# THE SHORTCOMINGS OF THE CONVETIONAL FOUR STEP TRAVEL DEMAND FORECASTING PROCESS

**Miloš N. Mladenović**
*Virginia Tech, milosm@vt.edu*
**Aleksandar Trifunović**
*COWI Ltd., alti@cowi.rs*

Review paper

***Abstract:*** *Originating from 1960s, and improved in the decades to come, four-step travel demand forecasting process is the central column of transportation planning throughout the world. However, despite numerous improvements, this modeling approach suffers from several serious drawbacks. This paper presents detailed shortcomings of each of the four steps, and the process in general. In addition, considering that the demand for improved transportation planning is greater than ever, we identify several recommendations for improvement.*

***Keywords****: transportation planning, sequential procedure, planning process*

## 1. INTRODUCTION

Before the World War II, transportation planning did not include travel modeling [1]. In the United States, the Federal-Aid Highway Act from 1962 and Urban Mass Transportation Act from 1964 allocated federal financial aid to highway projects in urban areas with population over 50,000 only if they were based on a continuing comprehensive transportation planning process [2]. This act consequently established Metropolitan Planning Organizations (MPOs). During this period, the four-step travel demand forecasting (4S-TDF) model became the central column of transportation planning in the U.S. The work by Chicago Area Transportation Study (CATS), that developed models for trip generation, distribution, and diversion along with land use model, was institutionalized by the 1960s legislation [3]. This was a turning point when four-step procedure started to be the universal approach for transportation planning in the U.S., and later on worldwide.

During this period, specific guidelines for conducting transportation planning studies were developed by Bureau of Public Roads, which later became Federal Highway Administration (FHWA) in 1966 [4]. In the 1970s, improvements were made with the development and integration of disaggregate travel demand forecasting and equilibrium assignment methods. The conventional planning approach was established as a four step travel demand forecasting (4S-TDF) process including:

1. Trip generation stage, aiming at estimating the number of person-trips originating in, and/or ending in given zones [5].
2. Trip distribution stage, which consists of distributing each of the trip origins from a specific zone obtained in the first phase across various destinations [5].
3. Modal split stage, where each of the origin-destination trip volumes are distributed in the various alternative transportation modes [6].
4. Traffic assignment stage, where the modal trips from a given origin to a given destination on a given mode are assigned to network's links, or specifically routes between given origin-destination pair [5].

Later expansions of 4S-TDF followed the laws of 1991 (ISTEA) [7], and 1998 (TEA-21) [8]. These subsequent laws imposed higher requirements, and attempted to delegate more planning power to MPOs for coordination on the regional level. After this period, 4S-TDF included a feedback procedure, for refining the travel cost used in trip distribution and mode split steps, as well as update trip distribution for more modeling consistency [3]. However, the end of highway expansion programs in 1990's, with continuing growth in urban travel, low density land development patterns, and increasing environmental considerations led many transportation agencies to enter into strategic management and planning processes to identify the scope and nature of these changes [4]. Moreover, agencies were trying to develop strategies to address these issues, and to better orient their organization to function in this new environment.

In general, the traditional 4S-TDF procedure takes on a top-down approach [5], from the decision to travel, to destination and mode choice, up to ending with the route choice. Consequently, each level is treated separately and sequentially, with the output from the previous step providing input for the next step. Considering the case when there is no congestion, a single iteration through these steps is sufficient, as travel times are independent of travel volumes and their relation to the transportation infrastructure and systems. However, when congestion exists, travel costs depend on travel volume, and vice versa. In order to consider this relation, travel demands are used to revise current estimates of travel costs at the link level, leading to revised estimates of the modal-route costs. This in turn implies new demand estimates at all levels. This iterative process is repeated until some form of convergence is reached, where both demands and travel times have attained stable “compatible” values.

Once the model has been calibrated and validated for base-year conditions it must be applied to one or more planning horizons [6]. In order to do this it is necessary to develop scenarios and plans describing the relevant characteristics of the transport system and planning variables under alternative futures. Having prepared realistic scenarios and plans for testing, the same sequence of models is run again to simulate future system performance. The output obtained usually focuses on traffic volumes (quantity) and average speed (quality). For determining among alternative solutions a comparison is then made between the costs and benefits.

Despite the improvements, the structure of 4S-TDF remained unchanged for decades [6]. Each MPO is responsible for developing a regional transportation plan and a transportation improvement program. Majority of MPOs commonly use 4S-TDF [1]. A wider acceptance of 4S-TDF models is due to their easiness to understand due to the breaking down of traveler’s decision-process [9]. By this breaking down, it is easier to develop and verify the models, considering that this limits the number of influencing factors. Effect-cause relationships are more likely to be apparent. In addition, for many years, federal and state governments provided technical support, documentation, training, etc., only for sequential models. Finally, 4S-TDF was implemented in many commercially available transportation planning software [5], especially in the major software development effort, the Urban Transportation Planning System, which was distributed by the U.S. Department of Transportation.

## 2. THE SHORTCOMINGS OF 4STDF

The sequential and aggregate nature of transportation forecasting has come under much criticism [9]. Here, this section presents some shortcomings related to each of the four steps. In the continuation, general drawbacks and concerns related to 4STDF procedure and models are presented.

### 2.1. Trip generation

- The factors of trip generation in the traditional approach are typically limited to zone or household attributes, and do not include attributes of travel modes (e.g., insensitivity to transit accessibility [5]).
- Trip generation is usually performed using linear regression [5], and this statistics technique is primarily considered as a “descriptive” and not a “predictive” technique, thus limiting the capabilities of this forecasting step.
- A number of listed trip purposes is limited [1]. Trip purposes are limited to only six to eight trips purposes causing for example all shopping trips to be treated as same (e.g., going to a grocery store, going to a mall, etc.).
- The trip distribution phase is performed separately for each origin zone, thus limiting the holistic perspective on transportation demand.
- Some trips are estimated based on factors that are dependent on trips themselves (e.g. shopping-attracted trips are calculated as a function of retail employment, while the number of retail employee depend on shopping trips).
- Zone’s characteristics and relationships that dictate trip-generation are frequently assumed to be stable over the entire planning horizon.
- An important drawback is the lack of consideration for land use density in trip generation. This further relates to the issues of accessibility and omitting of non-motorized modes, neglecting the important relation between land-use policies and effects on walking/biking [1].
- Current theoretical approach for modeling trip considers travel demand as independent of the provided transportation system [10] and neglects levels of road congestion in the region [1]. By splitting trips into productions and attractions, conventional approach does not consider travel impedance or any general measure of accessibility. Moreover, conventional approach does not take into consideration the development of new transportation systems and facilities, which can have a significant impact on the volume of travel and distribution on the network. As a result, network performance measures or attributes (e.g., travel time and

cost) are prevented from influencing the frequency of travel [5].

- The current approach assumes that household members are independent in their trips decision, thus greatly simplifying the complexity of traveler decision-making. In addition, there are still issues in the procedures for validation and calibration of observed and estimated household trips, observed and estimated regional trips, trip percentage by purpose, identifying unrealistic population growth patterns, high trip generating facilities, etc.

### 2.2. Trip distribution

- A usual approach to trip distribution, using gravity models, although easy to understand and apply, suffers from serious drawbacks and limitations. One of the major issues is the assumption that average travel time would remain constant in the future as well as through the day (i.e. no consideration for peak hour congestion).
- Destination choice problem requires that spatial interaction models have a predefined set of alternative destinations to choose from. The behavioral dilemma results from the lack of knowledge of what the choice set actually is, or how is it different across individual travelers, and their different originating locations and trip purposes. The usual approach is to allow the access to all traffic zones (or all zones chosen by survey participants) to be in the choice set. Although this approach recognizes that more distant or less attractive zones will receive fewer trips, these are still unsupported assumptions for all possible trips – especially considering the effect on those choice sets by multi-destination trip chaining opportunities. As a consequence, the configuration of the gravity concept tends to overestimate the near trips and underestimate the far trips. Consider a simple example – assuming the constant travel time budgets, if road travel becomes faster, people will travel longer distances. This in turn adds to vehicle miles traveled, that relate to greater congestion [1].
- Another issues is that socioeconomic dynamics that may occur during the planning horizon are ignored [11].
- Workers from households are not matched to job types by income [1] so the monetary cost of travel is not well represented.
- As part of the equilibrium modeling, there is a neglect of the effect of vehicle speed on trip length [1].
- Some trip distribution models have restrictions that neglects trip with other purposes and at different time of day (e.g., trips with home to work purpose only have to occur during the morning peak). Furthermore, the issue is treatment of travel cost in predicting auto driver behavior, since 4S-TDF predicts trip distribution using a cost related primarily to distance [10].
- Specifically, trip distribution gravity models have been shown to be strictly equivalent, both functionally and numerically, to “behavioral” models (e.g., logit model), but the focus on gravity models prevails [5].
- There is a need for great efforts in error checking, especially for unreasonable outputs in zones with very high or very low productions and attractions, zones without productions and attractions, future year matrix, observed and estimated trip lengths, home-based work trip distribution, and intra zonal trips.

### 2.3. Modal split

- One of the great drawbacks of modal split step is the often focus on auto driver, auto passenger, or transit passenger. This limited focus neglects other travel modes that can have a significant share (e.g., walking or biking). Not including non-motorized travel modes neglects the fact that walking frequently has larger mode share than transit, in medium-sized urban regions [1]. The reasons for this situation could be found in the fact that, in practice, the main purpose of the model is to be used as a tool for capacity analysis of road network, analysis of the network development scenarios, or analysis of the public transport system, etc.
- In addition, small MPOs often omit modal split step [1], and run something called “traffic model”, that represents only auto traffic. This might be a significant neglect, considering that the effective share of walking or biking might be significant in a smaller area. In addition, some MPOs use

simple diversion curves, or run simple mode split models sensitive only to auto travel times.

- Modal split computations are made using empirical evidence or socioeconomic data. [10]. This frequently oversimplifies the decision-making of travelers, relating the choice of mode to be only the function of household income, without consideration of other factors. Even if the model considers factors such as travel time and cost characteristics, there is still a range of unconsidered factors (e.g., security, attractiveness, etc.). Furthermore, there is a general neglect for access time and walkability in transit utility calculation.
- In the utility functions for mode choice, time value is often assumed constant for all trip purposes, and throughout the entire day/week.
- Similarly to the drawback of trip distribution models, modal split models are also functionally equivalent to logit models. Consequently, they can be interpreted as a result of the "utility maximizing" choices of individual travelers [5].

### 2.4. Traffic assignment

- Traditional traffic assignment models primarily represent urban networks with major streets and highways, without consideration for pedestrian areas or bike paths [9]. Similar as in the case of modal split, focus is on modeling of motorized travel modes. The reason might be because models are usually used for analysis of investment impacts in the network or system with high investment costs.
- The supply side in this step is represented with aggregate link performance functions that are static in nature. Traditional assignment methods consider only average speed or, at best, have several speed groups. Considering a large number of vehicles passing over a roadway segment during a significant time interval, this is a great oversimplification [9]. The quality of the network's performance dominates the limitations of the traffic assignment process. The estimation of road capacities, used in determining the levels of service, is often oversimplified and inaccurate. For example, capacity estimates do not take into consideration truck volumes, highway geometry, and other factors affecting the capacity [1]. In addition, intersection control or ramp metering delays are ignored or oversimplified. Link spillback and potential queue gridlocks are often completely overlooked since queues are not represented in space. Furthermore, the relation between vehicle flows and link speeds in traffic assignment models are poorly represented [1].
- Since frequently projected congestion levels are inaccurate, this is also affecting the emission estimation, that depends on the vehicle input and their speeds [1].
- One of the major simplifications is also that all trips begin and end at a single point in a zone's centroid.
- There is a discrepancy between trip forecasting, which is done on a daily basis, and traffic assignment, that is typically done for peak hour.
- There are issues with discretionary and off-peak travel activity modeling, since traditional models do not take into consideration the need to model both time of day and day within the week [12]. The overall percentage of non-work or non-peak trips can be even up to 78% of annual trips. In addition, further issues arise taking into consideration that many daily trip chains combine peak hour trips. This is especially important due to the relation to non-transportation control measures (e.g., staggered work hours), or the potential for mixed urban activity centers that encourage midday walk or paratransit for personal business.

### 2.5. General shortcomings

Besides the specific shortcomings of each of the sequential step, there are general conceptual and technical weaknesses in 4S-TDF, that span though several steps and relate to the conventional planning procedure originating from the four-step modeling approach.

- Sequential nature of the procedure

By breaking down the trip planning process into steps, the conventional approach is not established upon a single unifying rationale that would explain or legitimize all aspects of travel demand from a common perspective [5]. This has been further supported by isolated research and development, focused on individual models or steps [3], thus furthering the discrepancy from the holistic procedure. As a result, the sequential nature, besides that it does not represent the actual human decision-making process, has other practical consequences. In addition, this procedure requires more abstract thinking, thus making in harder to approach decision makers and the public.

- The lack of behavioral considerations

Although extensive efforts have been put in developing theories and procedures for travel demand forecasting, high accuracy has not been achieved due to the nature of behavioral analysis of human decision-making [10]. There is a lack of realistic decision-making frameworks in place for both household and company-based travel decisions within the traditional approach [12]. This further relates to the neglect of the specifics of household interactions, such that if in a one-car household someone uses the car for a work trip other household members cannot use it for a different trip at the same time [13]. Moreover, behavioral considerations do not include decision-making of special or vulnerable groups of transportation users, such as elderly or disabled people [14].

- Aggregation of behavior

As one of the larger issues in the 4S-TDF procedure is that these models represent the average behavior of a group of travelers [9]. Consequently, aggregate models are frequently unable to predict the behavior of individual travelers. By using macro-level analysis on regional zones, the process makes assumptions on individual's traveler's value of time, modal preferences, household forms, etc. The introduction of trip purposes/classes (e.g., home-based work, home-based school, etc.) mitigates some of the simplifications in the assumptions, but predictive capabilities remain marginal [10].

- Deterministic nature of the models

Considering the sequential procedure, models are not simulation-based, but have a rather mathematical modeling approach [9]. Consequently, they are not suitable for testing out of different scenarios and cannot simulate rather delicate details – such as for example even/odd number plate congestion control [13]. Moreover, this converts into a practical problem when generation of alternatives is often generated "in-house", developing only few alternatives, and usually presenting only the "Preferred Plan" in comparison to "No Action Plan" [1].

- The iterative nature of the process

When travel costs are used to compute trip distribution and modal split, travel costs are not in equilibrium condition (i.e., loaded network). Because in 4S-TDF traffic assignment is completed last, the equilibrium cost of travel by different modes cannot be known during the previous 4S-TDF steps. This weakness frequently underestimates the impact of congestion on passenger vehicle travel costs. Consequently, there is the need for iterative feedback procedure, where equilibrium travel costs are fed back into trip distribution and modal split calculations, until network equilibrium conditions are approached. Moreover, a search for convergence is frequently not guided by a goal of clearly specified state of the system. In addition, the iterative approach is typically not efficient computationally, since it requires large number of iterations to reach the point of convergence [5]. This limitation is even more important in the case of real-world networks size. Finally, there is little understanding of the iterative process or expectation of why improved consistency of equilibration should be achieved at all [3].

- Approach to prediction

Another issue of conventional planning approach is that it heavily relies upon trend extrapolation instead of developing a vision towards a rational goal. Most frequently used linear extrapolation of the past trend, based on population size, auto ownership, transit usage, etc. is extending the same trend in the future [10]. This relates to several other issues. There is an immediate issue of causation vs. correlation, which requires the model to be validated in a wide range of situations [14]. Although an extrapolation is a useful procedure, the underlying question is should it be directly used for planning, because it continually reinforces the development of the previous trends, without consideration of their long-term effects and development towards a rational goal. Thus, this approach is essentially denying the purpose and function of transportation planning in producing a desired transportation system or facility. Moreover, not checking whether the extrapolated trends result in the adopted long-term goals, a planner is not relating to the need for developing policies, actions, and construction/operation projects that would modify present trends.

- Integrated land-use and transportation models

One of the major drawbacks in the use of transportation models in practice is the absence of any feedback from transportation models on land use. This is essentially neglecting the fact that highways and transit investments not only respond to land use, but that they shape land use as well. For example, very few MPOs use some sort of land use model to allocate household and companies to the analysis zones in the future [1]. This further relates to misunderstanding of the relation between urban environment and transportation. Consequently, the impact of transportation on urban form (e.g., land use distribution, formation of sub-centers, establishment of pedestrian zones, sprawled, low density, segregated urban patterns [15]) were not given adequate consideration. An example of a related issue would be lack of consideration for the relations between locations of cooperating companies (e.g., supplier of raw material and production facility) and congestion levels [1]. As a result, even if they exist, integrated land-use and transportation models fail to provide the support for land use policies.

- Trip chaining

One of the frequently mentioned issues of four-step models is the lack of consideration for trip destinations in urban areas that are a part of the multipurpose, multi stop daily travel chains (e.g., work to shop to home trips) [12]. Furthermore, These destinations are selected based on their proximity to the commuting path, with the influence of the commuting mode too [10]. Ignoring this activity of trip chaining, conventional models fail to consider related time and cost savings. Finally, there is lack of understanding in the relation between trip chaining and congestion, that should usually lead to greater trip chaining in congested networks [1].

- The effects of congestion

In general, there is a lack of consideration of the effects of congestion in the four-step procedure [5], especially its effect on the time of travel [1]. One of the major pitfalls of traditional modeling approach is the ad hoc treatment of demand externalities, i.e., the effects of network and destination congestion. Various feedback loops introduced to represent the effects of congestion may or may not converge to a stable distribution of the respective demands. Consequently, the nature of the travel demands obtained after performing different feedback iterations may not entirely be clear. For example, in the case of traffic assignment, the solution obtained with the incremental approach clearly constitutes an approximation to the exact solution. The estimated solution that would be obtained with increments of one traveler where that is feasible. However, the precision of such an approximation is usually unknown. Furthermore, the same difficulties are there when several dimensions of travel demand are combined (e.g., multimodal network assignment). For example, this relates to the issue with fixed time-of-day factors, which cannot answer many policy questions related to addressing peak traffic spreading when peak period pricing is introduced.

- The relationship between trip frequencies and travel costs

This issue relates to the question of transportation costs or traditional forms of cost-based accessibility as the most important determinants of daily or weekly schedules of trip activity [12]. A part of the issue may be in the nature of past survey data. Cross-sectional trip sampling for a single day may not contain the information required to develop a behaviorally sensible and statistically consistent relationship. Moreover, there is a notion that transportation is a separate good, purchased independently from other household needs. But in the long-term perspective, other non-travel factors become important (e.g., housing, food, health) as they compete for the travel costs.

- Input data issues

Another issue is relying heavily upon household travel survey and the U.S. census data that frequently does not have sufficient data for developing and calibrating models of greater complexity required for adequate modeling [10]. As an example, future household auto ownership level is generated from the correlation to the existing auto ownership, coming from census data [1]. Moreover, the usual approach is that income is forecasted to stay the same in relation to the inflation. However, this masks actual changes observed in U.S., where for example, lower income groups have experienced a large drop in real income, along with some middle-income groups that have lost income. Another example is non-home-based trips, where neither origin nor destination is at the home and, therefore, no socioeconomic data can be associated with or used to constrain these trips [13].

- Output data issues

Some of the critique relates to the issues of the output measures used in the process. This relates to inadequate plan evaluation criteria, where outputs from models are measures of congestion (e.g., level of service on network links, person-hour of travel delay) [1]. As a result, current model output rarely present the evaluation of other economic outcomes.

- Induced travel

A recent critique of four-step modeling process related to the issues of induced demand, frequently originating from a construction of a new facility (e.g., changes in route or change in mode of travel) [14]. Due to its strong relation to user decision-making, this behavioral component is difficult to model and predict precisely. Current models do not embody elasticity or feedback mechanisms that directly or indirectly weigh generative impacts [16].

- Environmental assessment

Current models have limited capabilities for environmental impact assessment – for air quality, noise and vibration, cultural heritage, disruption during construction, landscape effects, land-use effects, water quality and drainage, geology and soil considerations [14], especially due to their inability to assess policies that may reduce the environmental impacts of car-based travel [17].

- Neglecting influence of new systems and technologies

Another set of identified issues is the capability of these models to incorporate the effects of demand management approaches, such as varying working hours, car-polling, telecommuting, road use charging, etc. [14]. This is essentially ignoring additional consideration for the supply side of the models, and consequently resulting in dramatic reduction in innovation and creativity in transportation system planning [10].

- The unclear desired roles of different transportation modes

The desired roles of different transportation modes are usually not clearly defined [10], with a general disregard for paratransit, bicycles, and pedestrians. For example, the dominant planning philosophy in the 1950-1970 period was focused upon the passenger vehicle-based travel. Mass transit was supposed to supplement it during peak periods and serving non-drivers. This resulted in the focus on highways, with particular emphasis on freeway construction. Process went further to assume that bus service can operate on existing urban network, with only some places considering rapid rail transit, and without any consideration for light rail transit. The plans thus resulted in increasing auto dependency.

- Issues with social justice in accessibility

Recent critique of four-step process relates to the fact that transport modeling that starts from current travel patterns may actually reinforce the existing differences in mobility and accessibility between various population groups [18]. This assertion implies that by ignoring the fact that current travel patterns are reflections of the way in which transport resources have been distributed in the past, transport models thus create an inherent feedback loop. The models use the high trip rates among car owners in the present to predict high trip rates among car owners in the future. These predictions favor policies that support this growth through improved services for car owners (e.g., road building or investment in costly rapid rail). These improved services, in turn, result in higher trip rates among car owners, thus circulating the process again.

## 3. CONCLUSION

The demands on urban transportation planning are now greater than ever since the range of issues that need to be addressed are continually expanding. For example, analytical requirements are more comprehensive, with some states having requirements beyond those of Federal Agencies [4]. A growing number of agencies across the U.S. are abandoning established traditional modeling techniques and exploring advanced practices in travel forecasting (e.g., tour- and activity-based models, land use models, freight and commercial movement models, statewide models, and dynamic network models). However, there are still many efforts left to assist urban transportation planning agencies to meet increasing demands and requirements. Most urban transportation planning agencies have not upgraded their travel forecasting procedures for some time and there is a need for a large scale effort to carry out this task. As a general recommendation, many authors are arguing for the return to the original concept of an integrated relationship among travel choices and road network travel times and costs, as opposed to a mechanical view of travel forecasting [3, 13]. Here, the next section presents some specific and general recommendations for improvement of the planning procedure.

### 3.1. Recommendations

- There is a need for dynamic supply models that require a more detailed understanding of the performance of network facilities, and for the development and implementation of network management and operations policies.
- Data collection problems could be handled by performing a household survey every year, or on the same household over time as panel survey [1]. Survey can be also used to support land-use modeling by asking questions on household and company location behavior. In addition, data can be collected on time-use by providing the information of what individuals do over the course of one or several days, including both activities in the home and outside the home [19]. Finally, there is a need for data collection at the smaller time interval (e.g., 15 min) for providing a higher level of details.
- The budget for data collection might be up to 20% of the overall cost of the model development. In order to avoid minimizing on data collection, these costs should not be subject to competitive tendering. That leads to reduction in model quality and usually occurs in the case of engagement of same consultant for both data collection and model development. It is better to split these two assignments or to specify a fixed value for inclusion in the pricing to cover the cost of surveys.
- Regional Transportation Plans should acknowledge feedback effects from transportation improvements on land use, and thereby not ignore these effects on project and plan evaluation [20]. Moreover, there is a need to model firms and households as point locations [1].
- In order to develop a robust, activity-based approach, there is a need to combine multiple trips into a single activity. Consequently, the destinations, modes, and routes in each segment of the trip would be interdependent [5].
- Freight planning needs to be integrated within the traditional transportation planning and programming process [21]. This requires identifying corridors and facilities of statewide or regional significance, and linking freight and land use planning in the transportation planning models. In addition, special focus needs to be dedicated to the goods movement models to represent the shipment of commodities by truck type and time of day, with included terminal costs [1].
- There is a need for incorporating safety into transportation planning goals, objectives, performance measures, analysis procedures, tools, data collection, etc. [22].
- Improvements in relation to accessibility and access management are one of the essential recommendations. On the practical side, planning process needs to prepare an access management plan as a component of an area-wide or corridor plan, and address access management in community planning as a means of accomplishing a broad range of transportation and land use goals [23, 24]. Moreover, some theoretical considerations of accessibility call for a social justice approach that would focus on the distribution of transport investments over population groups and the related performance of the network for each of these groups [18].
- One of the general recommendations is to take into consideration the issues of environmental sustainability [25]. Current practice relating to transportation and air quality is that long-range transportation plans and programs are completed for a 20-year forecast period. For transportation planning processes to integrate environmental sustainability objectives, the forecast period must be at least 40 years. In addition, a complete range of environmental impacts (e.g., the impacts of noise on the breeding and migration patterns of birds) still needs to be considered in transportation planning models [25].
- Transportation planning process should also conduct forward-looking analysis of demographics, market preferences, and job location trends, to be responsive to the emerging needs of future generations and user culture.
- Transportation planning models need to take into the account the inevitable relation to continuous technological developments (e.g., social networks, self-driving vehicle, etc.).

- Finally, as one of the most important recommendations is a need for a greater application of the behavior principles that underlie the established microeconomic and social science theories. This goes hand-in-hand with the necessary focus on activity-based models. These models allow for the splitting of time-of-day into much finer temporal units than traditional models [13]. These models base on individual behavioral properties by computing relative utility of completing a trip for individual travelers, and are better for minimizing modeling bias, maximization of model statistical efficiency, improved policy sensitivity, and improved model transferability. Although disaggregate models appeared in 1980s [9], and there is a broad consensus within the activity-travel demand modeling community that disaggregate modeling methods have considerable advantages over more aggregate approaches, they still need to be widely deployed in practice. An example of existing model is an open-source project called the Transportation Analysis and Simulation System (TRANSIMS) [23].

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