Development of a Travel Demand Modeling Training Manual

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ABSTRACT

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Travel demand models are widely used across the United States by various transportation planning and engineering firms and agencies to provide decision-makers with information that represents how travel demand changes in response to different outputs. These models are highly complex, involving many processes that make the entire model useful in transportation planning. As these models are widely used, there is a need to develop training materials to help those using the models understand the basics of travel demand modeling and the software used. The purpose of this project was to develop a training manual to help users, specifically students of an urban transportation planning class at Brigham Young University, understand the basics of travel demand modeling using Cube, a travel demand modeling software. The training manual consists of an overview of travel demand modeling and Cube, step-by-step instructions to build a model in Cube, explanations of the individual model steps, and an analysis of the model output.

Key words: Cube, four-step model, travel demand model.
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1 INTRODUCTION

1.1 Problem Statement

Transportation decision-makers are faced with decisions that will have a direct impact in their areas of jurisdiction. These decisions are often the answers to specific transportation-related questions such as what makes people travel or how many people will travel on a route (Wu et al., 2012). Planning organizations and agencies need to make transportation-related decisions that will impact not only current travel but also future travel within an area. Some of the questions commonly asked by these agencies as they make transportation-related decisions include the following (Castiglione et al., 2015):

- How will a transportation system in a specific area perform in 30 years?
- How would economic, demographic, or land use changes affect the transportation system performance?
- Will a new transit route attract more riders?

Decision-makers needing to answer transportation planning questions include metropolitan planning organizations (MPOs), transit agencies, departments of transportation (DOTs), counties, cities, and others. These decision-makers need an easy-to-understand method that helps them compare multiple alternatives to identify future investments and policies for their jurisdictions (Castiglione et al., 2015). A widely used tool used to present information to these decision-makers is the travel demand model. These models, therefore, are created to assist these
decision-makers by providing relevant quantitative information about travel demand and the transportation system performance to evaluate alternatives so the decision-makers can make informed decisions (Castiglione et al., 2015). Since the development of travel demand models, various model types and approaches have been developed to answer transportation planning questions. Two types of models are most widely used in the United States (U.S.): trip-based models and activity-based models. Currently, these travel demand models are created using computer software that makes the process more robust than the original manual calculations.

1.2 Research Purpose and Scope

The purpose of this project is to develop training material in written form to help students learn and understand travel demand modeling, specifically travel demand modeling in Cube. The training material consists of a written manual with an overview of travel demand modeling that is focused on trip-based models, a brief explanation of the software used, instructions on how to create a trip-based model and analyze it using computer software, and a set of assignments to test the learning of those using the manual. The manual is meant to not only teach how to create a trip-based model but also to understand how these models are used to address transportation planning questions in practice and how to interpret the outputs of the models. The development of this manual required in-depth study of travel demand models and available computer software and also the development of questions that would most effectively assess the knowledge of those using the manual.

1.3 Organization of Report

This report contains four chapters. Chapter 1 presents the problem statement, research purpose and scope, and organization of the report. Chapter 2 provides a literature review of
travel demand modeling, including a history of transportation planning, a description of travel
demand models, and a sample of computer software available to build these models. Chapter 3
describes the process followed to develop the training material, including the process of selecting
computer software and learning how to use it, developing the training manual, reviewing and
editing the training manual, and preparing the final version of the training manual. Chapter 4
presents conclusions associated with this project.
2 LITERATURE REVIEW

2.1 Overview

This chapter provides information about the literature review completed for this project. This literature review consists of three major sections: a history of transportation planning, a description of travel demand models, and a description of a sample of computer software available for travel demand modeling.

2.2 History of Transportation Planning

Transportation planning has its origins in the early 1900s, where major changes were occurring in U.S. cities. Before the 1920s, most movement of people and goods were by railroad (Jones, 2017), and the automobile was a very expensive transportation option that only a few could afford. Since the majority of the population did not use motorized vehicles, there were few roads that connected cities with the countryside (Weiner, 1997). As the automobile became more popular and widespread, the need for more highways connecting the different cities was recognized. A description of the major findings and improvements from the 1930s through the 1970s is presented in the following sections.
2.2.1 The 1930s and 1940s

During the 1930s and 1940s, the use of automobiles increased throughout the U.S. The production of automobiles increased from 70,000 in 1945 to 2.1 million in 1946 to 3.5 million in 1947 (Weiner, 1997); the need for highways connecting major cities was apparent with such an increase in automobile production. Since massive highways were a new concept in the country, there was not enough information or data to help plan for the increased traffic that the U.S. was experiencing. To obtain more information about the road characteristics and traffic volumes, several studies were conducted to map the transportation highway system and determine the capacity of the current highways using observers, cameras and aerial surveys (Cron, 1975). In addition to collecting physical highway conditions data, there was also a need for urban travel data to forecast the future travel patterns and plan the cities accordingly.

Although there was a need for urban travel data, there was not enough funding to perform the necessary studies throughout the country. To obtain this data, the Federal Aid Highway Act of 1944 allowed the allocation of funds for the study of travel patterns in the U.S. One of the first methodologies developed to obtain this information was the home-interview origin-destination survey. In this survey, household members were asked questions about the number, purpose, mode, origin, and destinations of all the trips they made during the day (Weiner, 1997). This was valuable information for designing and planning the transportation network of the city or state.

The data collected through surveys and studies were important for the urban transportation planning process being developed. The data were used to describe the current (existing) travel patterns and future traffic patterns using past growth rates and extrapolating them (Weiner, 1997). The planning and design process of the cities was exclusively done by planners and engineers who determined the needs and physical layout of the city. During the
1940s, there was no public involvement in decision-making. Transportation planners and engineers set goals based on the information available (previous studies and surveys) and created a plan to achieve those goals (Barnes and Davis, 1999). The 1930s and 1940s were a discovery phase in which highways, data collection, and travel forecasting were new concepts in the U.S.

### 2.2.2 The 1950s

During the 1950s, several findings and improvements in analytical techniques for transportation planning were accomplished. Using the surveys, a relationship was found between land use and the trips made (Black, 1990). These are the basic concepts applied in what is known today as trip generation. In 1955, the first notions of trip distribution using the gravity model were developed. At this time, the gravity model was developed using origin-destination surveys, and it was determined that home-based trips are attracted to different land uses based on “automobile driving time” (as a measure of distance) (Voorhess, 1956). In 1957, findings regarding traffic assignment were published, in which trips were assigned to minimum-time routes using computer algorithms (Weiner, 1997).

Several studies applying the first transportation planning concepts were conducted during the 1950s. The Detroit Metropolitan Area Traffic Study (DMATS) performed from 1953 to 1955 used trip generation, trip distribution, and traffic assignment to forecast trips in the area. For the trip generation step, trip generation rates were developed based on land use data. For trip distribution, a simplified version of the gravity model with growth factors was used. The last step, traffic assignment, used speed-distance ratios to determine the routes of the trips generated and distributed. Almost all of the work for this study was performed manually, with the help of computer programs in only a few of the steps (Weiner, 1997).
Another important study during the 1950s was the Chicago Area Transportation Study (CATS). CATS was the first study to apply the four-step model: trip generation, modal split, trip distribution, and traffic assignment. The first step, trip generation, was used to determine the person trip ends as a function of land use. The second step in the study, modal split, divided the person trips generated in the previous step into categories of public transportation and private car. The third step, trip distribution, connected the trip ends generated in the first step. The fourth and last step, traffic assignment, estimated the route that each trip would take using a minimum-path algorithm that calculated the optimal route based on minimum travel time. This travel time included out-of-pocket costs converted to equivalent time. The main output of this analysis was traffic volumes on the network (Black, 1990).

As the DMATS and CATS studies made major contributions to the development of transportation planning, the Federal Aid Highway Act of 1956 also marked an important improvement for the planning process. Before 1956, the interstate system consisted of 40,000 miles of roadway across the country. The Federal Aid Highway Act expanded the interstate system to construct another 1,000 miles and authorized $25 billion for the construction of the system in a period of 13 years (1957 to 1969). The act also stated that 90 percent of the cost would be covered by federal funding (Weingroff, 2017).

2.2.3 The 1960s and 1970s

During the 1960s, federal regulations standardized the urban planning process. The Federal Aid Highway Act of 1962 was the first act in the U.S. to outline the requirements for transportation planning. This act had three major influences in the planning process. First, it established that areas with a population of 50,000 or more required a continuing, comprehensive,
and cooperative planning process, known as the 3Cs of planning (TRB, 2007). Second, it established that the transportation planning process should be done by metropolitan areas rather than cities, making the transportation system more connected and uniform (Weiner, 1997). Lastly, it required each metropolitan area to have an urban transportation planning process in place in order to receive federal funding (TRB, 2007; Weiner, 1997). In 1965, after the implementation of the Federal Aid Highway Act of 1962, 224 metropolitan areas had an urban planning process in progress, and MPOs were established (Weiner, 1997).

Another type of federal regulation included in the urban planning process involved environmental concerns. As metropolitan areas implemented the Federal Aid Highway Act of 1962 requirements, concerns regarding congestion led to high opposition towards highway projects throughout the U.S. To address these issues, two new acts were created: the National Environmental Policy Act (NEPA) in 1969 and the Clean Air Act (CAA) in 1970. NEPA required extensive environmental studies that outline the impacts of projects regarding air, water, noise, historic sites, and neighborhoods. The CAA established air quality standards for automobile emissions and banned lead in gasoline (Solof, 1997).

All of the different regulations during the 1960s and 1970s shaped the urban planning process. The 3Cs of planning outlined in the Federal Aid Highway Act of 1962 included four steps or phases: data collection, analysis of data, forecasting of activity and travel, and evaluation of alternatives (Weiner, 1997). As these four steps were necessary to receive federal funding, it was also necessary to develop efficient methods that would help with the transportation planning process, and travel demand models were therefore used to more efficiently forecast travel patterns and evaluate different alternatives.
2.3 Travel Demand Models

As transportation planning evolved through the years, various tools were developed to assist the transportation planning process. Some of these tools were the Rule of Thumb, used in California from the 1920s to the 1940s (Jones 2017), and the travel demand model (developed in the 1950s). The most widely used tool today is the travel demand model. A travel demand model is a tool used by transportation planners and engineers to provide decision-makers with information that represents how travel demand changes in response to different inputs (Castiglione et al., 2015). These models provide quantitative information about travel demand and transportation system performance to compare and evaluate different transportation alternatives and policies, as well as demographic and economic trends (Castiglione et al., 2015). These models are useful for evaluating changes in population and employment, impacts of congestion pricing, changes in parking and/or fuel costs, changes in High Occupancy Vehicles (HOV) policies, transit ridership evaluation, HOV lanes and carpool incentives, and freight planning, among others (Cambridge Systematics et al., 2012).

Travel demand models are built based on a need. Therefore, it is important to identify the purpose of the model in addressing the need, which will determine the level of detail, data, specific requirements, funding, software, and model structure needed to achieve the desired output. For example, by federal regulation an urban area of 50,000 people must have an MPO in place. These MPOs need to address federal requirements in order to obtain federal funding for the project being evaluated. However, if the area has more than 200,000 people, the area is called a Transportation Management Area (TMA), and additional requirements need to be met (Cambridge Systematics et al., 2012). The needs and requirements of the project will define the type of model needed to address them.
In developing a model, several considerations need to be accounted for by the model. Some of these considerations are transportation modes and systems, population and demographics, employment and housing characteristics, land uses in the area, geographic size, tourist areas, travel conditions, policy issues, stakeholders, and timeframe of the project. In addition to these considerations, performance measures and metrics for the project need to be identified. These include metrics such as vehicle-miles traveled, vehicle-hours traveled, volume-to-capacity ratios, travel speeds, travel time reliability, level of service (LOS), hours of delay, and hours of congestion (Cambridge Systematics et al., 2012). Identifying who should be involved and what is needed will assist in generating more accurate and useful results without major setbacks. Another important step in the model development process is to calibrate and validate the model (Cambridge Systematics et al., 2012; Castiglione et al., 2015). Too often analysts trust the results of the model blindly; however, calibration, validation, and engineering judgment should be used in order to accept and use the model results.

There are several types of travel demand models that could be used in a project, such as sketch-planning models, strategic-planning models, trip-based models, and activity-based models (Castiglione et al., 2015). The use of one model over another will depend on the needs of the project as well as availability of a model. The following sections focus on the last two model types, which are trip-based models, commonly known as the four-step model, and activity-based models. The trip-based models section is primarily based on the National Cooperative Highway Research Program (NCHRP) Report 365: Travel Estimation Techniques for Urban Planning (Martin and McGuckin, 1998) with additional information from the NCHRP Report 716: Travel Demand Forecasting: Parameters and Techniques (Cambridge Systematics et al., 2012).
Although the NCHRP Report 716 is most current, it was found that the NCHRP Report 365 contained more detailed information relevant to the final product of this project.

### 2.3.1 Trip-Based Models

Trip-based models have been used in various transportation planning agencies and firms since 1950, when the first notions of analytical techniques began (Weiner, 1997). The trip-based model uses trips as the analysis unit (Cambridge Systematics et al., 2012; Castiglione et al., 2015). A trip is defined as a person or vehicle traveling from a point of origin to a point of destination without intermediate stops (Cambridge Systematics et al., 2012). Figure 2-1 shows an example of a trip.

![Figure 2-1. Trip from home to work.](image)

Trips can be classified by purpose as defined by the model; however, three general categories are used: home-based work (HBW), home-based other (HBO), and non home-based trips (NHB) (Cambridge Systematics et al., 2012). These categories could be more specific and include categories such as home-based school, home-based shopping, non home-based work, etc. Trip-based models are widely used today for regional, subregional, and project-level analysis and decision-making (Castiglione et al., 2015).

In a trip, an origin is the starting point of the trip, and the destination is the ending point of the trip. However, two other terms are used in travel demand modeling: productions and
attractions. Productions are what produce the trips (the home in a home-based trip and the origin of a non-home-based trip), and attractions are the zones that the trips are attracted to (non-home end of a home-based trip and the destination of a non-home-based trip) (Martin and McGuckin, 1998).

Such a trip-based model is also referred to as a four-step model, which consists of four main components: trip generation, trip distribution, mode split (or mode choice), and traffic (or trip) assignment. This type of model uses traffic analysis zones (TAZs) as a geographic unit including common demographic and socioeconomic characteristics (Cambridge Systematics et al., 2012). The following sections present an overview of trip generation, trip distribution, mode split, traffic assignment, and the data needed for trip-based models.

2.3.1.1 Trip Generation

The first step, trip generation, estimates the number of person or vehicle trips to and from activities in a study area. This step is related to land use, automobile ownership, income, household size, density and type of development, availability of public transportation, and the quality of the transportation system, among other factors that represent the TAZs. This step usually uses disaggregate models in which households are classified by size and/or income to determine the amount of travel in the study area (Martin and McGuckin, 1998).

The trip generation step estimates the number of productions and attractions by each zone in the study area. The productions in the study area are estimated based on the number of households in the zone. Household characteristics affect trip making, and households are therefore generally classified by household characteristics such as household size; number of workers, children, or vehicles; or income level (Cambridge Systematics et al., 2012). The
attractions are determined using employment by type and number of households (Martin and McGuckin, 1998). These are suggested data for the estimations of productions and attractions; however, it is up to the analyst to determine the data that will be used in the model. The number of trips (productions and attractions) generated by a zone is further divided by trip purpose (e.g., work, school, shopping, etc.) (Martin and McGuckin, 1998).

2.3.1.2 Trip Distribution

The second step, trip distribution, connects the trip productions and attractions between the zones. This process includes linking the trips between zones and also determining the number of trips that stay within the zone (intrazonal trips). The results of this step are trip tables showing the number of trips between the zones by purpose. This step is important in the model because the trips between zones are then assigned to the available transportation networks (Martin and McGuckin, 1998).

The distribution of trips depends on the land use patterns and network characteristics in the study area. These distributions are a function of the amount and type of land development and the spatial separation between zones. The most common model for trip distribution is the gravity model. As the name suggests, this model is based on Newton’s Law of Gravity. Similar to Newton’s Law of Gravity, the transportation planning gravity model is based on the theory that the number of trips between two zones (TAZs) is directly proportional to the productions and attractions (trip ends) and inversely proportional to the separation between them (e.g., travel time). This means that zones with higher activity (productions and attractions) will have more trips, and zones that are farther apart will have less trips between them. The mathematical expression for the gravity model is shown in Equation 2-1 (Martin and McGuckin, 1998).
\[ T_{ij} = P_i \frac{A_j F_{ij} K_{ij}}{\sum_{k=1}^{n} A_j F_{ij} K_{ij}} \]  

(2-1)

Where:

- \( T_{ij} \) = number of trips produced in zone \( i \) and attracted to zone \( j \)
- \( P_i \) = number of productions in zone \( i \)
- \( A_j \) = number of attractions in zone \( j \)
- \( F_{ij} \) = friction factor relating the spatial separation between zone \( i \) and zone \( j \)
- \( K_{ij} \) = optional trip-distribution adjustment factor for trips between zone \( i \) and zone \( j \)
- \( k \) = zone
- \( n \) = total number of zones

The friction factor variable quantifies the impedance or measure of separation between the two zones. These factors are inversely related to the spatial separation between the zones, which means that a higher travel time between two zones leads to a lower friction factor and results in fewer trips between the two zones (Martin and McGuckin, 1998).

In order to distribute the trips between the zones, two steps are usually used: estimation of friction factors and implementation of the gravity model. Estimation of friction factors requires the estimation of travel impedances between all of the zones. The impedance uses time and distance estimates, which require the link lengths and link speeds. Both of these values are usually obtained from the network files. With these values, the shortest travel time paths and travel impedance can be calculated using mathematical functions and parameters defined by the modeler. Friction factors often differ among trip purposes, and therefore different friction factors should be considered for the different trip purposes previously defined (Martin and McGuckin, 1998).

Once the friction factors are defined for each of the trip purposes in the model, the gravity model can be applied to estimate the trips between the zones. The friction factors can
then be calculated using lookup tables or friction factor equations that are used in the gravity model equation (Equation 2-1). Once this has been determined, the gravity model can be implemented to distribute the trips between all of the zones in the area, which will result in trip tables by purpose. The trip distributions also include an iteration process to balance the productions and attractions, so the total productions and attractions calculated match the total productions and attractions for each zone (Martin and McGuckin, 1998).

### 2.3.1.3 Mode Split

The third step, mode split (or mode choice), divides the zone-to-zone trips obtained from trip distribution by the modes considered in the analysis. The modes included in this step depend on the data available to the analyst. The modes could include only automobile and transit, or they could include automobile, transit, and non-motorized modes. They could also include very specific modes such as drive alone, carpool, local bus, express bus, rail, etc. (Martin and McGuckin, 1998).

Most mode split models use logit models to divide the trips among the modes in the analysis. Logit models are mathematical relationships that estimate the probability of choosing a specific mode. There are multiple types of logit models; however, the general equation of the basic logit model is shown in Equation 2-2 (Martin and McGuckin, 1998).

$$ P_i = \frac{e^{u_i}}{\sum_{k=1}^{k} e^{u_i}} \tag{2-2} $$

Where:

$ P_i $ = probability of a traveler choosing mode $ i $

$ u_i $ = linear function of the attributes of mode $ i $ that describe its attractiveness, also known as a utility of mode $ i $

$ k $ = number of modal alternatives
The utility function \( u_i \) variable in the logit model) takes into account in-vehicle travel times for each mode, out-of-vehicles travel times for each mode (walk, wait, and transfer times), cost of each mode, and different coefficients (constants) that describe the likelihood of choosing a specific mode. Equation 2-3 shows an example of a utility function (Martin and McGuckin, 1998).

\[
\begin{align*}
  u_i &= a_i + b_i \times IVTT_i + c_i \times OVTT_i + d_i \times COST_i \\
  (2-3)
\end{align*}
\]

Where:

- \( IVTT_i \) = in-vehicle travel times for mode \( i \)
- \( OVTT_i \) = set of variables measuring the out-of-vehicle travel times for mode \( i \) (walk, wait, and transfer times) may all be kept separate or combined, depending on the calibrate structure
- \( COST_i \) = the cost of mode \( i \)
- \( a_i \) = mode-specific coefficient (constant) to account for mode bias not measurable with the LOS variables
- \( b_i \) = coefficient for IVTT variables of mode \( i \)
- \( c_i \) = a set of coefficients for OVTT variables of mode \( i \)
- \( d_i \) = coefficient for COST variable of mode \( i \)

To determine a utility function, three variables may be included: modal LOS (e.g., automobile in-vehicle time, transit in-vehicle time, wait time, walk access/egress time, automobile access time, transit fare, parking cost, number of transfer), traveler characteristics (vehicle availability, household income, gender, age, worker/student status), and area characteristics (development density, pedestrian environment). The minimum information needed for mode-split models is the LOS variables because this information is used to analyze the effects of changes in LOS (e.g., fare increases, parking costs, etc.). The modal LOS should be available for each origin and destination zone pair, which are obtained using a skimming network process. The network skimming process sums the impedances that have the lowest cost
for a traveler along selected paths (Cambridge Systematics et al., 2012). This needs to be done for each mode included in the analysis. Because a skimming network process is needed for each mode, a network for each mode is needed. However, the individual modal networks are often subnetworks of the highway and transit networks. For example, for non-motorized modes, the network could come from a highway network without the links that only allow motorized vehicles such as freeways and ramps (Cambridge Systematics et al., 2012).

2.3.1.4 Traffic Assignment

The last step, traffic assignment, is done for both highway and transit networks. The level of precision of the traffic assignment step will depend on the level of detail in the network and the size of the system. For example, the analysis could be performed at a regional level or at a corridor level (Martin and McGuckin, 1998).

The traffic assignment process is done using a relationship between the assigned volume and the delay due to congestion. The more volume that is assigned to the network, the lower the travel speeds. Traditionally, a volume-delay function, called the Bureau of Public Roads (BPR) curve, is used to estimate the link travel times after the volume is assigned. This basic BPR curve equation is shown in Equation 2-4. Various volume-delay curves could be applied for the different facility types in the study area, so the volume-delay coefficients could be modified to meet the study area requirements (Martin and McGuckin, 1998).

\[ T_c = T_f \times \left(1 + \alpha \times \left[ \frac{v}{c} \right]^\theta \right) \]  

(2-4)
Where:

\[ T_c = \text{congested link travel time} \]
\[ T_f = \text{free-flow link travel time} \]
\[ v = \text{assigned link traffic volume (vehicles per unit of time)} \]
\[ c = \text{link capacity (vehicles per unit of time)} \]
\[ \alpha, \beta = \text{volume-delay coefficients (typically 0.15 and 0.4, respectively)} \]

Traffic assignment methods are designed to assign traffic volumes in a way to reach equilibrium in the system. This is often done through a combination of an incremental and iterative process. However, most software packages have a traffic assignment process in which assignments are applied until all travel paths have the same travel times (user equilibrium) (Martin and McGuckin, 1998).

Before the traffic assignment step takes place, two other sub-steps should be completed: automobile occupancy and time-of-day factoring. Automobile occupancy factors are used after the mode split step to convert automobile person trips to vehicle trips that can be assigned to the network. The use of occupancy factors is important because it better estimates the number of automobiles in the network. If no occupancy factors are used, the model would overestimate the number of automobile trips, and the levels of congestion would be far higher than they should be. Before applying occupancy factors to a model, the modeler should ensure that the output of mode split is in person trips and not in vehicle trips; if the mode split output is in vehicle trips rather than person trips, the automobile occupancy step is not necessary. Overall, the automobile occupancy rates have declined in past decades. Factors that could have influenced this decline are the increase in automobile ownership and decrease in household size. Automobile occupancy rates can be based on urban area population and trip purpose, time of day, income level, or facility type, as follows (Martin and McGuckin, 1998):
• *Automobile occupancy by urbanized area population and by trip purpose.* Trip purpose is the most significant factor in determining automobile occupancy rates. People going to work most commonly drive alone, whereas shopping and recreation trips are more likely to have higher occupancies.

• *Automobile occupancy by time of day.* Automobile occupancy is also related to time of day. Trips made in the AM peak are usually HBW trips, which are normally drive-alone trips. A similar pattern occurs during the PM peak. Generally, peak periods have lower automobile occupancy rates than off-peak periods.

• *Automobile occupancy by income level.* Generally, low-income travelers have higher automobile occupancy rates than high-income travelers. Automobile occupancy rates are also often related to income level and parking cost in the destination area.

• *Automobile occupancy by facility type.* Generally, vehicles travelling in higher-volume roads (e.g., freeways) have lower automobile occupancy rates than arterials and collectors because of the types of trips using those facilities. This may be related to the trip length in time or distance. For example, HBW trips are often the longest trips on weekdays, which are often made on freeways. Other trips such as shopping trips are more likely to be made on arterials.

The mode split output typically includes the total trips over a 24-hour period. However, often the analysis periods are specific times of the day. There are various applications requiring analysis at specific periods such as analysis of highway facilities, emissions, etc. Peak-period speeds and volumes are essential to assess the LOS of a facility, corridor, or area. In addition to geographic locations, time-of-day factoring can provide information to help identify unique
peaking characteristics. For example, an area with a large university or hospital will most likely have a different peak period than the typical AM and PM peaks (Martin and McGuckin, 1998).

Time-of-day factors are typically applied based on trip purpose and mode; however, these factors can only be applied if there is enough information for time-of-day factors by purpose and mode. If factors by mode are not available, it is assumed that the time distribution is the same across all modes (Martin and McGuckin, 1998).

Diurnal factors are used to produce peak-hour directional volumes. The mode split output has production and attraction trip tables that need to be converted to origin and destination tables by time of day. Production and attraction trip tables indicate the location of the home (productions) and other places such as work, stores, school, etc. (attractions); however, the direction of these tables is incorrect and needs to be adjusted. Although the home is the production end, it could be the destination of the trip and not the origin. Therefore, these production and attraction trip tables need to be converted to origin and destination trip tables. Directional split factors are applied to the production and attraction tables for this conversion. Equation 2-5 is used to convert the production and attraction tables into origin and destination trip tables for HBW trips (Martin and McGuckin, 1998).

\[
HBW_{od} = 0.5 \times HBW_{pa} + 0.5 \times HBW'_{pa}
\] (2-5)

Where:

- \(HBW_{od}\) = HBW trip table in origin-destination format
- \(HBW_{pa}\) = HBW trip table in production-attraction format
- \(HBW'_{pa}\) = transposed HBW trip table in production-attraction format

A similar equation applies to the various trip purposes. If the origin and destination trip table needs to be by time of day, time-of-day factors should be applied. The difference between
daily trip tables and time of day trip tables is the use of factors for the production-to-attraction direction and the attraction-to-production direction (Martin and McGuckin, 1998).

2.3.1.5 Trip-Based Model Input data

As trip-based models consist of major steps (i.e., trip generation, trip distribution, mode split, and traffic assignment), trip-based models also require input data that represent the area of study. Three major types of data are required in any trip-based travel demand model: socioeconomic, network, and validation data. Socioeconomic data includes population and household data that can be obtained from the U.S. Census Bureau or household surveys and employment data that can be obtained from the Bureau of Labor Statistics and other equivalent resources at the state and local level. Network data represent the roadway and transit network of the area of interest. The highway network data are available from sources such as the Census Bureau or Geographic Information Systems (GIS) departments, and the transit network uses the schedule and spatial location of the routes as well as the highway network. Lastly, validation data should be obtained and used to check the input data and all model components. Example validation tests include checking major station boardings, reviewing assigned versus observed vehicles by screenline or cutline, and checking speeds by time of the day (Cambridge Systematics et al., 2012).

2.3.2 Activity-Based Model

Activity-based models recently began to be implemented by various agencies in the U.S. These models rely on the fact that travel demand is derived and uses behavioral theories to represent how people travel through the transportation network (Castiglione et al., 2015). Travel demand in an area derives from the need to participate in activities (Cambridge Systematics et
al., 2012; Castiglione et al., 2015). People do not generally travel just to travel. These models represent very well how investments, policies, and other changes will affect travel behavior (Castiglione et al., 2015). Activity-based models represent activities that each traveler makes during the day, taking into account the types of activities, prioritizing the activities in a traveler’s schedule (e.g., work over shopping), and including a time budget in the analysis wherein the more activities that are scheduled, the less time is available for other activities (Castiglione et al., 2015). Due to the realistic representation of travel behavior, some planning agencies are considering switching their current models to activity-based models. As of 2011, MPOs within the United States that have developed an activity-based travel model include Portland, Oregon; San Francisco, Sacramento, and Los Angeles, California; New York, New York; Columbus, Ohio; Denver, Colorado; and Atlanta, Georgia (Cambridge Systematics et al., 2012).

Activity-based models use tours as the analysis unit (Cambridge Systematics et al., 2012; Castiglione et al., 2015; Donnelly et al., 2010). Tours are defined as a sequence of trips that start and end at home (Donnelly et al., 2010). Figure 2-2 shows an example of a tour; the Home → Work → Shop → Home sequence is a tour composed of three trips (Castiglione et al., 2015). The use of tours in modeling helps to account for demographic information of the individual making the trip (Donnelly et al., 2010). If the model uses trips rather than tours, only home-based trips will include the demographics, which is not an accurate representation in trip chaining.
Activity-based models focus on travel patterns, which include factors such as needs, preferences, habits, cultural/social characteristics, and travel services. In essence, these models include factors that answer the questions why, how, when, and where these activities are performed and the travel patterns associated with them. The resulting steps and output include the number of total activity stops by purpose and decisions of how the stops are best organized (Cambridge Systematics et al., 2012).

The following is an example demonstrating how an activity-based model is used when a change in pricing policy is being analyzed. Consider an individual with a travel pattern shown in Figure 2-3. This individual goes shopping after work during the evening peak hour because the store is on the way back home. However, the road that this individual takes to go home now will have a toll imposed during the evening peak (pricing policy change). In response to the pricing
policy, this individual decides to make a trip after the evening peak hour ends to avoid the toll. The new travel pattern of the individual is shown in Figure 2-4 (Cambridge Systematics et al., 2012).

Figure 2-3. Individual trips before pricing policy.

Figure 2-4. Individual trips after pricing policy.
The activity-based models can account for these changes in patterns to account for different temporal distributions rather than assigning the trips to another route (Cambridge Systematics et al., 2012). The following section describe general steps of activity-based models and the data needed for their development.

2.3.2.1 Activity-Based Model Steps

Activity-based models do not have a set of specific steps; however, there is a general sequence of steps that most models use. These steps include population synthesis, long-term model, generation model, tour-level, trip-level, and assignment as outlined in the following paragraph (Donnely et al., 2010).

The population synthesis step generates socioeconomic data at the individual and household level (Cambridge Systematics et al., 2012; Donnely et al., 2010). This is done by selecting representative households in the study area and using them as a control for household sampling (Donnely et al., 2010). During this step, other household attributes are also included, such as number of workers, number of children, age, etc. The output of this step is a table with one record for each household and individual in the area with the corresponding attributes (Donnely et al., 2010).

The long-term model step forecasts the long-term choices faced by the individuals and households. These choices include automobile ownership, workplace location, and school location. For automobile ownership, factors such as income and household size are used. These long-term choices do not change on a daily basis, so they are estimated in this step (Cambridge Systematics et al., 2012; Donnely et al., 2010).
The generation model step predicts the number of activities by purpose, how those activities fit into tours, and how they are interrelated in travel. This step includes the activities and travel patterns for the entire day. The output of this step is a set of activities and their sequence in a tour for each individual (Donnely et al., 2010).

The tour-level step determines the number of stops in a tour by purpose, the travel mode for each tour (mode choice), and the time of day and duration of each tour (Cambridge Systematics et al., 2012). Defining the activity importance is critical in this step because it prioritizes the different activities in a tour to determine the primary activity of the tour (Donnely et al., 2010). For example, in a tour including work and shopping, work will have a higher importance than shopping. The mode of each tour is also determined using the LOS of the roundtrip (Donnely et al., 2010). Lastly, the time of day is used to predict when each of the stops take place during the day (Cambridge Systematics et al., 2012).

The trip-level step converts the tours into individual trips. This step is very similar to the trip-based model, with the difference that the resulting trips need to be consistent with the tour previously defined. For example, if the mode choice determined a trip made by transit, the tour to which the trip corresponds needs to be transit as well; it cannot be automobile since the tour was already determined to use transit. The output of this step is a list of trips with destination, time of day, and mode (Donnely et al., 2010).

The last step is assignment. As in trip-based models, the assignment step consists of assigning trips to the highway and transit networks (Donnely et al., 2010).
2.3.2.2 Activity-Based Model Input Data

Activity-based models usually need very detailed input data to model travel behavior for individuals and households. However, the data required for these models are not much different from the data required for trip-based models. These data include household survey, land use, demographic, network, and calibration and validation data, as follows (Castiglione et al., 2015):

- **Household survey data** are used to determine the household and individual activities and travel (Donnelly et al., 2010). These surveys provide the necessary information about household level characteristics, individual level characteristics, and activity and travel information. This information is analyzed in great detail to determine the sequence of activities that help identify any gaps in the surveys. For example, individuals might not report trips because they did not consider them important. This would cause issues when developing the model; however, this analysis would identify these issues (Cambridge Systematics et al., 2012).

- **Land use data** contains characteristics regarding zones, blocks, and/or parcels (Cambridge Systematics et al., 2012; Castiglione et al., 2015). These data include number of households; employment by category; percent of commercial, residential, open space, and other structures; activity center intensity such a number of businesses within a certain distance of the network; and activity center density such as the number of businesses per square mile (Cambridge Systematics et al., 2012).

- **Demographic data** include the sociodemographic characteristics of the residents in the study area. These data include household size, household composition and life cycle, number of workers per household, household income category, age and gender of each person, employment and student status of each person, etc. Other information that could
be included is ethnical composition and housing type (e.g., single- or multi-family units) (Castiglione et al., 2015).

- **Network data** necessary for activity-based models includes highway and transit networks. These networks include the roadway characteristics (number of lanes, distance, etc.), time periods (AM peak, mid-day, PM peak, etc.), and transportation system performance data with LOS characteristics by time of day (Cambridge Systematics et al., 2012; Castiglione et al., 2015). Transit network data also contain the available and future routes for the study area.

- **Calibration and validation data** are used to compare the estimates in the model to the observed data. Calibration data include traffic volumes and travel survey data, and validation data include census data and other observed data sources such as Census Transportation Planning Products (Cambridge Systematics et al., 2012; Castiglione et al., 2015).

### 2.4 Computer Software

During the 1950s, computer software programs were developed to help with the transportation planning process, especially to forecast travel patterns. Some of the computer software currently available to build travel demand models are Quick Response System II (QRSII), EMME, TransCAD, Cube, and Visum (Reinke, 2012). The following subsections describe three of these well-known computer software programs: QRSII, TransCAD and Cube.

#### 2.4.1 QRSII

QRSII is a computer software used to forecast the impacts of urban developments and highway projects on travel patterns. The QRS computer program was first introduced in the late
1980s and allowed the analysis of trip generation, trip distribution, modal split, conversion of all-day person-trips to vehicle trips, traffic assignment, capacity, and highway spacing. The first version of QRS was used for relatively small network analyses, and, when a more complicated or sophisticated network analysis was needed, the first version would not work. More sophisticated models involved more zones, higher level of analysis detail, and/or more links and nodes. As these problems limited the capabilities of the first version of QRS, a second version was created (Horowitz, 2004).

The second version of QRS, or QRSII, was more flexible, allowing simple manual calculations or more detailed analyses. QRSII uses an interface called General Network Editor (GNE) to create the network and enter all of the input data required by the network. The network is created by drawing links and nodes (lines and points) in GNE, and the attributes such as travel time, speeds, and type are added to these links and nodes (Horowitz, 2004). Figure 2-5 shows an example of a network in GNE.

![Figure 2-5. Highway network in GNE (Horowitz, 2000).](image)
Once the network is created and data are added to the network, the network is imported into QRSII, and the analysis can be done using the four-step model within QRSII. When the model is run, the output can be exported and interpreted using GNE or spreadsheets. QRSII allows the analysis of models with up to 6,000 zones (Horowitz, 2004).

2.4.2 TransCAD

TransCAD is another software available for travel demand modeling analysis. TransCAD is more sophisticated than QRSII, allowing the complete travel demand modeling analysis using one computer program rather than two (GNE and QRSII). TransCAD does not have a hard limitation in the number of zones or links and nodes. TransCAD, as QRSII, allows the analysis of travel demand modeling using the traditional four-step model (trip-based models) (Caliper, 2017a).

Within TransCAD, there are several models that can be implemented to perform each of the steps in a trip-based model. The following provides a description of each step and possible tools in TransCAD (Caliper, 2017a).

1. *Trip Generation*. TransCAD provides four tools to estimate the number of trips by purpose, based on the needs of the modeler: cross-classification, regression models, discrete choice models.

2. *Trip Distribution*. TransCAD provides four tools or procedures to determine the distribution of trips: growth factor methods, calibrated gravity models, friction factors, and calibration of new model parameters.
3. **Modal Choice/Split.** TransCAD predicts the distribution of trips by mode using three procedures: multinomial logit models, nested logit models, or legacy methods. This model allows modeling for automobiles, transit, bicycles, and pedestrians.

4. **Traffic Assignment.** TransCAD provides four methods to assign traffic to the network: multiclass assignment, origin user equilibrium, equilibrium assignment with volume dependent turning delays, and dynamic equilibrium traffic assignment.

TransCAD also integrates GIS, which allows a more accurate representation of the roadway network (Caliper, 2017a). Figure 2-6 shows an example of a highway network in TransCAD.

In addition to allowing the creation of trip-based models, TransCAD also allows the modeler to build activity-based models. TransCAD has features in place to process large populations and heavy numerical calculations involved in activity-based models (Caliper, 2017b).

![Figure 2-6. TransCAD highway network example (Caliper, 2017a).](image)
2.4.3 Cube

Cube is another modeling software available to create and analyze travel demand models. Cube consists of a suite of several software packages based on the requirements of the modeler. The basic software is Cube Base that allows data editing, mapping, model development, and creation of scenarios. For demand modeling, three other packages are available: Cube Voyager, Cube Land, and Cube Cargo. Cube Voyager is used for urban, regional, and long-distance demand forecasting. Cube Land is a land use model for combined transport-land use modeling. Cube Cargo is used for commodity freight forecasting (Citilabs, 2017d).

Within Cube, the modeler can perform the basic four-step model (trip-based model). In order to process the data for each step, a script is usually necessary that processes the calculations needed to obtain the desired output. Models used in each step are described as follows (Citilabs, 2017d):

1. **Trip Generation.** Cube uses two primary models to generate productions and attractions in the area of study: growth factors and linear regression.
2. **Trip Distribution.** Cube has several tools used to determine the distribution of trips: uniform growth factor, singly constrained growth-factor methods, doubly constrained growth-factors, gravity model, and proportional fitting.
3. **Modal Split.** Cube has three models to determine the share of trips by mode: binomial split models, multinomial split models, and hierarchical split models. Cube also has tools to calibrate these models.
4. **Traffic Assignment.** Cube uses three models and methods to assign traffic to the study area network: all-or-nothing assignment, incremental assignment, and method of successive averages.
In addition to having tools to create travel demand models and analyze the output, Cube has an integrated GIS interface that allows the representation of the true shape of roadways and creates shapefiles from the output network. Cube also has a very easy-to-use interface in which modelers can easily drag and drop inputs and outputs. Figure 2-7 shows an example of a travel demand model created in Cube, and Figure 2-8 shows an example of a network in Cube.

Similar to TransCAD, Cube also has processes and tools to build activity-based models (Citilabs, 2011). Cube has modules within Cube Voyager that support the analysis and estimation of activity patterns (Systematica, 2017).

Figure 2-7. Travel demand model created in Cube (Citilabs, 2017d).
Figure 2-8. Example of transportation network in Cube (Citilabs, 2017b).

2.5 Summary

The literature review done for this project consisted of a historical overview of transportation planning, an overview of travel demand modeling including a description of trip-based and activity-based models, and an overview of a sample of computer software available to build travel demand models.

Travel demand models are the most widely used tool to forecast travel patterns. Travel demand models are used to present quantitative information to decision-makers regarding travel demand and transportation system performance. Information gathered from the research done showed that federal acts between 1930 and 1970 provided major guidelines to help plan areas throughout the U.S. such as providing government funding for travel pattern surveys, studies,
and methodologies. Information obtained from these studies helped develop models to assist the transportation planning process.

There are two main types of models used in the U.S., trip-based and activity-based models. Trip-based models are aggregate models that uses TAZs as geographic units representing demographic and socioeconomic characteristics. This model is commonly known as the four-step model and results in trip tables showing zone-to-zone trip information such as travel times, congested speeds, and volumes, as well as networks with assigned trips. Activity-based models, on the other hand, focus on travel demand as a derived demand that exists because people need or want to perform an activity. These models use tours (or trip chaining); and the trips that make up the tour share the same socioeconomic and demographic information. The result is a network with trips describing individual or household travel behavior.

Technology improvements in the last decades also had an impact in transportation planning. For example, new computer programs were developed in the 1950s to more efficiently and effectively predict trips occurring in a specific area. Currently, there are several computer software programs available to build and analyze travel demand models, such as QRSII, EMME, TransCAD, Cube, and Visum. In this section, a sample of three available computer software programs were described: QRSII, TransCAD, and Cube. Travel demand models are widely used by MPOs today to plan their transportation system 20 or 30 years into the future and analyze the impact of particular projects in future travel patterns in the area. Travel demand models are continually improved to predict travel patterns more accurately using studies and data obtained during the last few years.
3 STUDENT MANUAL DEVELOPMENT

3.1 Overview

This chapter provides information regarding the process followed in the development of the student training manual. The process consisted of three major sections: choosing the computer software for the training manual and learning how to use it, developing the training manual based on the available resources, and reviewing and editing the manual to develop the final version. A description of the final version of the training manual is also included in this chapter.

3.2 Software Selection and Training

The selection of the computer software to be used in the travel demand modeling training manual was based on the models currently used in Utah. The state of Utah currently has five travel demand models: a statewide model, the Cache MPO model, the Wasatch Front Regional Council (WFRC) and Mountainland Association of Governments (MAG) model, the Summit model, and the Dixie MPO model. All these models are currently built in the computer software Cube. Because of the consistent use of Cube software across the state and since the training material was meant to be used at Brigham Young University (BYU) in Provo, Utah, it was decided that it would be in the best interest of the students using the training material to learn the
basics of travel demand modeling using Cube. The following sections explain the process followed to learn how to use Cube.

3.2.1 Obtaining a Cube License

Citilabs, the firm that develops Cube is a global provider of mobility analytics for businesses and government agencies (Citilabs, 2017a). Citilabs has an instructional license that allows the user to have a trial of Cube that expires after 60 days of the date of issue. The licensing department in Citilabs was contacted to obtain an instructional license in April 2016. Citilabs approved an instructional license for BYU to download and install Cube to learn how to use the software.

3.2.2 Learning Cube

Once a license was available, Cube was installed and set up for use. The Citilabs website has a learning center, in which tutorials and video lessons are available. The first step in the learning process was to get familiar with Cube, which was done by going through the Discover Cube tutorial (Citilabs, 2017b). Discover Cube is a tutorial that introduces some of the features and capabilities available in Cube. The tutorial consists of seven chapters; however, only sections of the first three chapters were used to develop the training manual because these explained the basic functionalities and capabilities of the different Cube modules, and these chapters explored an existing model in Cube using Cube Base and Cube Voyager (these two modules are used to forecast personal travel using the four-step model). The remaining chapters go through making reports, exploring a freight model, and providing other training resources not applicable to the scope of this project. The tutorial uses a working model called Cubetown to explore the different functionalities of the software. This tutorial was used primarily to learn
some of the basic features and capabilities such as how things are organized in Cube, how to
open files, how maps are displayed, etc. (Citilabs, 2017b).

In addition to using the Discover Cube tutorial, a video lesson tutorial available through
the Citilabs learning center was used to learn how to build a model in Cube. The tutorial used a
working model to explain the basic features of the software; however, for the purpose of creating
the student training material, it was important to not only learn how to use Cube but also to learn
how to build a model in Cube from scratch. Citilabs has a Model Development Video Lesson
that explains step by step how to build a trip-based model from scratch. Citilabs also provides all
of the datasets and scripts necessary to build the model. The video lesson consists of five lessons;
however, it was determined that, for the purpose of this training manual, only the first three were
relevant as they go through the basics of travel demand modeling in Cube and also present the
steps to build a model from scratch and create scenarios. The other two lessons go through
advanced uses of the model and scenarios that are outside the scope of this project. Through the
first three video lessons, the following goals were achieved: gaining a basic understanding of the
data needed to build a travel demand model in Cube, understanding the steps taken to build a
basic model, and understanding how the different components of the model interact. Figure 3-1
shows a screenshot of the Model Development Video Lesson, Lesson 2: Building a Travel
Demand Model Application (Citilabs, 2017c).
3.2.3 Permission to Use Video Lesson

The video lesson available in the Citilabs website was exactly what the student training manual was envisioned to be. As such, Citilabs was contacted to ask for permission to use the instructions and data used in the video lesson to create the training manual. Citilabs agreed to give permission to use the video lessons and all their materials to develop the training manual with the following conditions:

1. BYU provides Citilabs with a copy of the training manual and associated materials upon completion.

2. Citilabs have intellectual property rights on the course notes and data.
3. All the training materials developed are not allowed to be distributed (either the existing or the new course) outside of BYU without prior written consent from Citilabs.

It was decided to agree with the conditions given by Citilabs, so BYU had permission to use and adjust the video lesson tutorial to create a new training manual.

### 3.3 Training Manual Development

The development of the training manual consisted of three main parts: transcribe the instructions of the first three parts of the video lesson, create an additional chapter to analyze the output of the model, and create assignments to assess the knowledge of the user.

#### 3.3.1 Transcribing Video Instructions

The video lesson tutorials were watched multiple times to be familiar with the steps and to write down the instructions. As the instructions were followed, it was noticed that the Cube version used in the video lesson was Cube 5.0; however, the version of Cube being used at the time (April 2016) was Cube 6.4. Although most of the features are the same in the newer version, some of them changed. As part of the transcription process, some of the commands used in the video had to be updated to match Cube 6.4.

Since the training manual was to be in written form, it was determined that it would be vital to have as many screenshots as possible to provide guidance to the users through the instructions. Because the manual was geared towards first-time users that have never used Cube before and only have a basic understanding of travel demand modeling, the student training
manual incorporated screenshots to help the users understand the instructions and to check that the instructions are followed correctly.

3.3.2 Creating the Output Analysis Section

The first three parts of the video lesson consisted primarily of an overview of travel demand modeling using the four-step model and the development of the four-step model in Cube. However, there was not a section to analyze the output after the model was run. It was determined that having a section in the manual that goes over how to use the output of the model would be beneficial for those using the student training manual. For that reason, a set of instructions to display certain highway network characteristics such as functional classes, speeds, and volume-to-capacity ratios was created. The purpose of this new section was to give the users an idea of how the models could be used to present information to decision-makers.

Figure 3-2 shows the highway network before and after the users go through the new Output Analysis chapter. Once the model was run, the network looked like the model on the left in Figure 3-2. Although not shown, the network had the information stored in the links and nodes in the network but had not been set up to show any particular metrics. However, after the users went through the Output Analysis chapter, they could display information contained in the network, as shown in the model on the right in Figure 3-2, to tell a story about the study area analyzed (e.g., show the roadway functional classes, highlight areas with high congestion, etc.) to decision-makers.
3.3.3 Organizing the Training Manual

To better organize the training manual, the instructions were divided into chapters. The chapters followed a logical order that would help the users understand the analysis being completed. The original version of the manual consisted of 11 chapters organized as follows:

- Chapter 1: Travel Demand Modeling Overview
- Chapter 2: Introduction to Cube
- Chapter 3: Exploring Cube
- Chapter 4: Skim Highway and Transit Networks
- Chapter 5: Trip Generation Step
- Chapter 6: Trip Distribution Step
- Chapter 7: Mode Split Step

Figure 3-2. Model network before and after output analysis.
Chapters 1 and 2 introduced the main concepts of the four-step model and the Cube software. Chapter 3 was a hands-on introduction to Cube, in which the users explored a working model in Cube. Chapter 4 provided instructions on how to create a process using Cube; the outputs of this process were the free-flow times and distances between zones, as well as the costs associated with transit. The output of this process was used as input for trip distribution.

Chapters 5 to 8 taught step by step how to accomplish each of the steps in the four-step model using Cube. Chapter 9 was an extra credit set of instructions that used a script instead of the programs in Cube to create the model; this was named Extra Credit because it used scripts, and scripts were not part of this introductory manual. Chapter 10 provided a set of instructions to create scenarios in Cube so different alternatives can be tested. Chapter 11 taught step by step how to display information available in the network in maps to analyze the output of the model.

3.3.4 Creating Assignments

As part of the training manual, assignments were created that would test the understanding of the user and check that the instructions in the manual were followed correctly. Each chapter had a set of assignments in which the user would explain concepts covered in the chapter or take screenshots of the model. Each chapter had two to five assignments.
3.4 Review and Editing

The training manual was initially used as part of an urban transportation planning course at BYU in the fall of 2016. The course had 11 students, and all of them used the manual. At the end of the course, a survey was sent out to all the students to get feedback on the manual and know what could be improved. Based on the results of the survey, various changes were made in the manual. This section describes the survey, the major changes in the content of the manual based on the results of the survey, and the new set of assignments created.

3.4.1 Survey

A survey was created at the end of the urban transportation planning course in the fall of 2016 to know how the manual could be improved. The survey is included in the Appendix. The results of the survey showed that the instructions were very well written and were easy to follow; however, the users did not understand what they were doing. For example, someone in the course answered, “[…] an explanation or more detail on what [the] concepts are for or do can be helpful,” and someone else said, “I think that there could be a few more questions in the assignments about the concepts of travel demand modeling rather than just features of the program.” As a result of the survey, major changes were considered for the training manual.

3.4.2 Major Content Changes

The results of the survey revealed that changes had to be made on the training manual for the users to learn the basics of travel demand modeling and the use of Cube, which is the purpose of this project. Based on the results of the survey, four major changes were made to the content of the manual: a thorough explanation of the content covered in each chapter, an explanation on
how the content covered is created or used in Cube, a description of the area being analyzed, and
the analysis of two different scenarios.

To thoroughly explain the content covered in each chapter, two reports were used: the
NCHRP Report 365: Travel Estimation Techniques for Urban Planning (Martin and McGuckin,
1998), and NCHRP Report 716: Travel Demand Forecasting: Parameters and Techniques
(Cambridge Systematics et al., 2012). Both of these reports are official documents available
through the Transportation Research Board and are used as guidelines by various firms and
agencies. Both reports were used to explain in detail each of the steps in the four-step model.
These explanations included the purpose of each step, the data needed, and a description of what
the step does in the overall process.

After each step was explained in general terms, a section in each chapter was created to
explain how what was explained in general terms was created in Cube. For example, the trip
generation chapter explained in detail the type of input data generally used (socioeconomic data),
how the trips were estimated (production and attraction rates), how TAZs were used (contain the
socioeconomic data), and the types of trips (HBW, HBO, NHB). After this was explained, the
next section explained the specific input files and data used in the model being built in Cube, the
output of the step, and what was being done in the background by Cube so the user can
understand the overall process and how the information is used.

After the steps and input data were explained, instructions were given for the users to
follow. It was intended that, when the users go through the instructions, they understand what is
happening due to the previous explanations.

Another major change to the manual was the addition of a chapter describing the area
being analyzed. Travel demand models are created to analyze a specific area; therefore, the area
of this model was described to give the users a context and a real-world application, rather than just having them blindly follow step-by-step instructions. For the purpose of the training manual, the area being analyzed was named Brownville. This chapter described the roadway network, the geographic units used for the model (TAZs), the socioeconomic and employment characteristics of Brownville, and the location of the central business district (CBD). This was meant to give the users some context to the model.

The last major change was the analysis of two scenarios and the assignment to compare the two. Travel demand models have multiple scenarios, so, to have a better real-world application, two scenarios were created in the model: the AM peak and PM peak. By creating these two scenarios, the users can understand the importance of creating scenarios and how these scenarios are used.

3.4.3 New Assignments

The results of the survey also showed that the assignments were not very challenging since most of them were just screenshots. Based on these results, most of the assignments were completely revised. The nature of the new assignments was to truly test the knowledge of the users. These new assignments could be classified in two categories: assignments that explain a concept or a step, and assignments in which the users analyze or manipulate the input or output files of the model.

An example of an assignment in which the users need to explain a concept or step is as follows: “Explain in your own words the purpose of mode split, including the information needed to perform the steps and its output. Discuss mode split in general; do not include information specific to this model.” In this assignment, the knowledge of the users is tested because they need
to explain the mode split step and how all the pieces tie together (i.e., how the input data are used).

An example of an assignment in which the users need to manipulate the input data is as follows: “The output file of the trip distribution step is the number of person trips between each zone pair. The gravity model was used to distribute these trips. Explain in your own words the gravity model, including the gravity model equation and the variables used. Report the specific values of the variables used in the gravity model to obtain the number of NHB trips between zone 12 and zone 4. In other words, report the variables $T_{12,4}$, $P_{12}$, $A_4$, and $F_{12,4}$ for the NHB trips. State how you found these values (i.e., report from which files these values come).” In this assignment, the user needs to understand not only the gravity model but also each of the Cube software files used in the trip distribution step to then know which values to report.

3.5 Final Version of Training Manual

The final version of the training manual was completed for an urban transportation planning course at BYU in the fall of 2017. The manual consists of 11 chapters organized as follows:

- Chapter 1: Travel Demand Modeling Overview
- Chapter 2: Introduction to Cube
- Chapter 3: Exploring Cube
- Chapter 4: Study Area
- Chapter 5: Skim Highway and Transit Networks
- Chapter 6: Trip Generation Step
- Chapter 7: Trip Distribution Step
- Chapter 8: Mode Split Step
- Chapter 9: Traffic Assignment Step
These chapters can be classified as (1) overview of travel demand modeling and Cube software (Chapters 1 to 3), (2) model development in Cube (Chapters 4 to 9), and (3) development of scenarios and output analysis (Chapters 10 and 11). To have a realistic practical application of travel demand modeling, the student training manual describes the need to develop a travel demand model for Brownville (a fictional city) to compare the roadway congestion levels in the AM and PM peak hours.

3.5.1 Overview of Travel Demand Modeling and Cube Software

The first three chapters of the training manual consist of an overview of travel demand modeling and the Cube software. Chapter 1 describes the basis of travel demand modeling, including the general framework of transportation modeling (transportation supply and demand theory) and the basics of the four-step modeling process (including a description of TAZs, network components such as links and nodes, and each model step).

Chapter 2 is an overview of the Cube software, which includes a description of the modules used in the training manual (Cube Base and Cube Voyager), the model structure used in Cube (how a model looks in Cube, where the inputs and outputs in the model are, etc.), and a description of the files types used in Cube. This chapter is meant to give the user a basic overview of how the model components are organized and used in Cube. Figure 3-3 shows an example of a model built in Cube, and Figure 3-4 shows a diagram of the model structure in Cube. Both figures are included in the training manual to exemplify the concepts described.
Chapter 3 is a hands-on exercise to familiarize the users with the Cube software interface and some of the basic commands in Cube. This chapter is based on the tutorial Discover Cube.
and Model Development Video Lesson 1: Intro to Model Development available in the learning center page of the Citilabs website. This tutorial uses an existing model named Cubetown, and the users go through a series of instructions to use simple commands in the software that will be useful for later chapters such as accessing a model, opening files, and displaying network attributes. At the end of each chapter, a set of assignments is included to test the user’s knowledge.

3.5.2 Model Development in Cube

The next set of chapters in the training manual consists of an overview of the study area to be modeled and a description and step-by-step instructions on how to create each of the steps in the four-step model. Each chapter that follows in this category is described in the following section.

Chapter 4 describes the main characteristics of the study area being modeled. Travel demand models are created based on a specific need in a specific area. As such, it was determined that it is important to include context for the model being built. For this reason, a description of the study area was included in the student training manual. For the purpose of the training manual, a fictional city was created called Brownville, and this chapter describes the roadway network (main interstates in the city and location of HOV lanes), geographic unit (TAZ) structure for the model, demographic and socioeconomic information, and the location of the CBD in the city. This chapter has no assignments since it is intended to give the users context on the model.
Chapter 5 is the first chapter in which the users create one of the model components in Cube. Chapter 5 creates the network skims to obtain the free-flow travel times and distances as well as transit costs, which are the inputs for the trip distribution step.

Chapters 6 to 9 provide a description of each of the four-step model steps. All of these chapters (including Chapter 5) have the same structure: (1) an overview of the step, (2) a description of the step in the model, (3) a list of main Cube commands and tools used, (4) exploring input files, (5) set of instructions, (6) exploring output files, and (7) assignments. The overview of the step (1) consists of a detailed explanation of the step based on the transportation planning literature, primarily the NCHRP reports (Cambridge Systematics et al., 2012; Martin and McGuckin, 1998). This section primarily explains the theory behind each step. The next section (2) explains how the theory ties into the model being built in the training manual with a description of the input and output files as well as what the model is doing in the background. The next section (3) includes a list of main commands and tools in Cube that will be used in the instructions. Section (4) includes a short set of instructions for opening the input files and understanding them. The purpose of this section is to familiarize the users with the format and information included in the input files so they understand what the model does. The following section (5) provides the step-by-step instructions for building the model, with multiple screenshots and notes to guide the user. Section (6) includes a short set of instructions for opening the output files and gaining an understanding of them. The purpose of this section is to help the users understand the output of this step. The last section (7) is the set of assignments. These assignments are included to help the users tie together all of the information given in the chapter (theory and practical application). Figure 3-5 shows an example chapter highlighting
each of the sections previously described. Note that the text of the report is blurred because of the agreement with Citilabs to not distribute the contents of the manual.

Figure 3-5. Chapter example.

Figure 3-5. Chapter example (continued).
Figure 3-5. Chapter example (continued).
3.5.3 Development of Scenarios and Output Analysis

The last set of chapters in the training manual consists of developing two scenarios and analyzing their outputs. Chapter 10 explains how to create and manage scenarios in Cube. Since the purpose of building the travel demand model for Brownville is to compare the roadway congestion levels in the AM and PM peak hours, this chapter provides a set of instructions to create an AM and PM peak scenario. In the chapter, the users determine which hour of the day is the AM and PM peak hour, create the two scenarios, indicate the scenario specific files (files that will be stored in the specific scenario folder), and run each scenario to obtain the outputs necessary to analyze them.

Chapter 11 explains how to display network attributes in maps and analyze the outputs of the model. One of the main outputs of a travel demand model is the loaded network, which contains roadway attributes and the final trip assignment. In this chapter, the users go through a set of instructions to display different network and TAZ attributes in a map. The factors that users display on a map are functional class, speed, toll locations, TAZ centroids, and zone numbers. All these factors are attributes included in the final highway network (e.g., functional class, speed, and tolls are attributes of the highway links in the network). In addition to these factors, users also add the TAZ structure to the map and display the true shape of the links (links are initially displayed as straight lines when in reality they are curved). In this chapter users also include a legend for the factors displayed. As most of the previous chapters, Chapters 10 and 11 include a set of assignments that the users need to answer and include in the corresponding laboratory reports.
3.6 Summary

The development of the student training manual was based primarily on the video lesson tutorial available in the Citilabs website. Citilabs gave BYU permission to use the instructions and data available for the video lesson tutorial with the following conditions: (1) BYU provides Citilabs with a copy of the student training manual and associated materials upon completion, (2) Citilabs have intellectual property rights on the course notes and data, and (3) all the training materials developed are not allowed to be distributed (either the existing or the new material) outside of BYU without prior written consent from Citilabs. By agreeing to these terms, BYU had access to the Citilabs training materials related to the video lesson tutorial used.

The student training manual was organized in 11 chapters to cover the material, which included an overview of travel demand modeling and Cube software (Chapters 1 to 3), the development of a basic model in Cube (Chapters 4 to 9), and the analysis of two scenarios within the model (Chapters 10 and 11). Two versions of the manual have been used in an urban transportation planning course at BYU, one in the fall of 2016 and one in the fall of 2017. After the first version of the manual was used in the fall of 2016, a survey was sent to all the students in the course to provide feedback for the improvement of the manual. Based on the results of the survey, four major changes were made to the training manual: a thorough explanation of the content covered in each chapter, an explanation on how the content covered is created or used in Cube, a description of the area being analyzed, and the analysis of two different scenarios. The second version of the training manual includes these changes and was used in the fall of 2017.
4 CONCLUSION

A travel demand model is a widely used tool for presenting quantitative information to decision-makers regarding travel demand and transportation system performance. Such a model is used to analyze how travel demand changes in response to different outputs so different scenarios and alternatives can be tested. As travel demand models are important in the transportation planning and engineering industry, it is important to develop training materials to help those using the models or developing them understand their basic components and applications. For this reason, a training manual was developed that would provide students at BYU with the basic knowledge of travel demand modeling concepts, especially regarding the four-step model, a type of travel demand model.

The student training manual was developed with the purpose of helping users understand the basics of travel demand modeling and the four-step model, as well as to understand how these concepts tie into a model built in Cube. Cube is a commonly used computer software that allows users to build travel demand models. This computer software was chosen to implement the student training manual because all of the models in Utah are built in Cube and, since the training manual was developed to be used as part of an urban transportation planning course at BYU in Provo, Utah, it was determined that Cube was the appropriate computer software to use.
The training manual was developed for a class setting, in which the students would be expected to write a report with answers to assigned questions. The training manual was first developed as a step-by-step instruction manual with general explanation and assignments that would require screenshots of what the users had done and basic explanations of what had been done. However, after the training manual was used and tested for the first time, it was found that the students did not understand the concepts; they simply followed the instructions. With these findings, a second version was developed that would (1) explain the theory and concepts using the literature, (2) explain how these concepts are being used in the model built in Cube, and (3) provide a set of assignments that would test the knowledge users had after completing the chapters. This second and final version of the training manual not only provides the user with step-by-step instructions to build a model but also explains the theory and concepts of travel demand modeling using the transportation planning literature. The training manual was meant to help the users understand not only the travel demand modeling theory and concepts but also to provide an opportunity for the users to get familiar with a computer software program used to create and apply these models.

The final version of the training manual is a training resource for users with a basic understanding of travel demand modeling, and it was meant to provide a practical application for them using the software Cube. The final version of the training manual was used by a group of students at BYU in the fall of 2017 to help these students understand the basics of travel demand modeling as well as to provide them with a new skill set for their future careers.
REFERENCES


### APPENDIX

This survey will help us review the lab and make necessary changes for next semester.

1. For each of the laboratory reports, how many hours did you spend using Cubex to complete each report?
   
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2. For each of the laboratory reports, how many hours did you spend writing each report?

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3. Were the concepts clearly explained in the lab report? Was there anything that you wish was explained better?

4. Is there anything that could be improved in the lab? (Less assignments, more assignments, more discussions in the assignments, shorter labs, etc.). Please be specific, this will help us review the lab and make changes for next semester.

5. Regarding the lab reports, would it have been helpful to have a sample report in Word format rather than PDF?

   Yes

   No
6. Please add any comments you have about the lab. We want to know your opinion.