where the EMPU are expressed as:

$$s_{m/d} = E\Big[\max_{k'}(V_{k'/dm} + \tau_{k'/dm})\Big]$$

$$s_d = E\Big[\max_{m'}(V_{m'/d} + s_{m'/d} + \tau_{m'/d})\Big]$$

and the models that represent the various steps may have any functional form provided that they can be obtained from the assumptions of random utility models.

4.3 Examples of Trip-based Demand Models

This section describes some of the models often applied within a four-step structure, and also introduces some possible extensions such as inclusion of parking type and location choice within mode choice models. An example of an entire model system for interurban travel demand is presented at the end of the section.

4.3.1 Models of Spatial and Temporal Characteristics

4.3.1.1 Trip Production or Trip Frequency Models

A trip production or trip frequency model estimates the average number of trips $d^i_{o.}[sh]$ undertaken in period h for purpose s by a user of class i with origin in zone o; this is called the *trip rate* $m^i[osh]$. The total production of trips by users of class i for purpose s in period h by zone o can therefore be expressed as follows.

$$d^i_o[sh] = n^i[o]m^i[osh] \tag{4.3.1}$$

where $n^i[o]$ is the number of users in zone o belonging to class i.

As explained above, the trip production models used in applications fall into two main categories: descriptive models and behavioral models (or more properly, random utility models).

Descriptive Models As discussed in Sect. 4.2, descriptive models are generally used to represent regularly made trips, such as home-based work and home-based school trips.

Classification tables are the simplest *descriptive trip production models*. For each user class i, assumed to be homogeneous with respect to a given trip purpose, the average number of trips $m^i[osh]$ for purpose s in period h is directly estimated, most commonly from travel survey data. Figure 4.4 is an example of a classification table showing the daily trip rates for home-based work, school, and other trip purposes, obtained as the average of the trip rates estimated in the mid-1980s in five medium-sized Italian towns. Note the different definitions of user class adopted for different trip purposes: workers in the various economic sectors for home-based work trips, students of different levels for home-based school trips, and the family for home-based other purpose trips. The main limitation of classification table models is that trip frequencies and demand levels are not expressed as functions of socioeconomic variables other than those used to define the classes. In addition, limitations in data availability and the difficulty of forecasting the future number of users for detailed user classes generally keep the number of classes relatively small, even when a more detailed breakdown might be appropriate.

Trip rate regression models are more sophisticated. These models express the trip rate $m^i[osh]$ for a user of class i and for purpose s as a function, typically linear, of variables corresponding to the user class and the zone of origin:

$$m^i[osh] = \sum_j \beta_j X^i_{jo} \tag{4.3.2}$$

The attributes X_{jo} are usually the mean values of socioeconomic variables such as income, number of cars owned, and so on, but they may also include level-of-service attributes such as zonal accessibility, defined by the inclusive variable Y_x in (4.3.5) or by some other variable. The name trip rate regression is derived from the statistical model, linear regression, which is used to specify the variables X_j and to estimate the coefficients β_j.

In early applications, model (4.3.2) was specified at the level of traffic zones. Thus, its explanatory variables represented attributes of an entire zone (e.g., population, employment, number of shops, etc.) More recently, these models have been applied at a more disaggregate level, typically households and individuals. The application of model (4.3.2) at a disaggregate level, however, can lead to problems because some combinations of variable values and coefficients may result in negative trip rates. Hence it is better to use logit or other random utility specifications for disaggregate trip rate models.

Random Utility Models Behavioral models are generally applied to represent trips that are not regularly made. In a random utility framework, the trip rate $m^i[osh]$ can be expressed as

$$m^i[osh] = \sum_x x p^i[x/osh](\boldsymbol{SE}, \boldsymbol{T}) \tag{4.3.3}$$

where $p^i[x/osh](\boldsymbol{SE}, \boldsymbol{T})$ represents the probability that a user in zone o undertakes x trips for purpose s in period h. Alternatively, the trip rate $m^i[osh]$ can be obtained as the product of the outputs of two models: a trip production model that covers a longer time period, for example, the whole day g, and a departure time choice model:

$$m^i[osh] = \sum_x x p^i[x/osg](\boldsymbol{SE}, \boldsymbol{T}) \cdot \sum_{yh} y_h p^i[y_h/osx](\boldsymbol{SE}, \boldsymbol{T})$$