Estimation of Bus-to-Bus Interchange Penalties in an Irish Context

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Abstract

This paper presents the results of research undertaken to quantify a time-equivalent transfer penalty for bus-to-bus interchanges in the Greater Dublin Area. With the re-configuration of Dublin's urban bus network as part of the BusConnects project, interchanging is set to become a major feature of public transport journeys in Ireland's capital. While interchange based networks can provide trip makers with greater levels of access to jobs, education, and services, the requirement to interchange imposes a disutility upon trip makers above and beyond quantifiable inconveniences of interchanging, such as waiting and walk times. Using a stated preference survey, and a representative sample of 1037 adults in the Greater Dublin Area, a multinomial logit modelling approach was used to estimate this deterrence to interchanging or "interchange penalty", accounting for travel time, public transport fare, and the facilities present at the interchange site. Interchange penalties of between 16 and 21 minutes were estimated for the interchange options tested, with no statistically significant difference being observed between dedicated interchange facilities and ordinary bus stops. Additionally, respondents were asked to rate the relative importance of a number of features that may either be found at interchanges, or that impact the interchanging experiences. These results show that service level features such as frequency are the most important, as well as shelter and the provision of clear real time information.

Introduction

The bus network in Dublin is currently undergoing a significant overhaul due to the 'BusConnects' project. This new network design involves increased levels of interchanging to access major trip attractors, and therefore prompts a better understanding of bus-to-bus interchanging, specifically within an Irish context.

With regard to bus network design, a subject which has featured heavily in literature reviews is the 'network effect' (Mees, 2009, Nielsen and Lange, 2008). The network effect treats the entire bus network as an actual network and not merely a collection of individual routes. As public transport must compete with the "everywhere to everywhere" convenience of the car and, for shorter distances, walking and cycling (Lange and Nielsen 2008; Mees (2009), such networks attempt to increase the ability of public transport to provide greater levels of connectivity between areas. Research has discussed the network effect (Lange and Nielsen, 2008; Mees, 2009; Walker, 2012), where public transport lines are organised into high-frequency lines along corridors of high demand, which are supplemented with less frequent

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services to reach as much of the urban area as possible. Where a given strategy aims to facilitate as many direct routes as possible, duplication and congestion can occur along corridors. Thus, transfers and interchanges are therefore an inescapable feature of a public transport network that seeks to provide a comprehensive alternative to other modes of transport (Lange and Nielsen 2008, Walker, 2012), while making best use of its bus fleet. This is exemplified in the highly simplified hypothetical model of 'Squaresville' (Mees, 2000 cited in Lange and Nielsen 2008) where, instead of a highly frequent system of non-connecting north-south routes, a transfer based network consisting of slightly less frequent north-south and east-west routes is provided, giving better coverage and connectivity across the city of 'Squaresville'. A transfer-based network can help also to serve a wider catchment area including and centres of demand outside of city centres, and thus attract greater ridership (Brown and Thompson, 2012; Badia et al, 2017). Examining Barcelona's new transfer based bus network Nova Xarxa (NX), where transfer based trips were up to 25% higher than other comparable networks, Badia et al (2017) suggested that more public transport users could be attracted to an integrated transfer-based network.

Interchange Penalties

Being on a route that involves a transfer, generally entails a level of inconvenience that is absent from a direct route. This includes disembarking from the first service, waiting for a second service, and boarding a second service of varying capacity. The phenomenon of this inconvenience is referred to as the transfer penalty. Currie and Loader define this as :"the perceived disadvantage of making a transfer measured in terms of in-vehicle travel time" (2010, p. 9). An alternative definition is provided by Iseki and Taylor (2009), who define transfer penalty as "generalised costs – including monetary costs, time, paid labour, discomfort, inconvenience etc. – involved in transferring from one vehicle to another in the same mode (e.g. bus to bus) or between different transportation modes (e.g bus to train, walk to bus etc)" (2009, p. 780). They further advise transport planners that "transit users hate to wait and dislike transferring even more". However, transfers are an inherent feature of transport networks. Currie and Loader (2010) concluded that the network effect, while "intriguing" was "an unsubstantiated theory that informs good practice but should be treated with caution when applied in the real world" (2010, p.8).

The mode of transport has been observed to affect the strength of the transfer penalty. Bus-bus transfers are generally found to have a higher transfer penalty than rail-rail or metro-metro (Currie, 2005; Iseki and Taylor, 2009; Navarette and Ortuzar, 2013; Cascajo et al 2016; Grisé and El Geneidy 2019). This can be attributed to greater perceived uncertainty of the reliability of buses due to the possibility of delays from general traffic, a relative lack of facilities, the need to cross roads to catch a connecting bus and the possibility of greater exposure to weather compared to rail stops (Currie, 2005). A review of several studies by Currie (2005) calculated an average transfer penalty of 22 minutes for bus-bus transfers compared to 8 minutes for subway-subway transfers. Both Currie (2005) and Iseki and Taylor (2009) cite a word of caution by Guo and Wilson (2004) who note a variance of the transfer penalty depending on the methodology used, as well as the location of study.

Frequency and schedule adherence have frequently been cited as important factors affecting the transfer penalty, as they impact on users' sense of control and the perceived and actual waiting time (Iseki and Taylor, 2009; Chowdury and Ceder, 2016; Cascajo et al 2019, Espino and Román, 2020). Grisé and El-Geneidy (2019) found a lower level of satisfaction among passengers using bus-bus transfers than those transferring between other combinations of modes, particularly subway-subway transfers, in Montreal, Canada. This led the authors to hypothesise that satisfaction in transferring can vary according to service frequency where transferring onto a high-frequency service will not cause concerns about timing and improved frequency would "likely have the most significant impact on improving satisfaction" (2019, p15). In a comparison of Madrid and the smaller Spanish city of Vitoria-Gasteiz, Cascajo et al (2019) found that users were more sensitive to frequency and reliability in the primarily bus-based network in Vitoria-Gasteiz, than the multimodal network in Madrid, probably due to the lower frequencies and distances in the former. Hine and Scott (2000) examined bus-bus transfers in Scotland and found that there was a perception of unreliability of services which impinged upon having a sense of control when making a transfer and reliability and frequency were the most important attributes in terms of the cost of a transfer

penalty. The danger of missed connections and resulting delays as well as a lack of familiarity of a route can increase anxiety and the sense of inconvenience which indicates the importance of scheduled adherence as well as frequency (Hine and Scott, 2000; Chowdury and Ceder 2016). Espino and Román (2020) found that travellers were willing to pay more to reduce waiting times. Meskell (2021) noted that the increase in frequency from two-hourly to hourly appeared to generate acceptance for replacing a direct route to Dublin city centre from the town of Blessington. 30km away, with a feeder route to a bus and tram interchange terminal in Tallaght in southwest Dublin.

The capacity of connecting routes has also been noted; Navarrete and Ortuzar's (2013) survey of Santiago de Chile's public transport network found that being able to board the first accessible bus was the most valued attribute for users of the network, who were willing to pay 21% more on their fare to overcome this perceived obstacle. Meskell (2021) found that concern about a lack of space on a connecting bus and the possibility of missing a connection were reasons for opposing the replacement of a direct route with a feeder route in areas of Dublin. Crowding at the Interchange facility can also impinge upon users' perceived waiting times. This tends to manifest itself in larger interchange facilities (Cascajo et al, 2019). Navarette and Ortuzar (2013) found that interchange users in Santiago de Chile were willing to pay 25% to their fare if it meant being able to avoid crowded stations. Interchange guidance documentation from Transport for London (hereinafter TfL) highlights the importance of designating areas of the interchange as 'decision spaces' (such as tickets gates or corridor junctions), movement spaces (where passengers are most likely to pass through) and 'opportunity spaces' (e.g. retail displays and entrances, seating) and the importance of keeping the first two of these clear of advertising and other non-essential furniture (TfL, 2021, p10-11).

While noting the importance of the interchange facility, and how the comfort and amenity of the facility plays an important role in reducing transfer costs, Iseki and Taylor remarked that it was "unlikely" that any such improvements "no matter how adroit, could have the same magnitude of effects on transfer penalties (and hence ridership) as service improvements like reduced headways or improved schedule adherence" (2009, p 796). However, several studies have noted that the nature of the interchange itself can affect travellers' perception of the overall journey. Hernandez and Monzon (2015) argue that making the interchange a 'place' and a social hub and not just a transfer point can attract greater number of passengers. For example, having retail outlets in the interchange makes it a potential place for people to meet and to pass the time while waiting for their connecting journey. This in turn could attract people to the interchange and thus to the public transport network (Hernandez et al, 2015). This is echoed by guidance documentation from TfL, who state that interchanges are also public spaces and the provision of retail, food and leisure facilities can enable passengers to "make the best of the waiting time for their next service and make the wait more enjoyable." (TfL, 2012, p.38)

Cascajo et al (2019) found that better facilities such as seating, shelter can reduce the perception of waiting time. Adamos et al (2022) found that interchange users in both Riga, Latvia and Thessaloniki, Greece rated their interchanges highly on physical attributes such as access, travel and wayfinding, but lower in the aesthetics of the facilities and feelings of comfort security and safety, leading the authors to conclude that these attributes should be given close attention when designing transport networks and interchange facilities. Both NTA and TfL cite the importance of provision of seating – particularly for those with mobility impairments as well as the importance of placing seating and other furniture in locations that are convenient, which do not create obstructions (NTA, 2012; TfL, 2012). Shelter was highlighted as an important attribute of interchange facilities, especially so at smaller ones (Meskell, 2021; TfL, 2021; Cascajo et al 2019; Grisé and El Geneidy, 2019; Hernandez and Monzon, 2015; NTA, 2012 Currie and Loader, 2010; Iseki and Taylor, 2009) with Cascajo et al noting that exposure to cold or wet weather can significantly increase the perceived waiting time. Abreu e Silva and Bazrafshan (2013) highlighted the importance of cleanliness at the interchange facility and noted that the presence of litter and graffiti can negatively impinge upon users' perception of security.
Several studies have cited the importance of the sense of security (including provision of lighting, CCTV, clear wayfinding and – for larger interchange points – staff) at the

interchange point in determining the extent of the transfer penalty. Hine and Scott (2000) found that one of the reasons for bus users fear of missing connections at interchanges (particularly smaller interchange points) in the Scottish Central Belt was the risk of a poorly manned, poorly lit or poorly designed facility attracting anti-social behavior (as well as a feeling of being stranded). The fear of missing a connecting bus and anxieties about antisocial or criminal behavior – particularly at night – was also cited by several respondents to Meskell's (2021) study as a reason for some of the opposition to the withdrawal of some direct routes in Dublin's bus network. Describing the sense of security as "indispensable" to users, Hernandez and Monzon (2015) note the importance of providing a sense of security in transfer and waiting areas (particularly at night) and in providing clearly marked emergency exits. Abreu e Silva and Bazrafshan (2013) noted clear signage and wayfinding help improve passengers perception of security and they also observed that increasing levels of security at stations could attract more users with higher levels of education (and thus higher income) and this was also cited as an important security factor in guidance documentation by NTA (2012) and TfL (2021). These guidance documents also cited clear lines of sight, natural surveillance, and CCTV as measures to provide a better sense of security but the NTA noted that this "is not substitute for the presence of staff who are able to combine a safety and security role with customer care and passenger information" (NTA, 2012, p. 16). Ceder and Chowdury (2013) found that users in Auckland were not willing to pay extra for increased security which led them to conclude that a network that is perceived as safe will not lead to a demand for additional security measures.

The provision of reliable information – both printed information and electronic or real-time information – has been found to be an important element in reducing the transfer penalty by giving users a greater sense of control of the time they are spending waiting, reducing uncertainty and providing a sense of security (Hine and Scott, 2000; Iseki and Taylor, 2009; Ceder and Chowdury, 2013; Navarette and Ortuzar, 2013; Hernandez and Monzon, 2016; Cascajo et al 2019). Navarette and Ortuzar found that some users were willing to pay extra for additional information and this was particularly so among younger travellers which reflected an ability to travel without the assistance of others. Cascajo et al (2019) found that younger users preferred using mobile apps to get their real-time information while older users preferred to receive their information in situ. Iseki and Taylor (2009) note that poor provision of information can increase perceived waiting time. Guidance documentation from the NTA notes the importance of providing short, clearly-marked routes and accessible routes linking different public transport modes at the interchange as well as measures to reduce vehicle speed (National Transport Authority, 2012). This is echoed by TfL (2021) who also call for sufficient spaces in areas where information is displayed, with particular attention being made to avoid congestion in 'decision-making' spaces (e.g. ticket gates).

Some studies noted the characteristics of people who used transfers. Some found that users of transfers were more likely to be male, younger and commuters, and less likely to be elderly and holders of concession tickets (Cascajo et al, 2019; Navarette and Ortuzar, 2013; Hine and Scott, 2000). Additionally, the purpose of the trip can impact upon the importance of frequency and the perception of the transfer penalty, with the cost being higher for those travelling for mandatory or work-based trips (Espino and Roman, 2020; Hine and Scott, 2000). It should briefly be noted that fare and ticketing structures have been widely noted as being a significant factor for the transfer penalty (e.g.: Espino and Román, 2020; Chowdhury and Ceder, 2016; Walker, 2012). This, however, is moot for the purposes of this study as a 90-minute Fare, allowing for unlimited travel within 90 minutes of payment of the first journey, has been introduced across the public transport network in the Greater Dublin Area (Transport for Ireland, 2024)

Methodology

This study sought to estimate bus-bus transfer penalties in Dublin, and was undertaken via a stated preference experiment within a large survey examining the desire to interchanges and the factors that impact such choices. The experiment was designed to estimate parameters for the NTA's strategic transport models, specifically the choice of attributes are informed by the model form we seek to replicate.

The multinomial logit model is estimated based upon the following format:

$$P_i = \frac{e^{U_i}}{\sum_{k=1}^{K} e^{U_k}}$$

Where

P_i = the probability of choosing option i from the k available alternatives

U_i = the utility derived from option i

Where the utility is a function of the attributes describing the various alternatives

$$U_i = a * x_{1i} + b * x_{2i} + c_i$$

a = the estimated parameter for fare

X_{1i} =the fare for option i

b = the estimated parameter for travel time

x_{2i} = the travel time for option i

c_i = the interchange facility parameter for option i

Note: As this is an unnamed experiment (both options are buses), no constant term is estimated.

In a stated preference experiment, any alternative within a choice will be defined by the attributes and attribute levels presented to the decision maker. Three attributes are considered to define the choice sets from this experiment, specifically:

- Total travel time: Time from boarding the first bus to disembarking the last
- Fare: The total cost of getting from the origin to destination
- Interchange type (including no interchange or "direct")

These attributes were selected due for the need for the estimated parameters to be consistent with the NTA's transport models. Attribute levels were selected to both reflect the interchange options available in Dublin, and typical travel times. At time of surveying Dublin had a relatively recently introduced €2 flat fare for public transport, however it was decided to include a fare variable to allow sense checking, such as the assessment of realistic values of time. Table 1 outlines the levels selected for the respective attributes.

Table 1: Attribute Levels

	Travel Time	Fare	Interchange
Level 1	30 minutes	€1.50	Direct
Level 2	40 minutes	€2.00	Facility
Level 3	50 minutes	€2.50	At Stop
Level 4	60 minutes		Walk

Each respondent completed 8 choice scenarios from a total set of 24. The scenarios were designed using the "dcrete" experimental design function in Stata 17. The specific 8 scenarios presented to a given respondent were randomly generated to avoid blocking issues. For the interchange variable, respondents were provided with images of the typical interchange types, as it was uncertain if most respondents would be familiar with the relatively new (at time of surveying) dedicated bus interchanges in Dublin.

Additionally, the survey was split in two, with half of the respondents being to imagine they were transferring to a frequent service (once every 5 minutes) and half being told they were transferring to an infrequent service (once every 25 minutes). Respondents were randomly assigned to each block. As interchanging is not very common with the current configuration of the bus network in Dublin, and as dedicated interchange facilities were only being rolled out at the time of the study, respondents were provided with images to help them differentiate between the interchange options.

Figure 1: Dedicated Interchange Facility

Figure 2: At Stop

Figure 3: Walk/Wheel Interchange

The questionnaire also asked a series of questions wherein respondents were asked to rank the most important factors when undertaking a bus-to-bus interchange, specifically in terms of the on-site facilities and the performance of the network.

The survey was distributed to both public transport users and non-users in January 2024, and was designed to be representative of the adult population in the Greater Dublin Area (counties Dublin, Wicklow, Meath, and Kildare) by age, gender, and employment status. The inclusion of non-public transport users is primarily due to the NTA's models being a multi-modal choice models, where the perceived penalty of transferring applies to all trip makers, not just those familiar with interchanging, or the region's bus network. In addition to the stated preference experiment, respondents were surveyed on their attitudes to public transport, their perceptions of safety, and their current travel behaviours.

The choice modelling was undertaken using the "cmclogit" function for estimating McFadden's Conditional Logit Model in Stata 17 (Stata, 2024)

Results

Table 2 outlines the results of the full sample multinomial logit model. Results show that all the attributes are highly statistically significant. Looking first at travel time and fare, both parameters are estimated as being negative, meaning that an increase in either the cost or the travel time of a trip will decrease its utility and attractiveness. This can be considered to be intuitively correct and provides a good sense check on the model.

The estimates for the different bus interchange options are expressed as both coefficients and as odds ratios (for easy of interpretation). Results show that there is a significant disutility associated with each of the interchange types, and that the respective odds ratios show that people are only about one third as likely to select an interchange option over a direct one, when all else is equal.

Interchange penalties are expressed both in terms of time and monetary equivalent penalties. Time based penalties vary from sixteen and a half minutes for at stop transfers to 21 minutes for transfers that involve a walk leg. It should be noted that the actual walking time is already accounted for in the total travel time, so the extra element of the penalty is assumed to reflect the further level of inconvenience from having to walk between stops. When the penalties are expressed in monetary terms, respondents are willing to pay between €1.15 and €1.46 to not interchange on trip, travel time being held constant. Results can be considered to be broadly in-line with the existing literature with regard to the magnitude of bus-to-bus transfer penalties.

Note: No significant differences were observed between inbound and outbound scenarios, therefore those results are not presented here.

Table 2: Full Sample MNL Results

	Coefficient	Odds Ratio	P>z	95% CI Low	95% CI High
Travel Time	-0.06		0.00	-0.06	-0.06
Fare	-0.88		0.00	-0.96	-0.81
Interchange					
Direct	0.00	1.00	N/A	N/A	N/A
Facility	-1.04	0.35	0.00	-1.15	-0.93
At Stop	-1.02	0.36	0.00	-1.13	-0.90
Walk	-1.29	0.28	0.00	-1.40	-1.18
Penalties	Minutes	Money			
Facility	16.91	€1.18			
At Stop	16.48	€1.15			
Walk	20.94	€1.46			
Observations					16,592
Cases					8,296
Respondents					1,037
Log likelihood					-4,313
Wald chi2(5)					1,773

Table 3 outlines the differences in the utility associated with interchange types from the same model as in Table 2, but presented with the dedicated interchange facility as the reference category. Results show that there is no statistically significant difference between the dedicated interchange facility and a standard at stop interchange.

Table 3: Interchange Types with Reference to Facility

	Coefficient	Odds Ratio	P>z	95% CI Low	95% CI High
Interchange					
Facility	0.00	1.00			
Direct	1.04	2.94	0.00	0.93	1.15
At Stop	0.03	1.03	0.53	-0.57	0.11
Walk	-0.25	0.78	0.00	-0.33	-0.17

To understand the impact of levels of familiarity with the bus network, the modelling was repeated for both respondents who take the bus at least once per week (for any reason) and those who take it less frequently. A number of frequency levels were explored but this split produced the most significant results. Looking at penalties from a time perspective, large differences are observed between the two groups, ranging from just over 4 minutes for changes at facility, to nearly 9 minutes for interchanges involving walking. From a monetary perspective, infrequent bus users are willing to pay nearly twice as much not to interchange as frequent users. It should be noted that apparently discrepancy between time and monetary penalties is a result of the different values of time estimated for the respective groups.

Table 4: Frequent vs Infrequent Users

Penalties	Minutes Infrequent Users	Minutes Frequent Users	Money Infrequent Users	Money Frequent Users
Facility	18.22	14.87	€1.47	€0.84
At Stop	19.11	12.73	€1.54	€0.72
Walk	24.32	15.79	€1.96	€0.89

Table 5 outlines the results of the ranked relative importance of the various selected interchange features, as well as a designation whether they are a feature of service, present at standard bus stops, or only present at dedicated interchanges. While some features may be more prominent at interchange facilities, it is clear that those that may be considered unique to such facilities, are rated as the least important. This indicates that, while such features might be nice to have, the most important elements of interchange can be provided by standard bus stops (with shelters) and well performing bus services. The results may also provide insight as to why at stop and dedicated interchange facilities do not emerge as significantly different in the choice experiment.

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Table 5: Features of Bus Interchange: Likert Scores

	Mean	Service	At Stop	Facility
Buses adhere to their schedule	4.42	X		
Onsite Real Time Information	4.26		X	X
Bus services at the interchange are frequent	4.15	X		
Shelter	4.02		X	X
The interchange point is accessible to everyone	4.00		X	X
Clear Wayfinding	3.98			X
Lighting	3.89		X	X
Seating or Standing Space on your second bus	3.87	X		
Seating	3.82		X	X
Seating Space on your second bus	3.59	X		
Printed Route Information (e.g. maps)	3.53		X	X
Printed timetables	3.48		X	X
Toilets	3.35			X
Presence of Staff	3.33			X
Café/Kiosk	2.66			X

Discussion

This paper outlines the results of a study undertaken to understand the magnitude of bus-to-bus interchange penalties in Dublin Ireland. The research was motivated by the reconfiguration of the Dublin bus network, specifically the need for bus users to interchange more to take advantage of the "network effect". Interchange penalties attempt to provide travel time based equivalents to the disutility experienced by having to undertake a transfer mid-journey, when all other factors are equal. Conversely they can be considered to provide information on how much faster does a trip involving interchanging need to be, when compared to an equivalent bus trip, to be equally attractive.

Results demonstrate that there is a significant disutility associated with interchanging between bus services, and the provision of dedicated interchange facilities does not appear to reduce this, with respective to existing bus stops. This can be partially due to the majority of the factors respondents consider important for bus-to-bus interchanging (such as shelter, real-time information and the frequency or reliability of bus services) either already being present at standard bus stops, or a function of the network. The three lowest ranked features – café/kiosk, toilet and presence of staff – would only be present at interchange facilities.

The results here largely reflect the findings of previous studies in terms of the importance that travellers attribute to frequency and reliability of bus services and the provision of shelters but suggests a contradiction of other studies which note the attractiveness of a well-resourced interchange facility.

The rollout of interchange facilities is a relatively novel concept for the Dublin area. While bus stations in regional towns and villages do act as interchange facilities, Dublin does not have the same facilities that can be found in the suburbs of similar sized cities in Europe. A future study which gives a direct comparison between this study in Dublin and a British or European city with a network of interchange facilities, could be beneficial. Similarly a comparative study in Dublin could be undertaken once the BusConnects project, and its interchange facilities have been fully rolled out, to ascertain if there is any difference in attitudes.

The estimated time penalties are found to be broadly in line with previous research, where the penalty for changing from bus to bus is considerably higher than for rail based forms of public transport.

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