Analysis of Multimodal Passenger Terminal Design and its Effects on Transfer Penalty

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Abstract

With public transit systems becoming more and more sophisticated, the likelihood of passengers having to transfer between modes or lines increases. Transferring burdens, the passenger with added mental and physical effort, referred to as transfer penalty, which has a negative effect on the travel experience. The physical design of multimodal transfer terminals, such as train stations, can have a significant effect on transfer penalties but has received relatively little attention in practice. The aim of this review essay is to create an understanding of the ways in which the physical design of terminals can influence the transfer penalties experienced by passengers. Our findings show that terminal design can influence transfer penalties through actual and perceived walking and waiting times at transfer as well as the pure transfer penalty. We identified distinct categories of design elements and of other parts of the transit systems that urban designers can employ in influencing these aspects.

1.Introduction

As opposed to freight transport, passenger mobility depends on the free choice of the traveller. Instead of being an inanimate cargo in the system, humans are free-floating objects in the mobility system and will decide not only whether to travel at all but also the time, route and mode(s) for traveling, depending on their perceptions of costs and benefits of the available alternatives. National and global mobility strategies strive during the ASI-strategy to shift passengers from private car mobility towards more sustainable modes, such as public transit. As public transit systems become more and more sophisticated and extensive, an increasing share of trips requires transferring from one mode or line to another. Transfers can be seen as a double-edged sword. While strengthening the network effect of public transit and offering more connectivity to passengers, transfers also disrupt the travel experience and weaken the competitiveness of public transit as opposed to private car mobility, the latter being able to provide door-to-door services (Guo & Wilson, 2011). The facilities where transfers take place have a significant effect on passengers transfer experience and consequently on the perceived 'transfer penalty' (Iseki & Taylor, 2009). Therefore, the analysis of the design and integration of terminals or hubs and how they affect the travel experience is a crucial step to understand travel mode choices, to improve comfort and to nudge travellers to change their mobility behaviour.

While a lot of research has been done on network and schedule design, analysis of the actual physical design of terminals, while declared important (Cascajo et al., 2017; Guo & Wilson, 2011), specific design guidelines seldomly surpass the level of solely fulfilling the operational needs. This essay provides an assessment of multimodal hubs in the context of existing research, focusing mainly on passenger perception, in an attempt to create a more passenger-centric understanding of transfer, as subjected by Duca et al. (2022). Our key concern is how the physical design of terminals can influence passengers' travel experience and how passengers' perceptions of transfer can be influenced. We concentrate mostly on multimodal trips that include at least one stage in public transport. While travels only with individual traffic are usually multimodal as well (even a plain car trip needs access and excess on foot), terminal design matters much less there and is usually considered with the keyword 'parking'.

The remaining essay is structured as follows. First, we explain the significance and necessity of transfers in public transit systems.

Second, we explore the concept of transfer penalties and transfer utility functions. This is followed by a review of the ways in which transfer terminal design can affect the magnitude of transfer penalties. After this, we present the practical design insights found in literature. The essay is concluded with a reflective section.

2. The role of transfers in the public transit system

The need for transfer arises from the characteristics of public transport network design. Conventional public transit consists of the provision of comparably high-capacity mobility that runs on set routes, at set schedules and serves distinct access points (stations). While other models, such as on-demand services, are experimented with and successfully implemented occasionally, most of the public transit fulfils the conventional criteria. Furthermore, there is an anti-proportionality between coverage density and travel speed, capacity and right of way between different modes and lines. Thus, a transit network usually relies on multiple layers that address different needs in connectivity and accessibility and together provide a network of interconnected services (Allard & Moura, 2015). As can be seen in many large cities, such as Helsinki Metropolitan Area, the heavy-rail modes (commuter-train, metro) usually fulfil the role of providing the backbone connection network in the city. Few people, however, live in proximity of a commuter rail or metro station and therefore rely on the close-meshed network of buses and trams to access these stations and transfer there to a 'higher level mode' or simply change lines. This becomes even more obvious when looking at intercity connections that offer point to point services between two stations but rely on an urban transport feeder system (Allard & Moura, 2015).

One of the biggest challenges of public transit trips is the first/last mile problem. How does the traveller get from their point of origin/destination to the station that serves as entry/exit point to the public transport service? Multiple solutions exist, many relying on individual micro-mobility, such as walking, cycling or e-scooters, but also Park & Ride solutions or drop-offs can play an important role. What these solutions have in common is that they make a transfer between modes necessary and rely on multimodal transfer terminals. To understand transfer behaviour, we must first consider the fact that there are different types of facilities for transfer. A crucial difference lies between *intermodal* and *intramodal* transfers. While in intermodal transfers the traveller changes the mode of transport, said mode stays the same in intramodal transfers, i.e., when changing between lines. Different types of transfer terminals for passengers involve distinct modes, depending on their function in the network. The requirements of each of the forms of transport involved should be considered when designing the physical station layout to reduce the negative perception of the transfer and fulfil the operational needs. This usually involves holding bays, parking, and waiting areas, drop-off zones, but also the connection between the different access points and an adequate guidance system for travellers.

While every station could be considered as a transfer station, since even a simple bus stop must be accessed in some way, we concentrate on terminals where transfers between a multitude of modes take place. This usually involves at least two different forms of public transport to can be called a transfer hub, even though both might be in the same mode (intramodal). Although our main focus is on the effect of terminal design on transfer experiences, easing the burden of transferring naturally benefits those passengers who are accessing or egressing the station on foot or via other individual modes.

3.Transfer penalty

Transfers confront the traveller with some unpleasantries. Next to the obvious loss of time due to walking and waiting, and the uncomforting need to change vehicles, Cascajo et al. (2017) define "mental effort and activity disruption" as two additional negative factors caused by transfers. Mental effort concerns how much alertness and mental work is needed for the transfer, for example, in remembering the right station for the transfer or checking for connection services, while activity disruption describes how much the transfer decreases the utility of the in-vehicle time. These negative aspects of transferring explain why travellers intend to reduce the number transfers as much as possible. In fact, passengers often accept a longer travel time if it means they can avoid a transfer (Allard & Moura, 2015). Therefore, in transport science and modelling, each transfer is usually attributed with a penalty to the rider's utility. Further observations have shown that riders are especially sensitive to the time spent out-of-vehicle (Cascajo et al., 2019), and the perception of how disturbing the transfer varies depending on the passenger's perception of the transfer facility. This influences travellers' choice of where and if to transfer. Therefore, instead of simply using a fixed penal value in the general transport utility function, there have been multiple approaches to further quantify the transfer penalty factors. These consist of (1) the actual time needed to make the transfer and (2) the econometric quantification of the transfer disutility due to loss of travel experience quality (Guo & Wilson, 2011). This created the wish to distil all factors into a 'transfer utility function', that is sometimes also described as 'transfer disutility function', since the results are usually experienced as "impediments" (Liu et al., 1997) in a multimodal trip. Iseki and Taylor (2009) propose a transfer penalty, expressed in generalized costs, including monetary costs, time, paid labour, discomfort, and inconvenience:

$$TP_b = (t_{walk} * w_{walk}) + (t_{wait} * w_{wait}) + TP_n$$

The transfer penalty (TP_b) can be described as the sum of the perceived waiting time, perceived walking time and the additional transfer penalty (TP_n) that contains the costs other than the easily quantifiable monetary and time costs (Iseki & Taylor, 2009). The factor w describes the relation between the actual time invest (t) and the perceived time invest for the traveller. This factorisation is needed to acknowledge the differences in time perception, depending on the task and physical environment, but also in personal traits and preferences. Cascajo et al. (2019), for example, discovered that usually out of all factors within a transfer, users penalise waiting time the most.

4.The influence of terminal design on transfer penalties

The concept of transfer penalty in relation to the design of transfer facilities has been studied extensively. Building on this research, various scholars have developed their own conceptualizations of the different components that influence transfer penalties. There is no consensus about the factors affecting transfer penalties found in literature (Cascajo et al., 2019), so this section of the essay will cover a few examples of conceptualizations developed by various authors. Lois et al. (2018) employs the node-place model to conceptualize the quality of transfer in terms of transport interchange hub as a *node* and as a *place*. Transport hub as a node refers to users' perceptions of the efficiency of the transit infrastructure and covers aspects such as the reliability and frequency of service, provision and clarity of travel information and the accessibility of transfer. Transport hub as a place is concerned with the user experience of transfer facilities and incorporates aspects such as perceptions of safety and comfort. Additionally, the model by Lois et al. (2018) considers different user profiles and recognizes that the perceptions of transfer quality may vary between different groups.

Iseki and Taylor (2009) conducted a literature review on the influence of transfer facilities on travel behaviour and identified three broad categories that contribute to transfer penalties. These categories include (1) operational factors of the transport system, such as headways, reliability and punctuality of service and availability of information, (2) the physical attributes of the transfer facilities related to comfort, safety and convenience and (3) passenger factors, such as whether the passenger is familiar with the transfer system, a frequent user, forced to wait at the transfer facility and able to engage in something productive while waiting. The authors specify that transfer penalties can be lowered by addressing *actual* and *perceived* walking and waiting times, *perceived* transfer burdens, and the fares paid. Fare policies and the lack of ticket integration can increase the monetary cost of traveling with transfers, having an increasing effect on the generalized cost of public transit travel. When it comes to walking and waiting times, the authors explain that these are determined by actual times with additional weights assigned by passengers. These weights in turn are influenced by different attributes and conditions at the transfer facilities, meaning that even though the design transfer facilities will not change for instance actual waiting times (since these are determined by operational factors), the *perception* of the waiting burden can be influenced by design.

A review by Cascajo et al. (2019) identifies six themes influencing transfer penalty: personal characteristics, trip characteristics, time, built environment, transfer characteristics and pure transfer penalty. The four last themes can be at least to some extent influenced by facility design. In fact, the authors report that some studies revealed the pure transfer penalty to vary significantly between different stations, highlighting the importance of station-specific environmental factors. The summary by Guo and Wilson (2011) offers a more simplified approach in relation to policy implications. They identify that walking times are determined by transit network and station design, waiting times by the operation and management of transit service, and the transfer penalty by a wide range of facility-related factors, such as safety and security, ease of wayfinding, availability of escalators and seating, weather protection and lighting.

Despite the differences in these conceptualizations, reoccurring themes emerge. These include actual and perceived walking and waiting times, availability of information and factors related to comfort and safety. In terms of factors directly influencing transfer penalty, we summarize them into (1) waiting times, (2) walking times and (3) pure transfer penalty. Literature indicates that perceptions of transfer experiences are crucial, which implies that even when certain attributes of transfer cannot be changed with facility design, the effect they have on transfer penalties on a psychological level can be influenced by design. Essentially, a distinction can be made between factors that influence actual walking and waiting times and the factors that influence passengers' perceptions of these times. The above review of literature shows that these factors, as well as the pure transfer penalty, can be influenced by facility design, operation and management of transit service, network design and fare policies. In this context, facility design can be divided into three very broad categories: (1) terminal layout, (2) wayfinding and the provision of information, and (3) factors related comfort. These three categories can be related back to the concept of interchange as a node and as a place by Lois et al. (2018). The two first categories are mainly concerned with interchange as a node since they are concerned with the functioning of the transit space. The third factor is in turn associated with interchange as both a place and a node.

Furthermore, literature emphasizes passengers' personal factors, such as whether they are familiar with the transit system, various socio-economic factors, and attitudinal profiles, as well as trip characteristics, such as the purpose of the trip (Iseki & Taylor, 2009; Lois et al., 2018; Cascajo et al.,2019). Although these factors depend on the individual and are external to terminal design, principles of inclusive design can be implemented in terminal design to ensure that even extreme users (a user with very particular needs) can use the service with ease (Duca et al., 2022). This type of an approach is expected to lessen the transfer penalties of different user groups. It is also likely that there are context-specific differences in the experiences of different factors that influence transfer penalty. For instance, Raveau et al. (2014) studied transfer experiences in London and Santiago metro systems and discovered differences in the ways passengers value waiting and walking times. In Santiago, metro users tend to be more willing to wait than walk, whereas in London, metro the users are more willing to walk than wait. The authors explain these differences in preference with the differing levels of complexity in the metro systems, the London metro being a more complex system with more possibilities for transfer in a single node. The user of this metro system might be more used to required transfers when travelling.

Figure 1 represents our summary and conceptualization of the factors affecting transfer penalty, based on the researched literature. The bottom section of the chart contains various elements of the transit system, including terminal design. The review of literature revealed that even when we are concerned with the effect of terminal design on transfer penalty, we cannot omit the other components of the transit system, given the fact that the other components have major influence on the factors that affect transfer penalty. For instance, the operation of public transit (i.e., scheduling and headways) determine actual waiting times at transfer. Similarly, walking distances in transfer are not only determined by terminal layouts but also by the design of the wider transit network (Guo & Wilson, 2011). The section above the components of the transit system contains the aforementioned broad factors that influence transfer penalties. The arrows represent the connections and influences between the different components of the chart.

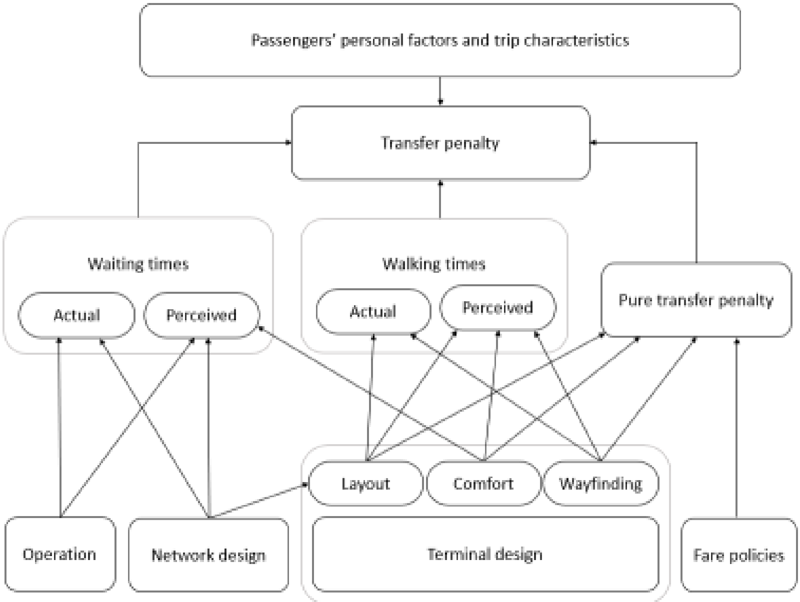

Figure 1: Conceptualization of the factors affecting transfer penalty, emphasis on terminal design. Source: authors

5.Towards passenger-oriented terminal design

Scientific literature is, on a general note, more concerned with conceptualizations of terminal design in relation to transfer penalties rather than practical design. Plenty of practical examples and for instance layout solutions are found in design manuals and best practice guides but not in scientific literature in the same volumes. Some practical insights are however found, and when it comes to the three identified categories in terminal design – layout, wayfinding, and comfort – and their relation to transfer penalties, scientific literature is mainly concerned with the first two. In terms of the third one, comfort, literature offers superficial and rather obvious suggestions that mainly have to do with the provision of amenities. For instance, Iseki and Taylor (2009) summarise that amenities, such as seating, restrooms, and weather protection, can increase passenger comfort and have a lowering effect on transfer penalties by affecting the perceptions of walking and waiting times.

In terms of wayfinding, Kalakou and Moura (2014) present that the importance of pedestrian wayfinding in indoor transportation facilities has been established in various studies and summarize that a high-quality wayfinding system can reduce actual walking times and uncertainty in navigation. In relation to the latter, easy-to-understand information can reduce the perceived burden of transferring (Iseki & Taylor, 2009). Li et al. (2021) studied the extent to which metro signs affect pedestrian wayfinding through short term memory and compiled practical recommendations for the design of transit signs and wayfinding. Based on their results on the changes in memory capacity over time, the authors recommend placing wayfinding signs with a maximum of 20-meter intervals to improve passenger efficiency. Similarly, the authors recommend reducing the amount of unnecessary information on the signs to ensure that passengers can remember the most crucial information on the signs.

As for terminal layout and walking routes, Raveau et al. (2014) conceptualize that transfers can be made between even, ascending, or descending levels. All these types of transfer can have varying levels of assistance that the authors classify into three categories: (1) assisted transfer that is made entirely with an escalator or a lift, (2) semi-assisted transfer which is partly made with an escalator or a lift and partly on foot and (3) non-assisted transfer that the user makes completely on foot. The authors studied user preferences and transfer experiences in relation to these factors in London and Santiago and discovered that an even-level transfer is the most preferred option. When transfer takes place between levels, ascending transfers are preferred since these are associated with less effort. In terms of assistance, the transfer experience tends to improve when the grade of assistance increases. As for reducing walking times and distances, Iseki and Taylor (2009) emphasize the importance of the physical distances between points of alighting and boarding as well as of the control of pedestrian flows, since the latter can influence walking speeds during rush hours. In fact, Molyneaux et al. (2021) points out that uncontrolled, bidirectional pedestrian traffic may increase travel times significantly, due to the 'slaloming' effect this type of flow has on pedestrian movement. The authors tested a simple control strategy – flow separators – in the context of railway stations and discovered that this type of pedestrian flow strategies can be very useful in transportation terminals. This is largely because demand for pedestrian space is induced by known timetables and that pedestrian flows egressing transit vehicles tend to happen in waves. In fact, crowded stations or platforms negatively affect the user's perception of the transfer, and Cascajo et al. (2017) even evaluate the level of crowding as being the biggest variable in transfer penalties.

Furthermore, station layouts and the positioning of platforms for different lines and modes has a significant effect on walking distances in transfer. As a positive examples of layout design, we would highlight the cross-platform design, as seen in Figure 2. The literature cited throughout the essay emphasizes the importance of minimizing walking distances and thus times as well as the need to change levels in transfer, and these ambitions are successfully met in cross-platform transfer. This type of design solution is found for instance in Stockholm's Tunnelbana network. On the contrary, for instance perimeter-oriented bus terminals, while offering more safety for passenger by reducing the number of conflict points pedestrians and vehicles, have been shown to increase walking distances (Iseki & Taylor, 2009).

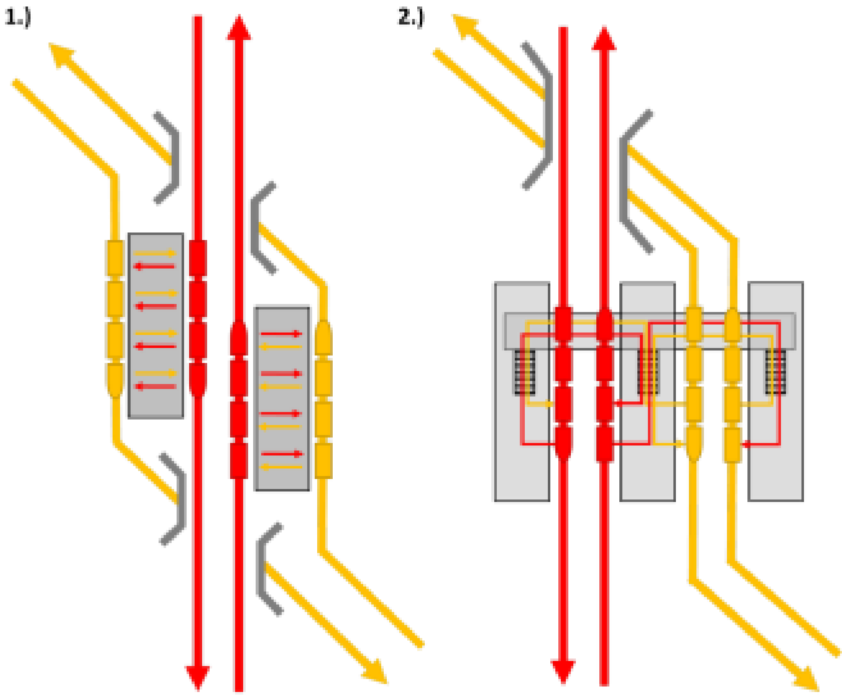

Figure 2: Two possible designs for the alignment of a two-line transfer, as 1.) cross-platform transfer and 2.) parallel indirect two-level transfer. Source: authors.

6.Reflection

The operators and users of public transport networks often have opposing interests when it comes to network and terminal design. For example, a cross-platform transfer has complex requirements for infrastructure and operations, while a parallel alignment, as seen in Figure 2, is much easier and cheaper. Good terminal design can reduce this contradiction by reducing transfer penalty (Allard & Moura, 2015). However, a general change in design mindset must occur. The perspective of the passenger and their perceptions of the transfer facility as end users must be taken into perspective (Duca et al., 2022). Therefore, research strives to understand these social psychological factors and implement design standards accordingly. To reduce the transfer penalty as much as possible the context of use of the hub must be understood and the tasks undertaken there acknowledged. Thus, the function of the hub as a node and as a place (Lois et al., 2018) must be considered, which contains not only its role as a transfer and transit facility, but also potential side roles, for example as shopping mall or exhibition centre. Exactly these competing interests have created many of the problems we perceive when looking at multimodal passenger terminals, not only between operators and customers but also between third party organisations, such as retail stores or restaurants. This implies that some of the stations valued as badly designed might not only have been the result of misled planning but a way to intentionally prolong walking and waiting to attract travellers as customers. Since every terminal is a point of access and egress, the factor of entrance and exit points has to be well considered, especially since some facilities important for the hub-function might be outside the actual station, for example, a bus stop or bicycle parking. Therefore, terminal design concerns not only the station building, but the whole functional transfer node which sometimes might even be multiple neighbouring stations. For this, street-level accessibility is fundamental keeping in mind the reduction of walking times, but also concerns like inclusivity, signing and information and the fusion with the built environment surrounding the terminal. To minimize transfer disutility, it must be intuitive for the passenger how to best get to the mode, line and direction they want.

The issue of transfer has been overlooked in public transit planning, and transportation planners and researchers have paid much more attention to the quality and quantity of the operation of public transit than on ensuring well-functioning transfers (Guo & Wilson, 2011; Iseki & Taylor, 2010). This seems logical, given the fact that operational factors of public transit most likely have larger effect on ridership than connectivity factors at transfer and that operators have much more control over their vehicles than stops and stations. Furthermore, multimodal terminals are crossing points of different modes that are often operated by different authorities, leading to situations where at the same time no one and everyone is responsible for the quality of the transfer environment. This becomes even more obvious when looking at the funding situation. Due to the unclarity of which mode a multimodal terminal belongs to, the monetary responsibility is equally vague, especially on intra-urban and regional level. Official promotion and intermodal budgets are often a very recent development, for example only since 2010 there is an EU fund pot to support the design of intermodal hubs (Allard & Moura, 2015). We believe that these types of institutional unclarities and the fuzziness of responsibilities are a major cause of many poor transfer solutions and facilities. Aesthetic and architectural values often override the functionality of transfer facilities in the design process (Guo & Wilson, 2011), which might lead to the neglecting of many of the functional and comfort-related aspects in design. However, the integration of responsibilities, planning and funding is incremental to create sustainable terminals.

What's more, as established earlier in the essay, the factors influencing transfer penalties are not only shaped by terminal design but also by the other components of the transit system, such as operation and network design. For instance, creating settings for cross-platform transfers requires a certain type of network with different lines meetings at certain stations and timetables with at least some degree of integration. If these conditions are not met, minimizing walking and waiting times with terminal design is very difficult, if not impossible. We argue that the elimination of any missing links in the network structure is indeed the key to creating possibilities for walking-distance transfers in the first place, meaning that high quality terminal design is much more difficult to create as an 'add-on' after the network has already been built. We conclude that creating efficient and positive transfer experiences starts from the design of the whole transit system and that terminal design should never be considered as a separate process from the design of the overall transit network. Consequently, we argue that this process requires a clearer institutional environment where the allocation of the responsibility of terminal design is unambiguous.

The typical analytical approach in evaluating transfers is the 'laundry list', consisting of positive and negative aspects of terminal design in relation to transfer penalties, which majorly fails to consider the relative importance of each aspect and other time and cost factors (Guo & Wilson, 2011). Additionally, Guo and Wilson (2011) argue that many aspects of transfer that passengers deem important are difficult to quantify and most likely have a small total effect on travel behaviour on individual level. Iseki and Taylor (2010) argue that most previous studies on this topic have been conducted from a design perspective and often result in rather obvious suggestions, such as providing adequate seating and lighting in waiting areas. However, the authors argue that research has clearly shown that passengers' evaluation of out-of-vehicle time is influenced by a wide range of factors that exceed factors related to the built environment and the design of stations. Although many of the findings of our essay are rather intuitive – increasing the comfort of transfer facilities and minimising transfer times and distances – and indeed compose a type of 'laundry list', we argue that this type of work is necessary for simplifying the basic principles of high-quality terminal design in a chaotic institutional environment, as established above. Conceptual and design-oriented work in transfer planning could lead to the creation of minimum standards that might find their way into the design of future transfer terminals. However, Iseki and Taylor (2010) summarise that we have only little knowledge about which aspects of transfer facilities are actually the most important and in which combinations when trying to ease the burden of transferring. This means that more research is necessary before we should try to formulate any sort of best practice guidelines.

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