The Effects of Out-of-Vehicle Time on Travel Behavior: Implications for Transit Transfers (Deliverable #1)

Under Contract 65A0194 for Project
Tool Development to Evaluate the Performance of
Intermodal Connectivity (EPIC) to Improve Public Transportation

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January 18, 2006

EXECUTIVE SUMMARY

This report constitutes an interim deliverable for the Project "Tool Development to Evaluate the Performance of Intermodal Connectivity (EPIC) to Improve Public Transportation" under Contract 65A0194 with Caltrans. Our primary objective in this project is to develop an evaluation tool that transit agencies can use to assess the quality of service at transit transfer facilities and use the findings of such evaluations to improve travel connectivity. Such improvements, can, in turn, help the overall transportation system operate more smoothly and can make transit a more attractive travel option and thus can eventually contribute to increases in ridership. This report focuses on a review of the literature in the area transit transfer facilities with particular emphasis on studies of the perceived burdens of transferring by passengers and their travel behavior as this is potentially a rich source of information to be used as input in the design of the evaluation tool.

Many factors affect travel choices, including time, labor, cost, security, convenience, and comfort of the entire trip. As such, privately-owned automobiles have many advantages over traditional fixed-route public transit in providing higher levels of accessibility, flexibility, convenience, comfort, and safety against crime. The relative burdens of public transit service vis-à-vis private automobiles help to explain why the majority of personal travel in metropolitan areas is in private vehicles, which poses a daunting challenge to transit managers. Given that travelers tend to consider out-of-vehicle travel time (walking, waiting, transferring, etc.) to be substantially more burdensome than in-vehicle travel time, attracting travelers to public transit in significant numbers requires transit agencies to focus increasingly on improving transit users' experience *outside* of their vehicles – walking, waiting, and transferring.

As cities have grown more dispersed and auto-oriented, the relative burdens of out-of-vehicle transit travel have increased. In an effort to accommodate increasingly dispersed patterns of trip-making, transit systems in many U.S. metropolitan areas have adapted "hub-and-spoke" route systems, which require transit users to frequently make transfers among lines and systems. In larger metropolitan areas with many transit operators, where the number of transferring passengers can be very high, transfer centers to facilitate passenger transfers are central parts of transit networks. Given the importance of out-of-vehicle times on travel choices, intermodal connectivity at such transfer facilities is a critical part of overall transportation network effectiveness. Transfer facilities that integrate various transportation modes in one location encourage people to use transit service by reducing the burdens of transfers.

What aspects of walking, waiting, and transferring do travelers find to be more burdensome, and what can transit managers do to cost-effectively increase the attractiveness of transit travel? This report examines this question by carefully reviewing the literature on the perceived burdens of transit travel.

We find that, despite its importance, efforts to increase connectivity at transfer facilities have proven less effective than expected for the following reasons: 1) not enough attention has been given to the effects of out-of vehicle travel on ridership; 2) it is difficult to comprehensively analyze transfer facilities using uniform criteria due to a large variation in size, modes served, location, and amenities of transfer facilities; and 3) there is a lack of a framework to theorize the effects of transfer facility improvements on people's travel behavior and transit ridership. In particular, the lack of causal clarity in the research on transit transfer facilities is an enormous drawback. Most previous studies of transit stops, stations, and transfer facilities have compiled laundry lists of positive and negative attributes, but have largely failed to consider the relative importance of each of these attributes, or whether they influence ridership differently alone or in

concert with other factors. As a result, we know little about which attributes are most important, under which circumstances, and in what combinations. Past studies on the subject have failed to lead transit agencies to implement planning practices that can effectively improve the quality of transfers at transit centers. Bridging this knowledge gap can lead to improvements of transfer facilities that will result in a ridership increase.

In this literature review, we identify the gaps in the current literature on factors influencing transit ridership, transfer penalties, and transfer facility improvements. We address the lack of a theoretical basis for understanding the relationship between transfer facility attributes and travel behavior and provide a brief review of determinants that affect transit ridership. This framework situates transfer penalties within the total cost of a transit trip. Finally, we examine the attributes of transfer facilities that influence transit transfers.

We situate the literature of travel behavior and valuation of time in the *transfer penalties* framework. Transfer penalties is a concept that represents *generalized cost*s—including monetary costs, time, labor, discomfort, inconvenience, etc.—involved in transferring from one vehicle to another between the same or different transportation modes, and is well-established theory in the travel behavior literature. When a traveler finds the total generalized cost of her/his trip by transit lowest among different means of transportation, she or he chooses to travel by transit. Value of time is another important concept in examining the relative importance of factors that influence people's travel behavior, particularly in mode choice. The *transfer penalties* framework provides the theoretical backbone for the importance of improvements pertinent to transit transfers.

According to previous studies on transfer facilities, we found that within a typical transit trip, a transfer accounts for approximately one quarter of total generalized costs (or time). The shorter the trip is, the more significant the impact of the transfer. Among several factors associated with a transit transfer, waiting time is generally the most important component to determine total generalized costs (and time) as long as safety and security are ensured. Time schedule and certainty of arrival time are two important factors to determine *actual* waiting time. In comparison to *actual* waiting time, *perceived* waiting time is very important in determining whether or not a traveler uses transit service. Perceived waiting time is affected by factors, such as safety, security, comfort, whether waiting is forced or not, and acquired knowledge about the arrival of the next vehicle.

In the examination of various attributes of transfer facilities that are thought to particularly influence transit transfers, we make a clear connection between improvements at transfer facilities and changes in people's travel behavior due to a reduction in transfer penalties. In other words, we distinguish two categories of improvements that are related to transit transfers: 1) those that affect *actual* time and costs of making a transfer, and 2) those that affect people's *perception* of transfer penalties. From this perspective, we identify the connection of transfer costs, time scheduling, and five evaluation criteria associated with transfer facility attributes that affect transfer penalties: 1) access, 2) connection and reliability, 3) information, 4) amenities, and 5) security and safety. The effectiveness of transit agencies' efforts to improve attributes of transfer facilities can be understood in terms of the effectiveness to improve travelers' experience at these facilities, reduce transfer penalties, influence travelers' behavior in mode choice, and eventually contribute to an increase in transit ridership.

We find that in order to improve the quality of transit transfers, transit agencies can work on the operational aspects that influence transfers (such as time schedule, on-time arrival, and transfer fare) and the physical aspects of transfer facilities (such as distance to make a transfer, lighting, seating, signage, streamlining, circulation lines, protections from weather, visibility). It is also an option for facility management to provide amenities at transfer facilities, such as commercial establishments including news stands, coffee shops, convenience stores, and dry cleaning stores. Physical aspects of transfer facilities can also affect walking time to travel between locations where people alight and board vehicles for transferring. Such aspects can also influence travelers' experiences at facilities, and therefore their perceptions of waiting time, walking time, and transfer penalties.

Because few studies have examined how the effects of physical improvements on transfer facilities affect travelers' choices to use transit service, it is important to investigate this issue in greater detail. At the same time, it is important to recognize that improvements of service operation are likely to have more significant impacts than physical improvements in facilities alone will have.

We conclude from this review that there are three ways to enhance the scope of study from our proposal: 1) as most transit transfers are intra-modal, these should be examined in addition to intermodal transfers, 2) operational and managerial attributes of transfer facilities should be examined in addition to the physical attributes of such facilities, and 3) steps need to be taken to begin to develop more systematic, quantitative tools for evaluating transit transfer facilities. Finally, it is important to examine the relative effectiveness of improvements on physical attributes of transfer facilities as well as service operation whenever possible.

Key words: transfer facilities, travel behavior, transfer penalties, generalized costs, value of time

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PREFACE

While private automobiles provide door-to-door travel, public transit requires people to walk to bus stops and rail stations, wait for services, and often make transfers from one vehicle or mode to another. Good interconnectivity in the transit system is essential to reduce the burden of walking, waiting, and transferring and to provide a high quality of service for transit trips. However, the transit system in California lacks interconnectivity between transportation modes and often fails to efficiently serve the public that travel by public transit. To improve interconnectivity in the transportation system, it is important to develop a methodology to evaluate the quality of transferring in order to improve transfer facilities. Such improvements at transfer facilities lead to a provision of seamless travel for transit users.

The research project, *Tool Development to Evaluate the Performance of Intermodal Connectivity (EPIC) to Improve Public Transportation*, will assist the California Department of Transportation (Caltrans), regional and local transportation related entities, transit operators, and other stakeholders in evaluating interconnectivity issues pertaining to travel and in identifying opportunities and solutions for improving transportation systems. This project contributes to Caltrans' goals of *Flexibility* and *Productivity* by assisting it in providing the appropriate tools to contribute to a transportation system ─ with both intermodal and intra-modal components ─ that maximizes safety, security, reliability, mobility, and access.

The larger scope of our research addresses the following three questions: First, what factors at transfer facilities are important from the transit users' perspective relative to determining their travel behavior? Second, what factors at transfer facilities are important from the operators' perspective relative to improving efficiency in transit service operation? Third, what factors at transfer facilities are important from the neighboring community perspective that allow the community to benefit from the presence of and services provided by such facilities?

In this literature review, we address the first question and investigate factors at transfer facilities from the users' perspective in relation to their travel behavior. This is the first step to develop a tool to evaluate the performance of connectivity to improve public transportation. We found it essential to: 1) understand where to improve the quality of transfers positioned within a group of factors that affect transit ridership, 2) establish a conceptual framework to relate improvements at transfer facilities to people's travel behavior, and 3) identify a systematic classification of transfer facility attributes in relation to the developed conceptual framework. By understanding these factors, we will be able to identify improvements at transfer facilities that will effectively lead to a transit ridership increase. While this literature review is theoretical in developing a conceptual framework to relate improvements at transfer facilities to travel behavior, we are producing a second literature review that examines the current practice of evaluating connectivity based on attributes of transit facilities from the traveler, operator, and community perspectives.

1. INTRODUCTION

When people choose to travel by foot, bike, bus, rail, or private automobile, they consider many factors, such as time, labor, cost, security, convenience, and comfort for the entire trip—from door to door. Needless to say, private automobiles have significant advantages in most aspects, which helps to explain why over 86 percent of all metropolitan person trips in 2001 were in private vehicles (Hu and Reuscher 2004). Private vehicles – cars, trucks, vans, and motorcycles – once owned, provide many benefits over public transit, including greater mobility, accessibility, flexibility, convenience, comfort, and safety against crime. This poses a daunting challenge to public transit agencies aiming to improve their transit service to compete with private vehicles. Given that travelers tend to consider out-of-vehicle time (walking, waiting, transferring, etc.) to be substantially more burdensome than in-vehicle time, attracting travelers away from private vehicles in significant numbers will require transit agencies to focus increasingly on improving transit users' experience outside of vehicles – walking to and from stops, waiting for vehicles, and transferring between vehicles.

The importance of intermodal connectivity has been recognized for a long time. The Committee on Intermodal Transfer Facilities of the Transportation Research Board in 1974 emphasized the importance of identifying factors to measure and be used to optimize total transportation network effectiveness:

> "*The intermodal transfer facility determines total transportation network effectiveness. As a connecting node, the facility integrates the various transportation modes to maximize the number of users. A poor connector would discourage potential users or cause them to be diverted to other modes. Poor transportation system operating practices sometimes introduce crowding and delay, which can be attributed wrongly to inadequacy of the transfer facility. There is a need to establish factors that optimize total transportation network effectiveness. More information is required on the effect of system operating practices on modal transfer efficiency and space use, and procedures should be developed to improve efficiency and reduce space requirements, passenger inconvenience, and delay* (Committee on Intermodal Transfer Facilities 1974)."

Attention to improving the connectivity of transit – between lines and systems – has been increasing for some time. The ongoing suburbanization of U.S. metropolitan areas puts traditional fixed-route transit service at a growing competitive disadvantage with private vehicles, and makes serving increasingly far-flung trip origins and destinations increasingly costly. In response, many cities, such as Boise (Idaho), Sacramento (California), and Seattle (Washington) (Pratt and Evans 2004), have adapted so-called "hub-and-spoke" route systems to serve growing service areas, increasing transfers in the process. A hub-and-spoke model derives its name from a bicycle wheel, which consists of a number of spokes jutting outward from a central hub. In the abstract sense, a location is selected to be a hub, and the paths that lead from points of origin and destination are considered spokes. This transit model requires that people be routed through a transfer station and make transfers among lines and systems before reaching their destination. In larger metropolitan areas with many transit operators, the number of transferring passengers can be very high. In such places, transfer centers are used to facilitate passenger transfers from one line to another, from one mode to another (car to/from bus, bus to/from rail, etc.), or from one system to another and are central parts of transit networks.

Despite long-time recognition of its importance, efforts to address connectivity at transfer facilities have proven less effective than expected. First, although connectivity at transfer facilities is very important, both practitioners and researchers generally pay more attention to quantity and quality of *transit vehicle services* (in-vehicle travel) for their more intuitively obvious effects on ridership. Second, because transfer facilities vary in size, modes served, location, and amenities, it is hard to comprehensively analyze transfer facilities using uniform criteria (ITE Technical Council Committee 5C-1A 1992). Third, most of the literature on transfer facilities lacks a theoretical framework for how improvements of transfer facilities affect people's travel behavior and, subsequently, the overall ridership of the transit system. This lack of causal clarity in the research on transit transfer facilities is an enormous drawback that this research seeks to overcome.

Most previous studies of transit stops, stations, and transfer facilities have compiled laundry lists of attributes that contribute to or detract from travelers' transfer experiences, but have largely failed to consider the relative importance of each of these attributes, or whether and how they influence ridership separately or in concert with other factors (Rabinowitz et al. 1989; Fruin 1985; Kittelson & Associates 2003; Vuchic and Kikuchi 1974; Evans 2004). As a result, we know little about which attributes are most important, under which circumstances, and in what combinations with other factors. In other words, we know very little about the effects of transfer facilities on transit ridership and network performance. This state of knowledge based on past studies on the subject is incomplete because it fails to guide transit agencies toward planning practices that effectively improve the quality of transfers at transit centers that actually result in a ridership increase.

This literature review addresses the lack of a theoretical basis for understanding the relationship between transfer-facility attributes and travel behavior. We do this by placing the literature in a *transfer penalties* framework. The concept of transfer penalties refers to *generalized costs* — including monetary costs, time, labor, discomfort, inconvenience, etc.— that is, those costs involved in transferring from one vehicle to another and, between the same or different transportation modes, and is well-established theory in travel behavior literature (Ortuzar and Willumsen 2004).

The implications of intermodal transit systems and the factors that affect transit ridership are discussed at three levels in this report. First, reviewing past studies on determinants of transit ridership, we find that policies and programs that transit agencies use to increase ridership have had only limited effectiveness. We have found that transit use is determined largely by factors outside the control of transit agencies, such as patterns of urbanization, regional economy, and demographic factors. Second, we introduce a framework that places transfer penalties within the context of total travel costs of a transit trip. The concept of travel costs is drawn from travel behavior modeling, and has been examined extensively in transportation economics, engineering, and planning literature. Value of time is another important concept in examining the relative importance of factors that influence people's travel behavior, particularly in mode choice. This section provides the theoretical backbone for the importance of improvements pertinent to transit transfers. Third, we examine factors thought to particularly influence transit transfers. In doing so, we make a clear connection between improvements at transfer facilities and changes in people's travel behavior through reduction in transfer penalties, so that we will have in turn a clear connection between transit agencies' efforts to reduce transfer penalties and increased ridership. From this perspective, we identify the relationship among transfer costs, time scheduling, and five evaluation criteria of transfer facilities which affect transfer penalties: 1) access, 2) connection and reliability, 3) information, 4) amenities, and 5) security and safety. The final section summarizes the gaps in the current literature by clearly defining the objective of this study, establishing a foundation for research on transit transfer facilities, and proposing an agenda for further research on transit transfers.[1]

2. FACTORS INFLUENCING TRANSIT RIDERSHIP

According to economic theory, transit ridership is determined by the level of service supplied in the system and travel demand in the service area. Transit systems operate in diverse urban

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[1] Our second deliverable — a continuation of the review of the literature — focuses on reviewing aspects of transfer facility evaluation and directly addresses the project's research questions and explains the next steps in our research that leads to the project deliverables.

environments where a variety of factors have been shown to influence service operation and travel demand. While aggregate travel demand is subject to people's socio-economic status, residential and work locations, and the state of the regional economy, transit agencies determine the level of service supply by taking into account their operating and financial conditions. Thus, actual consumption of transit services (i.e. transit ridership) can be considered a function of a set of factors that affect transit demand and a second set of factors that affect transit service supply.

Factors that affect transit ridership, according to criteria by Taylor and Haas (2002) and Transport and Travel Research Limited and European Commission (TTRL & EC) (1996), can be grouped into three categories. 1) *External factors*, such as physical geography and population demographics; 2) *Indirect measures,* which include policy factors external to public transit agencies — such as land use freeway plans; and 3) *Direct measures,* which include policy factors internal to public transit agencies—such as service frequencies and fare levels (See Table 1).

External factors directly affect transit travel demand and are not easily influenced by local governments or transit agencies.[2] *External factors* include factors such as population and employment growth, the regional economy, salary scales, residential and workplace locations, and migration of people.

Indirect policy measures can be influenced by regional governmental actors (TTRL & EC 1996). Local governments may be able to implement *indirect measures* to increase the relative attractiveness of public transit services and influence peoples' decisions about whether to take a trip and on which mode (TTRL & EC 1996). These measures include regulation, taxation, and pricing for automobile use, land use planning, measures to reduce travel demand, and enhancement of non-motorized modes. While *indirect policy measures* can strongly influence transit use, they are usually outside of the control or influence of transit systems from the perspective of transit agency managers (Taylor et al. 2002).

Direct measures are under the control of transit agencies, according to the framework of the study by Taylor et al. (2002). These measures enhance the advantages of public transit in absolute terms, and make public transit more attractive as a mode of transportation. These measures are related to the level of service provided, fare structure, service frequency and schedules, route design, and service information.

Although transit agencies have a variety of measures to take, their effectiveness is limited, compared to the impact of external factors. Direct policy instruments (or *direct measures*) have little influence on changes in people's choice over transportation modes for travel (TTRL & EC 1996; Taylor et al. 2002). TTRL & EC (1996) recommends that the most effective strategy is to "combine direct and indirect measures through a combination of physical, flow control and relative pricing measures." Despite their relatively low effectiveness, continuous efforts to incrementally improve service by transit agencies are important by helping to provide mobility and accessibility to transit dependents, reduce traffic congestion, improve air quality, and other issues related to automobile use.

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[2] Here we distinguish *travel demand* that arises to meet people's needs to travel to conduct other activities and *consumption of service* that reveals actual movement of people by driving and taking public transit. In other words, travel demand exists even though it may not be met due to the insufficient level of supply, as treated in general consumer theory.

TABLE 1 Direct and Indirect Factors Influencing Transit Ridership

INDIRECT MEASURES Improving the competitive position of public transport	CAR OWNERSHIP Taxation of car ownership Restrictions on car ownership Road pricing CAR USE (AREA SPECIFIC) Traffic calming Access restrictions Car vehicle specification CAR USE (GENERAL) Fuel tax Restrictions on car use OTHER Information on traffic conditions Land-use planning Tele-communications / tele-shopping Flexible working hours Increase in road capacity Improvements to non-motorized modes
DIRECT MEASURES How to improve the offer of public transport	PRICING Fare levels Ticketing regimes/fare structure Ticketing technology Subsidy regime Fleet size SERVICE PATTERN Extensiveness of routes Distance to/from stops Service frequency/travel time Operating hours SERVICE QUALITY Vehicle characteristics Bus/rail stop quality Interchange quality Quality/Number of staff PRIORITY MEASURES Link priority/right-of-way Junction priority Quality regulations REGULATORY REGIME Market regulation Operational regulations INFORMATION Information provisions Publicity/promotion OTHER Park-and-ride Integrated approach

Source: Taylor et al (2002) and TTRC & EC (1996)

2.1 Relative Effects of Factors Internal to Transit Agencies on People's Travel Behavior

Transit agencies can use *direct measures* to increase the relative attractiveness of transit service to encourage people to choose transit among various modal options. In this section, we review the effects of these measures that transit agencies can control, and carefully examine what aspects of a trip are influenced by these measures.

Many studies on the subject prior to 1990 examined the impacts of various measures on transit ridership or modal shift to transit service at an aggregated level. Subsequently, the focus shifted to a disaggregated analysis using discrete choice models, which can take into account various characteristics of individual travelers and trips. Since the impacts of various measures are likely to vary by socio-demographic characteristics of travelers (e.g. age, income, auto access) as well as by trip characteristics (e.g. trip purpose, travel time of day, trip length), it is necessary to examine the impacts of various direct measures on people's choice of travel mode by different market segments (Cervero 1990; TTRL & EC 1996). Past studies have reported that changes in service quality, such as frequency of service and schedule reliability, have more significant impacts on ridership than fare changes. However, few studies have examined how improving transit facilities affects ridership (Cervero 1990; TTRL & EC 1996; Paine et al. 1967; Wachs 1981).

Table 2 presents an array of approaches available to transit agencies to increase ridership, some of which are drawn from a list of *direct* measures in the TTRL & EC study (1996). In this table, italicized items are related to transferring. The concept of elasticity is often used to examine the effect of some measure on transit ridership. In this case, elasticity is defined as the ratio of a percent change in ridership to a percent change for that measure. For example, when transit ridership decreases by 10 percent with a fare increase of 20 percent, fare elasticity is -0.5 (=-0.1/0.2).[3] Since it is an algebraic calculation, it requires numerically quantifying a change in some measure. For this reason past studies have primarily focused on measurements that can be easily quantified, such as fare, service output, and headway, and less on other measures that can be only qualitatively evaluated.

Fare and subsidy

Of all measures, fare elasticity has been examined the most in past studies. Cervero (1990) reviewed studies up to 1988 with a focus of transit pricing and found that fare changes have relatively small effects compared to changes in service quality, such as average headway and speed. Most studies Cervero reviewed reported estimated fare elasticities between -0.1 and -0.5. Similarly, the review of TTRL & EC (1996) reports fare elasticities in the range of -0.2 to -0.5. In general, fare elasticities are approximately half of elasticities of changes in service quality. Gaudry (1974) has found similar conclusions in his regression study that compares relative effects of factors on transit ridership.

Studies on the effect of transit subsidies report a range of elasticities from +0.2 to +0.4 based on a review of 11 international cases (Bly, Webster, and Pounds 1980; TTRL & EC 1996). However, the mechanism of the effect of transit subsidies on ridership is complex. While transit

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[3] When elasticity is between negative infinity and negative one, demand is elastic, which means the percentage change in quantity is greater than that in price. When elasticity is between negative one and zero, demand is inelastic, which means the percentage change in quantity is smaller than that in price. The negative sign indicates that an increase in price leads to a decrease in demand, and vise versa.

subsidies certainly help to keep fares lower and increase service supply more than without subsidies, it is not clear which of these two factors is a main cause for an increase in ridership increase. Since part of the subsidies is often used to increase labor compensation, subsidies do not increase service output in the same proportion (Lave 1985), which, in turn, reduces the effects of subsidies on ridership.

A fare structure is likely to significantly influence ridership especially when it varies by time of day and trip distance, since it influences people's mode choice of travel differently for different socio-demographic groups and for different trip purposes. However, there has not been much study done in this field. Smartcard technology is also related to fare structure, but is still very new with little, if any, evidence of its impacts on ridership (TTRL & EC 1996).

TABLE 2 Measures Available to Transit Agencies[4]

Group	Factor	Elasticity
Fare and subsidy	fare level	-0.5~-0.1(half of that of service quality)
	subsidy regime	+0.2~0.4 (its effect is not clear)
	ticketing regime/fare structures,	-
	ticketing technology (smart card)	-
Service supply:	(vehicle-km of bus service)	+0.2~0.7
	route, stops	-
	station distance	-0.57~-0.49
	operating hours	-
Service quality	twice as much effects on ridership as fare changes)	
	service frequency/scheduled journey time	-
	waiting time	-0.54
	Reliability	-
	vehicle speed (in-vehicle travel time)	-1.16~-0.59
	vehicle speed (in-transit time)	-0.54
	link priority/segregated right of way	-
	junction priority	-
	vehicle characteristics	-
	fleet size	-
Transit facilities	bus/rail stop quality	-
	station facilities	-
	bus stop quality, station facilities	-
	terminal/interchange quality	-
	park and ride	-
	information provision	-
Others	safety/security	-
	publicity/promotion	-
	market regulation	-
	number and quality of staff	-
	operational regulations/quality regulations	-

Service supply: route, stops, and operating hours

Since ridership is determined by service supply and travel demand, the level of service supply certainly influences ridership. Elasticities of ridership to service supply measured by vehicle-kilometers of bus services are in the range of +0.2 and +0.7 (TTRL & EC 1996).

[4] Vehicle speed is the only factor in this table that is estimated by a discrete choice model study. Other factors are estimated by aggregate models or not specified at all in the literature.

Routing and the degree of route extension influence a transit system's coverage area, and therefore potentially influence ridership. The effect of these factors on ridership significantly varies by area. Some scholars critique the expansion of transit service into suburban areas as having the effects of lowering productivity, efficiency, and therefore effectiveness of transit service (Lave 1985; Garrett and Taylor 1999).

In contrast, the number or density of stops shows a relatively large impact on ridership, because it affects access distance and walking time for transit users. Transit service demand with respect to walk time is very sensitive (Cervero 1990). TTRL & EC (1996) cites a study by Gordon and Wilson (1985) to report that demand for light and heavy rail have elasticities of -0.568 and -0.485 respectively with respect to walking distance. Station distance also determines distance that rail users may have to walk to access and therefore affects walking time, which is perceived to be very onerous by travelers.

While some users may have a preference for longer operating hours, there has been no careful study to separate the effects of longer operating hours from the effects of an increased total service supply due to longer operating hours. In other words, is it the earlier and later hours that attract riders, or simply the greater number of vehicle runs?

Service quality: service frequency/scheduled journey time, vehicle speed, link priority/segregated right of way, junction priority, vehicle characteristics, fleet size

From TTRL & EC (1996), service frequency "refers to average frequency, length of operating day/week, and reliability." The most important objectives of scheduling and frequency adjustment in service quality are to reduce overall travel time and improve convenience for passengers (Evans 2004).[5] Scheduling changes can be made to improve the reliability of service that results in both actual and perceived waiting time for passengers and less anxiety (Evans 2004). While frequency of service, headway, and reliability influence opportunities for waiting time at stops/stations, vehicle speed is a main factor to determine travel time (or in-vehicle time). In general, changes in service quality, such as average headways and speeds, have twice as much effect on ridership as fare changes (Cervero 1990).

It is very difficult to reliably measure service elasticities in response to multiple service changes that often occur simultaneously – such as schedule changes that accompany a fare increase. Further, most transit ridership data are in terms of unlinked trips, while travelers make linked trips (*walk – wait – ride – walk*, or *walk – wait – ride – walk – wait – ride – walk* in the case of a trip with a transfer), where the out-of-vehicle aspects of the links have the largest influence of perceived travel burdens. Such methodological challenges notwithstanding, Evans (2004) reports an elasticity of 0.5 in response to service frequency changes. When changes in service hours and frequency were accompanied by aggressive marketing, such as direct mail campaigns, free ride coupons, and image building by new bus paint designs in Santa Clarita and Santa Monica, California, each transit system experienced significant ridership increases with elasticities of +1.14 and +0.82 respectively (Evans 2004; Mass Transportation Commission 1964).

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[5] In the TCRP report 95, Evans (2004) list the following types of scheduling and frequency changes for discussion: 1) frequency changes, 2) service hours changes, 3) frequency changes with fare changes, 4) combined service frequencies, 5) regularized schedules, and 6) reliability changes. Combined service frequencies is the approach to offer a combination of different transit services on the same corridors to accommodate diverse trips taken by different groups of transit users.

In general, higher values of elasticity are achievable when frequency changes are made to transit lines with previous service schedules with 60 minute or 30 minute headways and when riders are mainly in middle and upper income groups (Evans 2004). On the other hand, elasticity tends to be relatively low when previous service already has short headways and the majority of patrons are from lower income groups (Evans 2004). In addition, different groups of transit users have different responses to frequency changes. Off-peak riders are often more sensitive to frequency changes than peak period riders (Evans 2004). Since transit dependents are likely to use transit service even though service quality may not be satisfactory, an increase in ridership due to frequency changes is often attributed to an increase in new discretionary (choice) riders who are likely to be in middle and upper income groups (Holland 1974).

Scheduled journey time and vehicle speeds affect in-vehicle travel time. Cervero (1990) reports in-vehicle travel time elasticities in the range of -0.59 and -1.16 from two mode choice studies (McGillivrary 1969; Domencich, Kraft, and Valette 1968), in which the high end represents an elasticity in the peak period. Gaudry (1974) reports elasticity of 0.27 for in-transit time, compared to fare elasticity of -0.15.

Service frequency and reliability determine travelers' waiting time at transit facilities. Transit riders are found to be very sensitive to out-of-vehicle time, and among various types of out-of-vehicle time, waiting time is the most onerous factor to transit users (Cervero 1990). Gaudry (1974) reports elasticity of -0.54 for waiting time.

Reliability is one of the most important factors to attract transit ridership. Commuters in attitudinal studies conducted in Baltimore and Philadelphia considered "arrival at intended time" as the second most important for work trips, following "arrival without accident (Evans 2004)." Similar results were shown in a survey in Boston and Chicago; "arrival at intended time" is more important than travel time, waiting time, and cost measures (Evans 2004). Improvement in reliability and speed in urban bus services in Britain in the 1970s significantly increased ridership (TTRL & EC 1996). In the study conducted by Horowitz and Thompson (Horowitz and Thompson 1995), time-scheduling and reliability are the second most important attribute at transfer facilities following safety and security. Douglas (1991) found in a study in New Zealand that the value of *expected* delay was 8 times as much as that of walk time for rail users (TTRL & EC 1996). Waiting time with uncertainty of arrival of the next vehicle increases the value of waiting time by a factor of two (Webster 1977).

Link priority, segregated right of way, and junction priority generally influence ridership through their impacts on variability of travel time and in-vehicle travel time. The effect of bus lanes has been found to be less than expected in the studies reviewed by (TTRL & EC 1996). While one study reports that the reduction of travel time by increased speed of a light rail line using junction priority from 33 minutes to 22 minutes increased ridership by 10 percent, the measure of junction priority is not developed enough and it is still difficult to evaluate its effect (TTRL & EC 1996).

It is also difficult to quantify vehicle characteristics, and there is no hard evidence to support particular vehicle characteristics, although people generally prefer comfortable rides by rail vehicles to those by buses.

Transit facilities: Bus/rail stop quality, station facilities, terminal/interchange quality, park and ride, information provision

The quality of transit facilities can have significant impacts on attracting ridership to transit systems in several different ways. Since one of the main functions of transit facilities is to accommodate users' waiting time, factors such as comfort, security, safety, and convenience, influence people's experience in taking public transit service, and therefore increase their likelihood of choosing transit service over other modes. However, past studies provide little evidence that clearly indicates a *direct* connection between qualities of transit facilities and ridership. As we discuss in later sections of this report, qualities of transit facilities can *indirectly* affect transit demand and ridership by improving travelers' experience at facilities.[6]

Some studies examined the values transit users placed on components of terminals (e.g. including waiting facilities, lifts/escalators, catering facilities, and information displays), terminal/interchange quality, and park-and-ride facilities. Survey respondents in the study by Douglas (1991) value improvements on stations as much as those on trains (TTRL & EC 1996).[7] However, the effects on transit demand are unknown (TTRL & EC 1996).[8] The only study that took into account a component of transit facilities in a discrete choice model is the study by Guo and Wilson (2004), which showed that the presence of escalators to assist level changes for transferring at subway stations could reduce transfer penalties.

At the same time, it is not difficult to think that a small change in transit facilities will not dramatically change people's travel behavior. A study in Lima, Peru, showed that bicycle storage and easier access for the handicapped by replacing stairways did not have a statistically significant impact on people's choice of travel mode in the stated preference survey, while increase in feeder service to rails and in bus rapid transit service to downtown were found important (Martinez 2003).

Travel time interconnectivity at transfer facilities is very important. This is determined mainly by vehicle scheduling: "Specific benefits from adjusting frequencies so that services interconnect efficiently. Values of waiting time on transferring (or interchange) and delays are high (TTRL & EC 1996)." Several studies in recent years developed models to minimize the uneasiness, inconvenience, and other costs associated with transit transfers.[9] These studies used a modeling approach to optimize time-related functions such as time tables and vehicle dispatching to reduce waiting time (Shayer 2004).

In the survey study by Douglas (1991), respondents placed a value of seven New Zealand cents on at-stop (rail) information in addition to having leaflets, and also placed a similar value on a telephone inquiry system, and real-time information (TTRL & EC 1996). However, no

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6 One of the main problems in past studies that evaluated the qualities of transit facilities is a lack of a conceptual framework that explains how facility improvements can affect transit demand and ridership and how cost effective those improvements are. For example, although almost all transit users would like to have shelters and benches at bus stops, the presence of shelters and benches does not necessarily increase ridership, as the presence of refrigerators and laundry machines at bus stops, for an extreme example, does not necessarily increase ridership. This lack of causal clarity in the research on transit transfer facilities is an enormous drawback when transit agencies implement transit facility improvements in order to increase the overall ridership in the transit system.

7 Network Southeast have values for station appearance, station facilities (including catering) and information, although there is some debate about the plausibility of some of these values (See Cuthbertson et al., 1993).

8 London Underground and British Rail have determined the values passengers place on terminals (Case study 2.5). A look-up table of interchange (or transfer) penalties has been developed based on distance and connection time, to take into account that certain interchanges are more onerous than others. Evidence from Thameslink suggests that this method may have underestimated the penalty of cross London interchanges, which has implications for other rail schemes.

9 These studies include Bookhinder and Desilets (1992), Chowdhury and Chien (2001), Chowdhury (2001), and Boile (2002).

study has been found that provides evidence of a significant effect of route-specific service information on an increase in ridership.

There are other measures listed by TTRL & EC (1996). These include publicity/promotion, market regulation, number and quality of staff, and operational regulations/quality regulations. These measures, however, lack hard evidence of their effects on transit demand.

Safety and Security

While it may not necessarily attract new ridership, improving the built environment to reduce overall crime may have a significant impact on regaining transit users' confidence. Transit security is a serious concern in most metropolitan areas of the United States. Studies that examined the relationship between transit facilities and crime show certain built environment attributes contribute to higher and lower crime rates. Crime rates were higher for bus stops near alleys, multi-family housing, liquor stores and check-cashing establishments, vacant buildings, and graffiti and litter (Loukaitou-Sideris et al. 2001; Liggett, Loukaitou-Sideris, and Iseki 2001). In contrast, good visibility of the bus stop from its surroundings, large numbers of pedestrians, and the existence of bus shelters contributed to lower crime rates (Loukaitou-Sideris et al. 2001; Liggett, Loukaitou-Sideris, and Iseki 2001).

While the studies found that the most important predictor of crime is the location of bus stops, appropriate design and layout of the physical characteristics around transit facilities at the micro level can affect opportunities for and likelihood of criminal activity (Liggett, Loukaitou-Sideris, and Iseki 2001). In the case of the light rail system that runs through the median of the Century Freeway (I-105) in Los Angeles, the study found a high crime rate at park-and-ride facilities adjacent to stations. While these parking lots are partially fenced and adequately lit, a lack of pedestrian activity reduces the level of ambient surveillance and may facilitate criminal activities (Loukaitou-Sideris, Liggett, and Iseki 2002). Platforms of five stations with high crime rates are located in the middle of the freeway median and isolated from surrounding neighborhoods (Loukaitou-Sideris, Liggett, and Iseki 2002). These stations are likely to suffer from little visibility and natural surveillance as well as several hiding places (under stairs and behind pillars), and result in higher crime rates. There is certainly correlation between the built environment at and around transit facilities and the incidence of crime. The sense of security is so important in people's choice of travel mode, time of travel, and route that it may completely deter taking transit. Therefore, transit agencies should maintain a certain minimum level of security, taking measures of policing and improving the built environment.

Overall, measures available to transit agencies have only limited effects to increase ridership in comparison to the effects of external factors and indirect measures in policy options that are outside the control of transit agencies. Past studies provide more information on the effects of factors that are easily quantified, such as fare, service output, and headway, on ridership, and have resulted in an understudy of other measures that can be only qualitatively evaluated. There is no clear theoretical framework to relate qualities of transit facilities to transit demand, ridership, and travel mode choice. The majority of past studies that examined the effects of various factors used aggregated analyses that are not capable of examining the effects of qualities of *individual* transit facilities. Although disaggregated analyses using discrete choice models are capable of such examinations, only few studies actually took into account qualities and components of transit facilities. All of these contribute to a lack of evidence to evaluate the effects of qualities of transit facilities on transit ridership.

In addition, it is also important to take into account cost effectiveness as well as political feasibility of adopting various policies and programs, including improvements of transit facilities, so that policy makers and planners can choose the best strategies to increase transit ridership.

3. THE FRAMEWORK OF TRANSFER PENALTIES WITHIN TOTAL TRAVEL COSTS OF TRANSIT TRIPS

> "*Understanding what affects the transfer penalty can have significant implications for a transit authority. It can help identify which types of improvement to the system can most cost-effectively reduce this penalty, thus attracting new customers, and helping determine the value of improvements to key transfer facilities* (Guo and Wilson 2004)."

The concept of *transfer penalty* represents *generalized costs* — including monetary costs, time, labor, discomfort, inconvenience, etc. — involved in transferring from one vehicle to another between the same or different transportation modes, and is well-established theory in the travel behavior literature (Ortuzar and Willumsen 2004). The concept of travel costs is drawn from travel behavior modeling, and has been examined extensively in transportation economics, engineering, and planning literature. In the transportation literature, the term "transfer penalties" is used in two different definitions. In a broader definition, transfer penalties is a general term to represent all of the monetary costs, time, labor, inconvenience, and emotional distress pertinent to making a transfer, and generally work as an impedance factor for travel. In this broader definition, transfer penalties consist of factors, such as transfer fare, walking time and labor, waiting time and labor, comfort, safety, and convenience (Liu, Pendyala, and Polzin 1997).[10] In contrast, in a narrower definition, transfer penalties are an impedance factor in transferring after excluding factors that we can easily quantify, such as waiting time, walking time, and transfer fare. In other words, transfer penalties in the more narrow definition are the penalties beyond the monetary and time costs associated with making transfers (Liu, Pendyala, and Polzin 1997).

3.1 Example of Transfer Penalties in a Typical Transit Trip

In the following example, we will use a description from Currie's article (Currie 2005). A typical one-way transit trip consists of the following attributes (minutes in parentheses are numbers that we chose for this example):[11]

1) access by walking from a trip origin to a bus stop (8 minutes),
2) wait at a bus stop (4 minutes),
3) travel in vehicle from a bus stop to a rail station (20 minutes),
4) transfer from a bus stop to a rail station, involving walking (6 minutes), waiting (10 minutes), and other transfer penalties,

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[10] Other attributes of transfers are: seamlessness, flexibility, safety, security, comfort, convenience of both transferring and taking care of errands (e.g. buying a cup of coffee, magazine, and newspaper), ease of payment, ease of vehicle access/egress, in-vehicle time, seat availability, staff friendliness/helpfulness, familiarity of service, ease of comprehension, ease of finding out information, and image of public transport.

[11] Liu, Pendyala, and Polzin (1997) also states that "a typical transit user in New York-New Jersey area in their study would walk to a transit station, board a bus or the subway system, make one or more transfers, and finally walk to the destination."

5) travel in vehicle from a rail station to another (30 minutes), and
6) egress from a rail station to a trip destination (6 minutes).

Assuming we can convert all of time, fare, and qualities of travel into generalized cost, a formula to compute the total generalized cost (TGC) for this trip looks like:

$$TGC = \{(Walk_t * Walk_w) + (Wait_t * Wait_w) + (IVT_t * IVT_w) + (NT * TP_b) + MSC_m\} * VOT + Fare \quad \text{----- Eq. (1)}$$

Where:

$Walk_t$: time in minutes walking to and from the transit service

$Walk_w$: passenger valuation of walk time to and from transit stops

$Wait_t$: time waiting for transit vehicle to arrive at the transit stop

$Wait_w$: passenger valuation of wait time at transit stops

IVT_t: travel time in transit vehicles

IVT_w: passenger valuation of in-vehicle travel time

NT: number of transfers

TP_b: transfer penalty, including transfer walking and waiting in a broader sense[12]

MSC_m: mode specific constant for transit mode m

VOT: value of travel time

$Fare$: average fare per trip

Following the definition of transfer penalties in both the broad and narrow senses, we can further decompose TP_b:

$$TP_b = (Walk_{tt} * Walk_w) + (Wait_{tt} * Wait_w) + TP_n \quad \text{----- Eq.(2)}$$

Where:

$Walk_{tt}$: time in minutes walking to make a transfer

$Wait_{tt}$: time waiting for transit vehicle to make a transfer

TP_n: transfer penalty, including transfer walking and waiting in a narrow sense

In Eq. (2), weights represent different valuations of time for different attributes. Weights, in this context, can be interpreted as the differences between *actual* travel time and the time *perceived* by a traveler. In a mode choice, travelers make their travel decisions based on the total generalized cost of the trip in their calculation, which partly depends on their perception of transfer attributes, such as time and other burdens associated with different segments in transit trips.

Table 3 shows time and costs associated with components of a typical transit trip. Walking in Eq. (1) is further divided into different segments of a trip: 1) ingress, 2) transfer, and 3) egress.

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[12] TP_n and TP_b are equivalent to *Interchange I* and *Interchange II* respectively in Wardman's study (2001), which will be reviewed in a later section.

This example includes two kinds of waiting time: 1) waiting at a bus stop for the initial segment of trip and 2) waiting for making a transfer. It also has two types of in-vehicle time and two types of fare for bus and train. This example does not include *mode specific constant* in Eq. (1).

We assume the monetary value of in-vehicle time is $7.50 per hour—half of an assumed wage rate of $15 per hour. We use average valuation of walking time, waiting time, and other transfer penalties according to a study by Wardman (2001). Monetary value of walking time, waiting time, and other transfer penalties are computed to be $12.45 per hour, $11.03 per hour, and $1.32 per transfer respectively based on our assumptions. We have intentionally made costs associated with other transfer penalties comparable to other costs in this example—and $1.32 for "Other transfer penalties" in Table 3.

In this example, transfer penalties, including transfer walking and waiting time, account for 26 percent of the total generalized cost of the trip. In the fourth column which assumes that people can make a transfer without waiting, the total travel cost decreases by 11 percent. In the fifth column, which assumes no waiting time for transferring, the total travel cost decreases by 7 percent. In the sixth column which assumes no waiting and walking time (for example, a timed-transfer across a platform), the total travel costs significantly decreases by 18 percent. The proportion of costs associated with transfer penalties in total costs can be reduced from 26 percent to 9 percent in the case that transit users have to spend for neither waiting nor walking. Thus, the significant portion of the total generalized cost of a trip can be attributed to transfer penalties, and can be reduced by providing timed-transfers which do not require transit users to wait or walk long distance to transfer. We will extensively review these transfer penalties in a later section.

TABLE 3 Typical Transit Trip and Its Associated Time and Costs

		Typical	**No transfer waiting**	**No transfer walking**	**No transfer walking & waitin**
	Time (min.)	Cost	Cost	Cost	Cost
Access by walk from trip origin to bus stop	8	$1.66	$1.66	$1.66	$1.66
Wait at a bus stop	4	$0.74	$0.74	$0.74	$0.74
Bus fare ($1.35)	-	$1.35	$1.35	$1.35	$1.35
Travel in vehicle from a bus stop to a rail station	20	$2.50	$2.50	$2.50	$2.50
Transfer Penalities					
Transfer from a bus stop to a rail station: walking	***6***	**$1.25**	**$1.25**	**$0.00**	**$0.00**
waiting	***10***	**$1.84**	**$0.00**	**$1.84**	**$0.00**
Other transfer penalties*	-	**$1.32**	**$1.32**	**$1.32**	**$1.32**
Travel in vehicle from rail station to another	30	$3.75	$3.75	$3.75	$3.75
Train fare ($1.35)	-	$1.35	$1.35	$1.35	$1.35
Egress from a rail station to a trip destination	6	$1.25	$1.25	$1.25	$1.25
Total	84	$16.99	$15.16	$15.75	$13.91
Reduction in total costs		**-**	**11%**	**7%**	**18%**
% of transfer penalties in TOC		**26%**	**17%**	**20%**	**9%**

	Weight	Hour	Minute
Wage	2.00	$15	$0.25
In-vehicle travel	1.00	$7.50	$0.13
Walking**	***1.66***	$12.45	$0.21
Waiting**	***1.47***	$11.03	$0.18
Other transfer penalties**	***17.61***	$132.08	-

*: Other transfer penalties is further weighted by 0.01 to make its cost comparable to other costs.

**: The ratio relative to in-vehicle time is taken from Wardman (2001).

In the above example, we assumed that weights (or valuation of time) for different attributes are constant. However, weights for different attributes vary by differences between *perceived* time and *actual* time.

People perceive time differently under different circumstances. A traveler's *perceived* waiting time can be much more onerous than his *actual* waiting time (Moreau 1992; Hess, Brown, and Shoup 2005). Waiting time is perceived especially burdensome when travelers have to wait in difficult environments, such as in cold, hot, or rainy weather, or in a seemingly unsafe or insecure condition. Safety and security are particularly important, since it can increase *perceived* costs related to waiting infinitely; if travelers feel a waiting location is so insecure that he or she may get mugged, most of them do not take a risk to take public transit (ITE Technical Council Committee 5C-1A 1992).

There are other examples of factors that differentiate *perceived* time/costs from *actual* time/costs, such as whether or not waiting is productive, whether or not a wait is forced, and whether or not a traveler knows an arrival time of the next bus.[13] Thus, although *actual* waiting time is determined by the difference in arrival time of a user and a vehicle at a boarding location, *perceived* waiting time can be substantially longer depending on waiting conditions, and therefore the generalized cost of waiting time can also become higher.

Perceived walking distance and time also can be longer than *actual* walking distance and time. Physical conditions as well as other attributes at transfer facilities, such as availability of adequate information, are very important in two ways: 1) in determining *actual* walking distance for transferring and 2) in affecting *perceived* walking distance and time.

At first glance, we may think walking distance is determined simply by distance between two points where a traveler alights one vehicle and boards another for his/her transfer, and walking time is determined by this distance and a traveler's walking speed. But it is again not always this simple. When a traveler is familiar with a transfer facility and direction to a point where he/she rides on the next bus or train, it does not require him/her much time and energy to transfer. However, when a traveler does not have good sense of a facility without sufficient information, walking distance can be much longer since he needs to perform additional activities including where to go to board his next bus or train, where to exchange a bill into coins, and where to buy a ticket. While this traveler looks for these places and information, he/she needs significantly longer time to walk the longer *actual* distance. Furthermore, the burden and frustration that arise in looking for a place to board, ticket vending machine, etc. makes this traveler's *perceived* walking distance and time longer than *actual*. A layout of transfer facilities that is not intuitive and not easy to figure out can significantly make a traveler's experience of transferring unpleasant, and this raises the generalized cost associated with transferring.

Thus, conditions at facilities wherein travelers make a transfer can influence their *perceived* experience of transferring as well as *actual* walking distance/time and waiting time, and then affect their likelihood of taking the same transit trip in the future. If a transfer point is off-street, then the characteristics of the surrounding environment would also be relevant to the perceived walking time; for example, if the street provides a pleasant setting for walking, then perceived walking time might be less than if the transfer point were on a busy street.

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[13] We will review the difference between *actual* time and *perceived* time more extensively in a later section. It should be noted that some of these factors may also be taken into account by transfer penalties beyond waiting time, walking time, and transit fare.

3.2 Valuation of Time Associated with Components of a Transit Trip

In the above example that examined the proportion of transfer penalties in the total generalized cost of a trip, we explained how *actual* time/cost and *perceived* time/cost could be very different. The difference in *actual* time and *perceived* time is also viewed as different valuations of time in different activities, and has been extensively examined in the transportation literature. Since value of time is used to convert *actual* time into a monetary value of generalized costs, it is a significant factor in people's mode choice. This section reviews what we know about value of time with a particular attention to waiting time, walking time, and other transfer penalties.

Table 4 summarizes valuations of waiting time, walking time, transferring time, and transfer penalties relative to in-vehicle time.

TABLE 4 Overall time valuations (relative to in-vehicle time = 1.0)

Study	Location/ Type	Factor	Mean	S.D.	Obs
Parsons Brinckerhoff Quade and Douglas Inc. (1998)	Houston	Wait time	2.58	-	-
Barton-Ashman Associates (1993)	Cleveland	Wait time	2.13	-	-
Parsons Brinckerhoff Quade and Douglas Inc. (1993)	Minneapolis-St. Paul	Wait time (first 7.5 minutes)	4.00-4.36	-	-
		Wait time (over 7.5 minutes)	0.88-10.78		
		Transfer wait time	1.58-4.36		
		Transfer penalty (extra)	17.27-121.05		
Parsons Brinckerhoff Quade and Douglas Inc. (1999)	Chicago	Wait time	3.41	-	-
Kim (1998)	Portland	Various out-of-vehicle time, work trips	1.25-2.46	-	-
		Out-of-vehicle time, non-work trips	2.67	-	-
US Environmental Protect Agency (2000)	Review of 50 US studies	Walk time	2.0-2.72	-	-
Wardman (2001)	Review of British studies from 1980 to 1996	Walk time	1.66	0.71	140
		Wait time	1.47	0.52	34
		Walk and wait time	1.46	0.79	64
		Headway	0.80	0.46	145
		Interchange 1	17.61	10.93	8
		Interchange II	34.59	25.88	16
		Interchange III	33.08	22.73	23

Transit riders are very sensitive to out-of-vehicle time. Among various types of out-of-vehicle time, waiting time is the most onerous factor for transit users (Cervero 1990). In practice, the rule of thumb is that walking and waiting time are valued twice as much as in-vehicle time for non-business trips. This rule of thumb (or slightly higher values of walking and waiting time) is supported by several studies reviewed by Wardman (2001), while the relative value of walking, waiting, and in-vehicle time varies by conditions (MVA Consultancy 1987; Bruzelius 1979; Transport and Road Research Laboratory 1980). A few studies report a higher value of waiting time than that of walking time (Transport and Road Research Laboratory 1980; Steer Davies Gleave 1997). Several studies, including those reviewed by Bly, Webster, and Pounds (1980), show two or three times as much disutility of walk time as that of in-vehicle time. Recent modeling studies show that the value of walk time, compared to in-vehicle time, ranges between 2.0 and 4.5 — 2.58 in the case in Houston (Parsons Brinckerhoff Quade and Douglas Inc. 1998), 2.13 in Cleveland (Barton-Ashman Associates 1993), 4.0 to 4.36 in Minneapolis-St. Paul (Parsons Brinckerhoff Quade and Douglas Inc. 1993), and 3.41 in Chicago (bus and rapid transit) (Parsons Brinckerhoff Quade and Douglas Inc. 1999). In Minneapolis-St. Paul, the value of wait time over 7.5 minutes varies significantly by types of trip, such as home-to-work, home-to-other, non-home based-work related and non-home based-non-work related.

In contrast, the average values of walking time, waiting time, combined walking and waiting time are found less than two — 1.66, 1.47, and 1.46 respectively—in Wardman's review and meta-analysis of British studies from 1980 to 1996 on values of travel time and service quality (TABLE 4) (Wardman 2001). In the U.S. cases, Kim (1998) reports 1.25 to 2.46 for various types of out-of-vehicle time for work trips, and 2.67 for non-work trips in the case of Portland. In its review of travel demand modeling studies in the U.S., the U.S. Environmental Protection Agency (2000) also reports 2.12, ranging from an average of 2.72 for urban areas under 750,000 population to roughly 2.0 for large cities, and from average of 2.48 for 1990s models to about 2.0 for older models.

3.3 Weighting of Time Associated with Elements of a Transit Trip

The value of walking and waiting time is higher under certain circumstances. When a person is taking a trip on business, values of travel time are expected to be higher; the average values of walking and waiting times relative to in-vehicle time in 13 studies was found to be 1.80 (Wardman 2001). Wardman (1998) explains that a high value of time on business may reflect employers' willingness to pay for taxis to save time. Waiting in congested conditions, unacceptable waiting, and walking up stairs can have higher values (London Transport 1996).

In addition, waiting time with uncertainty of arrival of the next vehicle increases the value of waiting time by a factor of two (Webster 1977). Reliability is one of the most important characteristics of transit service known to both academia and practitioners in the transportation field, but is not achieved at a satisfying level in most transit systems — especially for U.S. bus systems. Transit users perceive less amount of waiting time when they feel less anxious, given the information on expected waiting time (Evans 2004). A study in New Zealand found that the value of *expected* delay was 8 times as much as that of walk time for rail users (TTRL & EC 1996). The literature review by Reed {, 1995 #1} reports that travelers perceive waiting time 1.5 to 12 times as long as in-vehicle time. In addition, the study conducted in Minneapolis-St. Paul found that commuters, who know the schedule and adjust their arrival time at the bus stop, did not view waiting time over the initial 7.5 minutes onerous at all, while people who make other trips less repetitively and more discretionary particularly consider longer waits very onerous (Parsons Brinckerhoff Quade and Douglas Inc. 1993).

As previously mentioned, the perception of length of waiting time varies significantly depending on the circumstances in which people wait. People are likely to overestimate waiting time when people experience time drag in a tiresome situation (Moreau 1992). Time drag is a condition that makes people feel that time is passing more slowly than it actually does. People tend to overestimate unfilled time and underestimate time filled by a compelling job (Moreau 1992). In the case of transit, time drag may arise when passengers think time spent for waiting is unproductive and/or burdensome — when people are not engaged in any activities, are anxious about something, such as being late for work, are not informed about delays of arrival or departure, feel poorly served, and travel alone (Hess, Brown, and Shoup 2005; Moreau 1992; Reed 1995).

The value of waiting time also varies by whether people are forced to wait or choose to wait. Hess, Brown, and Shoup (2005) examined value of waiting time in a natural experimental condition. In this situation, traveling students can choose either to pay the 75-cent fare and take a "Green" bus that arrives first at a bus stop or wait for the next "Blue" bus and take a free ride on the University Fare program. Hess, Brown, and Shoup (2005) found that waiting time estimated by people who decided to wait for the "Blue" bus was lower and much closer to the actual time (only 19 percent more than the actual time) while people who just wait for the next bus estimated waiting time much longer than actual waiting time (91 percent more than actual time).[14] This indicates it is important to reduce headway and uncertainty of arrival time, so that waiting time *perceived* by people does not become much longer than actual waiting time.

In Wardman's review (2001), service headway (or interval between services), which is related to unreliability of transfer through waiting time, is treated differently (TABLE 4). The value of service headway[15] relative to in-vehicle time is 0.80, while it increases to about 1.6 when arrival times of vehicles are uncertain. Transit riders are more sensitive to unexpected and unpredictable delays than expected and predicted waiting time (Evans 2004). When service is unreliable, people need to have a larger time margin to catch a bus to reduce the risk of missing the service. So the convenience of journey planning and risk reduction add value to reliable headway (Wardman 2001). The value of headway is also affected by the level of headway itself, since people do not care about waiting for a few minutes of headway while they do care about a few more minutes in addition to 10 minutes. It is also higher for a shorter distance trip and a business trip (Wardman 2001).

The value of making a transfer is significantly high. In Minneapolis-St. Paul, the value of additional transfer penalty varies significantly from 17.27 for home-other trips to 121.05 for non-home-based-non-work-related trips (Parsons Brinckerhoff Quade and Douglas Inc. 1993).

Interchange in Wardman's review refers to a transfer between trains, and have three different measures. *Interchange I* refers to an interchange penalty which reflects the disutility of making a transfer, excluding the disutility of time spent for waiting or transferring (or walking) for a transfer.[16] The average value of *Interchange I* is about 18 minutes of in-vehicle time, reflecting

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14 They found the value of waiting time is $8.50 (paying 75 cent to avoid the average of 5.3 minutes of waiting).

15 Headway represents the interval between public transport services and is a measure of how frequent the services are.

16 This is transfer penalties in a narrow sense discussed earlier.

both travelers' unfamiliarity with a given transfer and the risks associated with lower service frequencies (Wardman 2001).

Interchange II includes *Interchange I* penalties, plus a premium valuation of waiting and walking time. The value of *Interchange II*, according to Wardman, is approximately 35 minutes. Using the value of walking and waiting time of approximately 1.6 times in-vehicle time and the value of *Interchange I*, Wardman concludes that the value of *Interchange II* is both consistent and plausible.

Interchange III represents the combination of the pure interchange penalty and the connection time. *Interchange III* has a value of 33, which is lower than expected. Thus, in the studies reviewed by Wardman (2001), transfer penalties are substantially more burdensome than both wait/walk time and in-vehicle time. While Wardman's nomenclature is perhaps awkward, the point is clear: travelers strongly dislike transferring, and some aspects of transferring (e.g. uncertainty, fear) are substantially more burdensome than others (such as walking and waiting).

The value of the need to transfer varies by type of modal transfer among different combinations of transportation modes (Currie 2005; Liu, Pendyala, and Polzin 1997). Table 5 presents the valuation of transfer penalties for six studies using discrete choice models that were reviewed by Guo and Wilson (2004) as well as for their own study.

A reduction in the costs of interchange will lead to increasingly *seamless journeys* and such benefits which must be quantified. It should be noted that it is difficult to compare values in different studies in Table 5 because of differing sets of data. For international cases, conditions of a transfer and variables used in discrete choice modeling can differ widely as shown in Table 5 as well.

TABLE 5 Valuation of Transfer Penalties

Studies	Variables in the Utility Function	Transfer Types (Modal Structure)	Transfer Penalty Equivalence *
Alger et al, 1971 Stockholm	Walking time to stop Initial waiting time Transit in-vehicle time Transit cost	Subway-to-Subway Rail-to-Rail Bus-to-Rail Bus-to-Bus	4.4 14.8 23 49.5
Han, 1987 Taipei, Taiwan	Initial waiting time Walking time to stop In-vehicle time Bus fare Transfer constant	Bus-to-Bus (Path choice)	30 10 IWT 5 WT
Hunt, 1990 Edmonton, Canada	Transfer constant Walking distance Total in-vehicle time Waiting time Number of transfers	Bus-to-Light Rail (Path choice)	17.9
Liu, Pendyala, and Polzin, 1997 New Jersey, NJ	Transfer constant In-vehicle time Out-of-vehicle time One way cost Number of transfers	Auto-to-Rail Rail-to-Rail (Modal choice)	15 5**
CTPS, 1997 Boston, MA	Transfer constant In-vehicle time Walking time Initial waiting time Transfer waiting time Out-of-vehicle time Transit fare	All modes combined (Path and Mode Choice)	12 to 15
Wardman, Hine and Stradling, 2001 Edinburgh, Glasgow, UK	Utility function not specified	Bus-to-Bus Auto-to-Bus Rail-to-Rail	4.5 8.3 8
Guo and Wilson, 2003	Details in Table 6	Subway-to-Subway	1.6 to 31.8

*: minutes in-vehicle time except IWT (initial wait time) and WT (walk time)
**: Guo and Wilson had a value of 1.4, but it is corrected by checking the original article by Liu, Pendyala, and Polzin (1997)

Source: (Guo and Wilson 2004)

Algers, Hansen, and Tegner (1975) show a large variation of transfer penalty for different combinations of transit modes. The transfer penalty between subways (4.4 minutes in-vehicle time) is the lowest followed by the penalty between other forms of rail transit (14.8 minutes in-vehicle time). The significantly lower value of transfer penalty between subways can be explained by several factors, such as short walking distance, short headway, reliable schedule, and protected environment for the subway system. When a transfer involves bus transit, transfer penalty generally has a higher value; transfer penalty between bus and rail has the value of 23 minutes in-vehicle time. A bus-to-bus transfer has a significantly higher value (49.5 minutes in-vehicle time). This may reflect, in contrast to a transfer between subways, uncertainty of vehicle arrival time and a less protected environment at bus stops or terminals. A study by Alger et al. emphasized variables related to comfort and convenience that are measured by variables such as waiting time, the number of transfers, and seat availability (Guo and Wilson 2004).

A study by Han (1987) finds average transfer penalties equal to approximately 30 minutes in-vehicle time, about the same magnitude estimated for *Interchange III* by Wardman in his review (2001). Han estimated bus-to-bus penalties of about 10 minutes of in-vehicle time for the initial bus stop wait time, and 5 minutes walk time. A penalty estimated for a bus-to-light rail transfer was 17.9 minutes in a study by Hunt (1990). Liu, Pendyala, and Polzin (1997) examined transfer penalties and their effects on mode choice using discrete choice models with stated preference data; they estimated transfer penalties between automobiles and rail (15 minutes) to be substantially higher than between two trains (5 minutes). Liu, Pendyala, and Polzin (1997) speculate that the much higher intermodal transfer penalty is likely due to the fact that a transfer from automobile to a train is more cumbersome than between two trains because in the former the traveler must 1) find a parking spot, 2) traverse the parking lot/structure, 3) possibly purchase a ticket, 4) find the proper platform, and 5) then wait for the train. A similar study by the Central Transportation Planning Staff (CTPS) estimates transfer penalties of 12 to 15 minutes in-vehicle time for transfers among all types of modes (1997). Finally, Wardman, Hine, and Sradling (2001) presents relatively smaller values of transfer penalties: 4.5 minutes in-vehicle time for a bus-to-bus transfer, 8.3 minutes for an auto-to-bus transfer, and 8 minutes for a rail-to-rail transfer. Collectively, while these studies all find substantial penalties associated with transferring, the variance of these penalty estimates is substantial. While this is surely due in part to different types of data analyzed and methods used, it more likely reflects the enormous variance in the transfer experience from city to city, mode to mode, line to line, and trip to trip.

While these studies give a general idea of the valuation of transfer penalties on public transit in general, they do not offer much insight into how the variation in conditions at transfer facilities/locations affects transfer penalties. For example, it is likely that transfer penalties vary substantially among stops and stations within the transit system. To address this point, (Guo and Wilson 2004) conducted a substantially more detailed study of transfer penalties than had previously been conducted, parsing transferring time into walking time, waiting time, other transfer penalties, and the need to use stairs and escalators at different transfer stations in the Massachusetts Bay Transportation Authority (MBTA) subway system. TABLE 6 shows their results: the valuation of transfer penalty in terms of transfer walking time in the Massachusetts Bay Transportation Authority subway system.

TABLE 6 Estimated Subway-to-Subway Transfer Penalties at the MBTA

Varriable number and name		Underlying factors	The range of the penalty
1	Transfer constant	Model B: 7	4.8 - 9.7 WT
2	Walking time		
3	In-vehicle time	Model C: 1, 4, 5, 6	4.3 - 15.2 WT
4	Transfer walking time		
5	Transfer waiting time		
6	Assisted level change	Model D: 1, 4, 5, 6, 7	4.4 - 19.4 WT (peak) 2.3 - 21.4 WT (off-peak)
7	Station dummies		
8	Pedetrian environment dummies		

Note: WT means walking time. Source: (Guo and Wilson 2004)

Guo and Wilson develop different models (labeled B, C, and D in Table 6) using different variables to estimate the penalties of different components of transfers, compared to walking time savings between a subway station and a final destination. They estimate overall transfer penalties of 4.8 to 9.7 minutes of walking time saving depending on the station analyzed (Model B). When they parsed transfers into walking time, waiting time, level changes (escalator, etc.), and other transfer penalties for all stations (Model C), the total transfer penalty is estimated to range from 4.3 to 15.2 minutes of walking time saving, depending on the station. Their results also suggest that the range of transfer penalties perceived by travelers varies more for off-peak trips than for peak trips, probably reflecting the greater variation in the value of time perceived by off-peak travelers compared to peak travelers (Model D). When the estimated value in Table 6 is converted to a relative unit of in-vehicle travel time, the value of transfer penalties ranges from 1.6 to 31.8, and falls within the range of values in the past studies that estimated the value at a particular transfer facility or for the entire system. In short, transit travelers don't like to wait for buses or trains, and they like transferring among buses and trains even less.

In this section, we introduced the concept of transfer penalties that theoretically relate improvements on transit transfers to changes in people's choice of travel mode. We also presented total generalized costs of a typical transit trip that consists of costs of walking time, waiting time, in-vehicle travel time, transfer penalties, mode specific constant, and fare. We showed that approximately 26 percent of the total generalized costs are incurred by transferring for a typical trip, and that a significant reduction of costs can be achieved by reducing waiting and walking time — 18 percent of cost reduction can be achieved if passengers can make a transfer across a platform with no waiting and walking time.

We then reviewed past studies on value of time and the difference between *perceived* time and *actual* time. In short, walking time and waiting time are considered more onerous than in-vehicle travel time, and have values of approximately 1.4 to 1.7 relative to in-vehicle time. The difference between *perceived* time and *actual* time, particularly on waiting and walking, can vary by conditions and environments of the transfer facility. These conditions and environment includes; 1) operational factors, such as headways, reliability, on-time performance of service, and availability of adequate information, 2) physical environmental factors at facilities that are related to safety, security, comfort, and convenience, and 3) conditions on passengers, such as whether they are forced to wait or choose to wait, or whether they can be productive while waiting (Figure 1). Past studies show that transfer penalties have significant costs, and that those costs vary by each transfer facility, by a combination of modes of transferring, and by time of day.

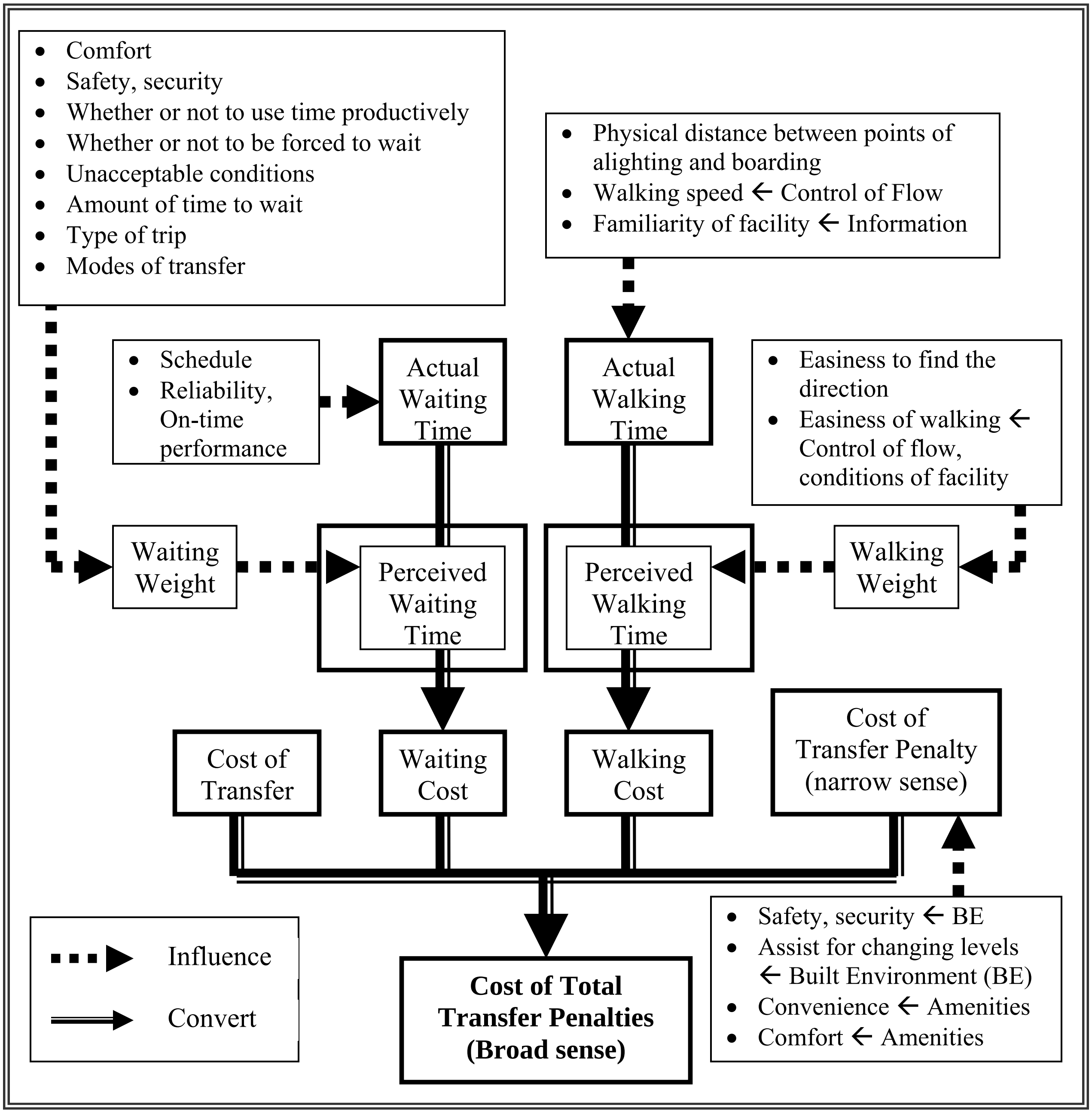
Transit agencies can reduce either *actual* or *perceived* time or both for transferring, and reduce costs associated with transfer penalties. This reduction in costs associated with transfer penalties increases attractiveness of transit trips compared to trips in other modes. In the next section, we review factors that influence transfer penalties in more detail to seek what transit agencies can do to reduce costs associated with transfer penalties.

4. FACTORS INFLUENCING TRANSFER PENALTIES

We have identified conditions and environments that influence generalized costs associated with waiting time, walking time, and transfer penalties. These are: 1) operational factors, such as headways, reliability, on-time performance of service, and availability of adequate information, 2) physical environmental factors at facilities that are related to safety, security, comfort, and convenience, and 3) conditions on passengers, such as whether they are forced to wait or choose to wait, or whether they can be productive while waiting.

Transit agencies can take various measures to lower the generalized cost of transferring that consists of costs associated with perceived waiting time, perceived walking time, transfer penalties, and transfer fare. Figure 1 shows a conceptual framework to determine the generalized cost of transferring or the cost of transfer penalties in a broad sense. Perceived waiting and walking time are determined by actual time and weights of waiting and walking. These components of the generalized cost of transferring are influenced by many factors—attributes, conditions, and environments of transfer facilities. We can group these factors into four groups depending on which component of the generalized cost of transferring each factor influence: 1) monetary cost of a transfer (transfer fare), 2) those that mainly affect the actual time and distance, 3) those that influence people's perception of waiting and walking (or weights of waiting and walking), and 4) those that affect perception of other transfer penalties (in a narrow sense) that are not taken into account by monetary cost, waiting, and walking. Transit agencies can effectively improve these factors to reduce the costs of transferring for transit riders, and this cost reduction in transferring leads to an increase in attractiveness of transit trips compared to trips in other modes.

FIGURE 1 Conceptual Framework to Determine the Cost of Total Transfer Penalties



According to the survey study conducted by Horowitz (Horowitz and Thompson 1995), the first priority at transfer facilities is security and safety. The survey by Shayer (2004) also reveals that transit users consider safety essential and they would not take a trip if they think the security level is inadequate. This is understandable; if travelers have to worry about being mugged or falling from a platform, they would not travel even if a transfer time is only one minute. A certain minimum level of security and safety has to be ensured.

Making a transfer can be more burdensome to users who are not familiar with the transit system and transfer facility. Travelers who are not regular users of a transit facility need to figure out "how to make a transfer, where to transfer, on which corner or bus stop or platform to wait, and so forth" (Reynolds and Hixson 1992). Bad conditions in terms of comfort, security, and safety also make travelers' experience of transit service unpleasant. Among these conditions, uncertainty in schedule and associated long waiting times are the worst to prevent potential transit users from using and re-using the transit service (Reynolds and Hixson 1992).

Table 7 lists factors that can influence either *actual* time or *perceived* time pertinent to transfer penalties and shows the major categories of factors that transit agencies can change and/or improve — transfer fare, time schedule and operation, and attributes of transfer facilities — and their relation to the grouping of factors affecting different components of the transferring cost. Each category is elaborated below.

TABLE 7 Factors Affecting Attributes of Transfer Penalties

	1) Monetary cost of a transfer	2) Factors affecting actual		3) Factors influencing perception of		4) Factors affecting other transfer penalties
		Time	Distance	Waiting	Walking	
<u>Transfer fare</u>	O					
<u>Time schedule</u>						
Vehicle scheduling		O				
Reliability/On-time performance		O		O		
Real-time schedule information		O		O		
<u>Transfer Facilities</u>						
1) Access: Station design to determine distance, control flow, and improve easiness of comprehension			O		O	
2) Connection and reliability: Time Schedule to determine time for transferring		O		O		
3) Information: Information for schedule, facility, and system			O	O	O	O
4) Amenities: Various amenities to enhance comfort and convenience				O	O	O
5) Security and Safety				O	O	O

4.1 Transfer Fare

Taking into account the total costs of a transit trip, a transfer penalty in terms of fare, which is usually less than $2, is not an important component as shown in the hypothetical case in Section

2. However, for a short trip, the fare may comprise a large portion of total costs, and significantly influence whether or not a traveler takes pubic transit. Because of this reason, low-income people may forego taking transit to travel short distances, and choose to walk instead.

4.2 Time Schedule of Transit Service

> "*[T]ime spent waiting, especially the traveler-perceived uncertainty in waiting, intuitively plays an important role in determining travelers' perception of transportation service quality, and, therefore, is an important determinant of transit–customer satisfaction* (Reed 1995)."

Transfer waiting time is determined by *actual* time schedules of vehicles before and after making a transfer. While a rail system generally has very good time schedule reliability with high certainty, a bus system's schedule is not as reliable because buses typically operate in mixed flow traffic and are subject to traffic congestion; however, the operation of exclusive busways dedicated to bus-only travel has much better schedule reliability than conventional bus travel.[17]

In some transit systems, time scheduling sometimes lacks coordination between modes, and significantly increases waiting time for transit users (Parsons Brinckerhoff 2002). Therefore, scheduling and frequency changes are made to reduce overall travel time, especially waiting time, and improve convenience for passengers, so that the overall service quality increases (Evans 2004). While transit users generally avoid transfers, they may not mind transferring when service schedule is certain and reliable. In a study in England, half of transit users chose the transfer service, compared to alternating direct service on the same line, when departure and arrival times for transfer buses were coordinated very well. On the other hand, only 24 percent of passengers used the service with a transfer without transfer service coordination (Tebb 1977).

Vehicle scheduling to coordinate transfers have been examined in the transportation engineering field (Abkowitz 1987; Charles River Associates 1981; Clever 1997; Dessouky 1999; Newman et al. 1983; Sacramento Regional Area Planning Commission. 1978; Sullivan 1975; Systan Inc. 1983; Vuchic et al. 1983). Timed transfers and timed-connections between vehicles are implemented at a point where two transit lines merge with each other in order to minimize waiting time and irregularity associated with transferring (Evans 2004).

Timed transfers reduce transfer time for passengers and improves service levels compared to unscheduled transferring (Abkowitz 1987). Two of the most common types of timed transfers are: 1) multiple vehicles converging at a transfer center or "focal point" to allow passengers from all vehicles to switch from any vehicle to any other vehicle before all vehicles' departures from the center,[18] and 2) coordinating arrival and departure times to allow passengers from both vehicles to switch to the other vehicle by keeping the first arriving bus waiting for a sufficient amount time (Abkowitz 1987; Reynolds and Hixson 1992). In addition, local suburban timed-

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17 While transfers are unavoidable in most transit systems, the level of needs in transfers depends partially on the type of transit system—a grid system, a hub-and-spoke system, and a combination of both. In general, a hub-and-spoke system requires transfer facilities to a larger degree than in a grid system, and therefore becomes more capital intensive. Availability of capital subsidy often gives transit agencies an incentive to more capital incentive projects, such as such as rail systems, transit malls, and transfer facilities, and conversion of a transit system to a hub-and-spoke system requires alternation of service routes and scheduling. However, their effects on the improvements of service quality and on ridership are unknown due to a lack of study.

18 "Timed transfer points have a many-to-many transferring pattern (Reynolds and Hixson 1992). It means that some traveler must walk a distance to make a transfer, and may have to cross streets."

transfer lines at a transfer center combined with a trunk line that serves downtown eliminate bus trips that directly connect suburbs to downtown, and may save substantial operating costs for an operator (Evans 2004).

A timed-transfer system at two transit centers was introduced to Oregon's Westside community in 1979. Its high service reliability and schedule efficiency contributed to a significant increase in ridership both in the peak and off-peak periods, while it should be noted that the 1979 gas shortage occurred during the changes (Kyte, Stanley, and Gleason 1982; Charles River Associates 1997). In a survey study of the Tidewater region in Norfolk, Virginia, the majority of users showed positive responses to service changes after an operator implemented an elaborate multiple hub system, in which trips with transfers shared 40 to 45 percent of bus trips, to reduce the operating subsidy (Charles River Associates 1997). This shows timed-transfers can significantly improve users' perceptions about service quality while its effect is hard to quantify.

When service is frequent enough, people may not perceive waiting as so much of a burden. When people know the service schedule with a high degree of certainty, they can adjust their arrival to a transit facility to reduce waiting time (Reed 1995; Evans 2004). Because of its readily available schedules and dependable service, people generally perceive waiting time for commuter trains less burdensome than for irregular bus service (Evans 2004). Therefore, reduction in the uncertainty (or increase in reliability) in waiting time is likely to reduce the disutility (or increase the utility) of transit service (Reed 1995).

Even if it is difficult to have on-time operation of transit service, people's perception of waiting time becomes significantly better when they have information on the arrival of the next bus. Therefore, real-time schedule information has the potential to significantly reduce the burden of waiting time for travelers by reducing the uncertainty of wait time for the next bus (Reed 1995).

In addition, schedules that are systematic and easy for transit users to remember may have positive effects on transit usage (Pratt and Bevis 1977). While any quantitative evidence is not available to support this argument, Webster and Bly (1980) provide anecdotal evidence. They state that ridership increased when bus arrival schedules are set at simple "clockface" times, such as 10 minutes, 30 minutes, and 50 minutes after each hour. The "clockface" scheduling practice was one of the service changes made by Omnitrans in Riverside, California, whose ridership increased by 20.4 percent between 1995 and 1996.

4.3 Transfer Facilities

Physical attributes of transfer facilities can potentially affect walking time, walking effort, waiting time, waiting effort, convenience, comfort, safety, and indeed many other components of transfer burdens. (Guo and Wilson 2004) found that transfer penalties were lower where escalators allowed passengers to change levels at transfer stations. In general, "passenger friendly" and "user friendly" transfer facility attributes (Parsons Brinckerhoff 2002) can be grouped into five categories described below.

First, facility design can affect *access* by defining the distance between alighting and boarding locations, improving off-vehicle passenger flow, and providing clear and comprehensible direction. Perimeter-oriented bus depots, for example, have been shown to transfer walk distances and inhibit pedestrian flows (Parsons Brinckerhoff 2002). Further, confusing or incomplete signage, poorly located ticket machines and information kiosks can significantly increase both the actual and perceived distances walked in transfer facilities.

Connection and reliability are determined by time schedules and schedule adherence, and have been repeatedly shown to have a strong influence on transfer burdens and transit use. Complete, concise, and easy-to-understand *information* has been shown to reduce the actual (by reducing wandering) and perceived burden of transferring, especially for new or occasional transit users (Parsons Brinckerhoff 2002).

Amenities, such as benches, shades, water fountains, and rest rooms, affect comfort and convenience while passengers are waiting and transferring. Through increased comfort and convenience, these amenities can affect perception of waiting and walking time as well as other burdens of transferring.

Lastly, *security and safety* also influence perception of waiting, walking, and transfer burdens. Safety and security can be a "deal breaker;" levels of perceived risk exceed thresholds over which travelers will no longer consider traveling by transit, and will instead travel by other modes or forgo the trip entirely.

Thus, we can systematically link various transit stop and station attributes to travel behavior by using a transfer penalties framework. These five types of stop and station attributes, plus wait, walk and transfer time and fares can all increase or decrease the perceived burdens of transit travel. Unfortunately, few studies have systematically examined these factors and, importantly, their relative importance; it is still difficult to make any statement on *how important* improvements of transfer facilities are in increasing ridership compared to other measures that transit agencies can take.

In addition, it should be noted that increasing ridership is not necessarily a main objective of transfer facilities. Only three transit agencies out of ten indicated that increasing ridership was a primary objective of the facility in the survey conducted by the Institute of Transportation Engineers (Hocking 1990). The survey reveals that common objectives of transfer facilities are to: 1) provide a rest area for operators, 2) enhance the public's image of transit, 3) provide a civic facility, 4) aid downtown development or revitalization, and 5) enhance passenger convenience by providing riders with protection from weather, facilitating a better waiting environment, and reducing the potential for accidents (Hocking 1990). Taking into account these multiple objectives of transfer facilities, even after the strong relationship is identified between improvements of transfer facilities and ridership, it might be difficult to allocate scarce resources to improve transfer facilities that are significant enough to positively affect people's travel behavior and result in an actual ridership increase.

5. SUMMARY AND CONCLUSIONS

In this initial report, we have drawn from the travel behavior literature to propose a *transfer penalties* framework within total travel costs of transit trips and *value of time* in order to more systematically evaluate how attributes of transit wait/walk times and transfers influence people's travel behavior. In doing so we have suggested a classification of factors relating to out-of-vehicle travel time (waiting, walking, transferring, etc) to show which aspect of transfer penalties would likely be affected by various improvements to transit service, stops, and stations. In doing so, we have offered a basis for developing methods to systematically evaluate the connectivity performance of transit stops and stations. Using this conceptual framework, we can systematically implement improvements to both the operation and physical environment of transit stops and stations to reduce the *total generalized cost* of transit trips and subsequently improve such facilities' overall connectivity. When the total generalized cost of a trip by transit is lower than that by car, a traveler will choose transit over driving. Finally, and more substantively, the merits of focusing more on improving perceived out-of-vehicle travel times are compelling, and that the potential to cost-effectively increase transit use may be substantial.

Our travel behavior framework suggests that there are three areas where transit agencies can reduce wait/walk/transfer burdens: (1) transfer fares, (2) operational aspects of service that influence transfers, such as headways and on-time arrival, and (3) the physical attributes of stops and stations, such as transfer walking distance, lighting, seating, signage at stops and stations, streamlining pedestrian flows at crowded stations, protection from the elements, and visibility. Such attributes may be classified into five categories: 1) access, 2) connection and reliability, 3) information, 4) amenities, and 5) security and safety. In particular, the literature suggests that improved schedule-adherence (or on-time performance) is one of the most effective ways that transit systems can reduce wait/walk/transfer burdens and cost-effectively increase ridership.

Other major findings from this literature review are summarized below.

1. External factors have the strongest influence on transit ridership. However, *indirect* and *direct policy measures* have only limited impact on attracting more transit riders. Incremental improvements in factors internal to transit agencies are still important to make a difference in transit ridership in the overall objective to publicly provide transit service.
2. Within a typical transit trip, a transfer involves about one quarter of total generalized costs (or time). Obviously, the shorter the trip, the more significant the impact of the transfer.
3. Among several factors associated with a transit transfer, waiting time is generally the most important component to determine total generalized costs (and time) as long as safety and security are ensured. The time schedule and certainty of vehicle arrival time are two important factors to determine *actual* waiting time.
4. In comparison to *actual* waiting time, *perceived* waiting time is very important to determine whether or not a traveler uses transit service. Perceived waiting time is affected by factors, such as safety, security, comfort, whether a wait is forced or not, acquired knowledge about the arrival of the next vehicle, and so on.
5. To improve the quality of transit transfers, transit agencies can work on: 1) operational aspects that influence transfers, such as time schedule, on-time vehicle arrival, and transfer fare, and 2) physical aspects of transfer facilities, such as distance to make a transfer, lighting, seating, signage, streamlining circulation lines, protection from weather, and visibility. It is also an option for facility management to provide various shops, such as news stands, coffee shops, convenience stores, and other commercial establishments as amenities at transfer facilities.
6. Physical aspects of transfer facilities can affect the walking time to travel between locations where people alight and board vehicles for a transfer. They can also influence people's experience at facilities, and therefore people's perception of waiting time, walking time, and transfer penalties.

While what transit agencies can do to increase ridership is limited, incremental improvements of transit service is still important to address many issues, such as provision of mobility and accessibility of transit dependents and reduction of traffic congestion and air pollution. While there is a substantial body of research on how walking and waiting affect transit patronage, the research on the physical aspects of transit stops and stations tends to be far less rigorous, more anecdotal, and more descriptive. More careful empirical research in this area is clearly needed, particularly regarding the *relative importance* of various attributes of transit stops and stations – though it is unlikely that physical improvements to transit facilities, no matter how adroit, could have the same magnitude of effects on transfer penalties and, hence, ridership as service improvements such as reduced headways or improved schedule adherence. In addition, transit agencies may not have jurisdictional authority at transfer points, and it may require tremendous effort to change the physical aspects of transfer facilities.

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