Access, the Built Environment, and Behavior

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Abstract

Access is an essential component of the built environment that measures the ease of reaching desired destinations; the level of access is a combined result from both land use and transport infrastructure. Other facets of the built environment include density, street design, pedestrian and bike infrastructure, policy, etc.. Individual travel behavior is shaped in part by the built environment, which has implications for both the well-being of individuals, and the sustainability and vitality of a city. The built environment of a city is in a continuous state of change; developments in Information and Communications Technology (ICT), and work-from-home (WFH) have the potential to redefine the meaning of the built environment, and access. This chapter discusses the evolving interaction between access, the built environment, and travel and activity patterns, and what these changes would mean for the future of transport.

Keywords: Access, built environment, digital access, work-from-home, travel behavior, activity patterns

1 Introduction

It has been known for some time that humans are products of their surrounding environment (Littré et al., 1881), and that their behavior often come under the influence of their surroundings. Where people live, and the characteristics of these places apparently have an impact on how people behave, and how they make travel decisions. Most people have a vague idea about travel preferences, and how behavior is shaped by the environment; but to analyze and improve cities would require more than vague ideas. In this chapter we separate science from folklore, and discuss the complex interactions between access, the built environment, and behavior.

The built environment is commonly defined as the "human-made environment that provides the setting for human activities, including homes, buildings, zoning, streets, sidewalks, open spaces, transportation options" (CDC, 2015). Access is a measure for the ease of reaching desired destinations within the built environment, which results from both the transport infrastructure and land use elements. Access also depends on specific modes of transport, and time of the day when the trip takes place. The built environment and travel behavior are a classic set of "chicken and egg problem". Cities are built by, and later improved upon based on people's travel behavior and preferences; yet the built environment also actively shapes travel behavior and activity patterns. Access and the built environment are intertwined in shaping each other.

Cities across the world differ in their built environment. Many European cities have compact urban land use, and city streets that are friendly to active modes of transport; on the other hand, most US cities are dominated by highways and parking lots used by automobiles, and the urban landscape characterized by vast distances between adjacent buildings. European cities have much higher mode share by active modes of transport than US cities (Pucher and Dijkstra, 2000), and physically reaching destinations are much easier in European cities by all modes of transport, including driving, walking, cycling, and by transit (Wu et al., 2021). As we will explain in this chapter, these differences in built environment are inextricably linked with differences in travel behavior and activity patterns.

The co-evolution of transport and land use has many examples where developments in transport drive changes in land use, and vice versa (Levinson, 2011). Buildings, urban spaces, and the interface between buildings and transport networks adapt to these changes. Therefore access and the built environment is in a continuous state of change. Travel behavior and travel patterns are both conditioned by changes in the environment, and are also actively changing the surrounding environment. People also vote with their feet by choosing where to live, and where and how to travel based on their preferences. Therefore it would be fair to say that "every city gets the built environment it serves" (De Maistre, 1860). In this chapter we discuss the intricate interactions between access and different facets of the built environment, and how travel behavior and activity patterns are shaped.

Disruptive new technologies or events are among the driving forces in changing travel and activity patterns. Throughout history, the size of cities has followed the steps of transport technology in allowing most of its residents to fulfill their travel needs within a 30-minute one-way travel time threshold; prior to 1800s, no city had a diameter of larger than 5km (Marchetti, 1994), which is around half an hour's walking distance from the center to the edge of the city. Modern cities became larger when disruptive technologies of the time, such as motorized trams and trains, and later automobiles, allowed for longer travel distances within the same amount of travel time. Urban sprawl in many US cities is an example of technology changing the built environment and travel behavior. Recent advances in information and communications technology (ICT) have reduced the need for some physical trips by making resources available on-line; the rise of work-from-home (WFH) reduced the need, or frequency for physical commute trips.

This chapter discusses the interactions and inter-dependencies between access, the built environment, and travel behavior, and how each one is shaped by the others. This chapter examines possible changes in the built environment that these disruptive technologies may bring, and how these changes may alter travel behavior. We recognize both the magnitude of upcoming changes in access and the built environment, and the important role of anthropological and innate tendencies in how people respond to these changes. We present and discuss possible future paths, including transformed travel patterns, and possibly the end of traffic - as we know it.

2 The concept of access: physical and virtual. The fundamental model of access

2.1 Measures of access by mode of transport

Access is an essential component of the built environment, reflecting the ease of reaching urban opportunities relative to the cost of travel. Travel time is a predominant cost factor for most modes of transport; both historical (Marchetti, 1994) and contemporary (Levinson and Kumar, 1994) evidence point to a one-way travel time threshold of around 30 minutes, which constrains the spatial distance of how far people travel to desired destinations, and limits the size of cities. Contemporary cities are larger than their historical counterparts, because more distance can be traversed within the same travel time with motorized modes of transport; the advent of information and communication technology further extends the spatial travel limit.

Other travel cost categories include monetary cost, safety cost, and externalities such as environmental and congestion cost imposed on other road users (and non-users)(Cui and Levinson, 2018), which may or may not be taken into consideration by the traveler. Travel time reliability as a result of congestion, as well as for transit with infrequent services often force travellers to include additional "buffer" time, which covertly increases their overall travel time. Perceived travel time differs by the level of comfort, and multitasking during travel, which has an impact on mode choice (Malokin et al., 2019). Safety cost is a major consideration for active modes of transport, as pedestrians and cyclists are more at risk than motor vehicle occupants. This risk poses a major obstacle for behavioral changes towards more sustainable modes of transport.

Different modes of transport have different sets of travel cost components, that provide different levels of access to urban opportunities. The general formulation of access is shown in Equation 1. This section discusses access by different modes of transport.

$$A_{i,m} = \sum_{j=1}^{J} O_j f(C_{ij,m}) \tag{1}$$

$$f(C_{ij,m}) = \begin{cases} 1 & \text{if } C_{ij,m} < t \\ 0 & \text{if } C_{ij,m} \geq t \end{cases} \tag{2}$$

$A_{i,m}$: Access measure for zone i, by mode m
O_j: Number of opportunities at zone j
$f(C_{ij,m})$: A function of travel cost between zone i and j for mode m
t: Travel cost threshold

2.1.1 Automobile

Automobile access is a commonly used measure because of the significant mode share of automobiles in cities across the world. Travel time and distance on road network are the most often used categories of travel impedance in measuring automobile access, and travel time rather than distance is used in more recent applications, as technology has allowed more accurate travel time data to be collected. Monetary cost for using automobile is often excluded in measuring access, because these costs vary between significantly between individual cases, and the cost of vehicle maintenance and ownership are less perceivable, and difficult to quantify.

Automobile access often uses a single in-vehicle travel time as the travel cost. Traffic conditions can be accounted for by adjusting travel time to network speed data (Owen and Levinson, 2015). The complete automobile travel time includes in-vehicle time, time cruising for parking, and walking time to and from parking facilities at both ends of a trip. Time cruising for parking (Shoup, 2006, Van Ommeren et al., 2012) and walking to and from parking lots can be significant, but is generally not considered within accessibility measures, so the resulting automobile accessibility tend to be over-estimated. Parking availability differs by location, and for different time of the day (Van Ommeren et al., 2012), for which the data is not widely available. With sufficient data, walking time to and from parking facilities can be added to automobile travel time using reasonable assumptions (Benenson et al., 2011), making automobile access more comparable with other modes. In practice, travel time is often the only consideration in automobile access, neglecting important costs, both private and social (Cui and Levinson, 2018, 2019).

2.1.2 Transit

Transit access is unique by its travel time composition, including in addition to the on-board travel time, the time cost of walking to and from transit stations, waiting and transfer time. These out-of-vehicle travel time constitute a significant amount of transit travel time, so are generally included (Owen and Levinson, 2015) in transit accessibility measurements.

Travel time is often considered as the most importance indicator of transit travel experience (Tahmasbi and Haghshenas, 2019). The total transit travel time for a one-way trip has often been measured as a summation from different stages of the trip (Lee et al., 2013). For transit trips involving first accessing the nearest transit station, on-board travel, and time egressing from the destination transit stop to the actual destination, the total amount of time cost can be expressed as a sum at each stage (Chang and Lee, 2008), with the addition of travel time penalties reflecting transfers and service frequency (Monzón et al., 2013), shown by Equation 3.

$$C_t = C_t^a + C_t^o + C_t^e + \Omega_t \tag{3}$$

C_t: travel time cost for a one-way transit trip
Ω_t: travel time penalties for waiting, transfers, service frequency, etc.
C_t^a: station access (a) time cost (t)
C_t^q: waiting (w) time cost (t)
C_t^o: on-board travel (o) time cost (t)
C_t^e: egress from station to actual destination (e) time cost (t)

Standardized and digitized transit schedule information (e.g. most transit schedule data adheres to the General Transit Feed Specifications, GTFS), and GIS platforms have allowed the point-to-point transit travel times with station access, egress and transfers to be estimated with reasonable accuracy. Therefore each of the travel time component in Equation 3 can either be an estimate, or a precise calculation using GTFS data.

Walking, waiting and in-vehicle time have different effect on passengers (Tahmasbi and Haghshenas, 2019). Walking and waiting are generally perceived as more tedious, and longer than they actually are. Different weights of time can be applied to components of transit travel time, to reflect the preference towards less walking and waiting (Tahmasbi and Haghshenas, 2019), and to reflect travelers' experience of the whole transit trip (Chang and Lee, 2008). Non-time costs are often excluded in transit access (El-Geneidy et al., 2016).

2.1.3 Walking and cycling

Walking and cycling can be modes on their own, or become part of the trip with other modes of transport, such as transit. Walking and cycling trips tend not to have monetary costs associated with them, nor significant externalities. In incorporating walking into other modes, walking access to public transport terminals can be expressed as an "equivalent walking distance", which is a summation of actual walking distance, and characteristics of the walking route, including terrain, number of road crossings and traffic conflicts (Wibowo and Olszewski, 2005), so routes with more negative experience will be weighted similarly as routes with longer spatial distances. People with disabilities, or using mobility devices may also experience longer travel distance to avoid obstacles, or to access facilities.

The amount of time or distance people willing to walk or cycle is an interesting research topic. Historical evidence suggest an anthropological one-way walking time limit of 30 minutes, mostly in an urban environment (Marchetti, 1994). A more recent study (Iacono et al., 2008) finds very few commute walking trips beyond 2 kilometers; there are very few cycling to work trips beyond 15 kilometers. Distance thresholds for recreational walking trips are slightly longer than work trips, but recreational cycling trips are generally shorter than commute cycling trips.

Active modes of transport require more physical effort, and sometimes expose users to more dangerous circumstances than motorized modes of transport. Weighting spatial distances to reflect user experience is very common with active modes of transport. Users of active modes of transport have varying levels of risk acceptance, and may not be comfortable using all available roads and links. Geller's four types of cyclists from "no way no how" to "strong and fearless" is a notable example of cyclists classification based on risk acceptance (Dill and McNeil, 2016); female and older adults are especially sensitive to safety risks associated with traveling (Boufous et al., 2021, Garrard et al., 2008). Therefore the actual level of access with active modes of transport might be lower than calculating access using all roads where walking and cycling are permitted. Accessibility by cycling often needs to be calculated separately using a low-stress network (Gehrke et al., 2020) to reflect accessibility by different types of cyclists. Therefore the provision of low-stress walking and cycling network tend to expand accessibility by active modes of transport, and potentially increase walking and cycling participation.

2.1.4 Taxi

Access by taxi (and for-hire-vehicles, as exemplified by ridesourcing providers Didi, Uber, and Lyft) meets travel demand from a niche market, that covers the gap between transit and automobile. Taxi accessibility differs from other modes in its more perceivable per-use monetary cost. Monetary cost per trip are either low, correlated with travel time, or not evidently perceivable for transit and automobile modes, so travel time alone explains much travel behavior for transit and automobile (Huang et al., 2018, Levinson and Kumar, 1994), and in measuring accessibility (Farber et al., 2014, Moya-Gómez and García-Palomares, 2015, Osland and Thorsen, 2008) of the two modes. But monetary cost is an especially important consideration in accessibility by taxi.

Travel time by taxi is also treated differently from automobile and transit services. A complete one-way taxi trip sequentially includes the passenger pick-up time, and in-vehicle travel time; for pooled taxi trips, additional time will be incurred for picking up and dropping off other pooled passengers, in exchange for reduced trip fare. A framework for combining time and monetary cost in access measures (El-Geneidy et al., 2016) uses hourly wages to convert between travel time and monetary costs. This framework is shown in Equation 4 where monetary cost is converted to time units.

$$C_{ij} = t_{ij} + \frac{M_{ij}}{V_I} \tag{4}$$

C_{ij}: Total travel cost between locations i and j
M_{ij}: Monetary expenditure (taxi fare) between locations i and j
t_{ij}: Time travel cost between locations i and j
V_I: Value of time

The passenger pick-up time with taxi accessibility depends on the supply of taxi vehicles in relation to the demand for rides, which in turn depends on the location, and the time-of-the-day for requesting a ride. In addition to the pickup location and time of the day, the type of taxi or taxi-like service (and the difference in fees) also has an effect on passenger waiting time (Smart et al., 2015), since services that charge higher fees will attract more drivers, and a service with more drivers on the road will more likely have a vacant vehicle near the user. Access by taxi is especially important for the elderly and people with disabilities, as their inability to drive and take transit limits their transport options.

2.2 Digital access, work-from-home and online shopping and services

There have been considerable difficulties in incorporating digital access into existing measures. Conventional access measures hinge on measuring the potential for spatial interaction, or its derived benefit. Digital accessibility does not include physical travel, so its spatial friction can be difficult to measure; digital resources are either completely or partially exclusive to physical access, so measuring digital access needs to consider competition from both the digital and physical world, and avoid double counting on the same resource.

One possible impact of digital access is reduced overall travel, as digital access substitutes for some physical travel. A framework for digital access treats the effect of digital accessibility as a partial substitution for existing travel (Shen, 2000), such as telecommute; no new opportunities are added and existing opportunities do not exclude non-digital modes. The entire effect of telecommute is defined as reducing the frequency of previously required physical trips (Shen, 1998*b*, 2000); its basic formulation is given in Equation 5. Travel impedance between places decreases if required trips (either physical or telecommute) are less frequent, or cost per trip becomes lower. This formulation of travel cost can be weighted by mode (Shen, 2000); and with physical travel partially substituted by telecommute, this weighted travel cost would be lower. The parameter ψ adjusts for traveler's perception, for example frequent short trips and infrequent long trips both give the same travel cost (C_{ij}), but will be perceived as different by travelers (Shen, 2000)

$$C_{ij} = (\psi/\eta) \times C_{ij}^{single} \tag{5}$$

ψ: traveler's valuation in travel time reduction, default '1'
η: relative decrease in trip frequency, $\eta \geq 1$; '1' if no change in frequency
C_{ij}^{single}: travel cost every time a physical trip is made

Some opportunities can be made exclusively digital, so digital access and work-from-home result in a disparity between people who have access to digital resources, and those without proper skills or equipment to access digital resources. In this case digital resources can more than partially substitute for physical opportunities and in reducing travel cost, as more opportunities are created on-line, so access needs to be measured separately for individuals with and without ICT skills. Access to opportunities in the digital space can be merged with physical opportunities using either the Hansen-type cumulative opportunities (Hansen, 1959), or Shen's competition factor (Shen, 1998*a*). When measuring digital access as cumulative opportunities, access of an individual is expressed as the summation of physical, digital-only, and opportunities that are accessible by both means, which depends on the ICT competence of this individual (Muhammad et al., 2008, Shen, 2000), the nature of such opportunities (e.g. shopping, meeting a friend), and individual preferences.

Digital access can also be measured with the dual measure, in which case the access is no longer measured by the number of cumulative opportunities reachable within a travel time threshold, but by the minimum amount of time required for reaching a threshold number of opportunities (Cui and Levinson, 2020). Although the time required for digital access is not exactly zero (e.g. time spent ordering online, picking up deliveries), it has become obvious that digital access requires much less time for obtaining the same set of opportunities. As we will discuss later in this chapter, how people would respond to this time saving benefit from digital access would have profound implications for the future of the built environment and travel behavior.

Digital access introduces a new set of digital urban infrastructure into the built environment, differentiating major urban centers with rural areas by the amount and quality of internet infrastructure (Tranos et al., 2013). Early conceptions of digital accessibility cautioned the reduction in access for workers without ICT skills, once a significant portion of opportunities became exclusively digital (Shen, 1998*b*). With the increasing ease in using information technology, barriers to accessing digital resources have been diminishing. However, the introduction of digital access does have the effect of expanding access for some individuals, while reducing the amount of opportunities for people without proper connection or skills to access the internet.

3 How the built environment shapes access

3.1 Density

Density refers to how closely things are spaced, and is measured by the number of residents or jobs spread over an urban area. Density itself is visible to anyone peering into the cascade of increasing building heights when nearing urban centers, as residential and office floors are stacked upon one another. Historically, higher density has been a contributing factor into economies of scale and agglomeration (Ortman et al., 2015), the formation of towns from villages, and it remains very relevant today. Sufficient density brings people and things closer together, reducing the cost of travel, and allowing them to be accessed with ease; this ease of access facilitates the division of labor, which makes economic production in the city more efficient than in the suburbs or rural areas.

Sufficient density also improves the transport infrastructure, which carries traffic to their destinations. Density allows urban infrastructure and related amenities, such as roads, sidewalks and transit services to be shared among a greater number of people. As a result of the sharing of cost, transport infrastructure tends to be better in cities, requiring shorter access times and less waiting for scheduled services, than in the countryside, and better in larger metropolitan areas than in smaller cities.

Too much density is associated with some negative aspects, including noise, pollution, and congestion. If there were no negative fall-outs with higher density, then the entire city should sit on a single point for the benefits of agglomeration, and not spread over an area. As density increases, the city will be left with less space for transport infrastructure; the capacity of roads, sidewalks, and transit are also limited, so there will be a point where higher density overwhelms the capacity of transport infrastructure, resulting in congestion, and lower access.

Since access is the number of opportunities reachable within a threshold travel time, both the density, and the transport infrastructure supporting movement are integral parts of access. Spatially, a higher density would make more opportunities available nearby, and thanks to their close proximity, these opportunities will also be easily accessible by transit and active modes of transport. It has been observed that in European and Chinese cities that have high urban density, there is also very high access by all modes of transport, including walking, cycling, driving, and public transport (Wu et al., 2021). We observe the increase in density does not reduce access. Congestion may reduce the speed of travel on the road network (mobility), but in practice it did not become an issue for reaching desired destinations in these cities because destinations are closer together, so access rises.

3.2 Street design (lighting, building and store fronts, "eyes on the street")

The design of store fronts, i.e. how buildings and businesses interact with roadsides, has an impact on access, particularity for transit and active modes of transport. The effect of street design on access is not limited to being able to physically using transport infrastructure, but also in determining whether people feel safe using these passages. In many cases an unsafe passage would not provide physical connection for a significant number of people. There is also a gender difference in how people react to safety measures on transit service (Yavuz and Welch, 2010), and in risk acceptance between male and female cyclists (Xie and Spinney, 2018), so the same built environment may result in different levels of access for different people.

Typical transit stops are located by the side of the road, while shopping malls and supermarkets in the United States are often fronted by a huge parking lot, which creates addition spatial barriers between pedestrians, transit riders and their actual destinations. People using automobiles will also need to exit from their vehicles and cross the parking lot as a pedestrian. Such car-oriented street designs waste enormous amounts of urban space. Store front parking lots represent wasted opportunities where there could have been other employment opportunities, like additional retail space, or other urban opportunities; these empty spaces lower urban density, resulting in lower access for all modes of transport, including automobiles.

The "eyes on the street" and street lighting are important elements in crime prevention, and in creating a comfortable environment for transit riders, pedestrians and other active modes of transport (City of San Diego, 2015). Some of the paths (and shortcuts) may not be as actively used during night time as daylight hours due to safety concerns, and this situation negatively affects access. The "eyes on the street" can be assisted with a number of methods, including adequate lighting, buildings directly facing the street, and mixed land use of residential and commercial buildings providing "eyes on the street" throughout the course of a day (City of San Diego, 2015). Vast distances between buildings, and parking lots in front of buildings that are common in US cities make it difficult to create a friendly environment for people using transit and active modes of transport.

3.3 Pedestrian and bike infrastructure

The level of access is often estimated using assumptions of travel behavior, such as walking or cycling on roads where walking and cycling are legal, not where walking and cycling are pleasant. However, not all travellers are identical in terms of accepting risks, and therefore not all travellers have the same of level of access. For most pedestrians and cyclists, the level of real-world access depends on the level of transport infrastructure. The presence of bike infrastructure increases the cyclists' perceived and actual level of safety (Heesch et al., 2012), and a study of 43 cities in the US affirms that new bike lanes will increase bike usage (Dill and Carr, 2003); the percentage of roads with protected bike infrastructure also has a positive effect on bike usage (El-Assi et al., 2017).

Different types of pedestrian and bike infrastructure provide different degrees of physical separation and protection from motorized traffic, and people with varying levels of risk acceptance will use roads with their discretion. For example, a common categorization (Geller, 2012) classifies cyclists into 4 categories based on their attitudes to biking, and estimated that the majority of the population (60%) belong to "The Interested but Concerned" group, and about 33% "No Way No How", 7% 'The Enthused and the Confident", and less than 1% belong to"The Strong and the Fearless" group. A U.S. national survey of 50 largest metropolitan statistical areas (MSAs) (Dill and McNeil, 2016) arrived at similar population composition of the four attitudinal categories (56%, 31%, 9%, 4%, respectively).

Therefore the provision of more and better pedestrian and bike infrastructure would expand the portion of road network that can be realistically used by active modes of transport, connecting more places with more direct and shorter paths, and therefore increase the level of access for active modes of transport. Better infrastructure for active modes of transport also increases the percentage of people that are comfortable with using these thoroughfares, prompting mode shift from motorized transport towards active travel (Murphy and Owen, 2019).

3.4 Policies

Government policies can shape the built environment in different ways, and can improve access by either directly reducing travel time, or by addressing safety issues that reduces safety cost.

European nations shifted their transport policies in the 1970s to curb automobile use and to promote transit and active modes of transport (European Conference of Ministers, 2002), and the higher transit, walking and cycling mode share in European cities compared to US and Canadian cities are widely attributed to government interventions (Pucher and Dijkstra, 2000). This policy shift coincided with the first and second oil crises which disrupted oil supply (Painter, 2014), but the end result of that policy shift resulted in more sustainable modes of transport, and overall safer walking and cycling environment in European nations. Specific policy interventions include a more coherent approach in the provision of bike and pedestrian infrastructure with urban planning, urban design and traffic calming devices in residential areas, restrictions of automobile use in cities, education and strict enforcement of traffic rules to protect pedestrians and cyclists (Pucher and Dijkstra, 2000).

Lowering speed limits in areas with high pedestrian activities is a common treatment for urban roads, which is in line with the "Movement and Place" (Diemer et al., 2018) framework bringing together neighborhoods with suitable thoroughfares. Although lower speed limits probably reduce access by automobile, this practice also reduces the safety cost for active modes of transport, so that the majority of people can enjoy better access.

Congestion pricing is an effective method used by governments to reduce automobile traffic (Pucher and Dijkstra, 2000), and to induce shift towards more sustainable modes of transport such as transit, walking and cycling. The reduction of automobile traffic improves conditions for walking and cycling, and creates additional road space that can be put to more effective uses, such as pedestrian zones and markets. Examples of this street transformation were abundant during the COVID pandemic, when automobile travel was reduced not by congestion pricing but by lockdowns.

Traffic signal timing is often an invisible, yet significant factor in determining the level of access by different modes of transport; it is often difficult to include time penalties at signalized intersections in measuring access. Buses and trams in mixed traffic will sometimes receive priority signal timing, which reduces the waiting time compared to other vehicles. On the other hand, pedestrians and cyclists often receive discriminatory treatment at signalized intersection; green times assigned to pedestrians are generally shorter than the time assigned to motorized vehicles travelling in the same direction. This discriminatory treatment of pedestrians and cyclists results in lower access for active modes of transport.

4 How access shapes the built environment

4.1 Residential real estate

Access is related to both population density and land value (Ingram, 1971). Theory and empirical evidence has shown that access increases the value of residential properties and residential population density. Among different modes of transport, access by transit has a pronounced impact on residential property value and population density. New urban rail lines and stations (and subsequently better transit accessibility) increase residential property value before and after opening (Grass, 1992, Pan, 2013); Bus Rapid Transit (BRT) prompts conversion to higher density residential development (Cervero and Kang, 2011); proximity to transit stops encourages conversion to higher density housing units, and the effect can be reinforced by reducing externalities, such as noise, and extreme proximity to bus stops (Cervero and Kang, 2011).

Population density and land value are closely related. Price is a signal for the desirability of residential land, and a price premium resulting from higher accessibility suggests more demand for the location, and more people willing to pay more in order to settle in areas with good access. On the other hand, a higher price also means everyone can afford less of the land (Alonso et al., 1964), so the residential population density will be driven higher in areas with good access. The increased property tax with higher property value also makes the residence less affordable as single family housing, facilitating its transition into higher density residence.

The type of jobs accessible also affects residential real estate. People locate their homes for both the access to urban amenities, and access to employment opportunities, so there is a tendency to locate in locations that provide better access to jobs in their income category (Wachs and Kumagai, 1973). The San Francisco Bay Area is an example where the concentration of tech companies with high salaries attract high-income IT workers, driving up the housing price, and displacing some of the local population (Chapple and Jeon, 2021). This housing affordability issue may have contributed to the increasing number of people in the US with extremely long commutes (Rapino and Fields, 2013).

4.2 Commercial real estate

Convenient access to other locations is a desirable attribute for both residential and commercial real estate, prompting commercial land development. For instance, Ingram (1971) measures access of a location as the average distance to other parts of the city, and finds a tendency for new commercial enterprises to locate in places with the highest access. When measured as cumulative opportunities, access of vacant land correlates with higher probabilities for development (Hansen, 1959).

Locations with good access have a higher tendency to become employment centers. For instance, Song et al. (2012) measures industrial agglomeration in each location in Seoul, Korea as Moran's I value, and find accessibility (travel cost measure) to associate with higher levels of industrial agglomeration. Locations with low travel cost to other places have more clustering of jobs.

Compared to residential properties, the value of commercial real estates are less affected by negative externalities, such as noise and other nuisances from the congregation of people. Extreme proximity to transit stops (Pan, 2013) and train stations (Ibeas et al., 2012) have been found to lower residential property value, or reduce the price premium bestowed by transit access when compared to properties at some distance away from transit stops (Cervero and Kang, 2011). On the other hand, non-residential land use appears unaffected by such nuisances (Cervero and Kang, 2011).

4.3 Services

Where different types of services locate themselves in a city depends on the level of access at that location, which is a result of land value incorporating the value of access (Alonso et al., 1964). Services such as retail, finance and consulting require small office spaces to be able to support themselves in a city center with high land prices. Better access provided in a city center reduces the travel cost between these services and their clients; this travel cost saving is valuable to these services, which voluntarily paid for access through higher land prices. On the other hand, services that are land-intensive relative to their revenue such as auto-repair or warehouse storage tend to locate further away from the city center with lower access but more affordable real estate; in this case travel cost savings from moving freight and goods doesn't justify higher land prices in a city center. This underlying self-regulation between access, land value and location of different types of services ensures the efficiency of economic activities in a city, and is the reason why milk is sold in retail stores in every neighbourhood, while milk farms are located in the exurbs.

Service providers (e.g. shops, restaurants) in an urban environment depends heavily on being easily accessed by their patrons. As a result of such dependency, services adapt their store fronts to accommodate patrons using different modes of transport. Much of these adaptations are based on the level of access provided by different modes of transport, and as a result, the number of patrons coming by different modes.

In city centers where transit and active modes of transport provide good access and carry a significant amount of traffic, services tend to locate near employment centers and major transit stations to be physically near their potential customers. Multi-story parking lots are either placed underground, or moved out-of-the-way so that they don't become a spatial barrier for pedestrians. At some distance away from city centers where automobile provides much better access than transit and active modes of transport, services can expect more patrons using automobiles than other modes of transport. In the U.S., huge parking lots separating roads and store fronts is a common sight, which further reduces access by transit and active modes of transport. Service providers often don't realize the mode of transport that provide them with access to the most patrons and generate higher revenues. In many cases higher patronage and more revenue came from pedestrians and cyclists with new bike lanes, or once bike parking replaces car parking spaces (Jaffe, 2015).

5 The effect of access in shaping travel and activity patterns

Access results from multiple facets of the built environment, including density, land use, and transport infrastructure. Access of a location reflects the level of convenience in reaching desired destinations using different modes of transport, therefore access has a profound effect in shaping travel behavior, and activity patterns.

5.1 Self-selection in the residential location choice

The residential location and commute mode choice are not separate decisions, but a combined package of decisions affected by transport, urban amenities and demographics (Song, 1994, Weisbrod et al., 1980, Zondag and Pieters, 2005). People appear to decide where they want to live in conjunction with how they would like to travel, therefore locations with good access by transit and by active modes of transport will attract residents that have a higher propensity to use transit, and active modes of transport. As discussed earlier, a price premium is bestowed to residential locations with better access, so in a sense residents who choose to live in areas with convenient transit access also pay monetarily for this convenience. It would be uncommon for a car-preferring person to pay extra in order to live in a transit-oriented neighborhood, where the driving experience isn't so great.

Since transport infrastructure and land use, and the resulting accessibility of a location are longer lasting than individual tenancies, this self-selection among residents ensures that transport infrastructure will be matched by its intended patrons, and not the other way around. Well-served transit areas tend to have a steady stream of transit users, and compact urban centers will have plenty of pedestrians. This process is efficient, because it would be prohibitively expensive to adjust transport infrastructure to account for changes in travel activity patterns.

5.2 Patronage of different modes of transport

Patronage and mode share of different modes of transport are determined to a large extent by the level of access provided by each mode. A mode with higher access means more opportunities reachable within the same amount of travel time than using other modes. For example, automobile provides the best access to jobs in most cities around the world (Wu et al., 2021), and automobile also has the highest mode share in most cities; in cities with an efficient transit system, the gap between automobile and transit in accessing jobs became less pronounced, and these cities typically have a higher percentage of transit commuters.

Within the same city, mode share largely depends on the level of access provided by a mode of transport, as locations where a mode provides good access also gains more patronage. Past research find access to jobs alone can explain much of the mode share between transit and automobile at different locations (Owen and Levinson, 2015), and access explains much of the residential density of transit commuters (Wu et al., 2019). Transit access to job opportunities is also a significant predictor for stop-level ridership (Gutiérrez et al., 2011).

In a broader sense, access provided by any mode of transport is constrained both by the travel time threshold, and by a range of other factors such as monetary cost (El-Geneidy et al., 2016), safety and environmental cost (Cui and Levinson, 2018), and physical exertion with active modes of transport. With automobile, the additional monetary cost per trip is perceived to be very low, especially in countries with low fuel taxes, and the safety cost and externalities imposed on the society are often not considered in trip making decisions, making the mode share of automobiles higher than it should have been.

The other example is cycling - the monetary cost with using bikes is almost negligible, and in many cities around the world, cycling can reach more than twice the number of job opportunities as transit within a 30-minute travel time (Wu et al., 2021); despite the great level of access provided by cycling, these cities do not have significant bike usage. This can be explained by the lack of bike infrastructure, and the level of danger involved with cycling, as cyclists are more at risk in any collision involving motorized vehicles. Research has shown dedicated bike lanes, which reduces the safety cost associated with cycling, to increase bike usage (Dill and Carr, 2003). Cycling requires more physical effort, and older adults with reduced physical abilities are found to be less likely to cycle (Aldred et al., 2016). The unfavorable perception and image of cycling from non-riders has also been a barrier to cycling participation (Daley and Rissel, 2011).

Cost per trip becomes very pronounced for some modes of transport. For instance, taxi and for-hire vehicle (such as Uber, Lyft) provide automobile-like levels of access, but have a much higher out-of-pocket cost compared to other modes; therefore not many people would use for-hire vehicles as a day-to-day commute mode choice. This is likely to change if autonomous driving technology catches up to replace human drivers, and therefore reducing the monetary cost.

5.3 Commute and travel duration

Although many people would prefer to have some spatial separation between home and work locations, shorter commute duration is generally preferable to long commutes (Redmond and Mokhtarian, 2001). Access to a significant number of jobs within a reasonable commute duration reduces the need to commute long distances, and lowers the average commute duration of the residential population. The abundance of jobs provides employment opportunities for different sectors and different income groups, which increases the chance of finding a matching between labor and employment in close proximity to each other.

This relationship between greater access to jobs and shorter commute duration has been observed by a number of research. For both transit and automobile, residence's access to jobs and workplace's access to labor reduce commute time in Washington D.C. (Levinson, 1998), Los Angeles (Hu, 2017) and in the San Francisco Bay Area (Kawabata and Shen, 2007).

In addition to providing employment opportunities, jobs also represent urban amenities. Locations with great access to jobs often overlap with locations with convenient access to urban amenities, such as schools, hospitals, and shopping centers. Having good access to jobs therefore reduces the need to travel great distances in order to attend employment and to obtain goods and services.

Access reduces commute and travel duration, which is especially valuable for promoting active modes of transport. It has been found that the majority of work and shopping trips by cycling are within 10 km of distance, and fewer trips are observed as trip distance increases (Iacono et al., 2008); at distances shorter than 2km, walking and cycling are potent alternatives to transit and automobiles (Hjorthol et al., 2013).

Providing access to sufficient essential services for residential areas has long been a goal for urban planning, and this is sometimes referred to as the "30-minute city"; other variants of the same idea include "10-minute" or "15-minute" cities or neighborhoods. By providing access to jobs and services, the aim is to reduce the distance of travel. Towards this aim, centrally planned cities such as many company towns, and in cities of the former Soviet Union, residential zones are planned to be largely "self-sufficient" by having a nearby band of social infrastructure, so that most of the daily needs of residents can be met by short trips (Andrusz, 1984, Sechi and Cera, 2020), and longer distance trips are mainly intended for commutes. Since most modern cities do not have the degree of central planning as company towns, and some physical travel will still be needed in the near future, providing good access on top of the existing land use and transport infrastructure remains essential for transport and urban planning.

6 The effect of travel and activity patterns in shaping access

Access has an effect in shaping travel and activity patters; on the flip side, travel and activity patterns can retrospectively affect access. Travel and activity patterns don't take place in a vacuum; in a real world with transport system operating costs and capacity constraints, the amount of people using a mode of transport can justify the continued service provision and expansion, and will have a notable effect on the level of service provided to all users.

6.1 Mohring and other positive feedback effects

Some travel behavior and activity patterns have the effect of improving access in a positive feedback loop. For instance, a positive feedback loop is formed when the initial travel behavior or patronage improves the thoroughfare, and more people and businesses relocate to take advantage of that improved thoroughfare, resulting in higher density land use connected by a better transport infrastructure (better access). This better access then further strengthens these types of travel behavior, attracting even more patronage. This positive feedback effect applies to all modes of transport, including transit and automobile.

Transit is particularly affected by such a positive feedback loop. A large initial patronage is needed to generates sufficient fare-box recovery, and to justify and allow higher frequency of service and transit network expansion, which brings in additional transit users. This type of self-reinforcing virtuous cycle (Bar-Yosef et al., 2013, Levinson and Krizek, 2018, Mohring, 1972) is referred to as the Mohring effect, and it provides a sustainable path to transit service improvement and expansion. As a result of this feedback system, city centers tend to have better transit services than other places. Figure 1 shows this feedback loop using transit as an example.

On the other hand, cutting transit services in response to a declining patronage tend to lower transit access, and further reduce transit patronage in a spiraling vicious cycle of lower service levels, and lower patronage. It's common for transit patronage to fluctuate even under normal circumstances, and from the perspective of maintaining ridership over the long term, cutting services is probably the worst response to a declining patronage.

This type of positive feedback loop also exists elsewhere, such as in the road transport system, where the road network in a city tends to be denser, be better built and maintained than in peripheral areas; air and sea ports in more populous cities also tend to be larger than in smaller cities.

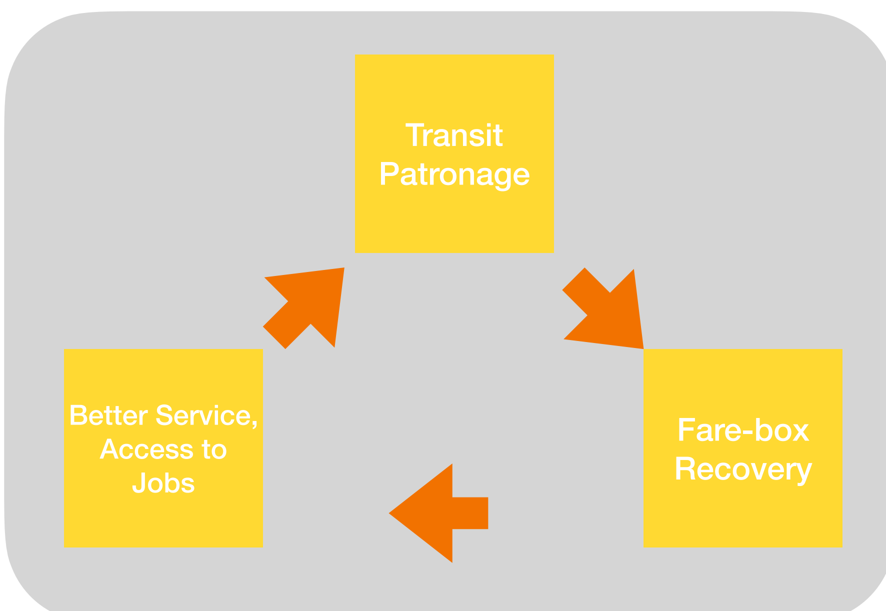

Figure 1: Positive feedback effects in a transit system

6.2 Congestion and crowding (negative feedback effects)

Congestion and crowding exceeding the capacity of transport infrastructure can result in negative feedback effects that reduces access. Without proper management, the effect of crowding can severely degrade the level of access.

Crowding can be especially problematic for buses and train services. When crowding occurs, the additional passengers, and the time required for passenger boarding and alighting causes delays, and such delays will propagate to all subsequent stops, as the delayed services will have to pick up additional passengers that are normally picked up by the next service. The more a transit service is delayed, the more additional passengers it will need to pick up, and more delay will ensue. If not properly managed, crowding within a transit service can cause "bunching" in buses and trains where delayed services arrive at the same time as the next scheduled service. These events have the effect of reducing access to jobs, and lowering transit patronage.

Crowding on pedestrian or road network can also reduce access, and lower patronage. As the number of automobiles or pedestrians on a road segment increases, the higher density of cars and people gradually results in lower speeds; and if density keeps increasing, then the roads or sidewalk will eventually become unable to conduct traffic at the same rate as the traffic enters, resulting in a congestion (Highway Capacity Manual, 2010).

Because of the negative feedback effects, congestion and crowding, and the subsequent reduction in access and patronage is *self-limiting*. Road congestion in the city center is not too bad, as long as an alternative modes of transport (such as transit) are provided. This is because a portion of the population dissatisfied with the drop in automobile access will start to drop out and switch to other modes of transport, therefore the level of congestion will be self-limiting, and the urban "gridlock" is unlikely to occur.

However, the self-limiting nature of congestion and crowding might be in doubt with autonomous vehicles. When the cargo of autonomous vehicles became freight rather than human beings, access provided by autonomous vehicles will no longer be limited by travel time. These autonomous vehicles will be less deterred by lengthy delays, or drop out from the traffic entering city centers, and the negative feedback effects limiting the size of congestion will no longer work. Without proper regulations or tolling, the dreaded scenario of autonomous vehicles slowly roaming the urban gridlock might actually materialize.

7 The future of the built environment, travel and activity patterns - effects from digital access, work-from-home

The emergence of digital access, and the recent trend in work-from-home is beginning to alter the built environment, and redefine access. A number of activities and services can now be obtained online without any physical travel, such as on-line shopping. An increasing number of jobs can also be located at anywhere with an internet connection, so the commute to work trips become less frequent, or even irrelevant for some people. If the current trend continues, the built environment of cities will become very different to what it used to be, and this change in built environment will further affect travel and activity patterns. In this section we discuss the likely scenarios that may result from a future with expansive digital access.

7.1 Re-purposing office spaces

Office spaces in city centers are priced at a premium for their convenient access to clients and to other businesses, and proximity to a highly developed network of transport infrastructure that traditionally supported the transport needs of the city center. The reduced need for physical interactions also reduces the need for such office spaces both in and outside of city centers.

Maintaining a high job density comes at a cost, including maintaining the expensive skyscrapers, which are less efficient the taller they get due to the need for more elevators and utilities serving the higher floors. When the benefits of physical interaction fades away, and as office spaces in city centers drop in prices, the job density in office buildings will very likely be reduced. The transport infrastructure that was built earlier will remain in place for some time, so the office spaces in a city center will maintain their advantage in the level of physical access to other places. Some of these office spaces in city centers may be re-purposed for activities that still require physical travel, such as recreational, or residential use. Office spaces in non-center locations are more likely to be converted to residential apartments than other uses, since these locations offer little other value.

It is recognized that even with digital access, some activities and services will still require physical access. Experience from the recent pandemic shows that people still desire some physical travel, even when all their needs can be met without physical travel. For instance, people still go to cinemas for movies (in reduced numbers), and experiences such as strolling a shopping mall cannot be directly replaced with on-line shopping. People living in residential apartments will still need physical travel to visit other places.

City centers already went through the transition from centers of industrial production to centers of service industry, mostly in the latter half of the twentieth century (Witt and Gross, 2020). This time with digital access, the re-purposing of office spaces will likely reduce the importance of city centers as a center for all types of employment. This process will likely be gradual, and take a great many years to complete; nevertheless, this process has already started. Empirical data show that traditional city centers are no longer the dominant employment centers that they used to be, as most jobs are already located outside city centers (Garreau, 2011, Sarkar et al., 2019). The recent surge in digital access and work-from-home appears to accelerate that trend, reducing the need for office spaces not just in centers, but everywhere across the city.

7.2 Re-purposing street spaces

Transport infrastructure has always been linked with population growth and land use (Lahoorpoor and Levinson, 2019), therefore the re-purposing of office spaces will be followed closely by the re-purposing of street spaces. The increasing popularity of digital access and work-from-home makes commute traffic less relevant. Since most of the existing transport infrastructure are built to accommodate the peak traffic flow during a few hours of a day, the reduction in physical travel, especially during the peak hour means the existing transport infrastructure will be identified as over-built with excess capacities. Keeping these over-built transport infrastructure means not only paying for the maintenance costs, but also having large areas of urban space that are un-used. Therefore eventually it will make sense to convert some of the roads with excessive capacity to other purposes, such as bike lanes, pedestrian paths, or other urban amenities.

7.3 Resulting changes to travel behavior

Given the significance of access and the built environment in shaping travel behavior, the rise of digital access is likely to have a notable effect in changing how people travel. The most direct effect of digital access appears to reduce the need and therefore time spent on previously required physical trips (Shen, 1998*b*, 2000), freeing up more time available for other purposes.

While it is clear that digital access would free up more time, there is little consensus regarding how people would utilize this additional time, and whether this additional time will be spent on other travel or used for other activities. Here we discuss two likely scenarios based on how people would utilize time savings from digital access, namely: "Anthropological travel behavior", where people find equivalents for previously required physical travel, and more or less maintain the same level of physical travel; and the second scenario, namely "Reduced travel and end of traffic", where physical travel is significantly reduced. These two scenarios are not mutually exclusive, since different people may respond differently to new abilities through digital access, and the same people may behave differently under different scenarios.

7.3.1 Anthropological travel behavior

Humans are generally territorial (DeScioli and Wilson, 2011), and the need for some travel is innate in human behavior. Research show some positive utility of commute trips, and some physical separation between work and residence is preferred to no separation (Redmond and Mokhtarian, 2001). If individuals were to hold on to that roughly 30-minute one-way travel time threshold, as they did throughout history (Levinson and Kumar, 1994, Marchetti, 1994), then individuals whose travel times are less than 30 minutes might be willing to travel longer distances using travel time savings from digital access; in this scenario, things that still requires physical access will be spread further apart, and the size of cities would expand once again.

Alternatively, people might compensate for lost travel time by making more frequent short distance trips, which are more suited for active modes of transport. People may also substitute recreational walking and cycling for lost physical trips. In this case, regional centers will witness faster growth than traditional CBDs. The recent experience from pandemic lockdowns, and a rise in recreational walking and cycling trips appear to reinforce the view that physical travel is an anthropological desire, and reductions in physical trips will need to be compensated in one way or another.

Digital access combined with anthropological travel behavior would greatly enhance the level of access. Digital access replaces some of the physical amenities, and at the same time adds more opportunities in the virtual spaces, some of which are not available through physical travel. With the additional travel time freed up, more physical opportunities also become available.

7.3.2 Reduced travel and end of traffic

Although people appear to desire some physical travel, it is not clear whether such behavior is anthropological, or if this is just a transition phase into a future with much less traffic. It is also not clear whether there is an upper limit where additional amenities through digital access would become unnecessary, or even excessive. If enough people eventually get used to substituting digital access for physical travel, and if their needs can be met with digital access, then physical travel will eventually become a thing of the past, and there will likely be a significant drop in physical traffic.

7.4 Implications for the future of transport

In scenarios where digital access plays a significant part, as it already does, the importance of physical access is greatly reduced, which has implications for the future of transport.

The existing transport infrastructure might be recognized as over-built, especially in traditional CBDs. If the history of disruptive technologies provides us with some guide, it is that the adoption of new technologies can initially be slow, and begin to gather path once a critical mass has been reached (Garrison and Levinson, 2014). This can also be the case with digital access. With critical technological and bureaucratic barriers overcome, digital access has accelerated in recent years. Transport infrastructure requires a long timespan to be planned and built, so it is quite possible that the transport infrastructure being built today will become obsolete by the time these projects are completed.

Significant changes in transport mode share are likely. On the one hand, automobile has a competitive advantage in serving long distance commute trips, in carrying bulky items, and in low density areas without an efficient transit system. On the other hand, digital access reduces the need for long commute trips, transport of bulky items is increasingly provided by delivery, and getting services in low density areas is becoming less reliant on physical trips, and car sharing, ride-sharing services provide alternative means of occasional physical travel. Although automobile currently has the highest mode share, and road infrastructure investment overshadows other transport investments in most cities, this is likely to change with digital access.

8 Conclusions

Access to jobs by different modes of transport is an integral component of the built environment, and together with other elements of the built environment, explains a great deal of the travel and activity patterns. People's preference for locations with good access help shape the transport infrastructure and the built environment. Both commercial and residential real estates are priced at a premium for the convenience of transport.

There is an inextricable link between access, the built environment, and people's travel behavior and activity patterns. In general, people are rational in choosing where to live and how they travel. Places with different types of built environment and varying levels of access attracts certain types of residents, and at the same time actively conditions its residents to adopt travel behavior that suits the characteristics of the place.

The landscape of access and the built environment is changing with the rise of digital access. By extrapolating how physical access has shaped travel and activity patterns in the past, we suggest there will likely be a reduction of physical travel. Part of that reduction might be offset by an increase in freight traffic, as goods are increasingly reaching people instead of people reaching goods. The ease of ordering goods at home may contribute to further increase freight traffic. Some anthropological travel behavior also suggest that this reduction in previously required physical travel might cause a compensatory increase in short-distance travel by active modes of transport. The resulting mode shift away from motorized transport presents new opportunities for infrastructure investment in sustainable modes of transport.

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