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Exploring satisfaction for transfers at intermodal interchanges: A comparison of Germany and India

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ABSTRACT

Multimodality in Public Transport has been proven to be one of the main drivers of sustainability and economic feasibility for the last few decades. Consequently, user satisfaction for transfers is the key to adequately serving demand. This research studies on commuters' perception of comfort at interchanges, focusing on the connection between metro systems and other modes. Satisfaction analysis and modelling is conducted using weighted regression, factor analysis and ordered logit models for nine transfers at major interchanges in two Indian cities (New Delhi and Kolkata) and one German city (Munich); aiming at revealing the differences in user satisfaction in developing and developed economy, and for different Public Transport quality and interchanges. The results indicate that factors of transfer quality, accessibility and physical hindrances are significant in Indian case and the human factor, and transfer quality are significant in the case of Munich, Germany. Additionally, it is found that perceived comfort differs on commuters' experiences with transfer distance and time.

Introduction

Public transportation (PT) is one of the most effective instruments for reducing traffic congestion in crowded metropolitan areas. With the urban population share expected to reach 66% by 2050, the need for efficient and multimodal transportation is more prominent than ever UN, 2018. This is acute in cases of developing economies, where resource allocation for Mass Rapid Transit Systems (MRTS) and multimodal integration is a crucial decision, as well as a challenge (Fouracre et al., 2003). The importance of these decisions is highlighted by the excessive demand-supply mismatch in public transportation systems in the cities (Pucher et al., 2004).

One of the inevitable aspects of using PT is the transfers at interchanges, which are also associated with discomfort and time delays (Olszewski and Krukowski, 2012). In many cases, the inadequacy of passenger-friendly intermodal interfaces cause transfers to be a discomforting event during a journey. Also, in many cases, multiple connections are taking place in the same station. The interchanges have merely become an area of multiple entries and exits between different transportation modes, instead of a common point of access to all the modes.

Although guidelines generally exist for stations and interchanges (Department of Transport and Main Roads, 2015; Brinckerhoff, 2013; Transport for London, 2009), they do not address aspects of users' comfort and satisfaction. Some of the previous studies, which considered the perception of commuters towards interchanges are mentioned here. Luk and Olszewski (2003), Bryniarska and Zakowska (2017) studied three major interchanges in Krakow, Poland, using quantitative indicators based on the distance between stops, additional facilities available, quality of basic infrastructure, accessibility for disabled, information for passengers, personal security, and traffic safety at road crossings; and ranked the stations, but did not take into account users' perception for determining these factors. Sadhukhan et al., 2014 also studied the transfer facility considering attributes based on time, level changes, and pedestrian environment in Kolkata, India and the attributes were ranked based on questionnaire survey responses, but did not include the performance of the stations; furthermore, the weights of importance of the attributes are unclear. Luk and Olszewski (2003) suggest institutional or administrative, fare, physical, transport network or connectivity and information as five categories of integration. Bernal (2016) further checked the level of integration of different cities across the world, but only on a macro level of the transportation network in a city. Kumar et al. (2013) studied the efficacy of multimodal urban public transit system in the context of MRTS for Delhi,

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India based on attributes such as demographics, travel time, and quality perception parameters; and ranked the metro lines using Data Envelopment Analysis. Eboli and Mazzulla (2009) considered route characteristics, service characteristics, service reliability, comfort, cleanliness, fare, information, safety and security, customer service, personnel, and environmental factors for evaluating metro stations' performance in Cosenza, Italy, but the connection of metro to other modes remains unanswered. While some studies have only focused on objective indicators, others have tried to explore both objective and subjective indicators. According to Alexander (2018), in order to be comfortable for passengers and accepted by them, transfer distances should not exceed 3 min, i.e., distance up to 180–200 m. The more local the character of a journey, the smaller should be this distance, but commuters' perception was not depicted. Recently, there has been comparatively more research on interchanges in developed countries, such as the Netherlands (Schakenbos et al. 2016), New Zealand (Chowdhury et al., 2015), the United Kingdom (Guo and Wilson, 2011), and Australia (Yen et al. 2018).

There have been plenty of studies on perception of satisfaction towards Public Transport as a whole, both in earlier and recent times (Tiglao et al., 2020; İmre and Çelebi 2017; Lierop et al., 2018; Noor and Foo, 2018; Morton et al., 2016; Nesheli et al., 2016; Mugion et al. 2018; Pineda and Lira, 2019; Sinha et al., 2020; Fan and Chen, 2020; Allen et al., 2020; Belwal and Belwal, 2010; Exel and Rietveld, 2010; Randheer et al., 2011); however, studies on interchanges, especially in the case of developing countries, are limited. These studies often consider multimodality as one of the factors of PT, thereby giving limited knowledge on the dynamics within the interchanges.

Some of the common techniques and tools used by researchers to analyse commuters' perception are factor analysis (Tyrinopoulos and Antoniou, 2008; Fellesson and Friman, 2012) and ordered logit models (Tyrinopoulos and Antoniou, 2008; Buehler and Pucher, 2012; Efthymiou and Antoniou, 2017), hybrid choice models combining latent variables in discrete choice models (Efthymiou et al. 2014, 2018), logistic regression models and neural networks, Structural Equation Models (SEM), as well as SEM-MIMIC models Allen et al., 2018, 2020. Tyrinopoulos and Antoniou (2008) suggest that less complex methods, such as factor analysis and principal component analysis, may give a quicker insight on relevant indicators of satisfaction.

As mentioned above, with limited studies focusing on interchanges, especially in the context of developing economies, there is a gap in realizing benchmarks of various attributes in an interchange. It still remains unclear how to address the integration of modes at interchanges for differential settings. Therefore, this paper aims to evaluate the satisfaction and comfort of commuters at interchanges in terms of intermodal integration in India (developing economy) in comparison to that of Germany (developed economy).

The contribution of this paper is double fold, (1) to obtain design insights by evaluating satisfaction and comfort of commuters at interchanges in terms of intermodal integration, and (2) to showcase comparative benchmarks of interchanges to the policy makers by comparing the case of a developing economy (India) to a developed economy (Germany). These comparative benchmarks help the policy makers in India to realise that resources can be utilized to achieve more efficient interchanges (comparable to those of a developed economy) to reduce loss of time and human resources, while effectively doing transfers. This is important, as it is a high cost to bear for a developing economy like India, provided a small saving in time for millions of commuters daily can save a lot for the country (Davis et al. 2017; Ali et al. 2014).

The comparative benchmarks are achieved by exploring and comparing the perception of comfort in two very different countries, India and Germany, using their representative cities with the same experimental settings. On the one hand, developing countries, like India, have recently started with MRTS as a public transport mode, integration of interchanges are still of secondary concern to the provision of public transport. On the other hand, many European cities experience high market penetration of PT [e.g., in the German city of Munich, the share of private vehicles is only 24% of the total trips, and out of the PT trips, almost 70% have at least one interchange, despite very short average journey lengths (Terzis and Last, 2000)]. For this study, the survey respondents were asked to rate how satisfactory they perceive the indicators for ordinal variables and to indicate their preference among given alternatives for categorical variables. Their responses were analyzed using Factor Analysis and Ordinal Logistic Regressions to identify the significant factors influencing perceived comfort at interchanges; therefore, indicating the factors which have to be considered upon to provide seamless transfers.

The remainder of this paper is structured as follows: study areas and the selected methodology used for the research are developed based on the above review, followed by a presentation of the data collection and analysis, development and estimation of models, and presentation of their results. The last section remarks a discussion about the research conducted and conclusions drawn.

Study area and methodology

Study areas

The stations chosen serve as major interchanges between the metro rail system with other modes in the city. Representative Indian cities of New Delhi and Kolkata are compared to the city of Munich, a representative city of Germany. The transfers between rail-based rapid transit systems, regional trains, regional buses, tramways, and airports were studied in both places. The interchanges studied in India are (1) between New Delhi metro station and New Delhi Railway station (main train station of New Delhi), where the metro station has two levels, underground concourse level and platform level below; (2) between Kashmere Gate metro station and Kashmere Gate Inter State Bus Terminal (ISBT), where the metro station has five levels, underground concourse and platform levels below, entry/exit and ground level circulation, overground concourse level and an additional platform level above that; (3) between Indira Gandhi International (IGI) Airport metro station and IGI Airport Terminals 2 and 3, where the metro station has five levels, underground platform level, two underground concourse levels, ground level connection to airport arrival and parking, a level connecting airport arrival and departure at the ground and first floor respectively via elevators and moving ramps; and, (4) between Dum Dum metro station of Kolkata Metro and Dum Dum Junction suburban railway station where the metro station is mainly overground, entry/exit at ground level and platforms overground.

The major public transport modes available in Munich are consisting of U-Bahn (Underground) and S-Bahn (suburban trains), buses, and tramways. The interchanges studied in the city of Munich, Germany are 1) between München Hauptbahnhof (Munich Central Station) U-Bahn (metro) station and city buses, trams, and regional trains such as Intercity trains, InterCity Express, Regional Bahn, where the station has five levels, the city buses, tramways, and regional trains at ground level connected to an underground concourse level leading to further underground S-Bahn platforms, further connected to six U-Bahn platforms via a concourse in between; 2) between München Flughafen (Munich Airport) S-Bahn (suburban railway) station and Munich International Airport Terminals 1 and 2, where the S-Bahn station has an underground platform below Terminal 1 and is connected to Terminal 2 at ground level through an atrium; 3) between Münchner Freiheit U-Bahn station and city buses and tramways, where U-Bahn platforms are underground and are connected to buses and tramways at ground level with an underground concourse level in between. The study areas in Delhi and Munich are presented in Fig. 1.

Fig. 1. Study areas in Munich, Germany (top) and Delhi, India (bottom) https://www.arcgis.com/home/webmap/viewer.html?useExisting=1.

Table 1
Indicators.

Factor	Indicator (s)	Unit/ response
Time taken	1. Time required to reach the platform of the latter mode from the earlier mode of the concerned transfer at an average walking speed of 1.4 m/s.	Minutes
	2. Time one spends at transfer as a percentage of the in-vehicle travel time in metro rail.	Percentage
	3. The amount of transfer time preferred by the commuters.	Minutes
	4. Transfer time as an issue for the transfer, excluding waiting time.	Minutes
	5. Amount of time seems to be wasted at transfers by commuters.	Y/N
Perceived comfort	6. Overall comfort as perceived by the commuter in undertaking the concerned transfer.	5 point scale
Number of level changes	7. Intermediate levels one has to rise or go down in order to get another mode which might include mezzanines, underground levels, ground level, levels above ground.	Number
	8. Preferred number of level changes.	Number
Universal Accessibility	9. Accessibility as an issue with(out) luggage/ wheelchair/ baby prams, etc.	Y/N
Distance	10. Transfer distance as perceived by the commuters.	5 point scale
	11. Actual transfer distance between the modes' platforms.	Meters
	12. Transfer distance as an issue for the transfer.	Y/N
Way finding	13. Language as a barrier for way finding.	Y/N
	14. Lack of continuous signage.	Y/N
	15. Lack of audio information.	Y/N
	16. Way finding as an issue for the transfer.	Y/N
Safety	17. Overall perceived safety by commuters.	5 point scale
	18. Perceived safety for women.	5 point scale
	19. Perceived safety for pedestrians against accident.	5 point scale
	20. Perceived safety against external weather.	5 point scale
	21. Perceived safety against theft/ crimes.	5 point scale
	22. Safety as an issue for the transfer.	Y/N
Ease of changeover to other modes	23. Ease of changeover to other modes available at the metro station other than the concerned destination mode of the transfer.	5 point scale
Steps	24. Number of foot-steps required between the platforms of the modes at an average foot step length of 750 mm/step.	Number
Physical shelter	25. Importance of physical shelter between the modes.	5 point scale
Socio-economic characteristics of demographics	26. Age	Categorical
	27. Gender	Categorical
	28. Profession	Categorical
	29. Education	Categorical
	30. Monthly net income	Categorical
Physical Hindrances	31. Hindrance faced by commuters due to level change modes like stairs, escalators, pedestrian over and underpasses, etc.	Y/N
	32. Hindrance faced due to pedestrian and vehicular conflict in between modes usually at road crossings and intersections.	Y/N
	33. Hindrance faced while transferring between modes due to the high pedestrian density at intermodal interchanges.	Y/N

Indicators

Following an analysis of the pertinent literature, a selection of both objective [to reduce bias according to Oña and Oña, 2014] and subjective indicators were made to study the perceived comfort of commuters for transfers at interchanges (Table 1).

Data collection

Data was collected using a survey, as mentioned above, complemented by on-site studies of the studied stations. Regarding on-site studies, quantitative station-related indicators viz. transfer time, actual number of level changes, actual distance between the modes, number of foot-steps between the modes and number of mandatory turns were measured, using software application "Google Fit" (https://www.google.com/fit/) by Google, while undertaking the process of transfer from one mode to the later mode (forward and reverse direction), 20 and 10 times in a day at every half an hour in Indian stations and Munich respectively. Regarding the survey, two similar questionnaires were prepared for both places, each consisting of a) personal information (socio-economic characteristics and general travel information) and b) specific questions on the chosen indicators. Socio-demographic questions were shaped upon the characteristics of each population (i.e., differences in working age, profession, income structure, and education structure). Also, questions regarding nationality and residency were added to the Munich questionnaire, because of a higher number of international people residing in the city. In India, both paper-based and online surveys were conducted (in English and Bengali) for three months. The link of the survey was distributed using social media platforms, academic groups, employee groups, senior citizen groups of the city, etc., and onboard metro rails in metro stations, railway stations, and bus stations. Almost 60 paper-based surveys of the commuters were conducted, mostly inside the Airport metro rail.

In Germany, an online survey was conducted (in English and German) for three months. The link and Quick Response (QR) code of the survey were distributed using social media platforms, like Facebook, emails to academic groups, employee groups, senior citizen groups, and persons with disability organizations of the city. Furthermore, 1500 flyers with Quick Response code and link of the survey were distributed in a planned manner, in households at locations in the city of Munich, where potential commuters of the study stations reside, as well as near the entry/exit of metro stations. Every day the response rates were tracked following further distribution accordingly. Almost 70% of flyers were distributed to houses, dorms, and 30% at metro stations. Despite our efforts for the data collection in Germany (dissemination of 1500 flyers, as well as promoting the survey on online platforms for three months), the first author (who undertook the data collection) faced constraints of a language barrier, and unfamiliarity with the place, leading to a relatively limited number of responses. A total of 387 and 146 complete responses of commuters with similar socio-demographics (Table 2) were collected for India and Germany, respectively.

Table 2
Socio-Demographics of both Samples.

City (s)	New Delhi and Kolkata	Munich	
Total	387	**Total**	146
Age in years (%)		**Age in years** (%)	
14–18	2.6	14–18	1.1
19–30	58.9	19–30	61.7
31–50	21.7	31–50	22.3
51–100	16.8	51–67	14.9
Gender (%)		**Gender** (%)	
Male	63	Male	57.4
Female	37	Female	42.6
Profession (%)		**Profession** (%)	
Student	30.5	Student	53.2
Service	41.3	Employee	33
Business	11.1	Self employed	4.3
Others	17.1	Unemployed	2.1
		Others	7.4
Highest education level (%)		**Highest education level** (%)	
10th and below	18.9	Elementary	0
Undergraduate	47.5	Secondary	9.6
Postgraduate and above	33.6	Tertiary level	56.4
		Post graduate and above	34
Monthly Income (net income) in thousands INR (%)		**Monthly Income (net income) in Euros** (%)	
0–10	5.2	0–2000	60.6
11–25	10.1	2001–3500	22.3
26–40	26.1	3501–5000	11.7
41–60	26.6	5001–6500	4.3
> 60	31.3	> 6500	1.1
Perceived comfort (%)		**Perceived comfort** (%)	
Very comfortable	14	Very comfortable	12.8
Comfortable	10.9	Comfortable	24.5
Neutral	44.2	Neutral	46.8
Uncomfortable	11.9	Uncomfortable	11.7
Very uncomfortable	19.1	Very uncomfortable	4.3

Methodology

Aiming at developing a proper model for satisfaction at interchanges that considers the characteristics of the stations and the user preferences, Factor analysis, and Ordinal Logistic Regression were deployed, based also on the finding of the literature review. Factor analysis is used to reduce the number of observed variables to latent variables in a data set Taherdoost et al., 2014. It has been frequently used by researchers to evaluate transit services in their studies (Tyrinopoulos and Antoniou, 2008; Susilawati and Nilakusmawati, 2017; Joewono and Kubota, 2006) as it allows for the identification of observable variables that are commonly loading to a latent factor. Exploratory Factor Analysis (EFA) is used to explore data, and Confirmatory Factor Analysis (CFA) is used to test hypotheses. This study uses EFA (hereon referred to as factor analysis). The observed variables X'_is with corresponding means μ_i's are expressed as linear functions of unobserved factors as shown below (Washington et al., 2010):

$$X_1 - \mu_1 = l_{11}F_1 + l_{12}F_2 + \ldots + l_{1m}F_m + \varepsilon_1$$

$$X_2 - \mu_2 = l_{21}F_1 + l_{22}F_2 + \ldots + l_{2m}F_m + \varepsilon_2$$

$$X_p - \mu_p = l_{p1}F_1 + l_{p2}F_2 + \ldots + l_{pm}F_m + \varepsilon_p$$

where p refers to observed variables reduced to m unobservable or latent factors and F's are the factors, l_{ij}'s are the factor loadings, the ε_i's are error terms that are associated only with X'_is. EFA seeks for the strongest correlations between variables and the factor. For this research, heterogeneous correlation is used for different types of variables (Polychoric correlation for ordinal, Pearson correlation for numeric). Among the various factor extraction methods tested, maximum likelihood yields best results (Costello and Osborne, 2005) and has been used for the study. Parallel analysis-based methods were used for deciding the number of factors (Baglin, 2014) along with orthogonal rotation, which produces interpretable results and it is slightly simpler than oblique rotation. This research uses varimax rotation for the factors. Henson and Kyle Roberts (2006) stated that in order to provide a meaningful interpretation, at least two or three variables must load on a factor Henson and Roberts, 2006.

Regarding user preferences, mixed logit models and multinomial logit models are usually used to study categorical discrete choices. However, they consider the alternatives to be independent of each other, whereas, for ordinal alternatives, e.g., Likert scale (Likert, 1932), these models fail to capture the interdependency of alternatives. To overcome this issue, nested or cross nested models and ordered logit models are developed. Ordered logit models estimate the coefficients of the independent variables for a dependent variable whose alternatives are ordered and also provide intercepts or threshold values between choices. For this research, perceived comfort at transfers is the dependent variable, which is measured using a five-point scale, 1: very comfortable, 2: comfortable, 3: neutral, 4: uncomfortable, 5: very uncomfortable; and the model estimates four intercepts for 1–2, …, 4–5.

Analysis and results

The data collected from questionnaire surveys and on-site studies was used for exploratory factor analysis for both places to reduce the independent variables (indicators) to latent variables, and ordered logit models were developed with indicators, as well as with extracted factors with perceived comfort at interchanges as the dependent variable. The site study data of the stations as collected at study areas are shown in Table 3. ISBT stands for Inter State Bus Terminal.

Modelling perceived comfort at interchanges

Using the data from the two questionnaires, factor analysis is performed, and the results are presented in Table 4. Each factor explains at least 10% of the total variance for both models. Iterations have been done by removing variables that do not load at all (or negligible loading) on any of the factors as they create noise for the analysis. Loadings greater than 0.45 have been shown. The factors identified were named based on the variables that contribute to their loadings. The identified factors for India are:

- *Transfer quality* comprising of indicators related to actual transfer distance, transfer time excluding waiting time, and number of footsteps between the modes' platforms.
- *Safety factor* comprising of indicators related overall safety of commuters, and mandatory turns
- *Level change factor* comprising of indicators related to in vehicle travel time, preferred number of level changes and actual number of level changes.

The factors identified in Germany are:

- Transfer quality comprising of variables of transfer distance, actual number of level changes, transfer time and number of foot steps required.
- Safety factor comprising of indicators related to perceived safety for women, against theft and pedestrian accident while doing transfer at the interchanges. However, the indicator for safety against external weather does not load significantly on factor of safety.
- Accessibility factor comprising of indicators related to issue faced due to universal accessibility and overall safety.

Therefore, the factors in common for both the cases are that of transfer quality and safety factor (with minor differences).

The factors determined from the factor analysis were used to

Table 3
Data from Preliminary Analysis.

Metro station	From	To	Distance	No. of steps	Time taken at an average walking speed of 1.4 m/s	No. of level changes
New Delhi	Yellow line	NDLS (New Delhi Railway station)	510 m	820	7.5 min	2
Kashmere Gate	ISBT	Red line	320 m	530	7 min	3
Kashmere Gate	ISBT	Yellow line	570 m	920	8.6 min	4
Kashmere Gate	ISBT	Violet line	350 m	580	6.2 min	3
IGI Airport	Airport metro	Departure	420 m	655	4.8 min	3
Dum Dum	Metro platform	Dum Dum Jn.	110 m	250	6.2 min	3
München Hauptbahnhof(Munich central station)	U1 platform	Regional train	370 m	540	4 min	3
München Hauptbahnhof(Munich central station)	U1 platform	Tramway	110 m	151	2 min	3
München Hauptbahnhof(Munich central station)	U1 platform	City bus	170 m	277	3 min	3
München Flughafen (Munich Airport)	S-Bahn platform	Terminal 1	70 m	121	1.2 min	1
München Flughafen(Munich Airport)	S-Bahn platform	Terminal 2	200 m	420	4 min	1
Münchner Freiheit(Popular downtown square in Munich)	U6 platform	Bus/ Tramway	90 m	158	1.5 min	2

develop ordinal logistic regression models, with perceived comfort as the outcome variable, ordered from 1 to 5, using McFadden's ρ^2 as model goodness-of-fit diagnostic. To develop models for perceived comfort, both forward and backward attribute selection were tested. Models were developed using factor scores of the extracted factors from factor analysis, other independent variables (which did not load significantly on any factor), and socio-economic demographics. The indicators, which already loaded significantly to factors during Factor Analysis, were not included to prevent a repetition of indicators. Two stable models were finalized for both places, as shown in Table 5 with the significant variables only.

From the models shown in Table 5, it is seen that a higher number of independent variables significantly influence commuters' perception of comfort in the case of India, as compared to that of Germany. Among individual indicators, occupation and income level are statistically significant in the case of Munich, while only age appears to influence commuters' comfort in the case of India. Accessibility related variables, like road crossing in between modes, and issues due to vertical circulation are significant in the case of India, which did not load to a group in a single factor, but were retained as independent variables with high unique values. Time related variables, including time taken at interchanges, percent of travel time spent while doing transfer, are significant in the case of India. Navigability related variables, like way finding and language barrier, are common for both cases. Among the extracted factors, all the factors (transfer quality, safety, and level change) are significant in the case of India, whereas only the factor of transfer quality is significant in the case of Germany. The insignificance of accessibility and safety factors in the case of Germany can be interpreted by considering that the interchanges there are already mandatorily accessible and safe in the perception of commuters that have not experienced inaccessible or unsafe interchanges. Therefore, contrarily, the significance of accessibility related, safety, and level change factors in the case of India can be understood.

Desired quantitative ranges

The quantifiable significant indicators obtained from Ordinal Logistic Regression are indicated with suitable ranges using locally weighted regression smoothing.

Transfer distance

Fig. 2 presents the perceived discomfort as a function of the transfer distance in Germany and India. In Munich (Germany) commuters feel comfortable at interchanges, provided the transfer distances are rather short (about 100 m). Discomfort then increases almost linearly until a bit less than 200 m and then is almost stable until more than 350 m. As expected, the tolerance in India is larger. In fact, transfer distances between 200 m and 320 m provide a rather good level of comfort, while distances between about 120 m and 430 m are still acceptable (and comparable to 100 m in Germany). Above 430 m, the level of discomfort increases rather steeply until more than 550 m, for which observations exist.

Furthermore, an interesting observation is the convex shape of the level of discomfort with respect to distance for Indian commuters. In fact, the level of discomfort increases for very small distances. One explanation is that short transfer distances would result in very crowded conditions, thus indicating the need for intermodal spaces, required to come out from one mode and navigate to the next mode. The need for such intermodal space in the case of India is also supported by the fact that the average daily ridership of India (Delhi Metro) is more than four times that of Munich U-Bahn (Metro).

Number of level changes

In the case of India, number of level changes between metro and

Table 4
Factor Analysis Results.

India (New Delhi & Kolkata)				Germany (Munich)			
Indicators	Factor1	Factor2	Factor3	Indicators	Factor1	Factor2	Factor3
% In Vehicle Travel time in transfer			**0.458**	Perceived Distance	**0.468**		
Preferred no. of level changes			**-0.754**	Safety - theft		**0.842**	
Safety		**0.518**		Safety - women		**0.827**	
Transfer distance	**0.998**			Safety_accident		**0.853**	
No. of level changes			**0.929**	Safety - external			
Transfer time	**0.51**			Transfer distance	**0.975**		
Foot-steps	**0.991**			No. of level changes	**0.397**		
Mandatory turns		**0.906**		Transfer time	**0.952**		
				Foot steps	**0.995**		
				Accessibility			**-0.803**
				Overall safety			**0988**
	Factor1	Factor2	Factor3		Factor1	Factor2	Factor3
Proportion Variance	0.30	0.26	0.22	Proportion Variance	0.28	0.18	0.14
Factor interpretation	**Transfer quality**	**Safety**	**Level change**	Factor interpretation	**Transfer quality**	**Safety**	**Accessibility**

Table 5
Ordered logit models with extracted factors.

	a) India (New Delhi & Kolkata)		b) Germany (Munich)	
Coefficients:	**Value**	**t value**	**Value**	**t value**
Age18–30	-1.39	-2.02		
Age30–50	-1.42	-2.04		
Age50–100	-1.34	-1.89		
Time taken at transfer_yes	0.32	1.54		
Way finding_yes	0.48	2.18	1.08	1.87
Changeover to other modes (L)[1]	0.59	1.97	1.59	1.66
21–50% of IVTT metro	0.40	1.69		
51–100% of IVTT metro	1.10	3.59		
Vertical circulation_Yes	0.52	2.05		
Road Crossing within transfer_yes	0.70	2.97		
Language_yes	-0.48	-1.98		
Time wasted 16–30 min at transfer			2.42	1.96
Profession Others (e.g., retired, home maker)			3.01	2.67
Income (L)			-3.86	-2.24
Crowded transfers_Yes			1.25	2.07
Transfer Quality	0.72	6.12	-0.10	-0.37
Safety factor	0.70	5.50	0.26	0.93
Level change factor (not applicable for Germany)	-0.14	-1.32		
Accessibility factor (not applicable for India)			0.28	1.36
Intercepts:	**Value**	**t value**	**Value**	**t value**
1|2	-2.62	-3.60	0.45	0.56
2|3	-1.71	-2.38	2.99	3.51
3|4	0.95	1.32	6.18	6.18
4|5	1.80	2.49	8.45	6.75
McFadden's R^2	0.34		0.26	
AIC	991.458		224.956	

(L) refers to linear fit.

other modes at interchanges is not statistically significant yet. The Munich case suggests, with other improved indicators in the future, the number of level changes might be a significant indicator for perceived comfort. Therefore, from the case of Munich, up to two level changes for intermodal transfer at interchanges are accepted to be comfortable. Moreover, people using up to one level change are acceptable to use up to two level changes.

A very interesting finding of this research is that perceptions of level changes are bounded by the expectations of individuals with regards to the interchange design complexity; and that there is a certain boundary, where comfort significantly deteriorates. This is evidenced by the analysis of differences between the actual and preferred number of level changes (Fig. 3). As it is clearly evidenced for level changes of 1–2 in Germany, respondents show little preference towards a lower number of level changes. This, however, becomes apparent when moving to 3 level changes, where people experience the discomfort and prompt towards a much lower number of level changes.

Transfer time

In India, transfer time up to 5.8 min is perceived to provide the same level of comfort as 2.3 min provides for Munich case, provided transfer times are much lesser in Munich than in Indian cities (Fig. 4**).** This is believed to be related to the fact that commuters in India have not experienced lesser transfer times; and the fact that PT arrivals are punctual in Munich; thus there are lower chances of missing a connection. Also, comfort decreases almost linearly from 5.5 min up to almost 9 min of transfer time in India, whereas it does not seem to change much between 3 and 4 min, for which observations exist.

Discussion of results and conclusion

This study aims at providing valuable insights on integrating multimodal transport systems by examining (dis)comfort at interchanges. With the goal to increase the PT market share, and as most major metro

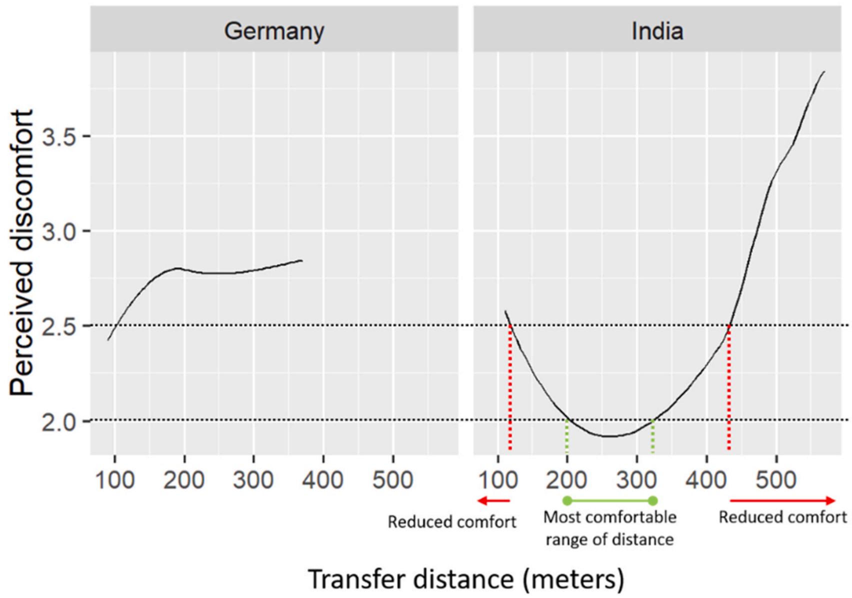

Fig. 2. Perceived discomfort as a function of transfer distance.

stations usually have one or more connections, the models developed and the understanding of the factors that affect (dis)comfort to commuters are important to better design stations and evaluate interventions. Therefore, seamless transfers could attract commuters, who otherwise hesitate to use metro rail and use private modes of transport, to avoid transfers.

Physical factors, like accessibility, road crossings, and vertical circulation, seem to be significantly influencing the perceived comfort of commuters in India, which is absent in German case adhering to the fact that German stations are well accessible. However, the significance of the number of level changes in India indicates that people are concerned about level changes, but not exactly how many times they need to change levels, provided that the metro is a newer add-on mode to the previously available PT modes. Also, transfer time does not significantly influence comfort in the German case. Of course, it is not that commuters in Munich do not value time, but they have not experienced longer transfer times to be uncomfortable transfers: the same level of comfort is achieved at 5.8 min of transfer time in India as compared to 2.3 min in the German case. Indicators related to safety are not significant in the Munich case, as safety is well established at transfers and is therefore not a significant variable to determine comfort. These differences in perceptions are not uncommon or difficult to explain, as a level of satisfaction is a function of the difference between perceived performances to expectations (Kaiman and Zani, 2013; Nur Najmah, Menudin, and Nooraneda, 2019). Expectations keep on changing with the availability of better products or services. However, the evaluation of the comparisons between the two situations is of high importance to provide an understanding of the perceptions in different settings.

Although also in favor of construction cost reduction (as reduced transfer distance and time requires compact and integrated design of interchanges), the lack of integration in design and execution is also an attribute of administrative (dis)integration (Luk and Olszewski, 2003), indicating a policy level implication. This might suggest to policy makers, an independent apex body responsible for designing of interchanges and stations, wherein the services in the form of availability of modes shall be provided by transport agencies, but their integration shall be looked upon by the apex body, including ticketing and other non-spatial interfaces. Also, while planning for the transportation network of a city, and thereby interchanges among different modes, this study can be used as one of the indications to select a suitable location for the interchange to be able to satisfy the significant factors. The policy makers in developing economies can benefit from the study, as comparative benchmarks are presented regarding different attributes of interchanges in both contexts.

The significant factors, as identified from the analysis, must be given priority when designing new interchanges. To conduct this study in different cities, the major time consuming input required is the survey of commuters and the stations' infrastructure data. Using the additional

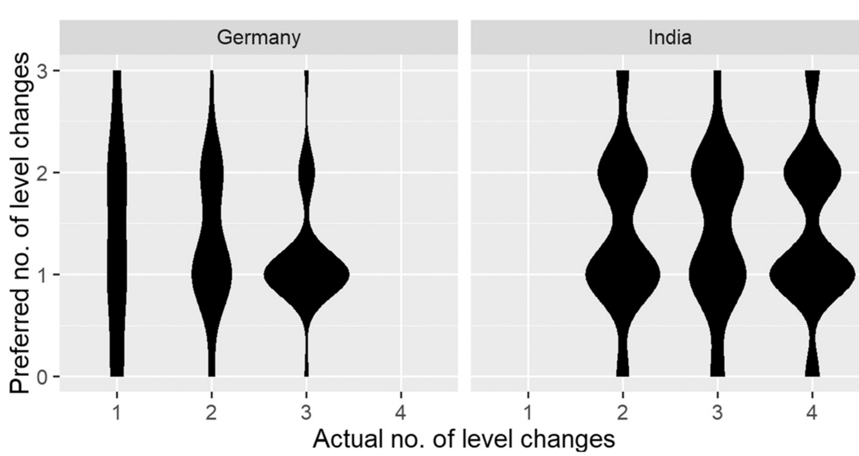

Fig. 3. Range for number of level changes.

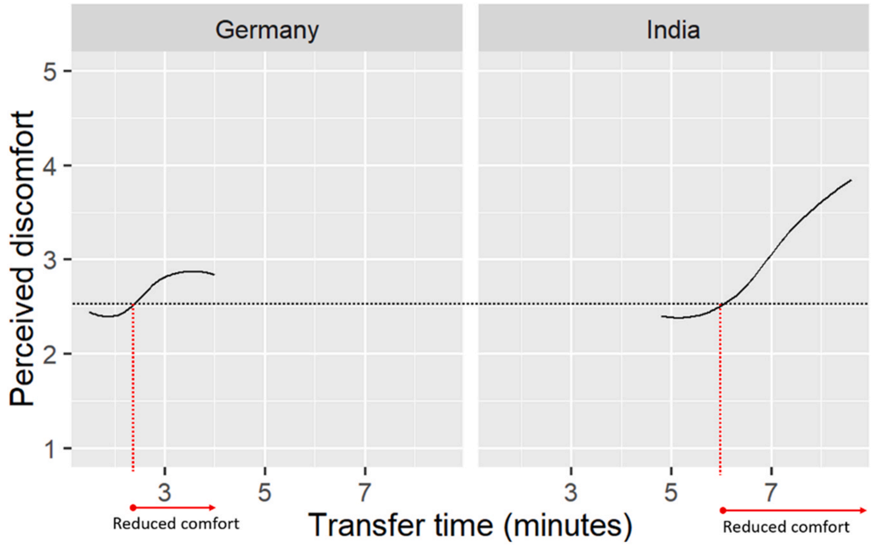

Fig. 4. Perceived discomfort as a function of transfer time.

data sets, the same statistical tools can be used to obtain comparable results. However, some of the categorizations for socio-economic data of the demographics might have to be revised for survey.

Thus, although this study cannot be generalised directly for other places, it is considered valuable, when taking into account local socio-economic demographics and the current situation. Also, to conduct this study in other study areas, the sample size should be considerably large to capture commuters' perception well. In this study, the sample size is a limitation in the German case study.

While the current study focuses on the interfaces between MRTS station and other modes, this should be extended in future research to other interfaces as well, including non-motorized vehicles, provided their significant role in first and last mile connectivity. For example, in smaller cities in India, the Government is envisaging a mini-metro system of public transport with reduced investment, shorter vehicle size, and reduced design speed, and also shorter average trip lengths. However, the interfaces between such mini-metro systems should not be deprived of the desired interfaces.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

The authors confirm contribution to the paper as follows: study conception and design: Ankita Sil, Uttam Kumar Roy, Emmanouil Chaniotakis, Constantinos Antoniou; data collection: Ankita Sil; analysis and interpretation of results: Ankita Sil, Emmanouil Chaniotakis, Uttam Kumar Roy, Constantinos Antoniou; draft manuscript preparation: Ankita Sil, Emmanouil Chaniotakis, Uttam Kumar Roy, Constantinos Antoniou. All authors reviewed the results and approved the final version of the manuscript.

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