



## Modelling Departure Time, Destination and Travel Mode Choices by Using Generalized Nested Logit Model: Discretionary Trips

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### PAPER INFO

#### Paper history:

Received 07 November 2019

Received in revised form 17 December 2019

Accepted 17 January 2020

#### Keywords:

Departure Time

Destination

Generalized Nested Model

Traditional Four-Step Model

Travel Demand Modelling

Travel Mode

### ABSTRACT

Despite traditional four-step model is the most prominent model in majority of travel demand analysis, it does not represent the potential correlations within different travel dimensions. As a result, some researches have suggested the use of choice modelling instead. However, most of them have represented travel dimensions individually rather than jointly. This research aims to fill this gap through employing the Generalized Nested Logit model for jointly representing three major travel dimensions; destination, departure time and travel mode. The suggested research methodology depends mainly on agglomerating alternatives that have similar error term's variances within specific gaps under common nests without any imposed restrictions. Moreover, different variance gaps lead to overlapped nesting system which can enable analysts modelling inner and inter-correlation. The proposed approach has been examined through modelling individuals' choices among the main shopping destinations in Eskisehir city, Turkey. In the light of estimation results, the proposed model attains a relatively good over-all goodness of fit which reflects a more prominent predictability power. Moreover, individuals in Eskisehir have been found perceiving more interest to the cost rather than time. From another hand, a behaviour of trading-off between performing such trips at peak periods by using transit or making them at off-peak by private car has been detected.

doi: 10.5829/ije.2020.33.02b.02

### NOMENCLATURE

U	Total random latent utility function	INC	Household monthly income
V	Deterministic component of the latent utility	SS	Student status (1 if student 0 otherwise)
ASC	Alternative specific constant	AGE	Age of the traveller
Q	Vector of alternative's attributes	t, d and m	departure time, destination and travel mode respectively
C	Vector of decision maker's characteristics	<b>Greek Symbols</b>	
I	Inclusive value (Maximum Expected Utility)	$\alpha$	allocation parameter
b	Parameter estimate of an explanatory variable	$\beta$	Vector of coefficients for decision maker's characteristics
f	specific trip dimension(s)	$\epsilon$	Error term or random component unknown to the analyst
P[·]	Probability of choosing a specific alternative	$\epsilon'$	Error term associated with a specific nesting level
R <sub>1</sub>	Large scale parameters' range	$\theta$	Scale parameter of an Extreme Value Distribution
R <sub>2</sub>	Medium scale parameters' range	<b>Subscripts</b>	
R <sub>3</sub>	Small scale parameters' range	t,d,m	Joint choice of a departure time "t", destination "d" and travel mode "m"
TT	Total travel time	x,y,z	Joint choice of a departure time "x", destination "y" and travel mode "z"
TC	Total travel cost	n	A decision maker
COW	Car ownership	i, j, k	GNL nests that have difference in scale parameters within ranges R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> respectively

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Please cite this article as: M. Elmorssy, T. H. Onur, Modelling Departure Time, Destination and Travel Mode Choices by Using Generalized Nested Logit Model: Discretionary Trips, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 33, No. 2, (February 2020) 186-197

## 1. INTRODUCTION

The world population rapid increment requires modern transportation demand strategies [1]. However, transportation demand forecasting introduces a very essential stage that affects directly the selection of different management policies [2]. Since 1940s, transportation planning studies rely primarily on travel demand forecasting models [3]. Nevertheless, the real concern towards travel demand models has started in US in 1960s [4]. From that date, four-step model has become the major object of most transportation planning studies due to its relative simplicity [5, 6]. However, some lacks associated with the fixed order of stages, aggregate orientation, and neglecting characteristics of decision makers in most steps, have made four-step model under some criticism [7].

Considering the trip distribution stage, over years, various methods for the distribution of trips among destinations have been developed such as growth factor method, gravity models, and destination choice models [8]. Despite the fact that destination choice models show better performance in terms of goodness of fit and predictability than other traditional models, all of such models ignore the potential interaction between destination choice and other travel dimensions that may exist inside the choice set. For example, through congested networks, all destination distribution models assume compensations between closer destinations. However, for discretionary trips, individuals may shift their departure times or change the travel modes to travel to their desired destinations. Thus, for such kind of trips, deeming the mutual interaction between destination choice from one side, departure time and travel mode choices from the other is a prerequisite in order to properly evaluate different policy measurements that aim to mitigate traffic congestion and accurately forecast their associated consequences. That can be sufficiently attained through advanced choice models that consider for the potential correlation that may exist between alternatives belonging to same or different travel dimensions [9,10].

As there is a gap in literature about representing a unified choice model that connects different travel demand dimensions and consider potential correlations between them, this research aims to contribute to filling this gap through proposing the application of the Generalized Nested Logit (GNL) model in jointly representing destination, departure time and travel mode dimensions of discretionary trips. The proposed framework can be represented as a more accurate and efficient alternative for the first three steps in traditional four-step model especially when it is applied to discretionary trips for small and medium scale forecasting and planning issues.

## 2. BACKGROUND

Nowadays, the methodology of four-step model is almost universally known and applied in most of the aggregate trip-based analyses (e.g. master plans) [11]. However, despite the widespread usage, the four-step travel demand forecasting model has some improper assumptions such as; the fixed sequence of steps among individuals [12], neglecting the effects of decision makers' characteristics [13], missing the influences of congestion on the travel time [3].

In order to overcome such restrictions, some researches have directed their interest toward using choice modelling approach as an alternative for some or all of the stages in four-step model. Indeed, choice modelling approach is usually used only at the modal split stage in most of the traditional four-step models with a little use in the trip distribution stage which is dominated by gravity models [10]. Recently and slowly, discrete choice models have been introduced as an alternative for gravity models for modelling destination choice and other travel choices (e.g. mode choice) either as a part of the four-step model [14] or independently as in activity-based models [15, 16]. Through the following paragraphs, we shed the light on some researches that focused on introducing various spatial and temporal travel dimensions (e.g. destination and departure time) under the context of choice modelling.

Regarding destination choice modelling, despite there are abundant studies that account for it, most of them were in fields other than transportation [10]. For example, in tourism, Seddighi and Theocharous [17] have examined individuals' destination choices for recreational travels. Similarly, Shaw and Ozog [18] have developed a Hybrid nested Multinomial Logit model that represents destination choices for overnight entertainment activities. Moreover, Shaw and Ozog [19] analysed touristic international destination choices in Germany through developing a Nested Logit model [19]. In the area of business, Lewis et al. [20] introduced a discrete destination choice model for young individuals' travels during holidays in Australia. In the field of consumer behaviour, a comparative study of single and multiple objective entertainment destinations has been introduced by Yeh et al. [21].

From another hand, it is crucial to model departure time along with other travel dimensions (e.g. destination and travel mode) in order to better represent the inter-relationship between congestion and trips' distribution over time in a day [7]. Regarding departure time scale, some studies have adopted discrete choice-based models such as Bhat [9] who jointly modelled travel mode and departure time through a hybrid Multinomial- Ordered Generalized Extreme Value (MNL-OGEV) discrete choice model. Bates et al. [22] have reviewed the

reliability for traveller’s departure time by using the discrete approach as well. Elmorssy and Tezcan [7, 23] have examined the inter-correlation between departure time, destination and travel mode by using discrete NL models. In contrast, other researchers have developed continuous time choice-based models such as; Bhat [24, 25] who formulated a multiple discrete-continuous Extreme Value (MDCEV) Model in which discrete travel mode choice is connected with continuous departure time choice without considering for correlation between error terms among both dimensions. This model has been enhanced later by Pinjari and Bhat [26] to relax the assumption of independency between error terms by connecting both travel dimensions via NL model which called multiple discrete-continuous Nested Extreme Value (MDCNEV) model.

Reviewing literature that represented joint choice of multiple travel dimensions (e.g. departure time, destination, travel mode, etc.) leads to conclude that most of them have used Nested Logit (NL) model, to connect such dimensions [27, 23] since it results in closed form expressions for choice probability. However, more advanced approaches that may better account for correlations between error terms (e.g. Mixed Logit) require a cumbersome simulation-based estimation procedure [26].

In the other hand, the basic NL model which is used extensively in most travel demand modelling applications is the two-level NL model [28], however, other multi-level structures (e.g. three-level) have been used in limited number of researches [7, 29, 30]. Such advanced NL structures, when applied to jointly represent various travel dimensions, differs in representing the correlation patterns as well as the degree of complexity [30]. By words, while simpler models (e.g. two-level NL) provide less complicated computational powers, they consist of a set of assumptions that limits the number of considered correlation schemes. In contrast, more advanced models (e.g. three-level, four-level NL and CNL) can represent various correlation structures; however, they are seldom applicable due to their complicated estimation processes. From another hand, such models have not enough flexibility to represent inner correlation (interdependence) within travel dimension(s) (e.g. correlation between similar travel modes) along with the correlation among different travel dimensions.

An approach which gathers both estimation simplicity and flexibility in introducing various potential correlation patterns is the GNL model [31]. GNL allows each alternative to occur with any other alternatives in any number of nests with a specific portion (i.e. allocation parameter) based on the real correlations existed within the sampled data. This paper argues that, an efficient joint model for departure time, destination and travel mode choices can be attained through using the GNL model.

### 3. PROPOSED METHODOLOGY

In GNL model, alternatives are free to occur with any other alternatives in any number of nests regarding or regardless of the rational interpretation of that aggregation. By words, the one thing that controls correlation patterns is the sample itself rather than assumptions of logically potential interactions between alternatives. Hence, it is not necessary for aggregated nests to be related to rational reading. For example, it is possible to observe relative similarities between all alternatives related to the same travel dimension (e.g. the same departure time) which can be read in a logical way. On the other hand, a correlation between different departure times with different destinations and various transportation modes which is uninterruptable may be discovered in the sampled data. The source of such correlation is due to unobserved common properties which are unknown to the analyst; however, accounting them may enhance the forecasting capability of the model. Fortunately, GNL model has the ability of introducing such phenomena. The following chart (Figure 1) illustrates a proposed methodology that is used to model departure time, destination and travel mode jointly under a GNL structure.

For a specific discretionary trip choice situation, a decision maker “n” chooses simultaneously to depart at time “t”, head towards destination “d” by using travel mode “m”, where  $t \in S_t = [t_1, t_2, t_3, \dots, t_n, \dots, t_T]$ ,  $d \in S_d = [d_1, d_2, d_3, \dots, d_n, \dots, d_D]$  and  $m \in S_m = [m_1, m_2, m_3, \dots, m_n, \dots, m_M]$ . The total number of mutually exclusive alternatives within the consideration set is  $T \cdot D \cdot M$  alternatives. The total perceived utility of choosing t, d, and m alternatives is  $U_{t,d,m}^n$ . For the sake of simplicity, the abbreviation “n” is dropped down from all equations so that, the utility associated with decision maker “n” is  $U_{t,d,m}$ . The following equation represents the general form of the total random utility associated with alternatives;

$$U_{t,d,m} = V_{t,d,m} + \mathcal{E}_{t,d,mj} + \mathcal{E}_j + \ln \alpha_{t,d,m|j} \tag{1}$$

$$V_{t,d,m} = ASC_{t,d,m} + \beta_Q \cdot Q_{t,d,m} + \beta_C \cdot C^n \tag{2}$$

The GNL probability function, of choosing “t, d, m” that occurs in a number of nests (1,2,3,...,i,...,j,...,k,...,J) through a GNL structure with total number of nests equals “J”, can be expressed as follows:

$$P[t, d, m] = \frac{\sum_{j=1}^J \frac{\exp\left(\frac{\theta_{t,d,m|j} \cdot I_j}{\theta_j}\right)}{\sum_{j=1}^J \exp\left(\frac{\theta_{t,d,m|j} \cdot I_j}{\theta_j}\right)} \cdot \frac{\frac{1}{\alpha_{t,d,m|j}} \exp\left(\frac{V_{t,d,m}}{\theta_{t,d,m|j}}\right)}{\sum_{t_n, d_n, m_n|j} \frac{1}{\alpha_{t_n, d_n, m_n|j}} \exp\left(\frac{V_{t_n, m_n, d_n}}{\theta_{t,d,m|j}}\right)} \tag{3}$$

$$I_j = \ln \sum_{t_n, d_n, m_n|j} \frac{1}{\alpha_{t_n, d_n, m_n|j}} \exp\left(\frac{V_{t_n, m_n, d_n}}{\theta_{t,d,m|j}}\right) \tag{4}$$

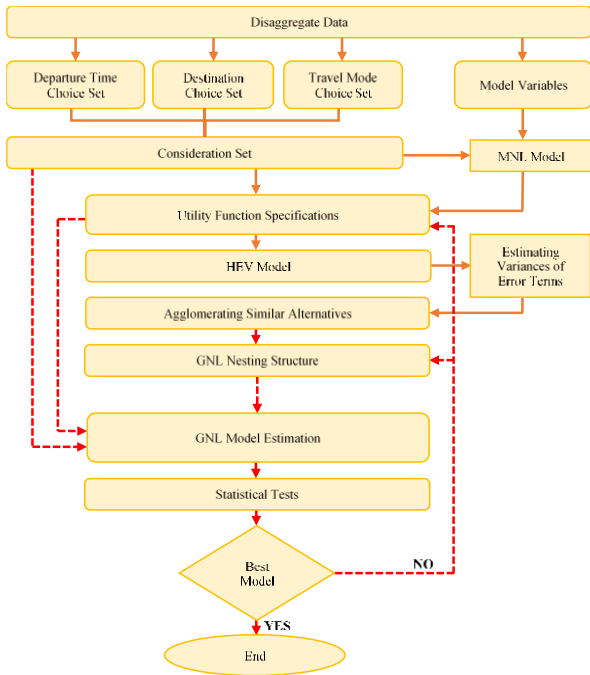


Figure 1. General Framework of the proposed approach

That leads to a covariance between any pair of alternatives (t, d, m and x, y, z) to be;

$$Cov(t, d, m \text{ and } x, y, z) = \frac{\pi^2}{6} \sum_{j=1}^J \sqrt{\alpha_{t,d,m|j} \alpha_{x,y,z|j}} (\theta_j^2 - \theta_{ij}^2) \quad (5)$$

Regarding the utility function and its associated explanatory variables, as the number of elementary alternatives increases, adopting alternative specific coefficients will result in a large number of estimates (i.e.  $D \cdot T \cdot M - 1$ ) which add more encumbrances in the estimation process and also complicate the interpretation of the results. Therefore, the alternative specific variables are proposed to be specific to travel dimension(s) rather than to all elementary alternatives. In order to reach the best set of specifications that may be used initially in estimating the GNL model, a traditional Multinomial Logit (MNL) model is proposed to be estimated at first to capture the best specifications that lead to best MNL parameters in terms of magnitudes, signs and degree of significance as well as the overall goodness of fit.

As illustrated previously, the GNL model provides satisfactory flexibility for alternatives to occur with any other alternatives in any number of nests

according to the correlation patterns within the sampled choice data. In order to clearly recognize the correlation patterns existing within a set of discretionary choice data, the Heteroscedastic Extreme Value (HEV) model that was proposed by Hensher [32] is proposed to be utilized. The proposed method is based on estimating a HEV model which assumes independent but non identical extreme value distribution for error terms of all elementary alternatives. Therefore, the value of scale parameters associated with alternatives can provide very useful conceptions about the existing correlation patterns. That is, alternatives which have their scale parameter in a specific range can be gathered in one group or nest. Further, changing the proposed range by decreasing or increasing it can divide or expand the produced nests into other bigger or smaller ones which yields the number of inter-correlated sets of alternatives.

A critical point related to this approach is; the ranges of scale parameters (or variances) that will be proposed to aggregate alternatives into nests are still ambiguous. In this paper, we purpose an empirical method by which initial accurate values of similar variances' ranges can be easily reached. These initial values can be used to find preliminary interacted groups (overlapped nests) from the elementary alternatives. The main idea of the proposed method is dividing the difference between minimum and maximum variance (i.e. the gap of variances) by distinct values to compute different ranges of variances (Equation (6)). The three ranges ( $R_1$ ,  $R_2$  and  $R_3$ ) given in Equation (6) can roughly refer to the sets of elementary alternatives that are suggested to be gathered under the same nest (Equation (7)).

Moreover, the using of three steps that differ from small to wide ranges will result in representing various levels of correlation among elementary alternatives. By words, in order to firstly get a small step that can capture inner correlation in-side of each travel dimension, the variance gap is suggested to be divided by the total number of alternatives produces from combining all travel dimensions. For a medium step, to calculate the value that may extract interactions between various travel dimensions; the gap is divided by the average number of joint alternatives from two different travel dimensions rather than the three. Consequently, a wider step that may separate alternatives according to each travel dimension can be attained through dividing the gap over the total number of travel dimensions which is three in our choice situation.

$$Variance\ Ranges \left\{ \begin{array}{l} R_1 = \frac{\pi^2}{6} * \frac{Gap\ of\ Scale\ Parameters}{Total\ Number\ of\ Elementary\ Alternatives} \\ R_2 = \frac{\pi^2}{6} * \frac{Gap\ of\ Scale\ Parameters}{Average\ Number\ of\ Alternatives\ in\ Two\ Travel\ Dimensions} \\ R_3 = \frac{\pi^2}{6} * \frac{Gap\ of\ Scale\ Parameters}{Number\ of\ Travel\ Dimensions} \end{array} \right. \quad (6)$$

$$\text{Cov}(\varepsilon_{t,d,m}, \varepsilon_{x,y,z}) = \begin{cases} \text{if } \text{var}(\varepsilon_{t,d,m}) - \text{var}(\varepsilon_{x,y,z}) < R_1, & \frac{\pi^2}{6} (\theta_i^2 - \theta_{ij}^2) \\ \text{if } \text{var}(\varepsilon_{t,d,m}) - \text{var}(\varepsilon_{x,y,z}) < R_2, & \frac{\pi^2}{6} [\sqrt{\alpha_{t,d,m|i} \alpha_{x,y,z|i}} (\theta_i^2 - \theta_{ij}^2) + \sqrt{\alpha_{t,d,m|j} \alpha_{x,y,z|j}} (\theta_j^2 - \theta_{ij}^2)] \\ \text{if } \text{var}(\varepsilon_{t,d,m}) - \text{var}(\varepsilon_{x,y,z}) < R_3, & \frac{\pi^2}{6} [\sqrt{\alpha_{t,d,m|i} \alpha_{x,y,z|i}} (\theta_i^2 - \theta_{ij}^2) + \sqrt{\alpha_{t,d,m|j} \alpha_{x,y,z|j}} (\theta_j^2 - \theta_{ij}^2) + \sqrt{\alpha_{t,d,m|k} \alpha_{x,y,z|k}} (\theta_k^2 - \theta_{ik}^2)] \\ \text{Otherwise Zero} & \end{cases} \tag{7}$$

Notably, the produced overlapped nests are initial nests which are subject to modifications in the light of the initial and subsequent GNL model estimation results. An example of such changes is; elimination of one or more alternatives from a nest or shifting alternatives from one nest to another. Moreover, some suggested changes may be based on the intuitive judgments by the analyst.

Finally, in the light of the estimation results associated with the proposed GNL nesting structures, we keep imposing modifications and exchanges over nesting structures along with variations on the utility function specifications until attaining best GNL model in terms of signs and magnitudes of parameters, and overall goodness of fit.

#### 4. CASE STUDY

In this paper, the proposed framework is tested with an application on shopping and entertainment trips' data collected from Eskisehir city, Turkey. These data have been collected from a household survey that was conducted in 2015 in the context of Eskisehir Strategic Master Plan studies. Eskisehir city (Eskişehir in Turkish). This is a small sized city in north-western Turkey with a population about 800000 (according to 2015 census data) distributed over 2700 km<sup>2</sup> area.

The considered shopping and entertainment trips' data are a part of large-scale revealed preference data which include; household-based and individual-based socio-demographics, individual's travel information and attributes of the used transportation mode(s).

In Eskisehir city, most shopping and entertainment activities are concentrated in three distinct regions (Figure 2) which are distinguished by having a lot of retail and entertainment activities. These three regions are; ESPARK shopping centre "s", Ozdilek shopping centre "z" and Local Bazaar "l". The departure time has been categorized into three different groups that present differences in traffic conditions and availability of individuals' free times. These three times are: peak time trips "p"; 7.00 am - 9.00 am, and 4.30 pm - 6.30 pm, off-

peak time trips "o"; 9.00 am - 4.30 pm, evening time trips "e"; time after 6.30 pm up to 10.00 pm. In the context of travel modes, three modes that allow access to the three destinations and available during the three departure times have been considered in our analysis as private car "c", public bus "b" and tramway "t". The total number of observations related to the determined alternatives has been found to be 529. The distribution of individuals among available alternatives of each choice subset is shown in Table 1.

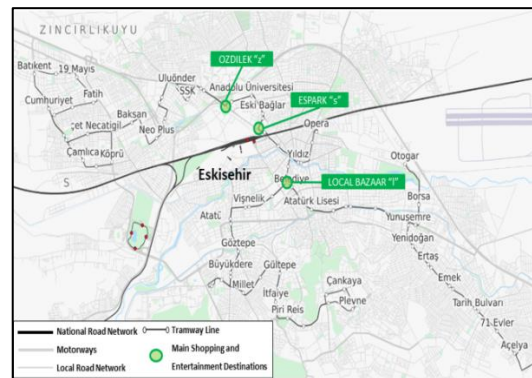


Figure 2. Map of the Study Area

TABLE 1. Sample Distributions among Alternatives

		# of Observations	Rate %
Departure time (t)	Peak (p)	104	19.66
	Off-Peak (o)	277	52.36
	Evening (e)	148	27.98
Destination (d)	Espark (s)	184	34.78
	Local Bazaar (l)	203	38.37
	Ozdilek (z)	142	26.84
Travel modes (m)	Car (c)	116	21.93
	Bus (b)	98	18.53
	Tramway (tr)	315	59.55

Finally, the considered explanatory variables include: total travel time “TT” and total travel cost “TC” as alternatives’ attributes, car ownership “COW”, monthly income “INC”, student status “SS” and age “AGE” as individuals’ characteristics. Other variables related to attributes of destinations such as number of shopping and entertainment activities might have significant effects, however, unfortunately they were unavailable within the collected data.

**5. GNL STRUCTURE**

The total number of alternatives equals 27 which includes all possible combinations of three departure times [p, o, e], three destinations [s, l, z] and three modes [c, b, t]. Equation (8) presents the general structure of the utility functions of alternatives that are formulated as linear-in-parameters (Equation (8)).

$$V_{t,d,m} = ASC^f + b_{TT}^f * TT + b_{TC}^f * TC + b_{COW}^f * COW + b_{INC}^f * INC + b_{SS}^f * SS + b_{AGE}^f * AGE \tag{8}$$

In order to capture the preliminary suitable specifications of the utility function’s parameters, different combinations of generic and travel dimension(s) specific parameters have been estimated through traditional MNL models. According to the estimation results, a set of specifications that lead to acceptable signs and achieve best goodness of fit is obtained as shown in Equation (9). This equation has been used to estimate variances of error terms by using the HEV model and utilized as the initial utility function while estimating the first GNL model as well.

$$V_{t,d,m} = ASC^m + b_{TT}^t * TT + b_{TC}^m * TC + b_{COW}^m * COW + b_{INC}^d * INC + b_{SS}^m * SS + b_{AGE}^t * AGE \tag{9}$$

The HEV model has been estimated with 27 degenerate nests. Table 2 shows the estimates of error term’s variance associated with each elementary alternative. In order to simply distinguish similar alternatives, the values have been sorted in ascending order.

**TABLE 2.** Variance Estimates of Elementary Alternatives Associated with HEV

t,d,m	$\theta_{t,d,m}$	t,d,m	$\theta_{t,d,m}$	t,d,m	$\theta_{t,d,m}$
o, l, tr	-0.13	o, l, c	7.29	p, l, b	19.76
e, s, tr	-0.05	e, s, c	7.35	e, z, b	20.97
o, s, tr	-0.05	p, s, c	7.55	e, l, b	22.83
p, l, tr	-0.05	p, z, c	7.7	o, l, b	23.21
o, z, tr	-0.03	p, l, c	7.99	e, s, b	23.41
e, z, tr	0	o, s, c	8.18	p, s, b	26.55
e, l, tr	0.02	o, z, c	8.44	p, z, b	30.23
p, s, tr	0.02	e, z, c	9.69	o, z, b	33.41
p, z, tr	0.07	e, l, c	10.87	o, s, b	33.97

As shown in Table 2, obviously, elementary alternatives can be clearly distinguished based on three main categories; tramway-based alternatives, private car-based alternatives and bus-based alternatives. Another significant issue is the large gap between tramway and bus as public transportation alternatives. Surprisingly, the HEV model suggests that there is no correlation between tramway-based and bus-based alternatives at all.

In order to reach an initial GNL structure, the proposed method for different variance ranges has been applied. That is, the error term variance’s gap of 34.10 has been divided by three different values to produce three different thresholds;

$$R_1 = \frac{\text{Variances' gap}}{\text{Number of travel dimensions}} = \frac{34.10}{3} = 11.37$$

$$R_2 = \frac{\text{Variances' Gap}}{\frac{\text{Av. number of alternatives in two travel dimensions}}{(9+9+9)/3}} = \frac{34.10}{9} = 3.79$$

$$R_3 = \frac{\text{Variances' gap}}{\text{Total number of alternatives}} = \frac{34.10}{27} = 1.26$$

Consequently, according to each range and the values of variances (Table 2) elementary alternatives have been distributed through different nests. Figure 3 illustrates the initial arrangement that is generated by applying the proposed method.

In the initial GNL structure, the total number of nests is 11. The first variance’s range ( $R_1=11.37$ ) suggests three distinct nests ( $N_1^i, N_2^i$  and  $N_3^i$ ). For  $N_1^i$ , surprisingly, tramway and private car-based alternatives are aggregated under the same nest. Opposite to most of the previous studies that assume extreme differences between public transportation modes and private car, the proposed method identifies the existence of such an untraditional correlation. Apparently, a similarity between tramway-based and private car-based alternatives is highly unexpected. However, common unobserved attributes such as reliability of on time arrival may represent some similarities. Regarding bus-based alternatives, they are distributed among two distinct nests;  $N_2^i$  and  $N_3^i$ . While  $N_2^i$  has no specific interpretation,  $N_3^i$  (o-z-b and o-s-b) may be interpreted as a “destination ordering” pattern since it gathers two alternatives with two adjacent destinations (i.e. Ozdilek and Espark). Another interpretation that may make sense is that Ozdilek and Espark have similar a nature since both of them are considered as shopping centres rather than the Local Bazaar that mostly consists of local retails.

The second variance thresholds ( $R_2 = 3.79$ ) resulted in a different nesting system;  $N_4^i$  and  $N_5^i$  are tramway-based nest and private car-based nest respectively.  $N_6^i$  consists of five bus-based alternatives and  $N_7^i$  involves two alternatives (p-z-b and p-s-b). Similar to  $N_3^i$ ,  $N_7^i$  has two potential similarity sources; destinations’ order and/or being shopping centres, but during another time of day (peak period).

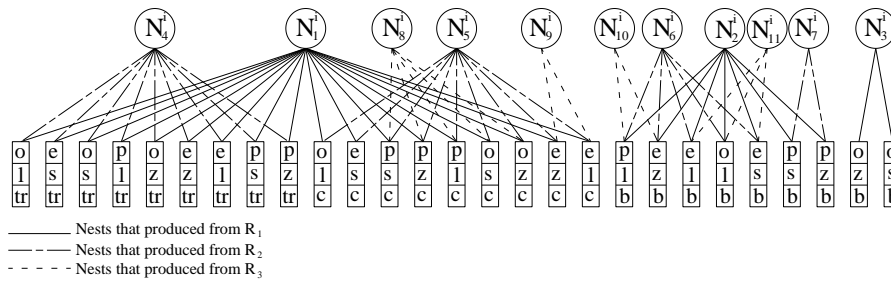


Figure 3. Initial GNL Structure

The third range (the minimum step of 1.26) obtains other cut-offs which produce new four nests;  $N_8^1$  through  $N_{11}^1$ . Notably, no inner correlations for tramway-nest ( $N_4^1$ ) exists. However, the nest  $N_9^1$  (e-z-c and e-l-c) suggests similarity between evening private car trips heading to Ozdilek and Local Bazaar. For  $N_{10}^1$  (p-l-b and e-z-b), correlation between bus-based trips heading to Local Bazaar and Ozdilek during different time of day is proposed. For  $N_{11}^1$  (e-l-b, o-l-b and e-s-b), on the other hand, two sources of correlation can be interpreted. The first one is the correlation between “o-l-b” and “e-l-b” which may be due to similarities between off-peak “o” and evening “e” departure times as medium and low congestion periods (temporal correlation). The second correlation is between “e-l-b” and “e-s-b” which may result from the apposition of the two destinations Espark and Local Bazaar (Figure 2).

The initial GNL model structure (Figure 3) that is generated from different variance’s range method has been estimated by using N-LOGIT 6 which uses constrained maximum likelihood estimation method. In order to decrease the complexity of the model, the scale parameters have been estimated by normalizing the lower level scale parameters to unity. Moreover, for upper level, some branch scale parameters have been fixed at specific values to be able to estimate other scale parameters within the accepted range (more than unity).

Even though the estimation of the initial GNL structure led to a converged model, some parameters have been found to be unacceptable (e.g. a positive sign for travel time’s parameter). At such a situation, some manipulations on the initial GNL structure have been applied until plausible estimates are attained. Such manipulations include; elimination or transferring some

alternatives from one nest to another according to intuitive judgments. In order to do so in an organized manner, the imposed changes are proposed to be applied individually to each set of nests associated with each variance’s range. Consequently, new GNL structures that result from the combination of individual changes have been estimated until reaching best model. Figure 4 illustrates the final set of nests which attains the best results.

Finally, in order to demonstrate the dominance of the GNL model over other traditional NL approaches, along with the final GNL structure, some 3-level NL structures with different travel dimensions arrangements have been estimated as well. Moreover, some Ordered Generalized Extreme Value (OGEV) structures that consider for spatial correlation between destinations have been modelled and estimated.

6. DISCUSSION OF ESTIMATION RESULTS

The estimation results of the final GNL structure that provides the best results in terms of the values of parameters and overall goodness of fit are shown in Table 3. The final utility function specification that is used to estimate the final model is shown in Equation (10). Worth mentioning, income and student status variables have not resulted in statistically significant parameters at all. Thus, in order to estimate certain parameters for other variables, they are eliminated from the final utility function.

$$V_{d,t,m} = ASC^m + b_{TT}^{t*}TT + b_{TC}^{t*}TC + b_{COW}^m COW + b_{AGE}^{t*} AGE \tag{10}$$

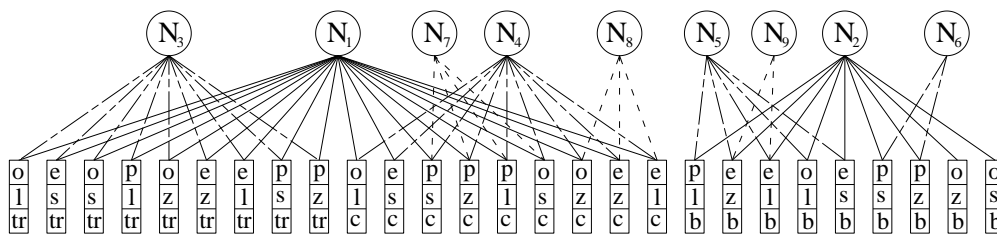


Figure 4. Final GNL Structure

**TABLE 3.** The Coefficient Estimates for the best GNL model

GNL	
<b>Constants</b>	
Car Specific Alternatives	-4.40 (-6.40) <sup>a</sup>
Bus Specific Alternatives	-1.80(-4.05) <sup>a</sup>
Tram Specific Alternatives	0.00 (F)
<b>Total Travel Time</b>	
Peak Specific Alternatives	-0.033(-3.04) <sup>a</sup>
Off-peak Specific Alternatives	-0.0012 (-2.90) <sup>a</sup>
Evening Specific Alternatives	0.00 (F)
<b>Total Travel Cost (Generic-TL)</b>	-0.30(-5.20) <sup>a</sup>
<b>Car Ownership (F=0&amp;T=1)</b>	
Car Specific Alternatives	2.70 (5.24) <sup>a</sup>
Bus Specific Alternatives	0.00 (F)
Tram Specific Alternatives (Base)	0.00 (F)
<b>Age (Years Old)</b>	
Peak Specific Alternatives	0.00 (F)
Off-peak Specific Alternatives	-0.001 (2.77) <sup>a</sup>
Evening Specific Alternatives (Base)	0.00 (F)
<b>Value of Time (TL/hr.)</b>	
Peak Specific Alternatives	6.60
Off-peak Specific Alternatives	0.24
Evening Specific Alternatives	0.00
<b>Scale Parameters (branches)</b>	
<b>N<sub>1</sub> (Tramway + Private Car)</b>	2.94 (1.60) <sup>b</sup>
<b>N<sub>2</sub> (Bus)</b>	7.14 (1.5) <sup>b</sup>
<b>N<sub>3</sub> (Tramway)</b>	50 (F)
<b>N<sub>4</sub> (Car)</b>	1.10 (F)
<b>N<sub>5</sub> (group of bus)</b>	1.17 (1.11)
<b>N<sub>6</sub> (Peak Bus-based spatial correlation)</b>	1.13 (0.11)
<b>N<sub>7</sub> (group of Car)</b>	1.25 (F)
<b>N<sub>8</sub> (Car-based spatial and temporal corr.)</b>	1.00 (F)
<b>N<sub>9</sub> (Evening Bus-Based spatial corr.)</b>	1.05 (0.01)
<b>Goodness of Fit</b>	
<b># of Observations</b>	529
<b># of parameters</b>	48
<b>LL(β)</b>	-1245.24
<b>LL(0)</b>	-1743.50
<b>LL(C)</b>	NA
<b>MLL(3-level NL, k=17)</b>	-1535.17
<b>MLL(OGEV, k=41)</b>	-1517.20
<b>-2LL(βvs.0)</b>	996.5
<b>Adjusted ρ<sup>2</sup>(βvs.0)</b>	0.28
<b>-2LL(GNL vs. OGEV, DF=7)</b>	543.92

F=Fixed Parameter, NA = Not Applicable, <sup>a</sup> Significant at 95% level, <sup>b</sup> Significant at 90% level, t-statistics in parentheses

In the light of estimation results, the following points can be inferred;

- The proposed GNL structure (MLL=-1245.24) accomplishes a recognizable improvement over traditional 3-level NL model (MLL=-1535.17) and over OGEV model (MLL=-1517.20) with remarkable log likelihood ratio of 543.92.
- The model attains a relatively good over-all goodness of fit with adjusted  $\rho^2$  value of 0.28. That refers to a more prominent predictability power of the proposed GNL approach.
- Since TT parameters are specific to departure time alternatives, the model expects a significantly higher effect of TT on shopping and entertainment trips during peak periods than on trips that are performed at other times of day.
- Individuals in Eskisehir city are increasingly interested in the cost of discretionary trips rather than time, especially during off-peak and evening times (i.e. times that are far away from working hours).
- Individuals in Eskisehir city are willing to pay 6.60 TL (in average) to decrease an hour from their peak discretionary trip's travel time. However, this desire decreases dramatically during other times of day (off-peak and evening).
- With a travel mode-based alternative specific parameter, car ownership (COW) variable is significant for car users with a positive effect. As expected, Eskisehir discretionary trips travellers have more inclination to use private car over other modes if they are car owners.
- Regarding age variable which has a departure time-based specific alternative parameter, surprisingly, elderly travellers may prefer performing their discretionary trips during peak or evening periods far away from off-peak periods.

Another important output of the proposed GNL model is the matrix of allocation parameters (Table 4). Reviewing relative values of allocation parameters (Table 4) indicates some important conclusions which we can summarize through the following points:

For the first nest ( $N_1$ ), substantial unobserved similarities ( $\theta = 2.94$ ) are likely to be among tramway at peak (p, l, tr & p, z, tr) from one side and private car at evening (e, l, c & e, z, c) from the other side. Obviously, individuals in Eskisehir city are more likely to compare between performing their shopping and entertainment trips at peak periods by using tramway or waiting until late times of day to avoid traffic congestion and use their private cars. Such a behaviour, however, is associated specifically with Ozdilek and Local Bazaar. Another significant indication from this correlation is the level of service of tramway. By words, it is possible to assume that tramway has satisfactory level of service that is high enough to make decision makers perceive it similar to private cars. The



TABLE 4. Matrix of Allocation Parameters for the Estimated GNL model

	N <sub>1</sub>	N <sub>3</sub>	N <sub>4</sub>	N <sub>2</sub>	N <sub>5</sub>	N <sub>6</sub>	N <sub>7</sub>	N <sub>8</sub>	N <sub>9</sub>
i \ $\theta$	2.9	50	1.10	7.14	1.17	1.13	1.25	1.00	1.05
o, l, tr	0.08 <sup>a</sup>	0.92 <sup>a</sup>	0	0	0	0	0	0	0
e, s, tr	0.17	0.83 <sup>a</sup>	0	0	0	0	0	0	0
o, s, tr	0.07 <sup>a</sup>	0.93 <sup>a</sup>	0	0	0	0	0	0	0
p, l, tr	1 <sup>a</sup>	0	0	0	0	0	0	0	0
o, z, tr	0.07 <sup>a</sup>	0.93 <sup>a</sup>	0	0	0	0	0	0	0
e, z, tr	0.15	0.85 <sup>b</sup>	0	0	0	0	0	0	0
e, l, tr	0.17	0.83 <sup>a</sup>	0	0	0	0	0	0	0
p, s, tr	0.68 <sup>a</sup>	0.32 <sup>a</sup>	0	0	0	0	0	0	0
p, z, tr	0.92 <sup>a</sup>	0.08 <sup>a</sup>	0	0	0	0	0	0	0
o, l, c	0	0	0.95 <sup>a</sup>	0	0	0	0.05	0	0
e, s, c	0.0 <sup>a</sup>	0	0.97 <sup>a</sup>	0	0	0	0.02	0	0
p, s, c	0.02 <sup>a</sup>	0	0.95 <sup>a</sup>	0	0	0	0.03	0	0
p, z, c	0.02 <sup>a</sup>	0	0.87 <sup>a</sup>	0	0	0	0.11 <sup>a</sup>	0	0
p, l, c	0.07 <sup>a</sup>	0	0.81 <sup>a</sup>	0	0	0	0.13 <sup>a</sup>	0	0
o, s, c	0.0 <sup>a</sup>	0	0.94 <sup>a</sup>	0	0	0	0.04	0	0
o, z, c	0.0 <sup>a</sup>	0	0.12 <sup>a</sup>	0	0	0	0	0.85	0
e, z, c	0.96 <sup>a</sup>	0	0.01	0	0	0	0	0.03	0
e, l, c	0.98 <sup>a</sup>	0	0	0	0	0	0	0.02	0
p, l, b	0	0	0	0.51 <sup>a</sup>	0.49	0	0	0	0
e, z, b	0	0	0	0.98 <sup>a</sup>	0	0	0	0	0.02
e, l, b	0	0	0	0.94 <sup>a</sup>	0.0	0	0	0	0.05
o, l, b	0	0	0	0.13 <sup>a</sup>	0.87	0	0	0	0
e, s, b	0	0	0	0.99 <sup>a</sup>	0	0	0	0	0
p, s, b	0	0	0	0.61 <sup>a</sup>	0	0.39	0	0	0
p, z, b	0	0	0	0.96 <sup>a</sup>	0	0.04	0	0	0
o, z, b	0	0	0	1 <sup>a</sup>	0	0	0	0	0
o, s, b	0	0	1	0	0	0	0	0	0

<sup>a</sup> Significant at 95% level

opposite is correct for bus service which has no considerable correlation with any of tramway or private car. Therefore, the level of service of bus is potentially low and this leads to draw bus mode far away from private car and even from tramway. In the context of policy implications, since inhabitants of Eskisehir have such a willingness to shift their travels from car to tramway and from congested peak hours to uncongested times of day, it would be logical to implement measures such as improving the public transportation system or imposing cordon congestion pricing schemes to encourage the use of public

transportation modes. Notably, such conclusions express the powerful analytical ability of the proposed GNL approach where it has the power of capturing unusual correlation patterns. These patterns are thoroughly specific, unexpected, and very difficult to be observed in the market. By words, we argue that there is no other approach as simple as the proposed one that leads to such a temporally and spatially specific deductions.

- For private car-based alternatives, along with those alternatives that are correlated with tramway alternatives (N1), all other alternatives except one

strongly belong to nest N4 (i.e. car-based nest) with 1.10 scale parameter. Therefore, for discretionary trips of Eskisehir city, most car-based alternatives are weakly correlated with each other. Besides, a higher correlation has been found among two specific car-based alternatives which are (p, z, c & p, l, c) where they somehow have considerable weights in nest N7 (i.e. 0.11 and 0.13 respectively) with a high scale parameter (i.e. 1.25). Clearly, this represents a spatial correlation pattern between Ozdilek and Local Bazaar during peak hours for car users only. This is another important advantage of the proposed GNL model where it can precisely extract those alternatives that have some mutual dependency with actual importance (weight).

- For bus-based alternatives, rather than the traditional correlation ( $N_2$ ), temporal correlation can be observed between two alternatives (p, l, b & o, l, b) in nest  $N_5$ . That is, individuals who do their shopping and entertainment trips in Local Bazaar by using bus mode, likely perceive some similarities for both peak and off-peak departure times.

## 7. CONCLUSIONS

In the light of estimation results, it is possible to argue that the proposed GNL approach has distinct improvements over all traditional NL approaches. Its simplicity along with the incomparable flexibility in representing a lot of correlation patterns within and among different travel dimensions under a unified model qualify it to be prominent. The proposed GNL model can provide very detailed analyses about the inter-relationships associated with various departure times, travel modes and discretionary destinations where other “simple” models cannot. That leads to more certain, specific, efficient and precise policy decisions. For example, in the case study, while heading to specific discretionary destinations, the model succeeds to discover the unanticipated correlation between using private car at peak periods from one side and public transportation at evening periods from the other. Such a multi-dimensional dependency can provide decision makers with extremely useful indicators prior to the application of different policy implications. The advantages associated with the proposed GNL approach perhaps qualify it to be a peer to the well-known traditional four-step models if applied on discretionary trips in small and medium-scale planning issues (small or medium sized cities) with limited number of alternatives within travel dimensions. The proposal of using GNL approach to model departure time, destination and travel mode choices under a unified framework is considered as a milestone towards developing joint models that can efficiently and accurately replace the traditional four-step models and keep on degrees of easiness to advocate

engineers and policy makers rely more on them. It represents a time of day-based trip end distribution model that can reproduce extremely more accurate origin-destination matrices dependent on time of day. Moreover, unlike traditional four-step models, parameter estimates produced from the GNL model can provide significant indications which precisely reflect the real behaviour of individuals. That can enormously help policy makers to reach to a solid perception about the effects of applying some strategies to manage demands through different times of day and towards different destinations.

Finally, when applied for the case study, the proposed methodology (Figure 1) has shown enough flexibility during its different stages; the estimation of a proper utility function, producing data-based GNL nesting structures and attaining the best GNL model. That result supports the applicability of the proposed methodology when applied on other cities that have similar socio-demographic and size conditions. Moreover, more complicated choice situations that have higher number of alternatives may be readily handled in future researches through computerizing such methodology under a sophisticated computer routine or by using more advanced statistical techniques.

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# Modelling Departure Time, Destination and Travel Mode Choices by Using Generalized Nested Logit Model: Discretionary Trips

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## PAPER INFO

## چکیده

### Paper history:

Received 07 November 2019

Received in revised form 17 December 2019

Accepted 17 January 2020

### Keywords:

Departure Time

Destination

Generalized Nested Model

Traditional Four-Step Model

Travel Demand Modelling

Travel Mode

با وجود اینکه مدل چهار مرحله ای سنتی برجسته ترین مدل در اکثر تجزیه و تحلیل تقاضای سفر است، اما این همبستگی های بالقوه را در ابعاد مختلف سفر نشان نمی دهد. در نتیجه، برخی از تحقیقات پیشنهاد کرده اند که به جای آن از مدل سازی انتخاب استفاده کنید. با این حال، بسیاری از آنها ابعاد سفر را بطور جداگانه و نه مشترکاً نشان داده اند. این تحقیق با هدف پر کردن این شکاف از طریق استفاده از مدل Nested Logit برای نمایندگی مشترک سه بعد اصلی سفر انجام شده است. مقصد، زمان عزیمت و حالت سفر. روش تحقیق پیشنهادی عمدتاً به گزینه های آگومراسیون وابسته است که دارای واریانس خطای مشابه در شکاف های خاص در زیر لانه های مشترک و بدون محدودیت های تحمل شده اند. علاوه بر این، شکاف های مختلف واریانس منجر به سیستم لانه سازی با هم تداخل دارند که می تواند تحلیلگرها را قادر سازد که از همبستگی داخلی و بین استفاده کنند. رویکرد پیشنهادی از طریق الگوبرداری از گزینه های افراد در میان مقصد های اصلی خرید در شهر اسکیشهر، ترکیه مورد بررسی قرار گرفته است. با توجه به نتایج تخمین، مدل پیشنهادی به خوبی نسبت به همه دارد که نشان دهنده یک قدرت قابل پیش بینی برجسته تر است. علاوه بر این، افراد موجود در اسکیشهر متوجه شده اند که علاقه بیشتری به هزینه دارند نه زمان. از طرف دیگر، رفتار متقابل بین انجام چنین سفرهایی در دوره های پرتراکم با استفاده از ترانزیت یا ساختن آنها در خارج از پیک توسط ماشین شخصی مشخص شده است.

doi: 10.5829/ije.2020.33.02b.02