MODELING MOTORCYCLIST'S BEHAVIOR: DEPARTURE TIME AND ESCORT

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1. Introduction

This research aims to understand the motorcyclist's departure time on school commute by considering the effect of intra-household interaction, such as parental escorting. This is important because the number of children's active commutes to school, such as walking, cycling, or using public transport in Yogyakarta has plummeted in the last 20 years[1]. Many children are more likely to be escorted by their parent. By understanding their departure time, we can precisely facilitate their travel mode to reduce the private vehicle usage and promote widespread use of public transport, walking, and bicycling in the immediate future.

2. Conceptual Background

(1) Traveler Behavior

Students who have to go to school have a designated time and place for their classes. If they arrive late at the destination point, they will be penalized for late arrival. Therefore they have to plan their home departure time to minimize the probability of being late. Since there is a relationship between departure time and penalty for lateness, it can be modeled as a function which depends on trip characteristics for each transport mode such as frequency and operation time for public transport or vehicle speed at every different time interval either for public transport or private vehicles[2].

If t_{d_1} is departure time and T_{ij} is travel time, the arrival time (t_a) can be specifically calculated by summing t_{d_1} and T_{ij}. However, since travel time varies depending on the operational feature of road vehicles, eventually t_a cannot be easily determined as described. Using a probability density function (PDF), t_a and T_{ij} are dependent on departure time (t_{d_1}) and distance (l_{ij}) from origin i to destination j and can be respectively denoted as $\emptyset_{t_a}(\tau|l_{ij}, t_{d_1})$ and $\emptyset_{T_{ij}}(\tau|l_{ij})$. The PDF of t_a is therefore determined by:

$$\emptyset_{t_a}(\tau|l_{ij}, t_{d_1}) = \emptyset_{T_{ij}}(\tau - t_{d_1}|l_{ij}) \quad (1)$$

If t_s is the designated starting time of school and lateness is defined as a condition where $t_a > t_s$, the probability of lateness (α) at a given home departure time t_{d_1} can be given as:

$$\alpha = \int_{t_s}^{\infty} \emptyset_{t_a}(\tau|l_{ij}, t_{d_1})d\tau = \int_{t_s}^{\infty} \emptyset_{T_{ij}}(\tau - t_{d_1}|l_{ij})d\tau = \int_{-t_{d_1}}^{\infty} \emptyset_{T_{ij}}(\tau|l_{ij})d\tau \quad (2)$$

Since the students are penalized if they late arrive at the school, they will minimize its penalty by leaving home early. This behavior can thus be formulated as a function of lateness probability ($D_1 = f(\alpha)$).

The flexibility or strictness of starting time either at workplace or at school and the differences in levels of tolerance of individuals towards being penalized cause α to vary for different types of groups. In example, the students at elementary school have a lower elasticity to shift their transport mode in regards to time[3]. This indicates that they have a low tolerance for being penalized if they late to arrive at school due to shifting to other transport mode. Whereas travelers who have a flexible work/school starting time will determine their departure time from home based on an intent to avoid the possibility of experiencing disutilities such as an over-early arrival time at their destination place or congestion charging[4]. Assuming that every group of traveler occupation has a different response in deriving lateness penalty (δ), D_1 as shown in Fig. 1 can be expressed as:

$$D_1 = \delta . f(\alpha) \quad (3)$$

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The Prospect Theory[5)] distinguishes the outcome of a decision in two arguments: a gain if the outcome is greater than reference point and a loss if lower. We will refer to this theory in deciding the departure time from home. Defining the earliest acceptable departure time as the reference point (t_{d_e}), students will obtain a gain when they depart from the origin after t_{d_e} and a loss before t_{d_e}. Using a simple linier function, D_2 as shown in Fig. 1 can be expressed by:

$$D_2 \begin{cases} 0 & \text{if } (t_{d_2} \geq t_{d_e}) \\ \omega(t_{d_e} - t_{d_2}) & \text{if } (t_{d_2} < t_{d_e}) \end{cases} \tag{4}$$

In this case, the gain that will be obtained by the students is assumed to be zero illustrating that they do not feel disutility if they depart later than earliest acceptable departure time.

Referring to the two disutility values above, D_1 and D_2, derived from the morning trip, it is depicted that students want to depart from home as late as they can, but in the other side they do not want to arrive late at the destination point. We thus can conclude that students decide the optimum departure time which has the minimum value on both disutility values $(t_d = t_{d_{12}})$. This can be accurately found by summing the derivative between the two given by:

$$t_d = \frac{\partial D_1}{\partial t_{d_1}} + \frac{\partial D_2}{\partial t_{d_2}}\bigg|_{t_d = t_{d_{12}}} = 0 \tag{5}$$

Each individual in every group of traveler occupation may judge of their maximum tolerable value of lateness probability (α_{max}) differently. Therefore, α_{max} is defined as random variable. The distribution of the random variable α_{max} follows a log normal distribution. The PDF of α_{max} is shown in Fig. 1 as curve of $f_{\alpha_{max}}(\alpha)$. This result in the departure time also being a random variable determined by the inverse-transform of $f_{\alpha_{max}}(\alpha)$ given by:

$$\emptyset_{t_{d_{12}}}(t|l_{ij}) = f_{\alpha_{max}}\left(\delta.f\,(\alpha)(t|l_{ij})\right)\left|\frac{d\delta.f\,(\alpha)}{dt}\right| \tag{6}$$

Further, considering the disutility attained by the motorcycle driver regarding the disagreements, mental and physical fatigue and the occurrence of traffic accidents[6)], we define D_3 as a function of average travel speed (v) drawn as follows.

$$D_3 = f(v) \tag{7}$$

Considering the relationship that if $v \to 0$ then $f(v) \to \infty$, D_3 is further assumed as a ratio function of average travel speed *(v)* and minimum tolerable travel speed *(v_{min})*:

$$D_3 \begin{cases} constant & \text{if } (v \geq v_{min}) \\ \beta_1 (v/v_{min})^{-\beta_2} & \text{if } (v < v_{min}) \end{cases} \tag{8}$$

When D_3 is a function of average travel speed (v) where average travel speed itself is a function of home departure time (t_{d_3}), total disutility in range of departure time (t_{d_3}) and arrival time (t_a) can be formulated as:

$$D_3 = \int_{t_{d_3}}^{t_a} \beta_1 (v/v_{min})^{-\beta_2}\ dt \tag{9}$$

However, there are difficulties in collecting the serial data of vehicle travel speed varying in both temporal and spatial dimensions. Therefore D_3 is approximated by the Eq. (10), where v_x is travel speed in x^{th} road section along l_x.

$$D_3 = \sum_{x=1}^{n} \beta_1 (v_x/v_{min})^{-\beta_2}.\, l_x \tag{10}$$

A motorcycle driver will decide departure time $(t_{d_{23}})$ by minimizing disutility accumulated due to earliness of home departure time (D_2) and road traffic congestion (D_3). However, in the case where the motorcycle driver does not feel disutility due to traffic congestion, he/she will consider the lateness of arrival, and therefore he/she would choose $t_{d_{12}}$. It thus can be concluded that the motorcycle driver would choose the earliest between $t_{d_{12}}$ and $t_{d_{23}}$(shown in Fig.1).

The personality differences of each person give each a unique rate in which they accumulate disutility related to the traffic congestion. We will therefore assume that D_3 is randomly distributed according to a log normal distribution. Due to this, departure time will also be randomly distributed and will be assigned the notation $\emptyset_{t_{d_{23}}}$.

Finally, considering the effect of intra household interaction on morning commute, a behavior of family member ride sharing will be taken into account. Assuming that each person has a different designated starting time at school/workplace, the person who has an earlier designated start time will be more dominant in determining home departure time. This argument can be described as:

$$t_{d_{min}} = \min_{z \in Z}\left(t_{d\,(z)}\right) \text{ , } z = 1, 2 \tag{11}$$

The other person who must adjust his/her departure time, will be reluctant to wait at workplace/school before starting time for a long time, therefore he/she will seek the optimum departure time considering lateness arrival at first destination and earliness arrival at second destination. The optimal departure time can easily be approached using a proportion of two departure times as shown in Eq. (12), where γ ranging from 0 to 1.

$$t_{d_{opt}} = \gamma . t_{d_{z=min}} + (1-\gamma) . t_{d_{z \neq min}} \tag{12}$$

(2) Transportation System

The effect of departure time decision on arrival time will depend on the traffic condition, such as travel speed. Given an l_{ij} distance section and a travel speed of v_{ij}, it is clear that travel time can be determined as $T_{ij}=l_{ij}/v_{ij}$. Since travel speed varies during every time interval and follows the probabilistic distribution, the PDF of T_{ij} is given by:

$$\emptyset_{T_{ij}}\left(T_{ij}|l_{ij}\right) = \Phi_{v_{ij}}\left(l_{ij}/T_{ij}\right)\left|\frac{dv_{ij}}{dT_{ij}}\right| = \frac{l_{ij}}{T_{ij}^2}\Phi_{v_{ij}}\left(l_{ij}/T_{ij}\right) \tag{13}$$

where $\Phi_{v_{ij}}$ is the distribution function of travel speed (v_{ij}) along l_{ij} road section and follows a log normal distribution:

$$\Phi_{v_{ij}}\left(v_{ij}\right) = \frac{1}{v_{ij} \,.\, \sigma_{v_{ij}}\sqrt{2\pi}} e^{-\frac{(ln\, v_{ij} - \mu_{v_{ij}})^2}{2\sigma_{v_{ij}}{}^2}} \tag{14}$$

Since T_{ij} in Eq. (2) represents the total travel time from door to door, total travel time consists of access travel time (T_{ac}), riding time along the road (T_r), and egress travel time (T_{eg}) as expressed by:

$$T_n = T_{ac} + T_r + T_{eg} \tag{15}$$

Assuming that the student departs from home at $t=t_d$ along l_{ac}, the PDF of arrival time along access road (denoted as $\emptyset_{t_{ac}}$) is given by:

$$\emptyset_{t_{ac}}(t|t_d, l_{ac}) = \emptyset_{T_{ac}}(t - t_d|l_{ac}) \tag{16}$$

where T_{ac} is the access travel time obtained by observation and is log normally distributed.

A very important factor in deciding home departure time is the variation of riding time along the route from origin to destination. To obtain a good estimate of riding time, a route along l_{ij} distance will be divided into x road sections. Total riding time is calculated by summing the riding time along all x road sections during the specific time interval when the vehicle passes on that road section. Given a specific road section with l_{x_1} distance, the PDF of arrival time at the end of point x_1 (denoted as $\emptyset_{t_{x_1}}$) is given by:

$$\emptyset_{t_{x_1}}(t|x_1) = \int_{t_d}^{t_s} \emptyset_{T_{r_{l_{x_1}}}}\left(t - t_{x_1}|x_1, t_{x_1}\right) \emptyset_{t_{x_1}}\left(t_{x_1}|x_1\right) dt_{x_1} \tag{17}$$

where $\emptyset_{T_{r_{l_{x_1}}}}\left(t - t_{x_1}|x_1, t_{x_1}\right)$ represents the PDF of riding time $T_{r_{l_{x_1}}}$ along a specific road section l_{x_1} that depends on origin x_1 and the arrival time at x_1 (t_{x_1}). $\emptyset_{t_{x_1}}\left(t_{x_1}|x_1\right)$ represents the PDF of arrival time at origin x_1.

Considering the travel speed distribution along the l_{x_1} road section ($\Phi_{v_{x_1}}$), by substituting the distance l_{x_1} and $\Phi_{v_{x_1}}(v_{x_1})$ into Eq. (13), $\emptyset_{t_{x_1}}(t|x_1)$ can be calculated. This calculation is repeated until x^{th} road section.

Finally, using the same equation for access travel time, the arrival time at school can be easily determined.

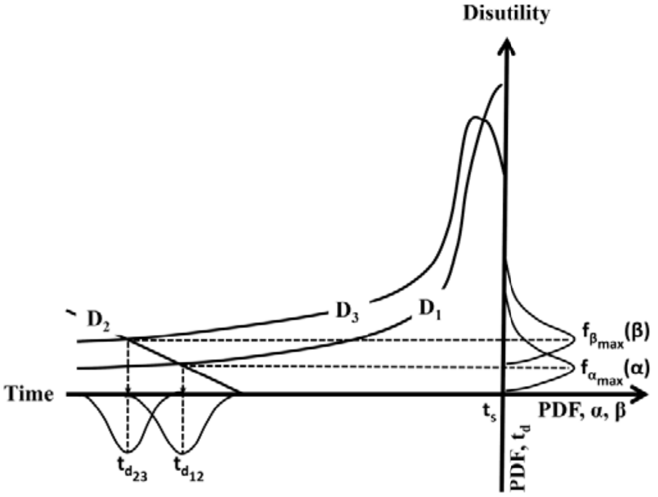

Figure 1: Disutility functions in regard to deciding of departure time

3. Model Application

(1) Data aggregation

Surveys were conducted to collect data of the school morning commute which consists of a questionnaire survey, a student arrival time survey, and a travel time survey. The students from Senior High School 1 in Yogyakarta, Indonesia were sampled as respondents. The questionnaire survey was conducted on March 17th, 2009. Out of 365 randomly distributed forms, 312 forms (85.5%) were recollected effectively. From 312 respondents, 74.36% were motorcycle users, 11.22% were bus users, 3.53% were bicycle users, 8.97% walked to school, and 1.92% were escorted by their parents using a car. However, only 232 sets of data will be used in this research due to limits of this research scope which focuses on travel behavior for motorcycle users.

To better understand the effect of intra-household interaction in morning commute mode choice, the students as motorcycle users were categorized into 3 types as follows:

1. Type 1: The student as the motorcycle driver.
2. Type 2: The student as a motorcycle pillion rider escorted by family member on the way to workplace.
3. Type 3: The student as a motorcycle pillion rider escorted by family member who returns home after escort.

The student arrival time survey was conducted in conjunction with the questionnaire survey. Surveyors note the respondent arrival time at school before the surveyors hand over the questionnaire form to respondent.

The final survey conducted was the travel time observation. Based on the questionnaire survey, there are 27 routes for motorcycle user respondents. Therefore, it will impossible to survey all motorcycle possible routes. We thus minimized the number of routes by lumping together the road sections with similar characteristics and then surveying a limited number of road sections as the representative of all road sections with the same characteristic. The selected route, observing points, and result of travel speed observation can be seen in Fig. 2.

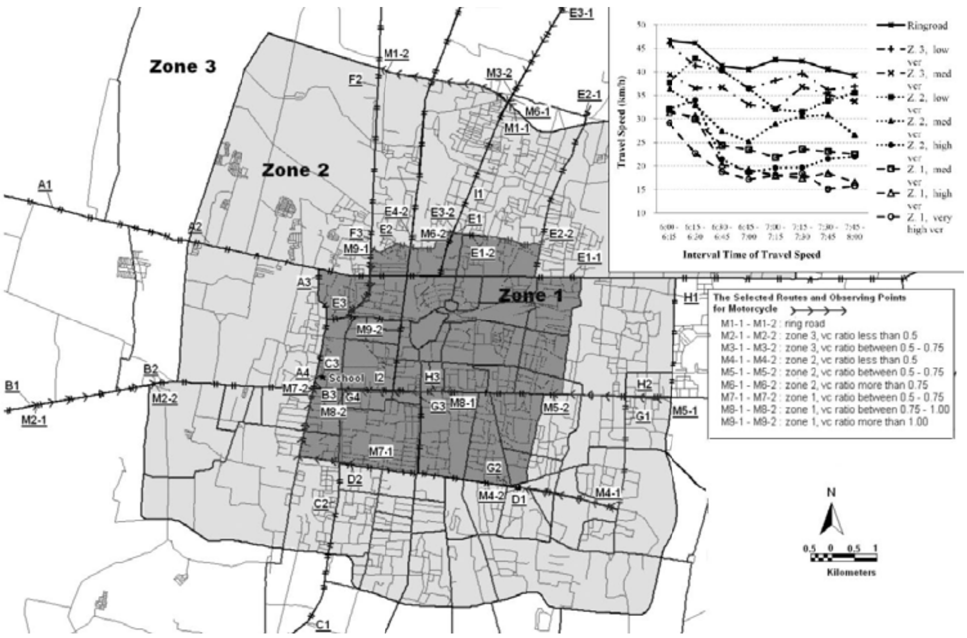

Figure 2: The area of study: motorcycle selected routes, observing points, and travel speed

(2) Model Result

Applying the above proposed model, the estimated parameters are shown in Table 1. In addition, the comparison between simulated and observed arrival time at school is displayed in Fig. 3. Using the chi-square test to compare the expected value and observed value, it is obtained that the chi-square value for motorcycle users from type 1 to 3 are 5.46 ($p < 0.95$), 1.64 ($p < 0.9$) and 2.37 ($p < 0.95$). This values show that the proposed model to understand travel behavior in regards to departure time can be accepted in case of motorcycle users.

Observing the psychological nature of individuals in regards to lateness avoidance, it was gained that elementary school students are the most fearful of being late (1.49), while workers have the most flexible arrival time associated with starting time at the workplace (0.84). From these results, it can be predicted that the elementary school students who are escorted to school by motorcycle have more difficulty to shift to public transport if the public transport service cannot guarantee a definitive arrival time at school.

Regarding the parents or family members who escort their children to school on the way to workplace, the model result shows that their children have a larger influence (0.89) in deciding the departure time and therefore result in an earlier departure time from home by the parents who are workers.

Students by motorcycle mode tend to arrive earlier than the designated starting time at school as shown in Fig. 3. This behavior is different with worker behavior that tends to arrive at the latest moment before their work starting time[7]. In case of escorted adolescent students, there are two conditions of school arrival time: (1) a very early arrival at school if the escorting family member returns home after escort and (2) an arrival time close to the designated school starting time if the escorting family member escorts on the way to workplace.

Table 1: The estimated coefficients of motorcycle users in deciding departure time

Coefficients	μ_{t_d}	σ_{t_d}	ω	β_1	β_2	v_{min}	δ_1	δ_2	δ_3	γ
Motorcycle mode	6:29	0.24	0.56	1.15E-03	1.95	34.5	1.49	1.00	0.84	0.89

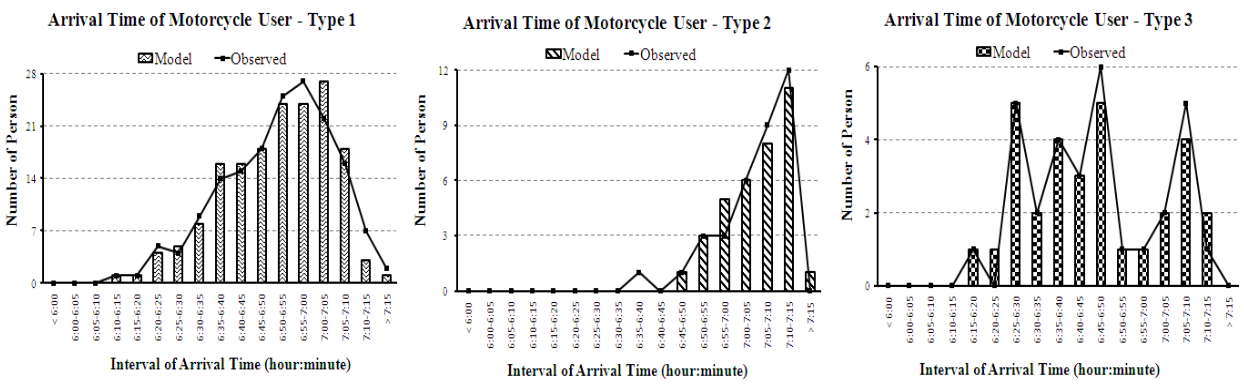

Figure 3: The measured and theoretical distribution of arrival time at school

4. Conclusion

We have successfully developed a departure time model on morning commute to school based on the psychological nature of students. This model considers disutility obtained by student in regards to arrival lateness, over-earliness of departure, and traffic congestion during the morning commute. The effect of intra household interaction, such as ride sharing, is also considered in the model. The model was calculated using empirical data obtained from a travel diary survey of students conducted in 2009 in Yogyakarta, Indonesia.

Observations show that adolescent students are more likely to arrive at school earlier than the designated school starting time. If escorted by family members, they tend to arrive very early if the escorts return home and arrive close to the designated starting time if the escorts are on the way to their workplace.

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