel, this results in a time equivalent of around 23 to 32 min per transfer—precisely the quantity required as a 'transfer penalty' in transport models.

This value can be compared with international research, albeit only in terms of order of magnitude. García-Martínez et al. estimate the pure transfer penalty in Madrid's multimodal network at 15.2 to 17.7 min of in-vehicle travel time [4]. The 12 to 17 min determined here for journeys under two hours are of the same order of magnitude, whereas the figures for long-distance journeys of two to five hours—23 to 32 min—are considerably higher. This discrepancy is plausible: the cited figures originate from urban transport, whereas the present survey reflects long-distance journeys with a considerably higher proportion of luggage and lower service frequencies. For inter-urban rail in Great Britain, the recommended interchange penalties likewise increase with journey length, but at around 40 to 65 min for journeys of 100 to 200 miles they are higher than the values determined here [11]; as they stem from demand-forecasting guidance and from models based on ticket sales rather than from stated compensation, this comparison also indicates plausibility rather than equivalence. The study thus provides a previously missing long-distance reference value for a metric that has predominantly been determined in the context of local transport. The non-linearity is also consistent with the literature: Grisé and El-Geneidy find no significant difference in trip satisfaction for a single transfer but 32% lower odds of a satisfactory trip for two or more transfers [10]; the stated willingness of direct travellers measured here likewise drops sharply from the first to the second additional transfer. Two methodologically independent approaches—satisfaction assessment and willingness surveys—thus arrive at the same qualitative conclusion: the second transfer marks the critical threshold.

In addition, the results allow an assessment of supply-side effects. The integration of Vienna's tram lines 1, 2, 65, J and N into transfer-free through services was accompanied by a passenger increase of around 23.6% on the affected lines as a whole, while seating capacity across the entire network remained virtually unchanged; the increases forecast in advance by the Austrian Institute for Spatial Planning, as reported in the annual report of Wiener Stadtwerke, were confirmed to within a few percentage points [32]. The willingness analysis in this study indicates a transfer resistance of around 70% for journeys under one hour, which is consistent with an increase in the order of 25 to 30% if the need

to transfer were eliminated. The observed growth and the survey results are thus of the same order of magnitude. The comparison is methodologically valuable because it contrasts the threshold values derived from a survey with an actual change in service provision; however, owing to the concurrent journey time savings, it should not be interpreted as validation in the strict sense (Section 4.6).

4.4. Travel Context Outweighs Socio-Demographic Characteristics

One finding of direct relevance to transport modelling is the limited explanatory power of socio-demographic characteristics. No association of transfer frequency or willingness to transfer with age, gender or occupation was detectable in this sample (all $p > 0.1$; $V \leq 0.09$, upper 95% confidence limits ≤ 0.13); no specific target group profile for transfer behaviour could be identified. Instead, journey-related contextual variables differentiate behaviour. As journey duration increases, the proportion of direct travellers falls from 72.9% for journeys under one hour to 12.4% for journeys over five hours (Cramér's V = 0.29); at the same time, the stated cumulative willingness to make one additional transfer rises from around 30% to around 48%. Travel frequency is not associated with the number of actual transfers ($p = 0.58$), but it is associated with willingness: 77% of daily travellers are not willing to make any additional transfer, compared with around 53% of occasional travellers (Cramér's V = 0.12). At the same time, the preference shifts from journey time savings to fare reductions: occasional travellers are more likely to require a fare reduction in return for an additional transfer, whereas frequent travellers weight journey time and fare roughly equally.

The role of luggage is particularly revealing. For journeys of less than two hours, 83.2% of respondents carry no luggage or only hand luggage; for journeys of more than three hours, 77.3% carry one or more pieces of luggage. The positive association between carrying luggage and transfer frequency (Cramér's V = 0.15) is therefore presumably not causal but mediated by journey duration. When the association is considered within journey duration categories of three hours or more, the picture is reversed: travellers with luggage show a decreasing willingness to make additional transfers, while those without luggage show an increasing willingness. Luggage may therefore act as an additional barrier that is masked in the aggregate analysis by confounding with journey duration—an indication that transport models representing transfer resistance exclusively via time and distance components may underestimate this resistance for journeys with substantial luggage.

International studies report increased transfer sensitivity among older travellers and people with reduced mobility [7,12,15]. In this sample, this is not evident in transfer behaviour, but it is reflected in the assessments: older travellers attach significantly greater importance to luggage services, short distances and step-free boarding and alighting (Section 3.5.1). The fact that this is not reflected in behaviour can probably be explained by the survey context: the survey exclusively included people who actually use rail and who have already managed the existing transfers. People who do not travel by rail at all because of transfer barriers are systematically under-represented in the sample. The limited socio-demographic differentiation should therefore not be interpreted as contradicting the literature but rather as an expression of self-selection; the actual transfer barrier for vulnerable groups is likely to be higher than measured here.

4.5. Implications for Transport Modelling and Service Planning

Three specific requirements for transport modelling follow from the results. First, transfer resistance in long-distance travel should be set as an absolute time equivalent in the order of approximately 23 to 32 min per transfer, which increases less than proportionally with journey duration, rather than being scaled proportionally to journey time.

Second, the non-linearity must be modelled explicitly; a constant penalty per transfer underestimates the effect of the second and third transfers, as shown by the decreasing ratios of successive transfer categories (0.59, 0.39, 0.16). Third, transfer resistance should be segmented by travel context, in particular by journey duration, frequency of use and luggage, whereas no additional explanatory power of age or gender for transfer behaviour was detectable in this dataset; age, however, is relevant for the weighting of accessibility and luggage services.

This yields a directly applicable decision rule for service planning: a connection involving a transfer is only competitive with a direct connection if it saves at least around 17% of the journey time for each additional transfer or offers a fare reduced by around 30%. Below this threshold, a through-service concept is preferable even if it is operationally more complex—the Vienna example, with a 23.6% increase, illustrates the potential scale of the benefits.

Equally important is the finding that individual measures have little effect. Only around 3.6% of passengers are prepared to accept an additional transfer in return for a single improvement, and around half of these are motivated solely by journey time. Journey time and fare are included together in around 90% of all combinations of motivations mentioned, while around 10% of respondents would only be prepared to transfer if all parameters were optimised simultaneously. Measures must therefore be bundled. In the prioritisation of influencing factors, guaranteed connections and service frequency are identified, alongside journey time and fare, as the most effective operational levers. This is reflected in the open-ended responses: around 27% of the free-text comments relate to guaranteed connections in the event of delays, and around 19% concern the quality of boarding and alighting and luggage services.

The luggage service plays a distinctive role. Viewed in isolation, it shows the lowest potential to motivate an additional transfer and is, on average, also rated as the least important factor (2.63); however, it is included as a necessary improvement in around 10% of all combinations of motivations and becomes significantly more important with increasing age. It thus acts less as a general motivator than as a segment-specific prerequisite. By contrast, no mitigating effect can be demonstrated for seat reservations: travellers with reservations actually rate the transfer phases less favourably, which is likely to be linked to their higher proportion of long journeys and luggage.

4.6. Limitations

Several limitations must be taken into account when interpreting the results.

The survey combines revealed-preference and stated-preference elements. The actual transfers during the current journey represent observed behaviour, whereas the willingness and threshold values are stated preferences. For the latter, a discrepancy between stated and actual behaviour cannot be ruled out; according to meta-analytical evidence, hypothetical statements tend to be overstated [37]. This issue was mitigated through triangulation across three assessments: willingness and threshold values are of the same order of magnitude (differences of 0 to 19 percentage points depending on the group), their structure aligns with the observed actual transfers, and both are externally supported by DB sales data and the Vienna network reorganisation. The combination of both approaches should therefore be regarded as a strength of the design, although it does not replace longitudinal behavioural observation.

The operationalisation requires that individual transfer components be assessed separately, even though they are linked in the actual journey. Interactions, such as those between transfer time, journey length and luggage, can therefore only be captured to a limited extent.

The sample comprises 903 valid questionnaires out of 1009 distributed; the age and gender distribution shows descriptive similarities with the comparative study [28] but does not demonstrate representativeness. Moreover, it is limited to three Austrian long-distance lines and a three-day survey period at the end of June. The timing of the survey, shortly before the main holiday season, results in a higher proportion of travellers under 20 years of age and in higher proportions of leisure travellers and passengers with luggage compared with the annual average. Occupational groups such as apprentices and manual workers are under-represented. Generalisations to local transport, commuter traffic or other national networks are therefore possible only with reservations.

Temporal validity is a further limitation. The survey data date from June 2016, the DB sales data from 2015 and the Vienna comparison from 2007 to 2013. Open-access competition on the Western Railway had already begun in 2011 and is therefore reflected in the data [25], but fares, ticket products and service levels have changed since then: the nationwide KlimaTicket, introduced in October 2021, allows its holders unlimited travel on public transport and thus sets the marginal fare of an additional trip to zero [26], and the COVID-19 pandemic has led to more teleworking and to expected lasting changes in the travel patterns of many train travellers [27]. Changes in the relative prices of competing modes also shift intercity mode choice, as shown for road toll discounts [38]. The fare-related compensation values and the findings by travel frequency are most likely to be affected, as the composition of frequent and occasional travellers and their fare sensitivity may have changed. The structural findings—the two-transfer threshold, the non-linear decline and the absolute time equivalent increasing with journey duration—relate to the transfer process itself and are less directly exposed to these changes; this, however, remains an assumption that has to be tested. No comparable post-2016 evidence on the number of transfers accepted in long-distance rail is available to the authors; a replication with post-pandemic data, ideally including transfer-specific stated choice experiments, is therefore required before the level values are used for current planning.

As an on-board survey, the study captures only passengers who have chosen to travel by rail. Latent demand that has already been deterred by transfer barriers is not captured. The resistance values determined should therefore be regarded as a conservative lower bound.

The distribution of actual transfers reflects not only transfer resistance but also the service structure: the number of destinations that can be reached without transferring is determined by the network. The shape and ratios of the transfer classes therefore combine supply- and demand-side effects. The same applies to the Vienna network reorganisation: as the through services simultaneously eliminated turnaround times and coincided with optimised traffic signals and the extension of lines 71 and D [32,33], the observed increase cannot be attributed solely to the elimination of the transfer.

4.7. Further Research Needs

Three priority follow-up questions arise from the results. First, the interaction of the transfer components should be investigated in an integrated model in order to overcome the assumption of independence required here. Second, the study should be replicated with post-pandemic data and extended to other networks and countries to examine whether the two-transfer threshold and the time equivalent of around 23 to 32 min in long-distance travel apply irrespective of the time period and network. Third, the barrier measured here should be complemented by a survey of non-users in order to capture the latent demand suppressed by the need to transfer—the decisive component in the evaluation of through-service concepts, which is inherently invisible in on-board surveys.

5. Conclusions

This study quantifies transfer resistance in long-distance rail on the basis of an on-board survey comprising 903 valid responses and compares it with the established elasticities of journey time and fare. Four findings are worth highlighting.

First, the decline in demand with an increasing number of transfers follows a multiplicative rather than an additive pattern ($y = 54.91 \cdot e^{(-0.720 \cdot x)}$; $R^2 = 0.975$; linear fit $R^2 = 0.908$), with the ratio between successive transfer categories falling from 0.59 to 0.16 (Research Question 1). Transferring thus appears to act as an independent barrier to travel that increases with each transfer. Flat-rate transfer penalties in transport models are likely to underestimate the effect of the second and each subsequent transfer.

Second, the practical acceptance threshold lies at two transfers (Research Question 1). Rail journeys with three or more transfers are rare (below 3% of respondents). The stated cumulative willingness of direct travellers falls from around 44% for one to around 4% for two additional transfers; in the threshold question, around 51% of respondents would look for an alternative at two or fewer additional transfers, assuming monotonic preferences. DB sales data independently support this pattern.

Third, this resistance can be translated into quantifiable compensation metrics suitable for planning (Research Question 2). On average, an additional transfer requires a time saving of around 17% of the total journey time or a fare reduction of around 30%. As the required relative time saving decreases less than proportionally from 33% to 10% with increasing journey duration, the directly surveyed absolute compensation requirement rises from around 12 min for journeys under one hour to around 23 to 32 min for journeys of two to five hours. This long-distance figure is considerably higher than the 15.2 to 17.7 min reported for an urban multimodal network [4] and provides a previously lacking reference value for the transfer penalty in long-distance travel.

Fourth, transfer behaviour is differentiated more by travel context than by socio-demographic characteristics (Research Question 3). No association with age, gender or occupational group was detectable in this sample, whereas journey duration, purpose of travel, travel frequency and luggage are significantly, albeit weakly to moderately, associated with transfer frequency or willingness to transfer. The proportion of direct travellers falls with journey duration from 72.9% to 12.4%; occasional travellers are more likely to require a fare reduction in return for an additional transfer, whereas frequent travellers weight journey time and fare roughly equally. Luggage may act as an additional barrier for journeys lasting over three hours.

In practice, this leads to a simple rule of thumb: a connection involving a transfer should only be preferred to a direct connection if it saves at least around 17% of the journey time for each additional transfer or offers a correspondingly reduced fare. Otherwise, a through-service concept remains advantageous even if it involves greater operational effort. The integration of several Viennese tram lines illustrates the potential scale of the benefits. As only around 3.6% of passengers can be attracted by a single improvement, measures must be bundled. Reliable connections and information in the event of delays—the framework conditions rated as most important—as well as, particularly for older travellers, the quality of boarding and alighting and luggage handling are prerequisites for the effectiveness of measures relating to journey times and fares.

The results are based on an on-board survey conducted in 2016 on three Austrian long-distance lines and cover active rail users exclusively. The reported levels are therefore specific to the period and network in question, and the resistance values determined should be interpreted as a conservative lower bound. The key structural findings—a multiplicative decline in demand, a two-transfer threshold and a time equivalent increasing with journey duration—are consistent with two independent operational data sources; whether they hold under current market conditions requires replication with recent data.

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Future work should model the interactions between individual transfer components within an integrated model, replicate the findings in further networks and with post-pandemic data, and capture the latent demand suppressed by the need to transfer through a survey of non-users.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su182111257/s1, Questionnaire S1: Survey instrument of the passenger survey (original German version); Figure S1: Number of transfers by age and gender; Figure S2: Distribution by occupation; Figure S3: Transfers by occupational category; Figure S4: Luggage and frequency of the current journey; Figure S5: Number of transfers by luggage carried; Figure S6: Number of transfers by travel frequency; Figure S7: Purpose of travel by age group; Figure S8: Purpose of travel by journey duration; Figure S9: Number of transfers by purpose of travel; Figure S10: Value of an additional transfer by luggage carried; Figure S11: Willingness and threshold values by actual transfers, with 95% confidence intervals; Figure S12: Willingness and threshold values by journey duration, with 95% confidence intervals; Figure S13: Main combinations of switching thresholds (fare increase, journey time increase in minutes, additional transfers), with 95% confidence intervals; Figure S14: Perception of single and multiple transfers by luggage; Figure S15: Perceived disruption of the transfer sub-processes by seat reservation (1 = no problem to 5 = very disruptive); Figure S16: Main willingness combinations for an additional transfer; Figure S17: Routing of Ring lines 1 and 2 after the reorganisation; Table S1: Group sizes and proportions with 95% confidence intervals for Figures 1, 3, 6, 8 and 11 of the main text; Table S2: χ^2 tests of independence with Cramér's V, 95% confidence intervals and minimum detectable effects; Table S3: Actual transfers by journey duration; Table S4: Required time saving per additional transfer by journey duration—directly stated and back-calculated minutes; Table S5: Willingness to transfer by actual transfers; Table S6: Willingness to transfer by journey duration; Table S7: DB data versus survey data; Table S8: Wiener Linien trams, 2001 to 2024.

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Institutional Review Board Statement: Ethical review and approval were not required for this study in accordance with Austrian legislation. The study is a non-interventional, anonymous questionnaire survey of adult and mature minor passengers (aged 14 and over; § 21(2) ABGB), conducted in June 2016 at St. Pölten University of Applied Sciences. Under Austrian law, ethics committee review is mandatory only for clinical trials of medicinal products and medical devices, the application of new medical methods and applied medical research on human beings (§ 30(1) Universities Act 2002; § 8c Federal Hospitals and Sanatoria Act, KAKuG; Medicinal Products Act; Medical Devices Act); the present study falls outside this scope. The survey collected no names, contact details, signatures or sensitive data, and the data are anonymous within the meaning of the Austrian Data Protection Act 2000 and Regulation (EU) 2016/679. Permission to conduct the survey on board was granted by ÖBB-Personenverkehr AG. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Informed Consent Statement: Verbal informed consent was obtained from the participants. Verbal consent was obtained rather than written because the survey was fully anonymous and a signed consent form would have been the only document containing participants' names; collected together with the questionnaire, it would have created identifying data that could be linked to the

responses. In addition, the survey was non-interventional, collected no sensitive data and posed no more than minimal risk. Before receiving the questionnaire, passengers were informed orally about the purpose of the study, the responsible institution, the voluntary nature of participation and the anonymity of the questionnaire; the purpose, the responsible institution and the exclusively scientific use of the findings were also stated in writing on the questionnaire (Supplementary Questionnaire S1). Consent was given by voluntarily completing and returning the questionnaire.

Data Availability Statement: The aggregated data supporting the findings of this study are contained in the article and the Supplementary Materials. The anonymised individual survey records are available from the corresponding author on reasonable request. The operator data were provided under confidentiality conditions and cannot be shared.

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