Time Use Distribution and Immobility Behaviour across Three Weeks Observation Period in the Bandung Metropolitan Area, Indonesia

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Abstract: This paper explores the patterns of time use and immobility behaviour in Bandung city, the second biggest metropolitan area in Indonesia. A three-week of time use and activity diary is used for this purpose. The between- and within-individual day-to-day variations in time use allocation are examined. The immobile behaviour and time use allocations are also examined by panel and multilevel models. The results clearly show distinct weekday and weekend patterns of respondents' time use distribution. Perceived accessibility measures were found to play more important roles in affecting immobile behaviour and time use allocations than residential built environment measures. An accessible residential location can encourage a higher travel and activity participations which lead to different time use distributions, compared to the ones who live within less accessible residential location.

Keywords: Time use, immobility behaviour, day-to-day variability, intra household interaction

1. INTRODUCTION

There has been a significant body of knowledge (e.g. Frändberg and Vilhelmson, 2011; Michelson, 2009; Papastefanou, and Gruhler, 2014) that agree that different groups of population have different patterns of time use, for different activities and trip purposes. The variability of the time use depends on the individual's socio-demographic characteristics and his/her commitments with others (Ellegård and Svedin, 2012; Hägerstrand, 1970; Merz *et al.*, 2009; Neutens, 2012). Using data from nine European countries, Joesch and Spiess (2006) showed that, on average, the population of those countries uniformly devoted almost 42-45% of the 24 hours of their time to physiological activities, 14% to family and house activities, 20% to public activities and 20% to personal activities. If one compares the time use patterns across gender and more detailed socio-demographic characteristics, however, it was evidence that there are large differences between employment status and between men and women.

In terms of time use for mobility and travel, some previous studies (e.g. Ahmed and Stopher, 2014; Newman, P., Kenworthy, 1999) have observed the constancy and stability of travel time expenditure at the aggregated level, which is that, on average, an individual would spend about 1 to 1.5 hours per day travelling. Some studies at the disaggregate level (Kitamura *et al.*, 2006), however, have shown that travel routines and travel time expenditure are not constant but rather are a function of several variables, which is different for different individuals and households. It is reasonable to assume that these similarities and

dissimilarities are related to unique conditions of an individual's time-space prism (Hägerstrand, 1970). Whilst there is a relatively clear limit on the amount of time that an individual can spend on a given day, different people from different socio-demographic groups have different commitments, resources, and external constraints, which subsequently lead to different time allocation patterns (Gershuny *et al.*, 1986; Susilo and Dijst, 2009; Susilo and Dijst, 2010). Some people have more stable activity and travel engagement patterns than others, whilst some others are more random across days (Heinen and Chatterjee, 2015; Susilo and Axhausen, 2014). One may be immobile for one or two days, but travel further on other days (Naess, 2006). The ones who are immobile do not necessarily mean that they are less active than the ones who are mobile on the given day (Susilo and Liu, 2016). Furthermore, in many circumstances, this allocation of time is not only a result of a sole individual's decision, but also a result from intra- and inter-household interactions (Arentze *et al.*, 2011; Chikaraishi *et al.*, 2010; Habib and Miller, 2009; Liu *et al.*, 2015; Susilo and Avineri, 2014; Zhang *et al.*, 2009).

Most of the previous studies on time use allocation, however, were based on cross-sectional data. Since an individual's needs and constraints are not constant from day-to-day, an individual's travel pattern is neither totally repetitious nor new every day. There are some activities (e.g., eating, sleeping) that are repeated every day, but other activities, such as shopping, personal business and social recreation, are not necessarily repeated on a daily basis (Cherchi and Cirillo, 2014; Susilo and Axhausen, 2014) but a weekly or bi-weekly basis (Bayarma *et al.*, 2007). Therefore, the distribution of time use should be treated as a dynamic process with learning and changing on the one hand and rhythms and routines on the other. Neglecting this dynamic nature of time allocation and activity participation would lead to over/under estimation of the influence of various different key determinants towards one's time use allocation and mobility behaviour.

Furthermore, most of previous studies were based on cases in developed countries. In many aspects, time allocation and mobility pattern within a household are intertwined with culture, expectation and habit of each household member. Thus, household members from different cultures would have different mechanisms in sharing responsibility, distributing activities and time allowance within a household. Therefore, evidence of time allocation patterns in developed countries may not be applicable in the cases of developing countries due to the differences in culture and social norms, etc. Some developing countries, such as Indonesia, have been through rapid development in the last decade. There have been enormous changes in infrastructure within a short time and this may lead to a rapid development in physical and social environments of trip making, which can be argued that the time use pattern is becoming more complex and less predictable (Susilo and Joewono, 2017). Various new commodities, appliances and services have been introduced to relax the time constraints for domestic chores such as cleaning, cooking and gardening. In more educated families, two-worker households have become a social norm rather than an exception, changing the way in which household tasks are carried out by its members. All of these changes affect the needs for, resources available for, and constraints imposed on travel (Susilo and Kitamura, 2008). These changes, however, may have different impacts towards different groups of population. Some may adopt the changes faster whilst others may response to the changes. The different adaptation abilities between rich and poor residents may widen the economic segregation and also equity issues on mobility opportunities between these groups.

To understand this phenomenon, in a multiday context, this paper aims to explore the patterns of time use and immobility behaviour in city of Bandung, Indonesia, across different individual and household socio-demographic groups. A three-week time use and activity travel diary is used for this purpose. The differences of time use and immobility members are

explored and discussed.

In the next section, the study area and the three-week time use and activity travel diary are introduced. Four time-use categories are defined. It is then followed by a section presenting descriptive analysis on individual's different time use allocations on different days and across different individual socio-demographic groups. The chapter is closed with a discussion section.

2. THE STUDY AREA AND THE DESCRIPTION OF THE DATASET

2.1 The Bandung Metropolitan Area (BMA)

The Bandung Metropolitan Area (BMA) is the capital of the Province of West Java and is approximately 200 km or two to three hours' drive south of Jakarta. With its conurbation, BMA population is about 7.89 million people, in a 3,382.89 square km size area and is the second largest metropolitan area in Indonesia after the Jakarta Metropolitan Area. As a typical city in developing countries, the BMA has an unplanned, mixed and monocentric land use, congested road networks, and poor public transport networks and services (Susilo *et al.*, 2012). Road congestion and the low performance of public transport/paratransit encourage the BMA's travellers to use motorcycles to reduce their travel costs and time (Susilo 2011; Susilo *et al.*, 2015; Tarigan *et al.*, 2014). At the same time, they usually have more choices within a closer range in which to conduct their activities along their travel routes, due to the highly mixed land use configurations (Dharmowijoyo *et al.*, 2014; Dharmowijoyo *et al.*, 2015a; Dharmowijoyo *et al.*, 2016)

2.2 The 2013 BMA Dataset

The BMA dataset contains household, physical activity and lifestyle, individual's subjective characteristics, time-use and activity diary, and subjective well-being data. The survey involved 732 individuals from 191 households and recorded the activity-travel information of 21 consecutive days. The household data section contains household composition, individual's perception on how far his/her accommodation is from city centre, public and transportation facilities as well as build environment variables. Time-use and activity diary survey captured twenty-three in-home and out-of-home activity classifications, travel time and mode characteristics, and multitasking activities for adults, young adults and children above 7 years old.

The data was collected in September 2013. This month was selected because during this month there were no special events and/or local or national holidays that may have diverted respondents from their normal patterns. Participant recruitment, survey introduction and survey-dry-run (pilot test) were conducted during August 2013 and at beginning of September 2013. From previous data collection experiences, it was found that personal relationships between the respondents and the survey team have to be built to ensure the success of the survey. To ensure that this happened, personal interaction between respondents and the surveyors was established at the beginning of the recruitment process, as well as when the surveyors introduced the purpose of the survey and began deploying the sections of the survey. In Indonesia, and in some other developing countries, the registration of residents is very poor. Therefore, the survey team cannot send the recruitment proposal by post or email. The recruitment began with direct interaction between the surveyors and the potential respondents, mediated by a community leader in a neighbourhood. After the interaction, the respondents

were asked to sign a commitment letter agreeing not to withdraw from the survey until it was completed. After signing the agreement, the surveyors began to distribute the questionnaires to the respondents. To quickly address any problems during the survey period, each surveyor had responsibility for managing two to three households at most with 10-12 individuals and for personally guiding each household in completing the survey. Furthermore, each surveyor had to meet with his or her respondents at least once for each part of the survey and more often in the case of the time-use and activity diary survey. Finally, as in previous data collection attempts, an incentive which was more than figurative, but smaller than a real payment was provided. Further description on the survey implementation and the dataset can be seen at Dharmowijoyo *et al*. (2015b).

In the survey design, time-use activity participation was classified into 23 different activities types, including travel. Those activity types are further classified into 4 distinct activity time categories based on the nature of activity time use (Akar *et al.*, 2011; Ellegård and Svedin, 2012; Hägerstrand, 1970; Susilo and Axhausen, 2014). The definition of those four distinct activity time categories are shown below and the classification is presented in Table 1.

TABLE 1 The Classification of Activity Categories

Activity categories	Original activity classification in the survey
Contracted time	Work School
Committed time	Household activities, such as cleaning the house, cooking or baking, washing cloth/dishes, etc. Babysitting activities including babysitting, playing with the baby, feeding the baby, etc. Selling and purchasing activities Daily grocery shopping Picking/dropping children
Necessary time	Sleeping Personal care activities, such as taking a bath, brushing teeth etc. Eating/drinking at home Organization/volunteer/political activities, such as youth/political/religious meetings, visiting mosque, etc. Maintenance activities, including going to hospital/health centre/medical doctor, visiting bank/post office Fixing mechanics, such as go to a mechanic store
Free time	Relaxing activities, such as watching TV, listening to radio, reading newspapers, relaxing, etc. Social/family activities, such as chatting with family members, visiting friends, etc. Eating/drinking outside, such as eating in a restaurant Sports activities, such as going to a gym, playing football, etc. Holiday

Contracted time: Contracted time refers to the time a person allocates toward an agreement to work or study. When a person is using contracted time to commute this person understands that this travel time is directly related to paid work or study and any break in this commute time directly affects job or school-related performance.

Committed time: Committed time, like contracted time, takes priority over necessary and free time because it is viewed as productive work. It refers to the time allocated to maintain a home and family. When a person uses committed time during commute, this

person may feel that the commute is a duty to family such as walking children to school.

Necessary time: Necessary time refers to the time required to maintain one's self as it applies to activities such as eating, sleeping, and cleansing and to a large extent exercising. People who commute using necessary time may feel that the commute is an important activity for personal well-being and may also take into account the well-being of the natural and social environment. Since sleeping is included in this category, necessary time usually constitutes the majority of people's time.

Free time: Free time refers to the remains of the day after the three other types of time have been subtracted from the 24 hour day. This type of time is not necessarily discretionary time as the term "free" time may imply, because people tend to plan activities in advance and creating committed free time in lieu of discretionary time. People who commute using free time are more apt to viewing the commute as a recreational activity.

3. THE DISTRIBUTION OF TIME USE ACROSS DIFFERENT DAYS AND GROUPS OF TRAVELLERS

The sample consists of a balanced distribution of socio-demographic profile. Most of the respondents (75%) come from low income (< IDR 3 million/month, approx. 300 USD/month) households. The sampled households on average have four household members with more than one child in household. It is a tradition in Indonesia that elders live together with their adult children, thus leading to a common phenomenon of a household with more than 4 household members. Although only a small share of sampled households own a car, most sampled households own at least one motorcycle, and motorcycle is the major motorised mode used in Indonesia.

Table 2 presents the time use patterns on different days of week. The average contracted time from Monday to Thursday of those who are working and studying on the given day is 404 min which is slightly lower than their developed countries counterparts, such as Sweden, i.e. 445 min (Liu *et al.*, 2015). The average committed time on weekday is 156 min compared to 168 min of that number on weekend. Similarly, the average necessary time on weekend is higher than that on weekday (636 min vs 609 min), although the difference is minor. The trend of free time shows a similar pattern but with a larger discrepancy between weekday and weekend. This indicates that those contracted time that is used for working and studying on weekday is allocated more into free time and less into committed time on weekend.

On average, 12% of the contracted time is for multi-tasking, while that number is 22% for the committed time. The multi-tasking activities in this study are defined as concurrent activities contained within primary and secondary activities for satisfying different needs and desires at the same time. In this case, multi-tasking activities will be defined as an individual combining mandatory activities (such as work/school, eating, sleeping), maintenance activities (such as nursing, grocery shopping/shopping), and active/passive leisure activities (such as doing sport or reading a book), with passive leisure activities such as entertainment and socialising. Only 4% of the necessary time is multi-tasking since a large share of necessary time is sleeping time. Free time has the highest share of multi-tasking, 35%, since it is the least physically and mentally intensive. 14% of the travel time is multi-tasking, which is mainly travel time by public transport and walking. It is also worth noting that the multi-tasking shares in all types of activity time use do not differ much between weekday and weekend. This seems to suggest a consistent multi-tasking activity pattern for a given activity time use, e.g. contracted time use, even when one may spend much longer/short time on that activity type on weekend compared to weekday. More detailed description of day-to-day

variability on the time use pattern can be seen at Susilo and Liu (2017).

TABLE 2 The Distribution of Time Allocation across Different Activities and Days of Week

Time Spent for different activities	Mean (Percentages)
Contracted time per day on different days of the week:	
Contracted time per day from Monday-Thursday (minutes)	231.76 (16.09%)*
Contracted time per day on Friday (minutes)	203.67 (14.14%)*
Contracted time per day on weekends (minutes)	114.42 (7.95%)*
Committed time per day on different days of the week:	
Committed time per day from Monday-Thursday (minutes)	156.03 (10.84%)*
Committed time per day on Friday (minutes)	156.62 (10.88%)*
Committed time per day on weekends (minutes)	168.08 (11.67%)*
Necessary time per day on different days of the week:	
Necessary time per day from Monday-Thursday (minutes)	606.76 (42.14%)*
Necessary time per day on Friday (minutes)	609.15 (42.30%)*
Necessary time per day on weekends (minutes)	636.19 (44.18%)*
Free time per day on different days of the week:	
Free time per day from Monday-Thursday (minutes)	433.52 (30.11%)*
Free time per day on Friday (minutes)	453.74 (31.51%)*
Free time per day on weekends (minutes)	504.59 (35.04%)*
Time engaging with multi-tasking activities jointly with other activities	
Time engaging with multi-tasking activities within contracted time activities on Monday to Thursday	29.63 (12.78%)
Time engaging with multi-tasking activities within contracted time activities on Friday	25.87 (12.70%)
Time engaging with multi-tasking activities within contracted time activities on weekends	12.60 (11.01%)
Time engaging with multi-tasking activities within committed time activities on Monday to Thursday	36.59 (23.45%)
Time engaging with multi-tasking activities within committed time activities on Friday	34.13 (21.98%)
Time engaging with multi-tasking activities within committed time activities on weekends	36.65 (21.81%)
Time engaging with multi-tasking activities within necessary time activities on Monday to Thursday	26.40 (4.35%)
Time engaging with multi-tasking activities within necessary time activities on Friday	24.31 (3.99%)
Time engaging with multi-tasking activities within necessary time activities on weekends	25.77 (4.05%)
Time engaging with multi-tasking activities within free time activities on Monday to	162.34

Time Spent for different activities	Mean (Percentages)
Thursday	(37.45%)
Time engaging with multi-tasking activities within free time activities on Friday	162.07 (35.72%)
Time engaging with multi-tasking activities within free time activities on weekends	166.81 (33.06%)
Time engaging with multi-tasking activities during travel on Monday to Thursday	11.17 (14.24%)
Time engaging with multi-tasking activities during travel on Friday	10.30 (13.60%)
Time engaging with multi-tasking activities during travel on weekends	10.72 (14.95%)
Total travel time spent from Monday-Thursday (minutes)	73.97 (5.14%)*
Total travel time spent on Friday (minutes)	75.76 (5.26%)*
Total travel time spent on weekends (minutes)	69.35 (4.82%)*

Note: *The percentages in brackets show the average proportions of time spent for travel and for each activity.

TABLE 3 Weekday Time Use Distribution and Immobile Behaviour among Individuals in Different Socio-Demographic Groups (Min)

		Necessary time			Contracted time			Committed time		
		Weekday	Weekend	Total	Weekday	Weekend	Total	Weekday	Weekend	Total
Household income	Low income	606.9*	637.2	615.5*	217.6*	111.1*	187.1*	166.3*	179.0*	169.9*
	Medium income	595.9*	627.5	604.9*	230.8*	112.3*	196.9*	169.9*	187.3*	174.9*
	High income	620.7*	635.4	624.9*	190.4*	94.2*	162.9*	147.1*	143.7*	146.1*
Gender	Male	594.1*	628.4*	603.9*	295.1*	152.7*	254.4*	77.7*	89.3*	81.0*
	Female	622.8*	645.1*	629.1*	146.7*	71.1*	125.1*	246.8*	258.5*	250.1*
Occupation	Permanent worker	581.0*	630.1*	595.0*	329.3*	165.4*	282.5*	89.3*	117.0*	97.2*
	Temporal worker	585.4*	616.6*	594.3*	355.8*	159.3*	299.6*	94.6*	140.6*	107.8*
	Part-time worker	598.4*	618.9*	604.2*	187.0*	129.5*	170.6*	205.9*	205.2*	205.7*
	Non-worker	681.3*	676.6*	679.9*	81.3*	70.5*	78.2*	191.2*	185.4*	189.5*
	Student	621.9*	673.8*	636.7*	297.0*	126.3*	248.2*	48.2*	66.0*	53.3*
	Household wife	626.8*	633.4*	628.7*	44.3*	23.1*	38.3*	324.6*	312.8*	321.2*
	Retired	692.3*	687.2*	690.8*	33.5*	26.5*	31.5*	167.4*	152.8*	163.2*
	Others	554.5*	569.1*	558.6*	194.6*	167.7*	186.9*	174.2*	128.8*	161.3*

Continued		Free time			Travel time			Immobile behavior	
		Weekday	Weekend	Total	Weekday	Weekend	Total	% of immobile days	Travel time per mobile day
Household income	Low income	440.8	497.7*	457.0*	71.8*	66.6*	70.3*	21.41	85.4*
	Medium income	443.3	512.4*	463.1*	95.7*	80.4*	91.3*	19.10	106.3*
	High income	438.7	529.4*	464.6*	92.5*	90.4*	91.9*	17.70	90.5*
Gender	Male	442.7*	534.2*	468.9*	98.2*	86.7*	94.9*	11.64*	105.4*
	Female	431.2*	469.5*	442.2*	54.3*	54.8*	54.4*	29.35*	72.7*
Occupation	Permanent worker	400.7*	501.4*	429.5*	106.9*	83.5*	100.2*	9.68*	107.7*
	Temporal worker	366.0*	486.1*	400.3*	88.9*	80.9*	86.6*	12.00*	96.9*
	Part-time worker	380.9*	405.9*	388.1*	78.6*	75.9*	77.8*	17.41*	88.7*
	Non-worker	528.9*	543.9*	533.2*	45.1*	49.0*	46.2*	38.69*	68.7*
	Student	438.7*	545.2*	469.1*	89.4*	82.2*	87.3*	10.44*	97.7*
	Household wife	486.6*	492.1*	488.2*	38.6*	48.0*	41.3*	37.79*	63.3*
	Retired	612.5*	625.8*	616.3*	59.7*	74.0*	63.8*	40.91*	100.9*
	Others	494.0*	506.3*	497.5*	77.7*	72.1*	76.1*	16.26*	88.8*

Note: * denotes that the corresponding time category is significantly different between socio-demographic groups at 5% level

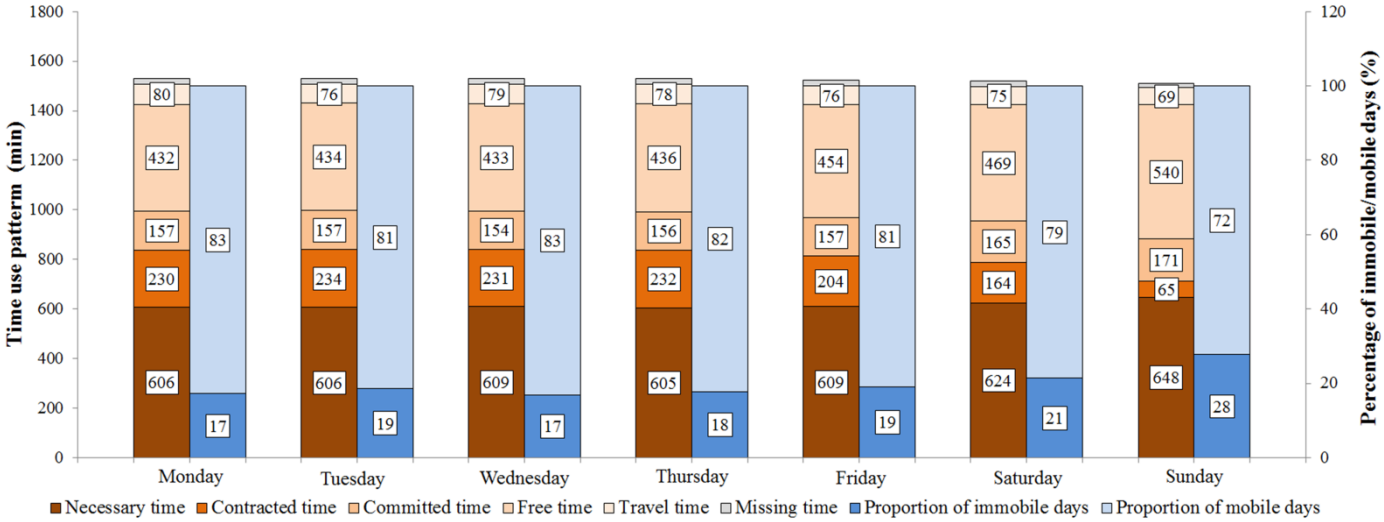

FIGURE 1 Day-to-Day Time Use and Immobile Behaviour Comparison

Note: In this study, an immobile person can be defined either as someone who has remained at home the whole day or as someone with no travel activity, due to whatever reason.

Figure 1 presents the day-to-day variability of activity time allocation. Time use from Monday to Thursday is quite stable. Free time increases by around 20 min on Friday compared to Monday-Thursday while a similar amount of decrease in contracted time is also observed. The time use distribution shows a gradual but considerable change from Friday to Sunday. The time use distribution on Sunday shows a clear difference compared to Friday and even to Saturday. Contracted time on Sunday decreases by 140 min compared to Friday and 100 min compared to Saturday. The contracted time on weekday is redistributed mostly into free time and partially into necessary time on weekend. Figure 1 also shows the immobile behaviour across days of week. The percentage of immobile days on weekend, particularly on Sunday, is much higher than that on weekday.

Table 3 presents the time use distribution and immobile behaviour across individual socio-demographic groups, including income level, gender and occupation. Respondents from the high income group in general have a shorter contracted time and committed time but a longer necessary time on weekday compared to those from medium and low income groups. Respondents from high income group may not need to work as long hours as those from low income group, but may have more maintenance activities and personal care activities as they can afford more personal properties which generate maintenance errands. Travel time of respondents from low income group is significantly shorter than that of those from medium and high income groups, both on weekday and weekend. On weekend, respondents from high income group also have shorter contracted time and committed time but a longer free time than those from medium and low income groups. On weekend, those from high income group are more capable and affordable to conduct leisure activities compared to those from medium and low income groups, and thus have a longer free time. Respondents from low income group seem to have more immobile days than those from medium and high income groups, although the difference is not statistically significant.

In terms of gender, women have shorter contracted time, free time and travel time but longer necessary time and committed time than men. Women, often as housewives in traditional households in Indonesia, are responsible for housework and maintenance activities, and therefore have a longer necessary and committed time. Females, as expected, are much more immobile than males.

In terms of occupation type, permanent and temporal workers in general have much

shorter committed time and necessary time but slightly longer travel time compared to non-workers, household wives and retirees. Household wives have a particularly high committed time, as expected, but a particularly low travel time, indicating that household wives may not travel far distance. Retirees and non-workers have the longest necessary time and free time. Retirees may need more sleeping time, while non-workers may also have longer personal care activities and maintenance activities since they do not have tight time constraints compared to workers. Non-workers, household wives and retirees have high percentage of immobile days compared to workers and students. However, retirees have much longer travel time per mobile day than non-workers and household wives. Retirees, although are limited by their physical conditions, also have a higher need to travel (Andrews *et al.*, 2012; Musselwhite *et al.*, 2015).

4. MULTIVARIATE ANALYSIS

In order to systematically explore the determinants of immobile behaviour, a binary logit model with panel data is developed to examine the immobile behaviour. The binary logit model with panel data has the following utility and probability expression.

$$U_{i,j,k} = X_{i,j}\beta_k + \mu_{i,k} + \varepsilon_{i,j,k} \quad (1)$$

$$P_{i,j,\mathrm{k}} = \int_{-\infty}^{+\infty} \frac{e^{U_{i,j,k}}}{\sum_{m=1}^{2} e^{U_{i,j,m}}} f(\mu_{i,k}) d\mu_{i,k} \quad (2)$$

In Eq.(1) and Eq.(2),

$U_{i,j,k}$: the utility of individual i, on day j choosing alternative k, where $k \in$ {mobile, immobile}.

$X_{i,j}$: the set of exogenous variables that influence the mobile/immobile behaviour.

β_k : the corresponding set of parameters for alternative k.

$\mu_{i,k}$: the individual level error term capturing the inter-individual heterogeneity of the remaining unobserved factors (e.g. psychological factors, weather, etc.).

$\varepsilon_{i,j,k}$: the independent and identically distributed (iid) error term.

A series of variables is included in $X_{i,j}$, including day of the week, individual/household socio-demographics, perceived accessibility measures and residential built environmental measures. The perceived accessibility is a measure by directly asking the household members: e.g. “How far is your accommodation from city centre (in minutes travel)”. This information can be considered as a proxy of the perfectness/imperfectness of an individual’s spatial knowledge towards the available opportunities which are surrounding him/her. It is assumed that $\mu_{i,k}$ follows normal distribution with zero mean and unknown variance Assuming a standard Gumbel distribution of $\varepsilon_{i,j,k}$ leads to the logit model with probability expression shown in Eq.(2). In Eq.(2), $P_{i,j,k}$ denotes the probability of individual i, on day j choosing alternative k, where $k \in$ {mobile, immobile}. $f(\mu_{i,k})$ is the probability density function of $\mu_{i,k}$, which is a normal probability density function.

The model estimation results are shown in Table 4. In this paper, the alternative, “mobile”, is chosen as the reference alternative. Therefore, the estimated coefficients are the coefficients on the alternative “immobile”. A positive value of coefficient denotes an increasing utility and probability of being immobile while a negative value would mean the opposite.

TABLE 4. Estimation Results of Immobility Behaviour

Reference alternative*: mobile*	Coefficients	T-values
Alternative specific constant	-1.929	-2.95
Day of the week		
Monday to Thursday (reference)	/	/
Friday	0.197	2.07
Saturday and Sunday	0.866	12.16
Individual and household socio-demographics		
Male (reference)	/	/
Female	1.437	7.522
Age 14-25 years old	-0.214	-0.93
Age 26-35 years old	-0.667	-2.51
Age 36-45 years old (reference)	/	/
Age 46-55 years old	-0.677	-3.14
Age over 55 years old	1.023	4.11
Low income: < IDR 3 million/month (approx. 300 USD/month)	-0.301	-1.22
Medium income: IDR 3-6 million/month (reference) (approx. 300-600 USD/month)	/	/
High income: >IDR 6 million/month (approx. 600 USD/month)	-0.607	-1.82
Income missing	-1.122	-2.54
Number of household members	-0.175	-3.20
Number of motorised vehicles per household member	-1.481	-2.55
Perceived accessibility		
Perceived number of public transport lines connected to home	-0.374	-5.35
Perceived travel time from home to CBD	0.018	3.789
Perceived travel time from home to nearest grocery store	0.022	1.58
Perceived travel time from home to nearest shopping centre	0.002	0.181
Perceived travel time from home to nearest park	0.012	2.05
Perceived travel time from home to nearest station	-0.016	-3.96
Residential built environment		
Population density at the home zone	0.045	3.64
Road density at the home zone	0.001	0.84
Industrial area density at the home zone	-2.211	-0.92
Commercial area density at the home zone	-6.657	-0.53
Error term		
Standard deviation of individual level error term	3.852	22.17
Standard deviation of the iid error term	1.283	Fixed
Model fit information		
Number of individuals	624	
Number of observations (days)	13104	
Log-likelihood at converge	-3907.2	
Log-likelihood for alternative specific constant only	-6515.7	
Adjusted McFadden's rho	0.567	

Note: the grids in grey denote the corresponding coefficients are not significant different from zero at 10% significant level.

The model achieves a good model fit, with adjusted McFadden's rho reaching 0.567. The standard deviation of individual level error term is almost three times larger than that of the *iid* error term, indicating considerable inter-individual variations.

As shown in Table 4, a given individual is more likely to be immobile on Friday than Monday-Thursday since the estimated coefficient of "Friday" (0.197) is positive. Similarly, it is even more likely to be immobile on weekend for a given individual than Friday, as the coefficient of "Saturday and Sunday" is much larger and positive (0.866) than that of "Friday".

Women as expected are more likely to be immobile than men. Elders (age>55 years old) are more likely to be immobile than the reference age group (36-45 years old) likely due to their physical/health constraints. Age groups, 26-35 years old and 46-55 years old, are less likely to be immobile than the reference age group. People from households with more household members are less likely to be immobile presumably because the chance of having household activities would be lower as household activities are shared by other household members. Similarly, people from households with more motorised vehicles (cars and motorcycles) per household member are also having fewer immobile days. The availability of motorised modes increases the accessibility of a given individual and thus triggers the travel.

In terms of perceived accessibility, those who consider their home being well connected to public transport network have fewer immobile days than those who do not. Similarly, those who perceive a shorter travel time from their home to CBD and nearest park have fewer immobile days. Those findings are not surprising since they reveal that an accessible and well-connected urban design perceived by individuals provide more activity location options and thus stimulate their trip frequencies. For residential built environment, only the population density shows a significant effect. More densely populated areas seem to correspond to a higher propensity of immobile behaviour. The findings seem to suggest that perceived accessibility plays more important role in explaining immobile behaviour than the residential built environment.

A series of log-linear multilevel models are estimated to explore the determinants of time use. Several inertia variables are included to take into account the influences of previous days' time use on the time use on the given day. The model has the following general form:

$$\log\left(T_{m,i,j}^{k}\right) = X_{m,i,j}^{k}\beta^{k} + T_{m,i,j-\delta}^{k}\gamma^{k} + \tau_{m}^{k} + \mu_{m,i}^{k} + \varepsilon_{m,i,j}^{k} \quad (3)$$

In Eq.(3),

$T_{m,i,j}^{k}$: the activity time allocated to time category k for individual i from household m on his/her day j, where $k \in$ {contracted time, committed time, necessary time, free time}.

$X_{m,i,j}^{k}$: the exogenous variables which are of the same set as used in examining immobile behaviour ($X_{i,j}$ in Eq.(1)).

β^{k} : the corresponding parameter of $X_{m,i,j}^{k}$.

$T_{m,i,j-\delta}^{k}$ the time use for activity type k on δ days prior to the measured day j. in this study, $\delta \in \{1, 2, 3\}$, denoting the time allocation one/two/three day(s) before the measured day.

τ_{m}^{k} : the random error term at household level.

$\mu_{m,i}^{k}$: the random error term at individual level.

$\varepsilon_{m,i,j}^{k}$: the iid error term.

TABLE 5 Estimation Results of Time Use Models

	Contracted time		Committed time		Necessary time		Free time	
	Coef.	T-value	Coef.	T-value	Coef.	T-value	Coef.	T-value
Intercept	5.839	28.18	4.598	20.67	6.186	108.94	5.613	40.63
Previous days' time use								
Time use one day before (/1440min)	0.034	1.01	1.204	13.46	0.292	13.21	0.457	13.78
Time use two days before (/1440min)	0.028	0.85	0.177	1.91	0.076	3.40	0.084	2.48
Time use three days before (/1440min)	-0.054	-1.63	-0.053	-0.60	0.027	1.19	-0.008	-0.23
Day of the week								
Monday to Thursday (reference)	/	/	/	/	/	/	/	/
Friday	-0.091	-9.60	0.020	1.31	0.007	1.94	0.063	8.44
Saturday and Sunday	-0.093	-10.41	0.106	8.97	0.045	16.77	0.164	27.74
Individual and household socio-demographics								
Male (reference)	/	/	/	/	/	/	/	/
Female	-0.147	-2.98	0.604	12.56	0.043	5.08	-0.031	-1.50
Age 14-25 years old	-0.154	-2.20	-0.388	-5.40	0.041	2.95	0.072	2.19
Age 26-35 years old	-0.037	-0.50	-0.062	-0.89	0.006	0.42	-0.005	-0.13
Age 36-45 years old (reference)	/	/	/	/	/	/	/	/
Age 46-55 years old	-0.079	-0.95	-0.039	-0.50	0.018	1.13	0.092	2.47
Age over 55 years old	-0.467	-4.08	0.003	0.04	0.062	3.57	0.231	5.47
Low income: < IDR 3 million/month (approx. 300 USD/month)	0.154	2.10	-0.043	-0.54	0.025	1.25	0.008	0.16
Medium income: IDR 3-6 million/month (reference) (approx. 300-600 USD/month)	/	/	/	/	/	/	/	/
High income: >IDR 6 million/month (approx. 600 USD/month)	-0.043	-0.39	-0.102	-0.87	0.031	1.08	0.017	0.24
Income missing	0.205	0.95	-0.415	-3.02	0.044	1.70	-0.051	-0.82
Number of household members	0.015	0.80	-0.012	-0.62	-0.002	-0.40	0.014	1.11
Number of motorised vehicles per household member	-0.002	-0.01	-0.182	-1.32	0.067	1.93	0.019	0.21
Perceived accessibility								
Perceived number of public transport lines connected to home	0.039	1.68	-0.036	-1.43	-0.020	-3.08	0.034	2.10
Perceived travel time from home to CBD	0.000	-0.11	0.0003	0.19	-0.0003	-0.55	0.003	2.94
Perceived travel time from home to nearest grocery store	-0.004	-0.62	0.009	1.50	0.001	0.35	-0.001	-0.24

Perceived travel time from home to nearest shopping centre	0.007	2.08	-0.007	-2.19	0.0001	0.07	-0.003	-1.21
Perceived travel time from home to nearest park	-0.001	-0.26	0.003	1.32	-0.0003	-0.56	-0.001	-0.72
Perceived travel time from home to nearest train station	-0.002	-1.16	0.004	2.37	0.0004	0.97	-0.002	-1.93
Residential built environment								
Population density at the home zone	-0.011	-3.09	0.008	2.24	-0.001	-1.42	0.001	0.60
Road density at the home zone	0.000	0.77	-0.0001	-0.26	0.0002	1.84	-0.0002	-1.10
Industrial area density at the home zone	-0.223	-0.47	-0.677	-1.22	0.083	0.55	0.416	1.10
Commercial area density at the home zone	2.267	1.07	-0.918	-0.45	0.041	0.08	-4.247	-3.49
Error term								
Standard deviation of household level error term	0.135		0.179		0.074		0.190	
Standard deviation of individual level error term	0.429		0.504		0.096		0.232	
Standard deviation of iid error term	0.240		0.464		0.128		0.277	
Model fit information								
Number of households	178		195		195		195	
Number of individuals	405		551		624		624	
Number of observations (days)	5350		7953		11226		11222	
Log-likelihood at converge	-766.7		-6031.4		-6220.7		-2500.7	
R^2	0.717		0.758		0.611		0.672	

Note: The variables ‘Income missing’ is a dummy variable denoting that the income of the given household is missing. The purpose of using ‘missing dummy’ instead of pairwise elimination is to keep as many observations as possible for estimation.

$T^k_{m,i,j-\delta}$ are included in the exogenous variable set, as those variables are supposed to capture the potential inertia effect (e.g. Cherchi and Manca, 2011) and inter-day trade-off effect (e.g. Kitamura *et al.*, 2006). It is assumed that all three error terms, τ^k_m, $\mu^k_{m,i}$ and $\varepsilon^k_{m,i,j}$ are normally distributed with zero mean and unknown variance.

It is worth noting that only non-zero observations are included in the model estimation as the logarithm term is used. The estimated variable effects should then be interpreted as conditional variable effects given that the given time use category (e.g. contracted time) is non-zero. The first three days are also excluded for estimation as they provide the initial condition information of the previous days' time use. The variable effects on a given time use category are the effects on people who spend time on that activity category on the given day.

For instance, the coefficient of "Friday" on contracted time use, -0.091, can be interpreted as those who work or study (have contracted time) on Friday have a shorter contracted time than those who work or study on Monday-Thursday. In order to keep the following interpretations concise, the discussions below would not repeat and emphasize the term "conditional". The estimation results are shown in Table 5.

Contracted time use on previous days show no significant effect on contracted time use on the given day. For committed time, necessary time and free time, only the time use one day before and two days before show significant and positive effects. This indicates the potential inertia effects that people tend to stick to previous time use habit. However, such a lagged effect does not last for more than two days. It is as expected that people spend more time on committed, necessary and free time on Friday and weekend compared to Monday-Thursday, and especially so for free time. Women have a marginally much shorter contracted time but much longer committed time than men. Women also have a slightly longer necessary time than men, as women in Indonesia are, in most cases, responsible for housework and babysitting. Teenagers, 14-25 years old, have a longer necessary time and free time but much shorter contracted time and committed time than the reference age group, 36-45 years old. Teenagers at their age interval are usually not responsible for household activities but may have the desire and energy for necessary time and free time activities. Elders, age >55 years old, also show a longer necessary time and free time than the reference age group. As people getting older, they naturally need longer necessary time such as sleeping time but also have more time for leisure activities as they retire. Income variables surprisingly almost all show insignificant effects despite the significant role of income in the descriptive analysis (Table 3). The only exception is the low income group having longer contracted time than the medium income group. One possible reason could be that the income level does not have a conditional effect but has a selection effect. For instance, people from different income groups who have leisure activities on the given day may not differ from each other in terms of their free time. However, there could be more people from low income group who decide not to have time for leisure activities on the given day than those from medium and high income groups. Vehicle ownership per person per household contributes to a longer necessary time since activities such as fixing mechanics is a part of activities for necessary time (see Table 1).

Perceived accessibility measures play important roles in individuals' daily time allocation. Those who consider their home being well connected to public transport network have a longer contracted time and free time but a shorter necessary time, which is likely due to workers' residential self-selection (e.g. choose to live closer to workplace). Those who perceive a longer travel time from their home to CBD have a longer free time, as those who live far away from CBD are likely to live in countryside. Those who perceive a longer travel time from their home to nearest shopping centre have a shorter committed time. This seems to indicate that there is a clear time trade-off between travel time and activity duration for shopping activities in shopping centre, the longer perceived travel time to shopping centre, the

shorter shopping duration in shopping centre. This is in line with previous studies (e.g. Susilo and Dijst, 2009) which showed closer destination locations would encourage individuals to do more frequent trips but with shorter durations. Finally, those who perceived a longer travel time from their home to train station would have a longer committed time but a shorter free time.

The residential built environment exhibits a less significant role than perceived accessibility measures. This finding is consistent with the finding in immobile behaviour. Given the highly mixed land use configurations in BMA, building block density within the home centroid buffer may not reflect the actual activity location options provided by the urban environment. However, perceived accessibility measures reflect individuals' experiences of their activity participations, and thus can better represent the actual activity location opportunities one may get.

After controlling all the variables that are used in the models, the remaining variance appears mainly at individual level for contracted and committed time use, as the standard deviation of the individual error term is the highest. For necessary and free time, the remaining variance evenly spreads among household level, individual level and day level.

5. CONCLUSION

Using a three-week time use and activity-travel diary collected in Bandung Metropolitan Area (BMA) in Indonesia this paper explored the time use allocation and immobile behaviour while controlling for between and within individual/household variation. In-line with the findings in developed countries, different weekday and weekend patterns of time use are observed for individuals with different socio-demographics. The gender difference in term of time use allocation, however, is still more contrast than in developed countries. As a typical patriarchal society in developing country, women are still responsible for housework and thus have a shorter contract time, free time and travel time but longer necessary time and committed time than men on both weekday and weekend. Housewives also have a particularly low travel time, indicating that household wives may not travel far distance. Retirees and non-workers have the longest necessary time and free time. Retirees may need more sleeping time as they are elders, while non-workers may also have longer personal care activities and maintenance activities since they do not have tight time constraints compared to workers. Although time use patterns for individuals from different income groups are different, income effects are mostly insignificant in the multivariate analysis. This indicates that income effects are likely to be reflected in the effects of perceived accessibility measures and residential built environment measures.

Individual level heterogeneity is more prominent for contracted and committed time use, while individual level heterogeneity and household level heterogeneity are of similar magnitude for necessary and free time use. The multivariate analysis also reveals the important roles of perceived accessibility. An accessible and well-connected urban design perceived by individuals provides more activity location options and thus stimulate their trip frequencies. The perceived accessibility measures can better explain time use and immobile behaviour than residential built environment measures. Perceived accessibility measures take into account individuals' experiences of their activity participations, and thus can better reflect the actual activity location opportunities one may get, especially in the highly mixed land use environment such as BMA.

It is important to remember that this study also does not consider residential self-selection bias, as the perceived accessibility and residential built environment variables

are directly used as exogenous variables. Therefore, the estimated effects of perceived accessibility and residential built environment variables may also include self-selection bias. Future works on modelling residential location jointly with time use and immobile behaviour can better control for residential self-selection. Finally, this study, although includes variables such as number of household members, does not model intra-household interaction. As father, mother and children play different roles in a household, their travel behaviour and time use are also intertwined with each other. Further model development can focus on modelling time use and immobile behaviour of each household member in an integrated model system. Those are possible future research directions.

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