A field of practical relevance

Evolving trends in how the transport and land-use relationship has been conceptualized and operationalized

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DOI
10.4337/9781800370258.00009

Publication date
2023

Document Version
Final published version

Published in
Handbook on Transport and Land Use

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INTRODUCTION

Public policies play a very dominant role in the development of transport systems. Transport infrastructure in most countries is largely, if not completely, publicly funded. And even if it is not, like toll roads in some countries such as France or Portugal, governments decide on where which transport infrastructure can be built. In addition, governments make decisions such as levying taxes on fuels and road vehicles, subsidizing on public transport, and setting maximum speeds on roads. In addition, land-use developments depend on government policies, such as zoning, infrastructure service areas, and development impact fees, although the degree of scope of these policies varies between countries. And so, when policymakers need to make many decisions in the areas of transport and land use, interdisciplinary researchers offer support and guidance for decision-making by studying the complex relationships between transport, land use, activities, and travel behavior, and by developing and applying a variety of models and tools.

Transport plays a vital role in all societies. The transport system allows people to reach destinations they want or need to visit, and allows the movement of goods between locations along the production chain (from delving raw materials to delivering end products to shops or customers). In many countries, 10–15 percent of total annual household expenditure is on transport (Shafer & Victor, 2000). Consequently, governments of modern societies spend huge amounts of money on new transport infrastructure, and increasingly on the maintenance and replacement of existing transport infrastructure. In addition, transport systems also produce a variety of external impacts on societies, such as climate change via greenhouse gas emissions, noise, air pollution, limited public space taken up for parking and driving vehicles, injuries and property damage from crashes, and lost time or energy in congestion. It is not a surprise that transport planning and decision-making often are subject to fierce debates because of the costs and impacts involved.

Furthermore, the interactions between transport and land use are challenging to unpack (Wegener & Fürst, 1999), which adds further complexity to even simple policy questions. Urbanization fuels arguments to build more transport infrastructure, such as new motorways, light or heavy rail lines or stations along existing lines. However, transport systems themselves may also influence land use: new (or strongly improved) transport infrastructure often induces land-use changes, encouraging some types of development (firm or household locations) or increasing land rents. This is expressed by the popular saying: "in the end, a new metro line always is in the right place", because urbanization often occurs alongside stations. The complexity of interaction between transport and land-use development implies that decisions made for either should be considered simultaneously with the other in order to understand the societal implications of decisions throughout a metropolitan region.

The aim of this chapter is to provide an overview of dominant trends in the field of land use and transport, focusing on empirical research, models used for practical applications, and important concepts that inform policy decisions. In this chapter, the policy relevance of these concepts is made explicit. The scope of the chapter is limited to interactions between land use and passenger transport only, and it focuses mainly on developments in the field since about 1970.

Researchers in this field often use the terms "land use" and "built environment" interchangeably, but strictly speaking, they are not synonyms. Land use often refers to the distribution of all categories of land use over space, examples being population and jobs and the location and mix of activities (e.g., shops, restaurants, schools) across metropolitan regions. But it also includes nonurban land uses, such as greenbelts, nature preserves, and farmland in rural areas. For the purposes of this chapter, the term "land use" is mainly used, but it could be replaced by "built environment" in most places and the message would remain the same. For a more detailed exploration of the elements of land use, please see Chapter 11.

The organization of this chapter is as follows. First, in the next section, we cover the major changes in society and corresponding policies that provide the context of trends in the development of modeling and applications. In the subsequent three sections we then discuss important concepts to understand land-use and transport interactions, followed by an overview of trends in modeling, and some relevant findings of studies on the impact of land use on travel behavior. We then discuss a conceptual model for the complex relationships addressed in the previous three sections. We go on to examine changing societal and policy perspectives relevant for the transport and land-use debate. Finally, we propose an agenda for future research and policymaking.

CHANGES IN SOCIETY AND POLICIES

As discussed in the introduction, changes in society, politics, and policy have always had strong influences on the evolution of research and modeling in the interdisciplinary field of transport and land use. In this section, we explore some of the pivotal changes in society at large that help to frame the context for foundational areas of work in this field.

Focusing on western countries, starting at around 1900, many urban areas witnessed drastic increases in population size and urbanization. The introduction of motorized transport—coupled with increases in incomes—led to rising car ownership levels. As a response, increases in vehicle ownership fueled the interest in expanding (paved) road systems, both at the urban and interurban level. While railway systems were already developed before 1900, new lines and stations were added, to provide interregional connections. In transport policymaking, decisions were not about whether new infrastructure was built, but where. This trend remained quite stable until around 1970, when the oil crisis of 1973 required many in the field to question existing methods or decision-making. The first and very important change in policy analysis has been the awareness that societies could not solve capacity problems with infrastructure extensions (alone), especially in central urban areas. The increased costs of fuel during this period highlighted the resilience vulnerabilities of fossil-fuel dominated transport systems, and many during this time began exploring the vast environmental externalities impacting the very communities these auto-oriented facilities aimed to serve. Vehicle-dominated infrastructure violated the quality of the urban environment, and some communities began to realize that it would be simply impossible to accommodate all additional travel demand with car use alone. This led to the desire to move away from the status quo, the *predict and provide* paradigm: predicting future levels of car use and providing road (and parking) capacity without question (Banister, 2002). During this time, many researchers, practitioners, and agencies began to question the uninhibited dominance of automobile facilities, particularly in urban areas.

While this *predict and provide* vehicle-driven paradigm is still mainstream in many countries today, since the 1970s others have pushed towards *predict and prevent*, largely in response to environmental concerns. In *predict and prevent*, we estimate the future demand of the transport system and the corresponding impacts on the environment and society, and work to accommodate that demand while preventing the negative impacts. In many western countries, air pollution and noise entered the urban transport planning debates in the 1970s, leading to various regulations for road vehicles and infrastructure design and evaluation. In the 1990s, concerns about climate change entered the discussion after recognizing the high share of the transport sector in CO_2 emissions. Even today, for example, the share of domestic and international transport in CO_2 emissions in the European Union (EU) is around a quarter (EEA, 2021). In the second half of the 1990s, the notion emerged that a car-dominated city would not be an attractive city, even if cars would be 100 percent clean and silent, and not emit greenhouse gasses. This is because driving and parked cars negatively influence the quality of the urban environment and the human lived experience. Since the late 2010s, climate change concerns have increased rapidly, probably because of the Paris agreement on the reduction of greenhouse gas emissions, and the growing awareness of climate change now that it has become more visible.

Another dominant trend has been increasing concerns about road safety and corresponding awareness about the correlation between transport infrastructure design and fatalities. In many countries, the number of fatalities and injuries has increased quickly since the Second World War, due to a rapid increase in motorized traffic. In response, governments have implemented policies that impose speed limits on roads, regulations for motorized vehicles, and mandatory inspections of the safety of road vehicles. In many countries these policies have been quite successful. For example, between 1990 and 2018, the number of fatalities in the EU has dropped by about two-thirds (European Commission, 2021), but it is important to realize that the trend in reductions cannot be fully attributed to road-related policies. For example, improvements in the quality of and access to health care have also played a role. For the land-use and transport system, some agencies have resisted the development of automobile facilities that would have routed vehicle traffic into cities and towns, thus improving safety and reducing local environment pressure.

It is important to realize the mutual influences between transport and land-use policy questions and modeling. The policy response dealing with increased car ownership and car use, and the corresponding expansion of road networks, fueled the *predict and provide* paradigm in modeling. However, that paradigm also influenced policy debates and the focus of policymakers to deal with growing car ownership and car use levels by expanding road networks. Such expansions reduced generalized transport costs, and next resulted in induced demand (more on this in the next section), leading to more capacity problems, more vehicle-dominated roads, thus continuing this expansion cycle. Later, the growing awareness of limitations of the *predict and provide* paradigm led to debates on other types of policies, such as pricing, parking restrictions, and a shift towards public transport and active modes. These debates stimulated the development of models that were more sensitive to these new types of policy strategies. Again, it is likely to assume that the changing focus of models also fueled different types of policy debates.

Societal trends have long been reflected in the general trends in transport and land-use modeling. Four-step transport models (see below) were developed in the 1950s, and their main aim was to model how policies that expand or upgrade roadways or rail lines might respond to increasing rates of travel demand. So, the focus was on infrastructure. Since the 1970s, the focus has gradually shifted to other (non-infrastructure) policy solutions, such as pricing and modal shift policies. The recognition that land use and transport mutually interact has been recognized since the 1960s, and consequently Land Use Transport Interaction (LUTI) models have been developed and refined since then, but their real-world applications have been limited. We explore the growth of LUTI models later in the chapter, but see also a more detailed explanation in Chapter 13.

IMPORTANT CONCEPTS TO UNDERSTAND LAND-USE AND TRANSPORT INTERACTIONS

This section introduces some key concepts underlying our general understanding of the interaction between land use and transport. We start with two concepts explaining *why* people travel anyway (derived demand, activities), followed by two concepts underpinning travel choices at the individual level (utility, generalized transport costs), and a theory explaining restrictions for individual choices (time geography). Next, we introduce an additional concept for travel at the aggregate level (a large group of people—the concept of constant travel time budgets), and an important implication of the latter concept: induced demand. Finally, we explain the concept of accessibility, being the core of transport policy worldwide.

Derived Demand, Activities

In transport modeling, all travel is generally considered a *derived demand*: people travel because they experience benefits from carrying out *activities* at destinations or locations. Activities are the things that people do at different locations including, amongst others: working and other work-related activities (such as visiting clients); shopping; recreation; and visiting other people and services. More recently, activities can include things facilitated by information and communication technologies (ICT), such as telecommuting or online shopping (see Chapter 21 for more discussion about the role of ICT). From the notion of derived demand, it is very obvious how land use influences travel behavior: land-use patterns determine the locations where people reside, as well as the locations of candidate activities and therefore destinations. The recognition that land use derives travel was made as early as the 1950s by Mitchell and Rapkin (1954).

Utility, Generalized Transport Costs

Utility theory underpins the majority of existing transport models, a concept that is very popular in economics and choice behavior studies. The "utility" of a choice (such as taking a light rail to the downtown area, or selecting a suburban residential location choice) expresses the value of a choice option for the user. The utility value—which is both unitless and measured relative to the value of other choice options— aims to include everything that "counts" for the user, such as whether the residential location has a backyard or balcony or how long the light rail travel option requires one to wait before boarding. In this theoretical framework, activities have utilities (benefits) to users and travel generally has disutility (costs) associated with the burden of traveling. The basic underlying idea in transport modeling is that people make decisions that trade off the utility of carrying out activities at locations, and the negative utility of travel (disutility). Disutility is generally expressed in terms of *Generalized Transport Costs*, travel time and monetary costs being dominant components, but also many other factors play a role, such as perceived risks, comfort levels, and perceived reliability. We refer to McFadden (1973, 2001) for an overview of discrete choice modeling and random utility, and to Ortúzar and Willumsen (2011) or other handbooks on transport modeling for more detail.

Time Geography

Time geography, developed by Hägerstrand (1970), postulates that people make decisions about where to carry out which activities within the constraints of time and space. Travel takes time, and depending on the speed of travel people can or cannot visit activity locations depending on where these activities are located through space relative to the traveler. In much of transport modeling research, activities can be constrained for different reasons (Table 3.1).

Table 3.1 Different types of time geography constraints and corresponding examples

Constraint	Examples
Capability	● Blind individuals cannot drive a car and may be constrained to mode choices that allow them autonomy to travel ● Someone who cannot bike would not select biking mode choices
Coupling	● Scheduling activities with others at the same time and place ● Having a dinner at a restaurant with friends ● Having a joint meal at home with family or roommates
Authority	● Activities cannot be completed if a retail shop is closed ● School may not take place if the kindergarten is closed

Similar to utility theory, people make trade-offs between the time for travel to activities, the location of those activities, and time for the activities. Time geographies allows for researchers and modelers to conceptualize the concurrent temporal and spatial decision-making that all travelers do on a daily basis.

Travel Time Budgets

For understanding the interactions between land use (activities), transport (infrastructure) and travel behavior, the concept of constant travel time budgets becomes very important. A *constant travel time budget* tells that people on average spend around 60–75 minutes per person per day on travel—including both commuting and non-commuting travel activities. This figure is relatively stable across countries and over time (e.g., Gunn, 1981; Mokhtarian & Chen, 2004; Szalai, 1972). However, on a disaggregate level, there is substantial variation in the amount of time different people spend on travel; so it is important to realize this is the aggregate outcome over a large group of people, such as all inhabitants of a country.

The implication of this constancy is that if the transport system becomes faster, on average people do not spend less time on travel, but they travel longer distances within the same time. For example, if a motorway is built to reduce congestion on another interurban road, people will not only change their route, but might also change the destination to which they are traveling, and therefore possibly their origin–destination (OD) patterns and trip frequencies. In the long run, they might, for example, accept a job that is a longer distance from their residential location because of the reduced travel time. Or they might move to a residential location further away from their job because the house is cheaper or bigger, or the environment is more attractive, and the travel time is acceptable. Or they start traveling to home and back to have lunch every day because the travel time for each trip is reduced. While the speed of travel may change (or the location or frequency of activities), the aggregate average amount of travel per person remains generally constant.

Peters et al. (2001) and van Wee et al. (2006) explain that theoretical underpinnings for the theory of constant travel time budgets can be found in several disciplines: from economics, to psychology, geography and even history, biology and zoology. However, economic explanations tend to be closest to the transport modeling discipline: people trade off the utility of activities and the disutility of additional travel time. Considering the time a person needs for sleep, personal care, and work, it does not make a lot of sense to spend all remaining time commuting. So balancing the trade-off between travel time and the utility at the destination might lead people to spend some, but not a lot of time, on travel. In other words, why choose the nearest job or restaurant if there is a better option available at a more reasonable travel time? Over a large group of individuals or households, such trade-offs could lead to quite stable average travel time budgets.

The policy relevance of the travel time budgets is that if one ignores the constancy of travel times, one could easily overlook indirect effects of changes in the transport or land-use system. For example, one could overestimate the impact of new motorways or motorway extensions on congestion. And one could easily underestimate the impact of such changes on emissions of CO_2, pollutants, and noise.

Induced Demand

Related to the concept of constant travel time budgets is *induced demand*, which explains that people will travel more if the travel resistance (time, money, discomfort) is reduced (Goodwin, 1996). For example, if a motorway will be built to replace or improve other connections between cities, people will increase the number of kilometers traveled overall. In other words: the motorway will induce new demand. The phenomenon of induced demand can easily be explained by the theory of constant travel time budgets: faster travel options result in more kilometers traveled within the same time (see above). Again it is important to make clear this does not have to be the case at the individual level, but it applies at the aggregate level, over a large group of people. For a recent overview of empirical evidence on induced demand: see Department for Transport and Rand Europe (2018).

Several older versions of four-step transport demand models (four-step or LUTI models, as discussed in the following section) did not include a framework for capturing induced demand. In other words, the OD matrices—which capture where people are traveling to and from on the aggregate—did not depend on the level-of-service characteristics (e.g., speed, travel times) of the transport system. As a result, estimates of traffic intensities (i.e., vehicles per time unit) were often quite inaccurate. The construction of the M25 motorway around London is a nice example. Model exercises (using a four-step model) forecasted that the motorway, originally designed as a 2 × 3 lane motorway (three lanes in each direction), would have enough capacity to support the growth in travel demand with limited congestion. But soon after the opening, this turned out to be completely wrong: congestion occurred frequently (Goodwin & Noland, 2003). Ignoring induced demand in these forecasts led to substantial forecasting errors. See Næss et al. (2014) for a discussion on modeling and induced demand.

The policy relevance of the concept of induced demand is the same as the relevance of constant travel time budgets. Both concepts have often been ignored in (older versions of) four-step transport demand models. More advanced versions of these models recognize that reductions in travel time lead to changes in other travel choices (e.g., activity location or frequency), and therefore other OD matrices. LUTI models show that faster transport systems lead to other urban development changes such as urban sprawl. Some portion of the induced demand actually results from land-use changes themselves, but not all: even if the land-use patterns remain the same, the distances between origins and destinations can become larger (i.e., when people accept longer travel distances because of the faster transport system).

Accessibility

Briefly summarized, *accessibility* expresses opportunities to reach destinations. Geurs and van Wee (2004, p. 128) define accessibility as "the extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)". It is a key concept in transport policy and research because it expresses what really matters for people as far as the transport and land-use system are concerned: they want to be able to carry out activities at different locations (Handy, 2020).

From that perspective it might seem surprising that transport models do not generally model accessibility explicitly. Rather, outputs of many transport models provide travel times, traffic intensity, and estimates of congestion levels as output. Transport models may sometimes be helpful to model potential accessibility: the number of opportunities (e.g., jobs) that people can reach, with jobs nearby counting more than jobs at larger distances or travel times (see Geurs & van Wee, 2004). The fact that accessibility has generally not been explicitly modeled and has played a limited role in policy debates has many reasons: the multitude of definitions and lack of clear and easy-to-understand indicators being two of them (Handy, 2020). Policy documents also often have a narrow-minded scope with respect to accessibility. For example, the Second Transport Structure Plan of the Netherlands (1990) limited the focus of accessibility to cars and motorways only and did not focus on travel times, but congestion (i.e., losses in vehicle hours due to congestion and the probability of facing congestion on motorways). In this example, the policy scope with respect to accessibility in the Netherlands has since changed to a multimodal focus, focusing on door-to-door travel times, although the land-use component still is ignored. See Chapter 12 for a more detailed discussion about accessibility as a concept, its use in corresponding metrics and tools, and issues for both transport *and* land-use applications.

TRENDS IN MODELING

These important concepts (explored in the previous section) have driven many improvements in transport modeling, and concurrently the policies for which the models were derived. Early on, the concepts of derived demand, utility theory, and generalized transport costs were generally recognized in the early stages of transport modeling (from the 1950s through the 1970s). Time geography has more recently driven improvements in state-of-the-art activity-based modeling. Since the 1980s, the concepts of constant travel time budgets and induced demand have strongly influenced improvements and expansions in policy-driven transport modeling. Accessibility, although hardly ever modeled explicitly, remains an important concept for future development as the main aim of transport and land-use policies is generally to provide access to destinations.

This section presents a brief description of the traditional four-step model, and the context in which it has been applied. Four-step models are still by far the most common model type applied in real-world cases. Next, we discuss LUTI models, which have been developed and improved over the last two decades. The output of four-step and LUTI models is quite similar: trends in travel behavior expressed by the number of trips and kilometers by mode, the spatial distribution of travel, and network performance (e.g., congestion levels, intensity-to-capacity ratios). LUTI models add to this output by making explicit changes in (expected) land-use development resulting from changes in the transport system (generally: infrastructure changes). Lastly, we also briefly present activity-based models (ABMs), which tend to be driving a substantial amount of academic research, although not yet commonly implemented in practice.

Four-Step Models

The traditional four-step model has been a very dominant model in the area of transport planning for decades. As the term "four-step model" expresses, these models assess travel behavior in four steps (Ortúzar & Willumsen, 2011):

1. Origin/destination trip generation: the overall departure and arrival of trips by area/zone (e.g., the derived demand). Trips generated are often referred to as production or generation of trips and attractions (destinations for which the trips generated are attracted to).
2. Distribution of those trips across space: how are total origin trips and destination trips distributed over areas/zones? The result of steps 1 and 2 is an OD matrix or table.
3. Mode choice of trips: what is the mode choice distribution for each OD pair?
4. Assignment/route choice: for each OD pair and mode choice, which route(s) do people choose?

In some cases, such tools may also model time of day. This is done because transport network extensions and expansions are often a response to capacity shortages (more demand than capacity) during peak hours (e.g., 7–9 am during the morning commutes or 4–6 pm during heavy evening commutes).

It is important to note that the first two steps are the trip generation and distribution of those trips in space (resulting in an OD table). This reflects in its entirety the concept of derived demand: people travel from one place to another to carry out activities. In other words, land use is the key to travel itself. Another key point of departure is that travel is valued negatively: the higher the generalized transport costs, the less likely it is that people travel to a destination.

The first generation of four-step models were aggregated models: the models forecast travel patterns between (and within) large travel analysis zones. Interactions between zones depended on the size of the zones and impedance (distances, travel times) between zones. The larger zones, and the closer by they are, the higher the interaction of travelers between zones. Conceptually, this is similar to the gravity model from Newton's laws of physics, that the closer and larger masses have more gravitational pull than masses that are smaller or further away. In other words, the explicit theoretical underpinning of four-step models comes from physics, but the implicit underpinning comes from utility theory: because travel is evaluated negatively (time, costs, other factors of generalized travel cost (GTC)) larger distances lead to lower interaction levels. Thus, these models are sometimes referred to as gravity models.

Since the 1970s, disaggregated four-step models were introduced, modeling individual choices with respect to travel. This improvement was dependent first on the increased computational power of computers, and second on developments in utility theory, which improved the ability to model discrete choices, such as residential location choice or mode choice for individuals or households (McFadden, 1973). Because of the shift towards modeling individual travel behavior, the theoretical underpinnings shifted from more gravity-based models towards utility theory.

Four-step models are mainly applied to personal- or household-level travel at the urban and regional context. Local municipalities or regions often have their own four-step transport model, and also consultancies or businesses have developed model systems that can be applied to specific cities and regions. The general pattern is that smaller cities and towns more often make use of pre-packaged models developed by consultancies, and those with larger budgets for analysis spend more effort and money on customized models and tools.

In four-step models, land use and transport are modeled separately. The transport model assumes a land-use pattern for future years, as well as (often: different scenarios for) transport systems, and then forecasts travel behavior and related indicators (such as congestion levels, or demand/capacity ratios). The assumptions are formulated by the analyst or client based on policy questions or discussions, and next translated into model inputs. Until roughly 1980, aggregate models dominated the field. These tools modeled transport departing from and to travel analysis zones. Zones are spatial units (such as census geographies) and, typically, zones are defined from indicators including: population size or the number of households, number of dwellings or jobs, and types of shopping options. The size of zones (expressed in such indicators or square meters) typically depends on the study area to be modeled. Zones can be small (e.g., less than 1 km × 1 km), especially in case of dense urban areas and local/regional models, but they can also be large (e.g., more than 20 km × 20 km), in the case of interregional modeling of travel. If the aim is to model travel behavior in a certain city or urban region, a rule of thumb for sizing zones is: if the distance between a zone and the core region is larger, zones also become larger, because a decomposition of remote zones would not, or hardly, affect forecasts in that region. The probability that travelers move between zones (e.g., interact between zones) decreases if distances and/or travel times between these zones increased (often called the "distance decay"). As explained above, with advances in more powerful computers and techniques or frameworks for understanding choice theory, disaggregated models became more popular and more feasible. These tools enabled the modeling of choices at the individual level, and, generally, they exercised utility theory to explain choices of people: people try to maximize their utility and the utility of a trip depends on the positive utility of the activity at the destination, and the negative utility of travel to get there (time, out-of-pocket costs, effort).

The popularity of the four-step model can be understood by the societal context within which it was developed. As explained above, in the decades (before and) after the Second World War, population growth (people and households) was high in many countries and regions—note that the number of households grew more rapidly than the number of inhabitants because households also became smaller. This household growth, combined with a trend in land-use zoning towards separating different land uses geographically (e.g., residential areas, industrial zones, shopping, service and recreational areas), induced a greater spread in postwar urbanization. In addition, income levels increased and more and more households could afford a car, leading to rapid growth in car ownership levels. Between the population growth and income increases, car ownership levels increased rapidly in many western countries since the 1950s, and in the USA even earlier. Following this, so did car *use*.

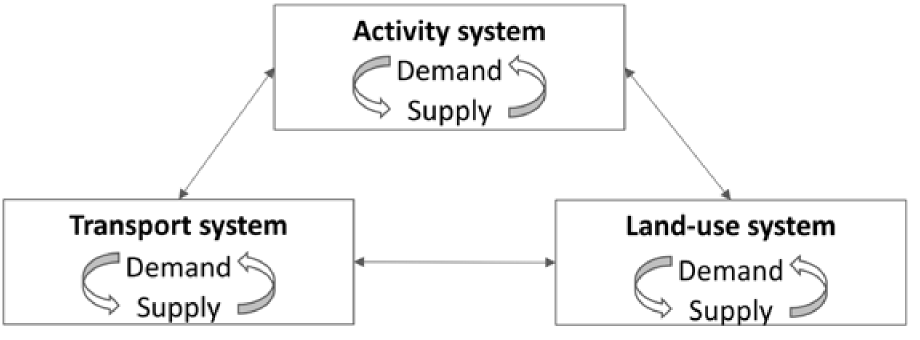
Congestion became a big problem in many regions, and the common paradigm was: *predict and provide* (Banister, 2002). In the years around 1970, cities increasingly recognized that the *predict and provide* paradigm would ruin central urban areas, and cities abandoned many plans to accommodate car traffic in such areas (Banister, 2002). But for other urban areas the paradigm remains popular. Because of that paradigm, the four-step model was used frequently: it supported the "predict" phase and its primary capability examined to what extent road extensions and expansions, and to a lesser extend public transport improvements, would support growth in travel demand (i.e., the "provide" phase). For more information on four-step models see Chapter 13 of this book.

However, four-step models do a bad job in modeling other transport policies than changes of transport infrastructure for motorized vehicles and public transport. For example, active modes (walking, cycling) are generally either not included at all (walking and cycling), or poorly (cycling), although some progress has been made in the past two decades, especially in the case of cycling, and in line with the huge increase in the scientific interest in cycling since the late 2000s. It is a bit speculative but I hypothesize that the popularity of the *predict and provide* paradigm can partly be explained by the fact that, in most countries, transport and land-use policies are developed by separate and siloed policy institutes or departments, across national and the local levels. So policy departments facing transport challenges likely included only transport-related solutions, and no other solutions, such as land-use policies. Thus, research and practice have responded to more complex and varying policy questions with more complex transport models.

Land-Use Transport Interaction (LUTI) Models

Over time, modelers increasingly recognized that conceptually speaking it is better to recognize the land-use and transport interactions more explicitly, and from that perspective, the four-step model was less satisfactory. This led to the development of LUTI models. Several of such practically applicable models were already developed in the 1980s, and an influential group of modelers collaborated in the so-called International Scientific Group on Land-Use Transport Interaction (ISGLUTI), leading to books comparing models and their outcomes (Webster & Dasgupta, 1991). The conceptual models were translated into mathematical equations using datasets. As in the case of the four-step models, the first generation of LUTI models were aggregate models departing from physics/gravity theory, and then translated using theories of special interaction (e.g., Lowry, 1964) which include underlying microeconomic theories. *Predict and provide* was still a dominant paradigm in the early years of the development of LUTI models. Later models were disaggregated, and choices modeled on more individual levels using random utility theory (McFadden, 1973). For LUTI models, another strong theoretical underpinning depends on time geography, which assumes that spatial interaction takes place within time and space constraints (see previous section). For more details on the theoretical underpinnings of LUTI models see Acheampong and Silva (2015).

Lopes et al. (2019) argue that ideally LUTI models would use the conceptual model as presented in Figure 3.1: they should include the land-use system, the transport system and the activity system. The activity system includes the activities that people carry out at different places. And Lopes et al. (2019) explain that all systems interact in both directions. Next, within each system, demand and supply should be modeled. However, they show that several of the LUTI models described in the academic literature miss some the boxes or arrows through simplification. Most frequently, the activity system is often not included.



Source: Adapted from Lopes et al. (2019).

Figure 3.1 Causal model of "ideal" LUTI models

Despite the conceptual advantages, real-world applications remain relatively limited, and the four-step model has continued to be the most popular model type in practice. Nevertheless, several applications for LUTI models can be found in policy discussions. For example, the ILUTE model has been applied to the Greater Toronto Area (Salvini & Miller, 2005), and the TIGRIS XL model has been applied to several regions in the Netherlands (Zondag et al., 2015). The main focus of LUTI applications has probably been the exploration of impacts due to changes in the transport system on land use, and next, the more general evaluation of transport scenarios and policies (e.g., transport indicators such as use levels by mode, travel times, and congestion/accessibility level changes).

But still, why have LUTI models not become more popular, despite their conceptual superiority over four-step approaches? It is difficult to pinpoint the precise reasons but, a bit speculatively, I think one of the reasons is that, as explained above, spatial planning and transport planning are often organized in different departments of local and regional authorities, which is not favorable for joint development of land-use and transport systems. This practical difference in applications is explored in more detail in Chapter 2. A second reason could be that LUTI models are more difficult to calibrate making the development of such models more time-consuming, and LUTI models have larger data needs. This is especially problematic because it is riskier to adopt transport–land-use interaction parameters from other models compared with four-step models. Travel behavior choices of homogeneous groups of people (including variables such as income, education level, gender, household structure) in given contexts (land use, transport) are relatively stable and parameters can therefore be relatively easy to transfer to other contexts. But the parameters from interactions between land use and transport are much more context specific, depending on the characteristics of the region at stake, and past policy decisions with respect to land use and transport. A third reason why LUTI models have not become as popular in practice may be that, for several policy and planning choices, the transport/land-use interaction may not strongly influence the indicators of concern (e.g., congestion). For example, the precise connection between a residential neighborhood and a specific existing urban ring road is complex—the policy discussion about decisions for the nearby ring road are not so closely tied to the specific residential development. Land-use and transport interactions are more important for network-wide strategic decisions such as important changes in transport infrastructure (new rail lines and motorways) and the location and characteristics of new residential and employment areas, relative to the main characteristics of the transport system (road, rail, other forms of public transport).

Activity-Based Models

Four-step models and LUTI models predict and represent travel trips, not activities. Conceptually speaking, it is more satisfying to primarily model activities and then to model trips as a result of the activities that people want to carry out at different locations. ABMs do this (Ettema & Timmermans, 1997): they depart from the notion that people first make decisions on which activities they want to carry out, and then at which places and in which order. Trips, therefore, result from choices with respect to activity programs (i.e., a derived demand). This point of departure is fundamentally different from four-step models and LUTI models, which depart first from modeling trips (e.g., trip generation step). Note that the A in ABM can refer to Activities, but in some cases, it refers also to Agents (in this case: people who carry out activities at locations).

ABMs are simulations models: they simulate the activity and spatial behavior of people. They are generally rule-based: they define a set of if-then rules (e.g., choice heuristics) specifying how a person or household carries out activities and travels. An example of a rule might be that an activity such as "visiting a theater" follows after "dinner" activities.

Despite high expectations in the late 1990s, ABMs have not become very popular and applications have been limited so far (Acheampong & Silva, 2015). Examples of ABMs include the FEATHERS model of the University of Hasselt, that has been applied to several regions in Flanders, Belgium, and other medium-sized regions (Baqueri et al., 2019), and the ALBATROSS model that has been applied in the Netherlands, e.g., to the Rotterdam Region (Rasouli & Timmermans, 2015). Recently, the first steps have been taken to combine activity based modeling (ABM – see below) and LUTI modeling (Hammadi & Miller, 2021), but since these applications are very limited, I do not further discuss ABMs.

EMPIRICAL STUDIES ON THE IMPACT OF LAND USE ON TRAVEL BEHAVIOR

As explained above, models are often used to estimate the impact of policy scenarios for land use and the transport system on travel behavior. Because people mainly travel to be able to carry out activities at different locations, it seems obvious that land use matters for travel behavior. But the estimations of the impact of land use on travel behavior have long been the topic of fierce debates. Understanding the impact of land use on travel behavior is very important for the future of modeling, and corresponding policy discussions. Therefore, this section summarizes the scientific debate in this area.

A first debate concentrates on the correlation between socio-economic variables and residential choice. Ignoring this correlation would result in an overestimation of the impact of land use on travel behavior. Take the example of densities: the higher the densities, the shorter the distances between origins and candidate destinations for trips. But if a researcher finds people in dense areas travel less than people in low density areas, this could at least partly be the result of the fact that houses in dense areas could be smaller and less expensive, as a result of which more people with lower incomes may live in denser areas than people with higher incomes. So the difference in, for example, car ownership and car use, could be the result of differences in incomes between areas. Therefore, most scientific papers in this field over the past three decades have included socio-economic and demographic variables to help explain the impact of land use on travel behavior.

Socio-economic characteristics are not the only variables that should be controlled when studying the interaction between land use and travel behavior. Since the seminal paper of Kitamura et al. (1997), researchers have considered personal attitudes, which are independent of socio-economic and demographic variables. Attitudes can relate to preferences for travel in general, as well as to preferences for traveling by specific modes, expressed by terms such as “car lovers” and “public transport lovers”. Attitudes can also be related to non-travel related factors influencing travel behavior. For example, pro-environmental attitudes can make people travel by public transport and active modes, not by car, and positive health attitudes can make people walk and cycle more. The notion that attitudes influence residential and travel choices is generally recognized, but the magnitude of the effects and the policy implications are still heavily under debate.

Attitudes not only directly influence travel behavior, they can also lead to so-called residential self-selection (RSS): that people select their residential location based on these attitudes. Since around 2005, many studies on RSS have been carried out. See Cao et al. (2009) for an early review of empirical studies, and Mokhtarian and Cao (2008) for a review of methodologies in this area. Chapters 6 and 7 explore this topic in greater detail. An important lesson of RSS studies is that the impact of land use on travel behavior can easily be overestimated, because part of travel behavior differences between different land-use categories can be attributed to attitudes. The question is whether or not this ends up being a practical problem. Næss (2014) labels the phenomenon of RSS as a “tempest in a tea pot”. He argues it is hardly relevant: even if people have specific travel relevant attitudes and then choose residential locations that match their attitudes, that does not downplay the role of land use. The land-use system should allow people to live in areas that match their preferences. If not, this is not only disadvantageous for these people, it could also force them to travel in a less sustainable way. In addition, it is not only possible that attitudes influence residential location; there is increasing evidence that land use influences attitudes (Kroesen et al., 2017; van Wee et al., 2019). Therefore, the impact of land use on travel behavior can also be underestimated, not overestimated, because there is an additional contribution (to the direct impact) of land use on travel behavior, via changing attitudes (Kroesen & Chorus, 2018). For example, a person moving to a dense area with mixed land use and stations nearby, but with hardly any experience with other modes than the car, and negative attitudes towards these modes, may become more positive about these other modes based on positive experiences of using them. In other words, people may realize that it makes more sense to travel in a certain way after they lived in a particular neighborhood for a while, and have experienced the use of other modes. Despite the progress in understanding the role of attitudes, residential choice and travel, there is still a lot of uncertainty, even with respect to the causal structures explaining relationships between clusters of variables (Cao et al., 2009; Heinen et al., 2018).

A third topic of ongoing debate in this field is the interpretation of the empirical findings that the impact of land use on travel behavior is limited. Research so far has revealed that many land use variables influence travel behavior: population and job densities, diversity (levels of mixed land uses), design of neighborhoods, and regional accessibility (Ewing & Cervero, 2010). Ewing and Cervero give elasticities, expressing the quantitative impacts of these variables on travel behavior expressed by the number of trips made, and vehicle miles traveled. Overall, the literature shows that land use does influence travel behavior, but not to a large extent, relatively speaking (i.e., the elasticities indicate significant, but less elastic relationships). For more discussion related to this area of research, see Chapter 5. An important question, therefore, is whether it is recommended to consider travel implications of alternatives for future land use? The low impact of these alternative on travel behavior is largely the result of the fact that providing land use (and transport) scenarios that provide options to travel shorter distances and using other modes than the car also improve accessibility, and in line with the concepts of constant travel time budgets and induced demand, people benefit from higher accessibility levels by choosing destinations further away (van Wee, 2011a). In other words: even if the travel behavior impact of land-use policies is small, they are still important because of the improvements in accessibility.

The policy relevance of the empirical studies is first of all that spatial policies influence travel behavior. Second, the quantitative effects of land use on travel behavior could be overestimated or underestimated. Overestimation can occur because too much impact on travel behavior is attributed to land use—a part of the assumed impact follows from attitudes. But underestimation is also possible, especially if attitudes change, such as changing preferences after moving residential location to a certain type of area. Third, even if the real effect of people living in “favorable neighborhoods” (dense areas with mixed use, short distances to public transport, etc.) would result from the attitudes and preferences of people living in such neighborhoods, there are good reasons to provide such neighborhoods, so that people can travel in their preferred sustainable way.

As explained above, the relevance of these observations for transport modeling is that a better understanding of the conceptual and quantitative impacts of land use, the transport system, residential choice, attitudes, and sociodemographics is needed to be able to better model the interactions between land use and transport, and then next the societal relevant outcomes of land use and transport scenarios.

LINKS BETWEEN THE TRENDS

To build on Lopes et al. (2019), in this section, I expand on their conceptual framework for LUTI models with the additional factors discussed in the previous section (see Figure 3.2). Traditional four-step models do include the impact of the land-use and transport system on travel behavior, the impact of socio-economic and demographic variables on travel behavior and generally depart from given residential choices, which are linked to socio-economic and demographic variables. Residential choice influences activity patterns, location choices and next travel behavior. The impact of the transport, land-use and activity system on residential choice is often not included in four-step models because they depart from given residential choices. As explained above, the interactions between the transport and land-use system are not modeled. LUTI models do include these mutual interactions, but are limited to explicitly modeling the interactions between the transport and the land-use system on the one hand, and activities on the other hand (Lopes et al., 2019). Travel behavior choices further result in congestion and crowding (public transport) levels—and therefore also influence the transport system and indirectly the land-use system—but such effects are generally ignored in four-step and LUTI models.

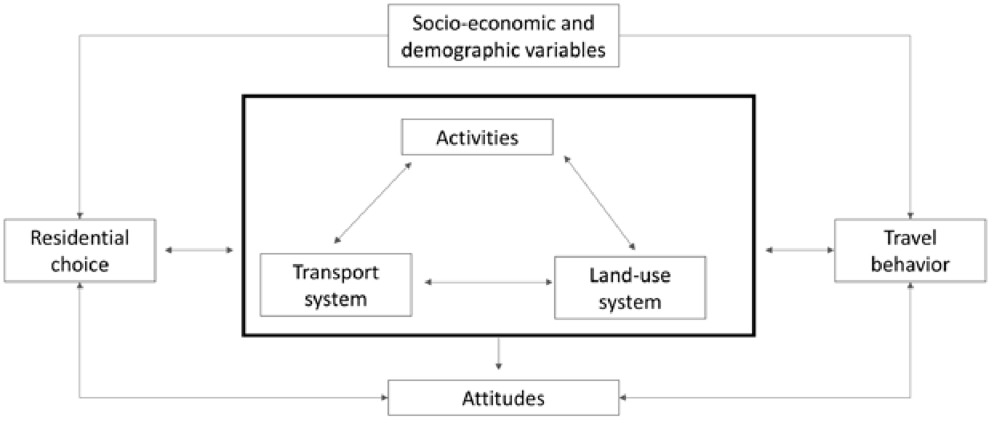


Figure 3.2 Links between land use, transport, activities and travel behavior

Broadening the scope from models to research in the area of transport and land use, the role of attitudes-based RSS on travel behavior is conceptualized explicitly, and so are the impacts of the transport and land-use system (and travel behavior) on attitudes. The impacts of land use, the transport system, and travel behavior cannot easily be separated, because living in a specific residential area per definition cannot be isolated from living in a more general land use and transport context, and some of the related attitude changes are the result of travel behavior experiences, that result from the land-use and transport system.

To conclude, the causal links between land use, transport, activities, and travel behavior result in a complex conceptual model. Currently, LUTI (and four-step) models do not recognize this full complexity. This leaves ample room for further model developments.

CHANGING SOCIETAL AND POLICY PERSPECTIVES

What could be the future of land-use and transport modeling? This future first of all depends on a better understanding of the causal mechanisms, and the quantitative sizes of relationships between clusters of variables, as explained in the previous section. It also depends on general progress in individual-level choice modeling, and the availability of datasets and methods to analyze datasets, especially "big" data, via artificial intelligence and machine learning (see Chapter 21 for more discussion). Third, it depends on trends in society and policy, discussed in this section.

A first trend is the increasing interest in equity issues. In the policy analysis literature, there is some consensus that "sound" policies should be effective, efficient, and fair (Young & Tilley, 2006). Until about 2010–2015, fairness was only very limitedly on the radar of transport planners and researchers. An important topic that has been recognized frequently since then is the unequal distribution of accessibility levels and travel options, for different groups of people, e.g., by income, car ownership level, and region. Equity issues did not only receive attention within countries, but also in supranational organizations such as the United Nations (UN), the World Health Organization and the EU. For example, the 2017 UN sustainable development goals include a specific goal in the area of fairness: goal 10 is to "reduce inequality" (United Nations, 2017). Another related topic that has received attention, not only in research but also in policies of countries such as the UK, is social exclusion, expressing that people cannot adequately participate in society because of the combination of a lack of travel options and the spatial distribution of activity locations (Lucas & Musso, 2014). Equity has increasingly received attention during the past decade, and now equity and transport have, often in the context of accessibility (Martens, 2016), or from a wider perspective (for example, van Wee, 2011b). Although equity is a heavily studied topic, and in several countries also a topic that has more explicitly received the attention of policy and planning. For example, the Minneapolis Transportation Action Plan (TAP) explicitly aims to improve equity by: "build[ing] and operat[ing] a transportation system that contributes to equitable opportunities and outcomes for all people, and acknowledge and reverse historic inequities in [their] transportation system" (City of Minneapolis, 2020, p. 12). The literature on fairness and equity sometimes has a normative nature (Martens, 2016), but in most cases the focus is on evaluations without normative judgment—see, for example, Lucas et al. (2019). The tools that transport and land-use planners have available, such as the four-step model, generally do not provide any explicit information on fairness and equity. But the output of such models can be used for additional calculations in that area. For example, Lucas et al. (2016) provide a methodology to calculate distribution of accessibility indicators, which can be used for the evaluation of distribution-related fairness. In this book, Chapter 12 provides a more nuanced discussion about accessibility as a measure and policy tool, and Chapter 17 provides a greater discussion about the past and present roles of equity in transport and land-use topics.

Another trend is the increasing awareness of the relationships between transport and health. For example, the transport policy plan of the State of Minnesota, USA, has a set of objectives under the umbrella theme of "Healthy and Equitable Communities", one objective being "increase the availability and attractiveness of transit, bicycling, and walking to encourage healthy communities through the use of active transportation options" (State of Minnesota, 2018, p. 30). Since 2013, there is even an academic journal titled *Journal of Transport and Health*. The transport system influences health (1) via the exposure to noise and pollutants, and (2) the occurrence of incidents, because (3) travel behavior can be a form of exercise (walking, cycling), and finally (4) transport and well-being/happiness are mutually correlated (De Vos et al., 2013). But the mutual relationships between transport and health, directly and via intermediate factors, are still limited in understanding (van Wee & Ettema, 2016) and not integrated in tools to evaluate land-use and transport systems. An example expressing the importance of health is provided by Sælensminde (2004) who studied the benefits of cycling policies in Norwegian cities, concluding that health benefits did count for 55–75 percent of all (monetized) benefits. See Chapter 19 for a more detailed exploration of the increasing role of health in transport and land-use topics.

A final trend notable in this field is the increasing impact of information and communication technologies (ICT) on travel behavior. Due to the Covid-19 pandemic, this has become a topic increasingly discussed. During the first year of the pandemic, many people switched on-site activities to online activities: teleworking, e-learning, and e-shopping being important ICT-based activity types. While this chapter was being written, many researchers were studying whether it was likely that the pandemic will have lasting effects on activity and travel behavior, possibly because: people now are more knowledgeable with respect to using online communication platforms (e.g., Zoom, Microsoft Teams, Webex); platforms have also improved; people might be positive about the travel time saved; and observed increases in the flexibility in scheduling activity patterns (van Wee & Witlox, 2021). A study based on Google data revealed that in mid-April 2020, there was a worldwide 40 percent reduction in work-related travel (Medimorec et al., 2020). The notion that ICT influences travel behavior was already a topic of research around 1990 (e.g., Mokhtarian, 1991, Mokhtarian & Salomon, 1997), showing that online activities can be a substitute for on-site activities and related travel, but ICT based and on-site activities can also be complementary. Hence, ICT influences on-site activity patterns and related travel behavior, and can lead to a changing role of land use. For example, households may accept longer commuting distances if they can e-work partly (or fully). In the 1980s, online banking changed the frequency of trips to banks. Similarly, the prevalence and growth for e-shopping may reduce the need for bricks-and-mortar (in-person) retail land uses. In addition, ICT can influence accessibility in multiple complex ways via all four components of accessibility: the land-use, the transport, the temporal, and the individual component (van Wee et al., 2013). Real-time route navigation technologies, for example, can reduce travel resistance by providing detailed information while en route, and comprehensive information about the availability of nearby destinations through platforms such as Walk Score can influence the land-use component. Chapters 20 and 22 in this book explore the role of new mobility technologies and the rise of e-commerce, respectively.

Relevance for the Land Use and Transport Debate

The relevance of these changing perspectives and trends for the land-use and transport debate is, first of all, that this debate should include all modes. This discussion should not be limited to only the car and some forms of public transport, but also active modes because of their role in improving access to local destinations, health, and well-being. A second relevance is that the land-use and transport debate should put the concept of accessibility in a central place (Handy, 2020). The transport and land-use system should primarily allow people to carry out activities at different locations, so the concept of accessibility is vital. Understanding underlying influences of travel behavior is also important, mainly because of the negative externalities (incidents, pollution, greenhouse gasses, noise, congestion) and positive externalities (health, well-being) that different travel modes and travel patterns produce.

Livability should be a central focus in the outcome effects in land-use and transport discussions. Livability is a broad concept incorporating accessibility, health, and well-being, but also several other aspects, such as the quality/attractiveness of the urban environment, the options the transport and land-use system provide for recreation, social interactions and meeting other people, and options for children to meet and play on streets. The literature on how to address livability in design and evaluation of land-use and transport scenarios is not mature yet and could provide substantial support for the quality of life of different communities. Finally, addressing equity aspects of such scenarios will play an increasingly important role in the future. Equitable access to destinations will probably be a dominant theme in the evaluation literature for at least the next decade, likely including detailed exploration discussion around the distribution of all pros and cons of policies across (groups of the) population, and guaranteeing minimum levels of access for all (Lucas et al., 2019).

A topic that has been on the radar since the early days of the transport and land-use literature is the recognition of the importance of synchronizing land-use and transport policies. This topic is still important because simultaneous policymaking of land-use and transport policies is still not common worldwide, maybe partly—as explained above—because land-use and transport planning are often the responsibility of different departments of municipalities. In this book, Chapter 2 provides more detailed discussion about this issue in the past and present.

AVENUES FOR FUTURE RESEARCH AND POLICIES

I conclude this chapter with a discussion about some avenues for future research, policymaking and planning in the area of transport and land use. A first challenge is to help practice move towards evaluating land-use and transport scenarios not only on travel behavior and related effects, but also on accessibility effects. Several quantitative indicators are available (Geurs & van Wee, 2004), and in many cases their values can be calculated on data that are calculated by models anyway. For example, the numbers of jobs, supermarkets or hospitals accessible within a time limit for specific modes (car, walking, cycling, public transport) can be calculated based on location data and travel times. Similar data can be used to calculate potential accessibility but weighting nearby destinations more than remote destinations combined with distance decay functions that can be based on empirical data. So, no new research is needed to do this (assuming distance decay functions are available). But further improvements can be made, options for improvements being, for example, the inclusion of so-called option values (the value people attach to having options available, over and above the value of the actual use, as a kind of risk premium—see Geurs et al., 2006), and better assessing accessibility via active modes (van Wee, 2016). Planners and policymakers can apply the new insights in future transport and land-use plans.

The assessment and valuation of livability impacts is still in its infancy. Based on previous research we do have an idea about which factors are important for livability (see above), but methods for quantitatively assessing the impact of land-use and transport scenarios on these distinguished components of livability are an important area of future work. A next challenge is the evaluation (*ex ante* and *ex post*) of the overall livability effects via a Multi-Criteria Analysis (MCA) or Cost–Benefit Analysis (CBA). Illustrating how badly current methods sometimes assess such benefits: the recently converted motorway through the Dutch city of Maastricht, from ground level to a tunnel, had about six times more impact on house prices (an indicator for livability) than assumed in the CBA *ex ante* carried out for the project (CPB, 2018). Again, planners and policymakers can benefit from the new insights in their analyses. Addressing livability is likely to become more dominant in policymaking and planning as awareness increases about the full livability effects of candidate plans. There may, however, be competing interests between trade-offs in livability (including accessibility-related livability effects) and accessibility outcomes. Livability increases if the role of motorized transport decreases, but decreasing that role can come at the cost of accessibility. Improving access by active modes (and to a lesser extent by public transport) may be the way out, and this access improves by building compact and mixing use, combined with improving the quality of cycling infrastructure and pedestrian connectivity and safety. Addressing this trade-off is a key challenge of policymakers and planners.

Next, we need to better understand the complex relationships between the land-use and transport system and the various implications on different health outcomes. It is increasingly important to dig down into the underlying factors that play into our choices, which include addressing such topics as RSS effects, the interaction between travel as a form of activity and other forms of being active, and the diminishing additional benefits of being increasingly active (van Wee & Ettema, 2016). As our discipline furthers foundational knowledge, we should aim to support policymakers and planners so that they can better address health effects in their plans. An example to illustrate the complexity: cycling for half an hour is healthier than driving, because cycling is a form of exercise. But how large are the benefits of policies that substitute cycling for driving? And then we need to know if people substitute other forms of exercise for cycling. It could be that the net increase in exercise is limited if such substitution occurs. On the other hand, if people cycle more, they may feel fitter, and take the stairs instead of the elevator, and then there could even be larger health benefits than those related to cycling. These questions are both individual-specific in their nature—the root of a person(s) choices—but the implications of such policies and behavior outcomes are often desired to be measured as higher-level aggregate outcomes. Thus, we need to do more work linking this behavioral research to be more readily understood and adopted in practice.

As explained earlier in this chapter, RSS has been studied frequently since around 2005, but several research challenges remain, such as the precise causal structure(s) between travel behavior, the built environment and attitudes (Heinen et al., 2018) and also addressing the impact of the built environment on attitudes (Kroesen & Chorus, 2018). Another research challenge is to better understand the role of the housing market in RSS: households cannot always self-select in their desired way because of housing market restrictions, leading to mismatches between preferences and residential locations (Manaugh & El-Geneidy, 2015; Schwanen & Mokhtarian, 2005). One research challenge is improving our understanding about the expected utility (value) at the time of decision-making, versus the real experienced utility (De Vos et al., 2016). In discrete choice modeling, we assume the utility at the time of making a decision (expected utility) should match the experienced utility, but this does not have to be the case. For example, expected and experienced utility might differ because people have incorrect expectations (or imperfect information), or—using an example related to the built environment—because the built environment changes after moving to a place and the decision maker was not aware of the changes. While this topic supports a more general, basic understanding of behavior, it remains relevant to the transport and land-use debate, and it would help planners and policymakers to better understand to what extent travel behavior changes result from the built environment, or from attitudes, or from both.

Following this, people can self-select in other ways, such as with respect to job location and other destinations, the exposure to the negative effects of traffic (noise, pollution), and travel behavior (van Wee, 2009). These other forms are hardly studied in central transport/ land-use avenues, providing a challenging opportunity for future research. Collaborations with those in additional disciplines, such as consumer sciences or those in marketing, may push the envelope in this area. Again, the results could have implications for policy and planning, but it is difficult to say if (or where) this applies and how. Similarly, the role of the social context of people and households for making decisions on residential location and travel behavior has also been poorly studied so far (Van Acker et al., 2010). People are social animals, and decision-making can be influenced by the social environment as well.

Finally, it will become increasingly important to better understand the role of ICT for activity and travel behavior, and the related implications for the transport and land-use system. ICT will become better over time, and consequently maybe a better substitute for on-site activities. The Covid-19 experiences with teleworking and other online activities may boost the development of better ICTs and may also change people's attitudes towards online activities because of their experiences. However, by leaning into research that unpacks behavior at a root level, we also provide a better opportunity to understand the role that ICT technologies may play in terms of adoption and use. This is explored in more detail in Chapters 20, 21, and 22, focusing on new mobilities, the Internet of Things (IoT), and e-commerce, respectively.

Relevance for Models used in Policymaking

After presenting these challenges an important question is: what could be the implications of all such future research for transport models to be used for real-world cases? We should not be too optimistic: state-of-the-art four-step and LUTI models do not include many of the insights that emerged from past research in the area of transport, land use, travel behavior, and activities. An important reason could be the additional costs and increasing complexity of such models, a lack of data, and maybe the (expected) limited benefits for decision-making.

But, nevertheless, models could benefit from the research as suggested above. First of all, it is important to realize that, despite the conceptual advantages, real-world applications of LUTI models have been relatively limited, more limited than several experts thought in the 1980s and 1990s. But, especially for strategic planning purposes, such models could add substantial value to four-step transport models. Future LUTI models could better address activities, as argued above. And several of the research challenges help us to better understand the complex relationships as addressed in Figure 3.2. One option is to combine LUTI models with ABMs, but again the high expectations of such models in the 1990s have not been materialized yet. The rapid evolution in data generation might stimulate the development of ABMs in the future and, if so, LUTI models might benefit. If better models were developed, they could lead to better informed decision makers, and thus to a higher quality of the final decisions and, next, the land-use and transport systems. In addition, such models can also help to better explain the mechanisms via which land-use and transport policies have all kinds of societally relevant effects (accessibility, the environment, safety, health, livability).

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