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Accommodating flexible daily temporal constraint on a continuous choice model of departure time for urban shopping travel

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This paper attempts to propose departure time choice model of travellers for one-day shopping travel based on the consideration of the availability of flexible temporal constraint during noon until evening, namely praying time. The model assumes that travellers decide their departure time to minimize the disutility of shortage stay time at the shopping centre, disutility of lateness home arrival time, and disutility of the flexible daily temporal constraint. It is applied to urban shopping travellers on the basis of their home-shopping, centre-home travel pattern. The model is confirmed by a goodness of fit test. It can be applied to develop a model of travel patterns and chosen in further studies.

Keywords: departure time; disutility model; shopping travel; flexible temporal constraint

1. Introduction

Departure time choice in a day of a traveller is one of the determinant factors in travel demand analysis, particularly in order to overcome urban transportation congestion problems on travel demand management (TDM). In any case, individual departure time is important to: (a) predict temporal demand in planning development and construction of a new transportation infrastructure; (b) test demand responses related to improvement of operational strategies of traffic control or transportation measures; and (c) assess the effectiveness of implementation of travel demand management measures related to specific time (Bhat & Steed, 2002). In recent years, a departure time choice model with higher temporal resolution is also needed for modelling source emission and air quality (Popuri et al., 2008; Gadda, Kockelman, & Damien, 2009).

The significance of the departure time choice study is ascertained from many studies over the past three decades. Generally, most earlier research used the discrete choice method that usually is based on the random utility model (RUM) approach. In this regard, the logit model and its development dominated the studies. For example, Abkowitz (1981), McCafferty and Hall (1982) and Small (1982) developed

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the multinomial logit model (MNL) in order to model departure and arrival time choices of travellers, where their choices depended on demographic variables such us income, age, etc. and chosen mode. Also, the MNL model was used by Hendrickson and Plank (1984) to construct a simultaneous choice model of departure time and travel mode with 28 alternatives. The alternatives were a representation of a combination between four different modes (i.e. drive alone, auto, shared ride and transit) and seven different departure times within 10-minute intervals. Mannering (1989) investigated the determinants of commuter flexibility in changing departure times and routes for the morning trip to work using the Poisson regressions estimation method. Furthermore, Chin (1990) developed a morning departure time choice model that used an MNL and nested logit (NL) model in the case of Singapore commuters. In addition, Hunt and Patterson (1996) also developed the logit model to examine how people are influenced in the selection of a departure time for a hypothetical trip in Calgary, Canada. In this regard, McFadden (1978), and Ben-Akiva and Lerman (1985) formerly used the NL model to overcome violations of the independence of irrelevant alternative (IIA) properties in the MNL model. In contrast, Jou (2001) developed a joint model for departure time and route decisions with and without pre-trip information for commuters in Taiwan using a probit model.

Previous research has been focused on the departure time choice models for commuting or for a work trip. However, a lot of earlier research also focused on non-work trips such as shopping trips, recreation trips, etc. Bhat (1998a) developed a departure time and travel mode choice model simultaneously for urban shopping trips. He used a nested structure to construct the choice hierarchy, where the travel mode choices were the higher level and departure time choices were the lower level. This form of the simultaneous choice model adopted a MNL form for the travel mode choices, and an ordered generalized extreme value (OGEV) form for departure time alternatives. Bhat (1998b) also applied a mixed multinomial logit model to an analysis of travel mode and departure time choice for home-based, social-recreational trips for the San Francisco Bay area. Furthermore, Steed and Bhat (2000) studied the departure time and trip purpose choices simultaneously for home-based social/recreational and shopping trips for the Dallas–Fort Worth region. They used a similar models approach as in Bhat (1998a). This research focused on a non-work trip due to at least two reasons, i.e. non-work trips contribute to increasingly large proportion of urban trips, especially in peak periods, and non-work trips have a more temporal flexibility of the individual than work trips (Bhat & Steed, 2002). In addition, the non-work trip provides more or less congestion and some environmental problems in the central business district (CBD) of a city (Ramli, Uemura, Ooeda, & Sumi, 2010a, Ramli, Ooeda, & Sumi 2010b).

All the above-mentioned studies of departure time choices, not only for work or commuting trips but also for non-work trips, are treated time as discrete variables. The alternative of the departure time choices is represented by several discrete time periods, such as the time period in morning, the time period at noon, the time period in afternoon, the time period in evening and the time period at night. There are four limitations in using this approach (Bhat & Steed, 2002). First, the approach requires the rather ad hoc partitioning of time in a day into several time intervals, as a consequence differences of the partitioning time lead to different results of a model. Second, a point of time is treated as part of an interval time nearing the boundary of the interval. Third, the model provides departure time choices only in intervals of a time aggregate, resulting in the loss of time in resolution. Last, the approach requires the same property of aggregate interval for forecasting utilization. Furthermore, utilization of the logit model approach in this method leads to insufficiency of those models in the transform capability (Sumi et al., 1990). It is often difficult to clarify how each the particular factors affects the observed result when using the approach model comprehensively, particularly when conforming to the real world.

Regarding the limitation of the above discrete choice method, the continuous method has been developed by some scholars in order to model departure time on a continuous scale. Most of the exploration of the continuous method used Cox's (1972) proportional hazard (PH) model approach. For example, Wang (1996) modelled the revealed preferences of the activity start times for the Canadian case by using a parametric-baseline, hazard-rate model of duration. The model examined how travellers maximize their total timing utility in order to determine their time choice. A hazard-based model was also used by Bhat (1996) to develop a shopping duration model that was grouped in a 7.5-minute interval level. The model adopted a nonparametric baseline hazard distribution, while the covariate effect was controlled parametrically. Furthermore, Bhat and Steed (2002) proposed a continuous-time approach to develop a departure time choice model for shopping trips in the Dallas–Fort Worth case using a similar semi-parametric model. Their model was utilized to forecast temporal shift in urban shopping travel in the context of a congestion pricing evaluation. In addition, Lee and Timmermans (2007) developed an accelerated hazard model using a latent class specification, in order to grasp heterogeneity and tendency of accelerated or decelerated activity durations. Most recently, Komma and Srinivasan (2008) used the Gamma mixing distribution in non-parametric hazard model-to-model departure time choices, while Gadda et al. (2009) utilized the Bayesian estimation method in an accelerated hazard model. Lemp, Kockelman, & Damien (2010) introduced a continuous cross-nested logit (CCNL) model in order to propose the advantages of a RUM approach in a continuous choice setting. The model used Bayesian estimation technique to estimate a work-tour departure time model.

In the context of the continuous method utilized in order to relieve the limitation of the discrete method relating to the transform capability limitation, Sumi, Matsumoto, & Miyaki (1990) began to introduce an approach model to reduce the transferability limitation issues. The model assumed that departure time decision of work travellers are affected only by the operational features of a transit system. Basically, the proposed approach model used marginal utility or disutility of primary factors related to the points of time during one day of commuting travel, such as departure time, arrival time, stay time and travel time. Further, the approach model leads to utilization of the threshold time of disutility, which has to be avoided by individuals in order to choose their departure time or arrival time from origin or to destination place. In other words, the model used contrary assumptions from the RUM approach, where a disutility minimizing model (DMM) approach was introduced. In this regard, the DMM approach assumes that travellers made their choice based on the minimization of sum types of disutility faced by individuals. In addition, a comprehensive choice model of departure time and a travel mode choice, simultaneously for commuting travel using the DMM approach was developed by Li, Ooeda, Sumi, & Matsuzaki (2003).

Furthermore, specifically for a non-work trip that used the DMM approach, a previous study proposed a disutility model to consider the one-day life cycle for non-work trips (Sumi et al., 1994). It was expanded to take in account of more short-time behaviour (Sumi et al., 1995), also for the travel with a series of destinations (Ooeda, Uemura, & Sumi, 2005). The model provided a basis for taking account of excess-day travel (Ooeda, Sumi, Nakanisi, & Tubaki, 1997) and taking account of the frequency of a non-work trip (Chen, Dejima, Ooeda, & Sumi, 2004; Chen, Ooeda, & Sumi, 2005). In the last three of the previous studies the authors of the present paper have proposed a choice model of departure time for trip to shopping place for certain purposes based on minimizing disutility (Ramli et al., 2010a). The model particularly regarded daily shopping trips that consider lunch activity around noon as a flexible daily time constraint of travelers to decide their departure time. Further, we take into account another activity constraint in the morning to choice model of leave time from shopping place for short time shopping travel (Ramli et al., 2010b), and also consider praying time activity during noon until evening as a flexible temporal constraint on a decision model of leave time from the shopping place (Ramli, Ooeda, Sumi, & Chiaki, 2011).

The last constraint above is for travellers of shopping travel in an Islamic society in most developing countries. There is a different situation for the travellers in choosing their departure time in a society compared to people in developed countries. Whereas people in the Islamic society in developing countries choose their departure time to do their activities, not only considering lunch time at noon and/or dinner time in the evening, but also a specific time for the daily obligations from noon until evening, namely praying time. The difference in choosing the time causes the different choice of departure time from their home or place of origin (for more discussion related to the praying time constraint, please see Ramli et al., 2011). Moreover, the temporal constraint may affect simultaneously others' decisions on one-day shopping travel attributes in the practical view point such as travel pattern decisions, travel destinations and travel modes. Therefore, the constraint incorporating departure time causes an accumulative impact on urban congestion problems, such as evening congestion becoming much more severe, and/or affects on the destination/shopping place choice.

In order to contribute towards expansion and improvement of the analysis technique on the departure time choice model of shopping travel using the DMM approach, this paper aims to continue to develop a departure time choice model of shopping travel particularly in the travel for home-shopping centre-home (H-SC-H) trip pattern that considers the availability of a flexible daily temporal constraint during noon until evening on one-day shopping travel. Regarding this, we adopt not only a time constraint for lunch activity around noon as the author's previous research, but also a time constraint for praying time activity during noon until evening as a daily obligation of religious activity as explained above.

In summary, this paper formulates and applies a continuous time model using disutility threshold model, it is called the disutility minimizing model (DMM), for a departure time choice of one-day shopping travel under H-SC-H trip pattern. Specifically, the model accommodates some flexible temporal constraints in a day, such as lunch time around noon, and specific time of daily obligations, namely pray time during noon until evening. These are commonly available to shopping travellers in an Islamic society in developing countries. The model is applied to analyse the departure time choice on shopping travel of individuals under different life-stage properties by using data from an activity survey that was conducted in 10 residential areas in Makassar, Indonesia, a country that has the biggest Islamic society among the developing countries in Asia. Since a vast majority of individuals who made a trip for shopping travel during the survey, made only one such trip with home-shopping centre-home (H-SC-H) trip pattern. Furthermore, we focus only on the departure time choice modelling for the shopping travel of the day and the pattern.

The remainder of this paper is composed as follows. The next section presents the development of the model structure. Then, section 3 demonstrates the application of the model. The final section provides a discussion related to the result of the model implementation and summarizes important findings.

2. Development of model structure

2.1. Constraint of the activity-travel pattern and disutility on shopping travel

In context of human activity travel patterns, an individual is constrained by three restrictions (Hägerstrand, 1970): (1) capability constraint; (2) coupling constraint; and (3) authority constraint. Related to shopping travel, individuals face capability constraints and authority constraints to be considered in deciding their departure time. Commonly, the departure time to a shopping centre is restricted by lunch time at noon, dinner time in the evening and/or praying time during noon until evening, the opening time of a shopping centre is usually between 10:00 to 22:00. Generally, travel to a shopping place should be done in these timeframe restrictions.

With reference to the capability and authority constraints on urban shopping travel in an Islamic society in Asian developing countries, travellers consider praying time activity during noon to evening on their decision of one-day shopping travel attributes (Ramli et al., 2011). In this regard, the travellers have to conduct three praying activities, *dhuhur, ashar* and *magrib*. The time limitations to conduct each type of praying are 12:00–15:00, 15:00–18:00 and 18:00–19:30 respectively, where each obligation needs approximately 5–15 minutes to complete.

From another point of view, travel has been generally regarded as disutility. Addressed to shopping travel behaviour, travellers have at least two categories of disutility in their travel: (1) disutility at the origin of place, and (2) disutility at the activity place, particularly at the shopping centre or the shopping place. All elements of both categories of disutility should be assessed by travellers in the timeframe constraints mentioned above in order to decide their departure time according to smallest disutility total that they may take.

In previous research (Ramli, et al., 2010a, 2010b, 2011), the authors of the present paper have already introduced some types of disutility for H-SC-H pattern, regarding three main processes in accordance with the places about which decisions are made. The types of the disutility include two types of disutility; the disutility due to earliness in the morning and the disutility of lateness at night are assumed to express the variation of activity level that mainly dealt with the origin place processes (for example, the leaving home process and the returning home process). The others types of disutility are assumed to express the behaviour in order to stay enough time at the shopping place: one is due to the shortage of stay time for expressing the behaviour to have enough stay time, and the other is due to the length of stay time to express the stay time is not extended if people feel it enough. Furthermore, this research also introduces disutility of lunch activities and praying time activities, in order to respond to the availability of temporal constraints of activity travel behaviour in a day, as mentioned above.

The functions of all the types of disutility, as shown by Figure 1, are shown in the following expression (for more discussion on these types of disutility see Ramli et al., 2010a, 2010b, 2011):

(1) Disutility of earliness home departure time on leaving home process, D_1

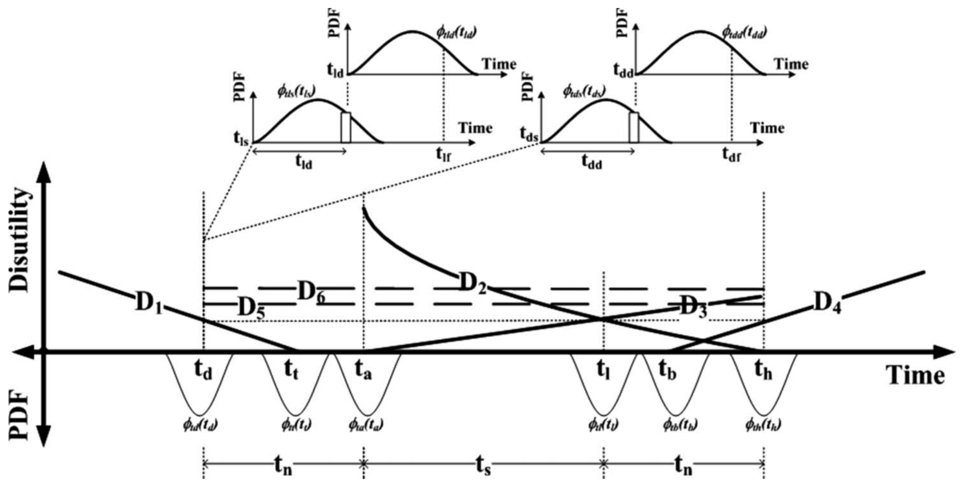


Figure 1. Disutility of shopping trip.

$$D_1 = -\begin{cases} A(t_\mathrm{d} - t_\mathrm{t}) \ldots\ldots\ldots\ldots\ldots (t_\mathrm{d} < t_\mathrm{t}) \\ 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (t_\mathrm{d} \geq t_\mathrm{t}) \end{cases} \tag{1}$$

Where t_d and t_t are the departure times from home and the time when people do not mind the earliness, i.e. the time corresponding to the threshold value of D_1, and A as positive parameter. A linear function was adopted here for simplification. Note that the upper portion of the right-hand side of Equation (1) always gives a positive value since it considers the value of t_d less than t_t.

(2) Disutility of shortness stay time at shopping place, D_2

$$D_2 = e^{-\alpha t_\mathrm{s}} \tag{2}$$

Where t_s is the stay time at the shopping centre, and α as the positive parameter.

(3) Disutility of the lateness stay time at shopping place, D_3

$$D_3 = \beta t_\mathrm{s} \tag{3}$$

Where β is the positive parameter.

(4) Disutility of lateness home arrival time on returning home process, D_4

$$D_4 = \begin{cases} B(t_\mathrm{h} - t_\mathrm{b}) \ldots\ldots\ldots (t_\mathrm{h} > t_\mathrm{b}) \\ 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (t_\mathrm{h} \leq t_\mathrm{b}) \end{cases} \tag{4}$$

Where t_h and t_b, express the arrival time at home and the time corresponding to the threshold value of the disutility due to late arrival time at home respectively, and B as the positive parameter.

(5) Disutility of lunch activity, D_5

$$D_5 = \frac{1}{t_{\mathrm{lf}} - t_{\mathrm{ls}}} \tag{5}$$

Where t_{ls} and t_{lf} are start and end time of lunch activity respectively.

(6) Disutility of praying time-activity, D_6

$$D_6 = \frac{1}{t_{\mathrm{df}} - t_{\mathrm{ds}}} \tag{6}$$

Where t_{ds} and t_{df} are start and end time of praying activity in the noon–evening period, respectively.

2.2. *Departure time choice model of shopping travel for the H-SC-H travel pattern*

This paper completes the departure time choice model that has been proposed in previous research (Ramli et al., 2010a), where the disutility of the flexible time constraint for daily praying time activity in the noon–evening will be added into the previous model. Furthermore, regard that people choosing their departure time to the shopping centre consider at the same time the decision not only in regard to the leaving time from the shopping centre but also the arrival time at home. This emphasis leads to derivation of the model into a two-step decision-making case. The first step is the condition where the threshold time to have disutility of earliness home departure time (t_{t}), is less than optimum departure time (t_{d0}), or threshold time to have disutility of lateness home arrival time (t_{b}), is less than arrival time at home (t_{h}). The second step is that t_{t} and t_{b} are equal or more than t_{d0} and t_{h} respectively. The model derivation of the departure time model as a two-step decision will be deduced in the next part.

2.2.1. *The first step of departure time choice*

As in Ramli et al. (2010a), regard that an individual will consider his/her departure time to the shopping place in order to minimize all of his/her disutility and, assuming that all the types of utility are addable, the sum of disutility according to the places where decisions are made for the first case (D_{23}) is given as a function of stay time (t_{s}), as follows:

$$D_{23}(t_{\mathrm{s}}) = D_2(t_{\mathrm{s}}) + D_3(t_{\mathrm{s}}) \tag{7}$$

Where the minimum of the sum disutility is given as an optimum point of stay time (t_{s0}), as below:

$$\left.\frac{D_{23}(t_{\mathrm{s}})}{dt_{\mathrm{s}}}\right|_{t_{\mathrm{s0}}} = 0 \tag{8}$$

Because there are following relations among the variables relating to time such as arrival time (t_{a}) and leave time (t_{l}), at and from the shopping place, travel time (t_{n}) is as below:

$$t_l = t_s + t_a \tag{9}$$

$$t_a = t_d + t_n \tag{10}$$

$$t_h = t_n + t_l \tag{11}$$

In addition, the assumption that total time consumption for the activity is less than the time interval from t_t and t_b, the person can choose the departure time from home and the arrival time at home later than t_t and earlier than t_b, respectively. Hence, the distribution of departure time from home, $\phi_{td1}(t)$, can be stated as an unit of distribution as follows:

$$\phi_{td1}(t) = \frac{1}{t_{d0} - t_t}, \quad (t_t < t_{d0}) \tag{12}$$

Where t_{d0} is a constant value given by the following equation:

$$t_{d0} = t_b - t_n - t_{s0} - t_n \tag{13}$$

2.2.2. The second step of departure time choice

The second step assumes that people cannot choose their departure time within the range $[t_t,\ t_{d0}]$ or $t_t \geq t_{d0}$. It means that their decision on departure time also takes into account D_1 and D_4. As a similar assumption with the first case, in particular that all the types of utility are addible, the total disutility in this case is D_{1234} and is given as follows:

$$D_{1234}(t) = D_1(t_d) + D_2(t_s) + D_3(t_s) + D_4(t_h) \tag{14}$$

With regard to the relationships among the time variables in Equations (9), (10) and (11), Equation (14) can be restated as function of departure time (t_d), as below:

$$D_{1234}(t_d) = D_1(t_d) + D_2(t_d) + D_3(t_d) + D_4(t_d) \tag{15}$$

Then, the optimum departure time of an individual is given as following condition:

$$\left.\frac{D_{1234}(t_d)}{dt_d}\right|_{t_d = t_{d2}} = 0, \quad (t_t \geq t_{d0}) \tag{16}$$

Hereafter, we shall regard every decision as conditional on the travel time and the stay time in order to consider the group of individuals and availability of the travel time distribution.

2.2.3. Consideration of the choice behaviour dispersion

In order to represent the fact that in the real world that human behaviour always has dispersion, as a consequence of individual and occasional differences, we have to define some parameters as random variables. In this case we define t_t, t_b and α as random variables to express the dispersions of the departure time, the leaving time and the stay time, respectively. Their probability density functions (PDF) are denoted by $\phi_{\mathrm{tt}}(t_{\mathrm{t}})$ and $\phi_{\mathrm{tb}}(t_{\mathrm{b}})$ respectively and we assume their dispersions are independent from each other.

Regarding the above assumptions, Equation (12) and (16) are rewritten into the following expressions:

$$\phi_{\mathrm{td1}}(t|t_{\mathrm{n}}) = \int_{-\infty}^{\infty}\int_{t^{*}_{\mathrm{b0}}}^{\infty} \frac{1}{t_{\mathrm{d0}} - s}\phi_{\mathrm{tb}}(\tau)\phi_{\mathrm{tt}}(s)d\tau ds, \quad (t_{\mathrm{t}} < t_{\mathrm{d0}}) \tag{17}$$

The distribution of arrival time at destination for a given travel time (t_{n}), is given as follows:

$$\phi_{\mathrm{ta1}}(t|t_{\mathrm{n}}) = \phi_{\mathrm{td1}}(t - t_{\mathrm{n}}),\ (t_{\mathrm{t}} < t_{\mathrm{d0}}) \tag{18}$$

Considering the distribution of the threshold time of the home departure time, $\phi_{\mathrm{tt}}(t_{\mathrm{t}})$, and the threshold time of the home arrival time, $\phi_{\mathrm{tb}}(t_{\mathrm{b}})$, the optimum departure time is given by equation (16) which provides the distribution of departure time as follows:

$$\phi_{\mathrm{td2}}(t|t_{\mathrm{n}}) = \int \phi_{t_{\mathrm{b}}}(t_{\mathrm{b}})\left|\frac{dt_{\mathrm{b}}}{dt_{\mathrm{d2}}}\right|\phi_{\mathrm{tt}}(s)d\tau ds, \quad (t_{\mathrm{t}} \geq t_{\mathrm{d0}}) \tag{19}$$

Then, the distribution of arrival time at the destination is again obtained as follows:

$$\phi_{\mathrm{ta2}}(t|t_{\mathrm{n}}) = \phi_{\mathrm{td2}}(t - t_{\mathrm{n}}), \quad (t_{\mathrm{t}} \geq t_{\mathrm{d0}}) \tag{20}$$

Because those above distributions have limitation from time constraints in the parentheses, they are not PDFs in normal sense. Then, the PDF of the departure and arrival times are given by the sum of Equations (17) and (19), and Equations (18) and (20) respectively as follows:

$$\phi_{\mathrm{td}}(t_{\mathrm{d}}|t_{\mathrm{n}}) = \begin{cases} \phi_{\mathrm{td1}}(t|t_{\mathrm{n}})\ldots\ldots\ldots(t_{\mathrm{t}} < t_{\mathrm{d0}}) \\ \phi_{\mathrm{td2}}(t|t_{\mathrm{n}})\ldots\ldots\ldots(t_{\mathrm{t}} \geq t_{\mathrm{d0}}) \end{cases} \tag{21}$$

$$\phi_{\mathrm{ta}}(t_{\mathrm{a}}|t_{\mathrm{n}}) = \begin{cases} \phi_{\mathrm{ta1}}(t|t_{\mathrm{n}})\ldots\ldots\ldots(t_{\mathrm{t}} < t_{\mathrm{d0}}) \\ \phi_{\mathrm{ta2}}(t|t_{\mathrm{n}})\ldots\ldots\ldots(t_{\mathrm{t}} \geq t_{\mathrm{d0}}) \end{cases} \tag{22}$$

In order to take a human group into account of travel time's PDF, $\phi_{\mathrm{t_n}}(\mathrm{t_n})$, Equation (21) and Equation (22) can be restated as below:

$$\phi_{\mathrm{td}}(t_{\mathrm{d}}) = \int_{0}^{\infty} \phi_{\mathrm{td}}(t|t_{\mathrm{n}})\phi_{\mathrm{tn}}(t_{\mathrm{n}})dt_{\mathrm{n}} \tag{23}$$

$$\phi_{\mathrm{ta}}(t_{\mathrm{a}}) = \int_{0}^{\infty} \phi_{\mathrm{ta}}(t|t_{\mathrm{n}})\phi_{\mathrm{tn}}(t_{\mathrm{n}})dt_{\mathrm{n}} \tag{24}$$

The above argument leads to a possible complementary calculation. Later this paper will show the comparison of the departure time distribution derived from the above equation to the observed departure time distribution.

2.2.4. *Consideration availability of the flexible time constraint in the noon–evening period*

When the effect of the lunch activity constraint is considered on the departure time decision, the model becomes much more complicated. Let us denote the lunch start time and the lunch time duration as t_{ls} and t_{ld}, and the distribution of the both as $\phi_{\mathrm{tls}}(t_{\mathrm{ls}})$ and $\phi_{\mathrm{tld}}(t_{\mathrm{ld}})$ respectively. Then the probability that a given arrival time is included in the lunchtime (P_{L}) is obtained by the multiplication of the probability that lunch has already started and the probability that lunch is still continuing. The equation is as follows:

$$P_{\mathrm{L}}(t_{\mathrm{a}}) = \int^{t_{\mathrm{a}}} \phi_{\mathrm{ls}}(\tau) \int_{\mathrm{t_a}-\tau} \phi_{\mathrm{ld}}(s) ds d\tau \tag{25}$$

If the arrival time or departure time is included in the lunch time, we simply assume that the trip is restrained. The distribution of departure time and arrival time is corrected as follows:

$$\phi^{c}_{\mathrm{t_d}}(\mathrm{t_d}) = \{1 - P_{\mathrm{L}}(t_{\mathrm{d}})\}\phi_{\mathrm{t_d}}(t_{\mathrm{d}}) \Big/ \int \{1 - P_{\mathrm{L}}(\tau)\} d\tau \tag{26}$$

$$\phi^{c}_{\mathrm{t_a}}(t_{\mathrm{a}}) = \{1 - P_{\mathrm{L}}(t_{\mathrm{a}})\}\phi_{t_{\mathrm{a}}}(t_{\mathrm{a}}) \Big/ \int \{1 - P_{\mathrm{L}}(\tau)\} d\tau \tag{27}$$

The main purpose of this paper was to introduce another flexible time constraint related to availability in the daily specific time activity, namely praying time, during noon until evening, and now we will introduce the constraint into the departure time choice model. In this regard, there is a different situation where the traveller's behaviour gives more emphasis to the effect of the praying time activity during the noon–evening period rather than the lunch activity around noon. In other words, the traveller decides the departure time when considering the disutility related to the place where the decision is made, and also the disutility of the flexible time constraint in the noon–evening period as instead of the disutility of lunch. Similar to the treatment of the lunch activity constraint, let us denote the noon–evening activity start time and time duration as t_{ds} and t_{dd}, and the distributions of these two as $\phi_{\mathrm{ds}}(t)$ and $\phi_{\mathrm{dd}}(t)$, respectively. Also, the probability density function is denoted as $\phi_{\mathrm{dn}}(t)$. Then, the probability that a given noon–evening activity time, t_{dn}, is included in the departure time, P_{dn}, is obtained by the multiplication of the probability that the activity has already started and the probability that the activity is still continuing. This probability is expressed in the following equation:

$$P_{\mathrm{dn}}(t_{\mathrm{a}}) = \int^{t_{\mathrm{a}}} \phi_{\mathrm{ds}}(\tau) \int_{t_{\mathrm{a}}-\tau} \phi_{\mathrm{dd}}(s) ds d\tau \tag{28}$$

If the arrival time or departure time is included in the short-time activity, the distribution of the departure time and the arrival time in Equations (26) and (27) is again corrected as follows:

$$\phi^{c*}_{\mathrm{t_d}}(t_{\mathrm{d}}) = \{1 - P_{\mathrm{dn}}(t_{\mathrm{d}})\}\phi^{c}_{\mathrm{t_d}}(t_{\mathrm{d}}) \Big/ \int \{1 - P_{\mathrm{dn}}(\tau)\} d\tau \tag{29}$$

$$\phi^{c*}_{\mathrm{t_a}}(t_{\mathrm{a}}) = \{1 - P_{\mathrm{dn}}(t_{\mathrm{a}})\}\phi^{c}_{\mathrm{t_a}}(t_{\mathrm{a}}) \Big/ \int \{1 - P_{\mathrm{dn}}(\tau)\} d\tau \tag{30}$$

3. Application of model

The proposed model above can be applied to all travel behaviour especially for travelling to a shopping centre in Islamic developing countries. The shopping centre travel is particularly correlated to the H-SC-H travel pattern, the duration of departure from home to arrival at home is not so short, since travellers have chance to do some activities in the shopping centre such as buying daily goods, visiting a book shop, watching a movie or eating at a restaurant. In addition, it is not necessary for travellers to leave their home and their shopping place early in most cases of the H-SC-H travel pattern, because they generally have only one destination place in a day, hence they have enough time to enjoy their travel time to the shopping centre. Therefore we can simplify the model to apply this behaviour. Essentially, Equation (19) does not need to be applied, so that travellers' behaviour can be sufficiently expressed by Equations (17) and (18) by conditioning minus disutility of the length of stay time, and also by Equation (29) which is simplified to only consider the praying time activity constraint from noon until evening, instead of as a lunch activity constraint. In other words, the application of Equation (29) can be change by Eequation (26) in terms of the praying time activity constraint being changed to the lunch activity constraint. Thus, the parameters that are used to represent the behaviour of travellers are now only $\mathrm{t_b}$, α, $\mathrm{t_{ds}}$ and $\mathrm{t_{dd}}$. In the next sections we will explain application of the above simplified model.

3.1. Calculation method to estimate parameters of the model

The calculation method used to estimate the model parameters in this research is based on the higher multiple integrations that have to be made repeatedly, similar to those used in Ramli et al. (2010a, 2010b, 2011). The method is not a procedure to find a mathematical solution of integral equations, but is a procedure to find a set of numerals possibly regarded as the parameters, subsequently the calculated values depend on the set of assumed initial values. Therefore we have to have some trial and error processes to find the possible parameters' values. The following method was applied for this purpose:

1. Replace the four parameters, t_b, α, t_{ds} and t_{dd}, that were defined as random variables before, with their average and standard deviation values, μ_{tb}, σ_{tb}, μ_α, σ_α, μ_{tds}, σ_{tds}, μ_{tdd} and σ_{tdd} respectively. Then, give the initial value for the all parameters.
2. Generate a set of large numbers of random numerals using the average and standard deviation for each the parameters.
3. Calculate the arrival time and its distribution by taking one of the numerals for each parameter that conditional to a certain value of travel time. Repeat the procedure until the set of random numbers are all taken into account.
4. Repeat step (3) for the changing values of travel time according to the observed distribution until the full range of travel time is covered.
5. Weight the departure time distribution by sharing it with the travel time and arrival time distribution, and suppose that the departure time distribution is obtained for all members of the group.

(6) Compare the calculated distribution of departure time with the observed one, and calculate the square difference between them, R^2_{Min}, as in the following equation:

$$R^2_{Min} = \sum (N_{\mathrm{t_d}\mathrm{Observation}} - N_{\mathrm{t_d}\mathrm{Calculation}})^2 \tag{31}$$

Where $N_{\mathrm{t_{d_{Observation}}}}$ and $N_{\mathrm{t_{d_{Calculation}}}}$ are the number of people resulting from observation and calculation respectively.

(7) Change the assumed values of the parameters in an iterative manner to reduce the square difference. A certain type of non-linear optimization program, using a non-linear simplex algorithm, is used to reduce it until criteria for the judgement convergence is achieved.

(8) Stop the calculation when the variation of the parameters become small enough and regard the assumed values as the estimated values for the parameters.

In order to represent different properties of individual property, as mentioned in the introduction, and also to consider sufficient reproduction capability of the model, the calculation values of parameters of the random variable t_b and α for each category of the individuals property is done simultaneously. It means that we have to distinguish t_b and α between the individual categories of each other. Since we consider two categories of age in this research, there are 12 parameters calculated in the model: μ_{tb1}, σ_{tb1}, $\mu_{\alpha 1}$, $\sigma_{\alpha 1}$, μ_{tb2}, σ_{tb2}, $\mu_{\alpha 2}$, $\sigma_{\alpha 2}$, μ_{tds}, σ_{tds}, μ_{tdd} and σ_{tdd}.

3.2. Implementation of survey

A survey was conducted using a questionnaire based on the home interview method at 10 residential areas in Makassar, Indonesia, the biggest Islamic country among Asian developing countries. The residential areas included three in the north, four in the south and three in the east of the city. These residential areas were chosen to represent the variant of shopping trips characteristic of travellers from a residence to a shopping centre in the city. The people who had been living in the residential areas mostly practise the Islamic religion. Travel demand of the city citizens is serviced by para-transit and taxi as formal public transport and some informal public transit such as tricycle and motorbike. However, almost all the people in the residences utilize private cars and motorcycles for their travel to the shopping centre. Regarding this, individuals have specific time constraints to choose their departure time to the shopping centre, and they have to conduct their praying during noon until evening. These circumstances provide a good opportunity to test the application of the model.

Table 1 shows the characteristics of the survey and Table 2 shows the execution of the survey. The questionnaire sheets were distributed by the surveyor to all the houses in each of the residential areas that were selected, based on random sampling selection. The questionnaires were issued and collected by each surveyor by using the home interview method. The number of respondents, as a representation of household, is 1,490, while the number of respondents that travelled to the shopping centre with the H-SC-H trip pattern, as focus of data analysis in this research, was 758 respondents.

Table 1. Characteristic information in questionnaire.

Category of attribute	Respondent attribute
Individually attributes	Sex, Age, Car ownership, Resident area, Family size
Attributes' time of shopping trip pattern	Departure time from home, stay time at shopping place, leave time from shopping place, and arrival time at home
Others attributes of shopping trip	Origin and destination place of trip, mode travel, and number of trip

Table 2. Number of questionnaire.

Location of survey (Residency)	Number of respondent target	Number of respondent for H-SC-H trip pattern
Area A		
– Telkomas	41	18
– Bumi Tamalanrea Permai (BTP)	372	176
– Dosen UNHAS	255	152
Area B		
– Bukit Baruga	57	9
– Perumnas Antang	198	94
– Dosen & Pegawai UNHAS	107	56
Area C		
– Residen Alauddin Mas	42	19
– Gerhana Alauddin	43	32
– Bumi Permata Hijau	62	42
– Minasa Upa	313	160
Total	1490	758

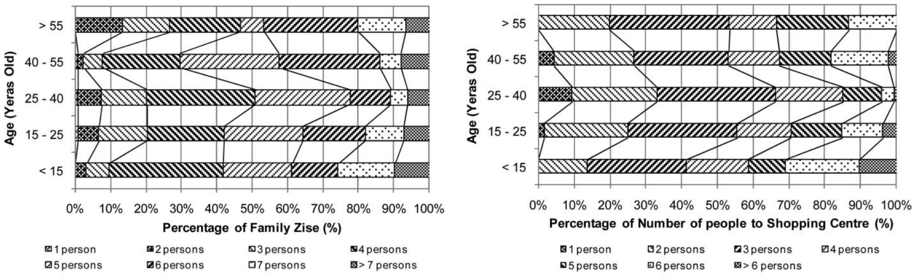
3.3. Results of the survey

The results of the survey relating to some of the primary characteristics of a trip to the shopping centre from people of the residences in the city are described in Figure 2.

Figure 2(a) shows the relations between the distributions of family size and the age categories. The notation 'age' in the figure generation, means the generation of the representative person of a family in a household. As shown in the figure, around 80% of the households have four or more than seven family members, where the dominant categories in each of the age categories are families with four, five or six persons. Furthermore, the figure shows that the categories of age 15–25, 25–40 and 40–55 years old form the largest component of people that travelled to the shopping centre in the Makassar.

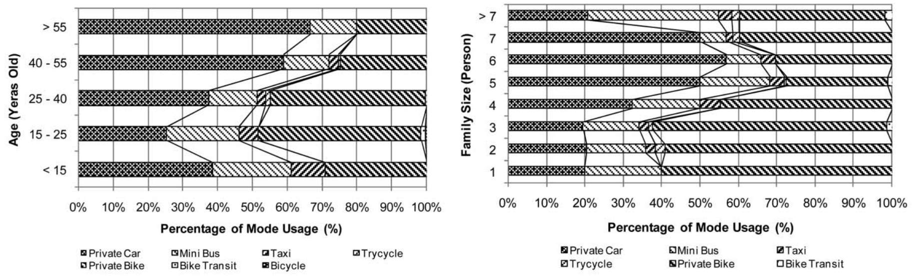
Figure 2(b) shows the distribution of the number of people that the shopping centre trip was done by: an individual of a household or a family for each category of age. The figure shows that an individual usually makes the shopping centre trip with two, three, four, five, six or more than six persons; whereas the trip was dominated by two to four persons collectively. This phenomenon occurs for all of age categories; moreover, both age categories, <15 years old and >55 years old, never travel to the shopping centre alone.

Figures 2(c) and 2(d) show the distribution of transit mode usage for both categories, which are age and family size, respectively. As shown by Figure 2(c), the majority of people from all of age categories utilize private cars and private



(a) Family size for age categories.

(b) Number of people to shopping centre for age categories.



(c) Mode usage for age catogories.

(d) Mode usage for family size catogories.

Figure 2. Characteristic of shopping trip of people in Makassar city.

motorcycles as major mode of their travel to the shopping centre, as well as in Figure 2(d) in view of family size categories. Furthermore, Figure 2(c) shows that the age category of 15–25 years old has a larger usage of private motorcycles than private cars, in comparison with the age category of 40–55 years old. This phenomenon is similar to mode usage based on family size categories, where the family size categories with one to four persons dominate private motorcycle utilization. In contrast, the use of a private car occurs mainly for the people who have five to seven family members.

According to the above survey results, specifically in the difference and similarity of individuals' properties in conducting urban shopping travel such as number of people to shopping centre and mode usage, we need to grasp time behavioural properties of the individuals on the basis of life stage differences. Therefore, we classified the respondents into two categories of life stages: 25 years old or less and more than 25 years old. Both categories are also useful in testing of the application and the reprodution capability of the model.

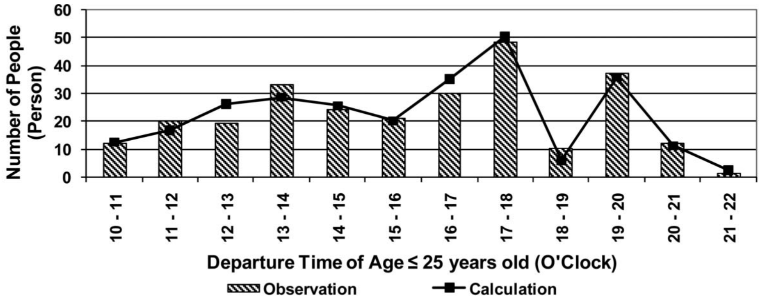
3.4. Results of calculation

The estimated parameters for each category of the respondents are shown in Table 3, along with the statistics showing the minimized square difference values, R^2_{Min}, and significant level of fitness, α, between the calculated and observed departure time distributions by using χ^2 and Kolmogorov–Shirinov (KS) test.

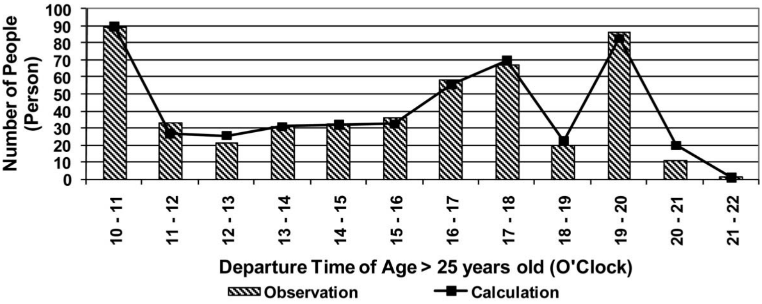
The departure time distributions obtained from the calculation are shown in Figure 3. It was revealed, on the one hand, that the calculation reproduced the observed distributions well, although, the Chi-square tests gave small values of goodness of fit ($\alpha = 5\%$) for the two categories. On the other hand, the significant levels of goodness of fit by K-S test reached 20% for both categories.

Table 3. Result calculations of parameters.

Parameter of model	Category of individuals	
	Age $\leq$ 25 years	Age $>$ 25 years
μ_α	-0.0283	-0.0787
σ_α	0.1335	0.1621
μ_{tb}	20.2097	21.0658
σ_{tb}	1.2567	4.9365
μ_{tds}	17.1824	
σ_{tds}	0.2535	
μ_{tdd}	1.9218	
σ_{tdd}	0.1672	
Number of data	267	485
Square error minimum (R^2_{min})	319.9415	
Degree of freedom (df)	9	
α of χ^2 test (%)	5	
α of KS test (%)	20	



(a) Category of age 25 years old or less.



(b) Category of age more than 25 years old.

Figure 3. Comparison between departure time of the calculation and the observation.

Furthermore, Table 3 shows that the parameters' values give a positive sign as expected, except the average of α parameter, μ_α. The comparison of the parameters' values of the random variables α and t_b on both age categories also shows significant difference. The average of random variable α, μ_α of age 25 years old or less category is smaller than the more than 25 years old category, as well as the dispersion or standard deviation of the random variable, σ_α. Further, the parameters' values of the random variable t_b show that the average value of t_b, μ_{tb}, for the age more than 25 years old category is approximately one hour later than the age 25 years old or less category. In this regard, the older category also has dispersion, σ_{tb}, wider of about 3.5 hours than the younger category.

In relation to the parameters' values of the praying time constraint, both categories start to conduct, on average, the noon–evening activity at 17.00 approximately with its standard deviation about 0.25 hours. In addition, individuals in both categories have duration in conducting this activity around two hours in average, and its dispersion about 0.16 hours.

4. Discussion and conclusions

4.1. Discussion

Based on the comparison of the parameters' values between both categories of age categorization, as shown in Table 3, we can find that the value for the younger generation, 25 years old or less category, is slightly different from the other category. The older generation category has parameters' values of the random variable t_b that is bigger than the younger generation, as well as for the random variable α . These results indicate that the older individuals stay at the shopping centre a little bit longer than the younger individuals. These also showed that the individuals of age more than 25 years old category have a threshold time of arrival home, t_b, and is later than the individuals of age the 25 years old or less category.

Meanwhile, the parameters' values of the random variables related to the time constraint in a day cycle, in this case a constraint of specific time for daily obligation, indicates that the constraint suffered by most individuals of having a shopping centre trip for both categories. The parameters' values of this constraint indicate that the individual's concern to conduct *ashar* praying activity at the lateness of the time role or their praying time is near to the *magrib* praying time in the evening. This phenomenon leads to most individuals delaying their departure time to the shopping centre during the evening between 18:00–19:00, as shown in the departure time distribution of both categories in Figure 3.

In relation to the travel mode usage of individuals for a trip to the shopping centre, as previously mentioned, the above phenomena can be dominant factors that are considered by individuals in choosing their transit mode, as well as their trip pattern and shopping centre as destination place.

According to the results, we may state that the model can represent the factual phenomena regarding the availability of the flexible time constraint for praying time activity during noon until evening as a constraint that is considered by individuals when deciding their departure time to the shopping centre. This constraint can be, instead of a lunch activity constraint, one of the primary considerations to choose a departure time of travellers in different environments in reference to cities in developing countries, where citizens of the cities are dominated by Islamic religion and located in Asian developing countries. In addition, for the combination of the different situations, the constraint also can be added to complete the departure time choice model that considers only the lunch activity as a constraint of the traveller, as we proposed, and given evidence in the previous research (as in Ramli et al., 2010a). However, the proposed model could improve and complete the leave time choice model considering the praying time constraint as in the previous proposed model of the authors (see also Ramli et al., 2011). Finally, we expect that the proposed model in the present paper can be tested in further studies in order to improve and complete the model with other choice models. In other words, we expect to use the phenomena as dominant factors that influence individuals to choose their departure time, travel mode, trip pattern and/or shopping centre simultaneously.

4.2. Conclusions

In this paper, the authors have proposed a model to describe the departure time decision of travel to the shopping centre for multi-purposes based on the home-shopping centre-home (H-SC-H) travel pattern. The model is derived from three processes: the process of the departure time from home; the process of stay time at the shopping place; and the process of the return time to home. These considerations lead to four types of disutility, such as the disutility of earliness departure from home, the disutility of the shortage of stay time at the shopping place, the length of the stay of the place, and the disutility of lateness arrival at home. Particularly, the model introduced a specific time constraint of daily obligation for religious activity, namely praying time, from noon until evening as a constraint that is considered by individuals to decide their departure time to the shopping centre/place. Taking account of the constraint into the model, as proposed in previous research, is used to represent different behaviour of travellers in an Islamic society of an Asian developing country compared to citizens in developed countries. However, the model was simplified to apply the properties of the shopping centre trip, which took into account the duration of time spent at the shopping place and necessity to leave home earlier.

The proposed model was applied to the shopping centre travel in 10 residential areas in Makassar, Indonesia, which is the biggest Islamic country among the developing countries in Asia, and also where the majority of people are practicing the Islamic religion. Also, it was revealed that the model and estimated parameters provided acceptable reproducibility of the departure time choices. The calculated results also indicated that the behavioural property of younger generations is slightly different from older generations, particularly the stay time at the shopping centre and threshold time of arrival home. Concerning the flexible temporal constraint of daily praying time from noon until evening instead of the lunch time constraint in the daily life cycle, the model can be observed in all categories of cases. In the future, the model could be revised and expanded in order to combine both constraints, and to develop the model with other choice models such as trip patterns, travel modes and shopping centre choices, simultaneously.

Briefly, the model with estimated parameters is to be tested further by applying other situations, and we can expect that the model will provide a basis to develop more advanced and expanded models such as mode, trip pattern and destination choice models.

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