Commute Behaviour Changes During Rain Season in Jakarta Metropolitan Area ジャカルタ都市圏の雨期における通勤行動変化に関する研究

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Rain environment causes significant increase in commute duration and congestion length in Jakarta Metropolitan Area (JMA). Simultaneous change of commute departure time and route is the most common commute behaviour adjustment under heavy rain influence. Nested Logit model analysis shows significant influence of flood risk exposure to route change decision which contra productively does not show expected outcome, in terms of maintained arrival time at work. Stable route choice results in better arrival time, thus flood preventive measure will be highly valuable for transport-related outcome as well.

1. Introduction

Jakarta Metropolitan Area (JMA) is the capital area of Republic of Indonesia consisting of 5 municipal areas in DKI Jakarta Province. About 98% of JMA's mobility relies on road transportation. Home-to-work trip dominates JMA's travel purpose, generating around 620,690 pcu trips/day or about 48% of total JMA trips⁷⁾. Motorcycles and cars dominate commuting mode share, making up roughly 62.2% of total commute mode share¹¹⁾.

JMA is situated in tropical climate region, influenced by two monsoons, resulting in two distinctive weather seasons: wet season, from November to March; and dry season, from May to September, with peak of precipitation occurs in December-January²⁾. In JMA, "adverse weather" is normally associated with precipitation, which can occurs for more than 20 days/month during peak month (data: www.mundomanz.com/).

Informal observation witnessed increased instability of road network level of service in already congested JMA during rain season. Commuters are forced to adjust their commute decision in order to be punctual at work. However, this adjustment may or may not be capable of generating the expected outcome (i.e. maintained arrival time) and has potential of reduced travel welfare (e.g. loss in free time at home due to depart earlier).

Importance of investigating the impact of rain environment on commute trip emanates from the necessity to maintain and improve desired travel welfare and outcome in the presence of rain. Rain environment prevalence and regular occurrence, which suggest long term and recurring impact amplifies this necessity. Rain record data from 2008-2014 shows rain poured down during at least 55%, and up to 95% of working days in rain peak months (data: www.mundomanz.com/).

In JMA's situation, impact of rain environment is not solely dependent on the intensity. Incapable drainage system sometimes exaggerates the impact of light and moderate rain because it causes water to remain on the road and disrupt the transportation.

This research aims at analysing the impact of rain environment on road travel, analysing travel behaviour change due to influence of rain environment, and evaluating the consequence of travel behaviour change. Investigation is oriented towards JMA's dominating travel purpose and mode, being morning commute trips with motorcycles and cars.

Rain impact on road travel is expressed by change in network level of service. Among many level of service variables, travel time (commute duration) and congestion length experienced by commuters are chosen as the parameters. Since at the point of constructing this research travel data with large spatiotemporal coverage was unattainable, reliance on commuters' self report travel data was the consequence. Therefore, result of this research will reflect tendency rather than actual preference. Commute duration is naturally observable by commuters so it will not burden the data collection process and provide more assurance on the attainment of near-objective travel data. Congestion length is also expected to be more reportable than other level of service variables as commuters have been familiar with already congested JMA's road network. However, in order to maintain consistency, the term "congestion length" is then defined uniformly, as *"total time in one commute trip in which commuters feel the road is so crowded with traffic as to hinder their movement and cause stoppages"*.

Commute behaviour aspects to be investigated are commute mode, departure time, and route. Commute mode change means usage of mode other than car for car commuters, and usage of mode other than motorcycle for motorcycle commuters. Departure time change translates to any departure advancement or delay, relative to departure time when no rain influence is present. Route change means usage of route other than the routine commuting route under no rain influence. Pattern of commute mode, departure time, and route change is the aim of investigation.

Subsequent investigation point aims at revealing factors influencing commute behaviour change. Apart from network's level of service and commuters' socioeconomic background, particular attention is given towards influence of flood risk and influence of exogenous information. Due to frequent failure of drainage system's carrying capacity, one can assume that JMA's road users get accustomed to and therefore tolerate certain level of inundation. This can discourage flood reduction effort since the necessity is felt less. Proving how flood risk is influential to important travel like commuting is expected to strengthen the necessity of total flood risk reduction measure, not only for extreme level of flood, but for the lower flood level as well. Flood risk map issued by the government is used as data source. There are three levels of flood risk to be investigated, being risk of up to 30cm flood, risk of up to 100cm flood, and risk of deeper than 100cm flood.

Consequence of commute behaviour adjustment is expressed by change in travel welfare as well as outcome of commute trip. Travel welfare loss is represented by reduction of free time at home due to timing change, longer travelled distance, travel time, and congestion, as well as higher exposure towards flood risk. Commute behaviour outcome is measured by up to what extent arrival time at work can be maintained under the influence of rain environment, with commute behaviour adjustment being done.

Previous studies showed different adverse weather

intensity resulted different degree of disruption on network level of service. It is presumed that different type and intensity of commute behaviour adjustment and its outcome will also take place with varying rain level. Impact of three rain levels based on categorisation by Indonesia's Meteorological Agency is investigated: light rain (5-20mm/24h or 1-5mm/h), moderate rain (21-50 mm/24h or 5-10mm/h), and heavy rain (51-100mm/24h or 10-20mm/h). Precipitation higher than heavy rain is excluded from the analysis since it is assumed to be an exceptional occurrence that does not trigger common consequences.

2. Area Description

The term "Jakarta Metropolitan Area" refers to 5 municipal areas in DKI Jakarta Province, Indonesia: Eastern (Timur), Southern (Selatan), Central (Pusat), Western (Barat), and Northern (Utara) Jakarta Municipality. JMA is Indonesia's central economy. JMA's economy attracts mobility from surrounding regions: Bogor, Depok, Tangerang, and Bekasi. JMA and these four regions are usually referred as one agglomeration called Jabodetabek (Greater Jakarta). Fig.1 displays JMA setting.

Almost 98% of JMA's urban transport relies on road transportation and only less than 3% of trips are on rail by KRL Jabotabek⁶⁾. Other than cars, Transjakarta BRT services, taxis, and motorcycles, modes widely available in JMA are motorcycle taxis (*ojek*), 3-wheeled cars (*bemo/bajaj*), and paratransit, consisting of non-BRT buses and public wagon/cars (*angkot*).

JMA has been experiencing rapid motorisation within the last decade. In 2001, the number of motorcycles accounted for about 1.8 million units and in 2010 it reached 8.7 million units. The number of cars in 2001 was 1.1 million units and within a decade this number has doubled to be 2.3 million³⁾. In spite of rapid and continuous motorisation, addition of road area in JMA is only about 0.01% per year⁶, which has been cited as the major cause of severe traffic congestion. Current congestion alleviation measures include designation of 5 road corridors for high occupancy vehicles during 07.00-10.00 and 16.30-19.00 on weekdays, provision of 15 corridors of BRT service with exclusive lane and air-conditioned buses to encourage mode shift from cars, and development of monorail network, which is planned to be completed in 2018.



Fig.1 Map of Jakarta Metropolitan Area

3. Method

As a consequence of resource limitation, the size of sample is determined by quota. The number of research subjects is defined to be 300 people. Although representing less than 0.1 per mill of the almost 3.15 million private-mode (car & motor- cycle) commuters population, 300 is deemed operable in statistical analysis. Probabilistic sampling technique is applied to define sample composition. Number of car driver commuter samples and motorcyclist commuter samples is defined by assigning weight according to their mode share. Car drivers : motorcyclists proportion is 13.5% : 48.7% = 1 : 3.6, resulting in 65 car driver samples and 235 motorcyclist samples. Data collection is limited into JMA's CBD area. It is plausible to assume that CBD is main commute destination where the most trip attraction is present. The delineation of CBD follows Map of Spatial Structure Plan (year 2011-2030) from DKI Jakarta Provincial government. Samples are equally distributed in the data collection area by assigning 50 grids with equal size onto JMA's CBD area. Each grid is represented by 6 samples.

Data collection process employs questionnaire and route recording is carried out by making use of Google Map on mobile device (tablet). Data collection covers 6 main research variables: 1) mode, departure time, route choice; 2) level of service (commute duration and congestion length); 3) route characteristics (route length and % of route under 3 classes of flood risk area); 4) information access (intensity of pre-trip & en-route traffic information and weather information access); 5) socioeconomic and workplace characteristics; and 6) arrival time. The questions address respondents' choice on commute mode, departure time, and route, then the resultant level of service and arrival time from the chosen mode, departure time, and route in situation when rain influence is absent (termed as "routine commute") and in situation under the influence of light, moderate, and heavy rain. Regarding route choice, respondents were asked to draw their routine route (the route being used the most in past one year) and the secondary route (route they use/trust the most during rain season). Respondents' choice towards mode and departure time other than routine mode and departure time, as well as choice towards secondary route in situation under rain influence indicates mode, departure time, and route change. In order to get expression about impact of rain on network level of service during morning commute hours, respondents were also asked their expected level of service with imposing scenario that they do not make any commute adjustment at all. Network performance is product of collective travel behaviour decision, thus imposing no travel behaviour change scenario will give proxy to the net effect of rain on neon network level of service.

In order to ensure consistent analysis and interpretation, uniform perception over 3 levels of rain needs to be set. To achieve this, respondents are provided with objective definition of rain level along with illustrative situation representing the objective definition, for example, "heavy rain is situation when 51-100mm/24h or 10-20mm/h rain pours down; in an hour, over 1m² area you can collect 10-20 litres of water from this rain; heavy rain occurs often in January 2014".

4. Result and Discussion

Commuters' Characteristics

Most of commuter respondents live in Inner JMA area (68.44%). Outskirt JMA area with most respondent is Bekasi (13.95%). Dominating commuters' categories are: male (90.03%); 21-30 years old (37.54); married (74.09%); highschool graduate (55.81%); lower than 450

US\$ monthly income (79.07%); living in a household with only either motorcycle or car is available (67.77%); having easy access to any vehicles available at home (91.69%); perceiving routine commute route prone to flood risk (66.11%); having no flexible work schedule (62.46%). Respondents with intensive traffic and weather information access (frequency: often, always) are fewer than commuters with low information access intensity (frequency: never, seldom, occasional). Percent of commuters with intensive pre-trip, en-route traffic information, and weather information access is 32.89, 22.26 and 27.57, respectively. Mean length of residing current address is 15.54 years, while mean length of work in current address is 6.97 years.

Impact of Rain on Commute Trips

Table 1 shows % increase of commute duration and congestion length in 3 rain levels relative to commute duration and congestion length in routine commute trip. The result confirms previous studies that rain environment is associated with worsened network level of service, in terms of travel time^{8,10,12)} and congestion duration^{1,10)}, which also reported that the worsening level gets more severe with rain intensity increases. Point to note is that the degree (%) of travel time and congestion length increase in this research is much higher than other studies. Apart from difference in network's empiric situation, this dissimilarity plausibly emanates from difference in the analysis unit as well. This research employs trip-aggregated travel data while studies mentioned above used link-aggregated data.

| Table 1. | mpact | of | Rain | on | Commute | Trip |
|----------|-------|----|------|----|---------|------|
|----------|-------|----|------|----|---------|------|

| | Mean Commute Duration Increase | Mean Congestion Length Increase |
|---------------|-----------------------------------|------------------------------------|
| Light rain | 20.127% ** | 12.138% * |
| Moderate rain | 39.009% ** | 22.271% ** |
| Heavy rain | 49.059% *** | 29.849% *** |
| | | |

significantly different at * = 0.05; ** = 0.01; *** = 0.001 level from respective value in routine commute

Pattern of Commute Behaviour Change

Table 2 shows the most occurring commute behaviour adjustment in 3 rain levels. As expected, the inertia reduces with increasing rain severity.

Commute adjustment involving mode change is the least applied regardless rain intensity. This is in agree-

ment with previous researches which reported departure time and route change as more applicable adjustment types^{4,5,9)}. There are only 5.30% commuters at most making mode adjustment under heavy rain influence, either for other type of private mode or to transit mode. In light, moderate, and heavy rain, 1.33%, 2.66%, and 2.99% respondents shift to transit mode, creating niches for public transport use promotion.

Number of commuters advancing their departure is more than those who delay. This tendency gets clearer in heavier rain levels. The comparison in light, moderate, and heavy rain is 13.95% vs. 12.93%; 25.25% vs. 16.61%; and 33.55% vs. 18.61%. Commuters adjusting their departure and route simultaneously increase in heavier rain level. In light, moderate, and heavy rain, the number is 30.89%, 20.6%, and 5.65%, respectively.

With small number of commuters changing mode, modelling work to reveal influential factors in commute behaviour change adjustment exclusively addresses departure time and route change. It is hypothesised that departure time and route change decision is not independent to each other, thus Nested Logit model is applied.

Table 2. The Most Occurring Commute Behaviour Adjustments

| Rain Level | Commute Behaviour Adjustment |
|---------------|--|
| Light rain | No change (54.82%); change departure time |
| | (20.60%); change route (17.61%) |
| Moderate rain | No change (28.57%); change route (26.58%); |
| | change departure time (21.27%) |
| Heavy rain | Change departure time & route (30.89%); ch. route (22.93%); ch. departure time (21.25%) |

Influential Factors in Commute Behaviour Change

The nest structure is given in Fig. 2. Dependent variable is decision whether or not to change departure time and/or route. Changing departure time and changing route are defined as decision to choose secondary departure time and secondary route (departure time and route other than routine departure time and route). A model for each rain level is produced. Result is presented in **Appendix**.

Flood risk variables result in negative sign, indicating lower exposure to flood risk encourages choosing secondary route. Although exposure to flood risk up to 100cm inundation level does not enter the model significantly at light rain model, in general exposure to flood risk becomes more influential with rain level increases. In heavy rain environment, route exposure to flood risk deeper than 100cm shows the highest significance level. This indicates that under heaviest rain level, sensitivity towards severe flood risk gets higher and encourages commuters to detour. In general, route's exposure to flood risk variables show the highest significance level than other variables entering lower level of the model.

Exogenous-sourced information variables do not enter the model significantly. Notwithstanding its contrast with general travel behaviour theory, this finding may emanate from the low intensity of information access by JMA commuters. Length of residence has significant and positive influence on choosing secondary route, suggesting that commuters are more reliant on their own experience about the road network compared to information provided by exogenous sources. Independency of commute behaviour adjustment with weather information access intensity may emanate from the fact that JMA has distinguishable rain season in which rain occurrence is prevalent, thus making rain occurrence is expectable without necessity of accessing weather information intensively.

Outcome of Commute Behaviour Change

Outcome of commute trip is measured by arrival time. Routine arrival is assumed to be ideal situation as standard for evaluating the outcome of adjusted commute's outcome. **Table 3** shows outcome of commute behaviour adjustments, which do not involve mode change.

Commute adjustments involving departure time change results in better outcome relative to non-adjusted commute or commute adjustment involving only route change. Arrival time of commuters who adjust their departure time moves away from their routine arrival less than arrival time of commuters who do not make any adjustment or adjust only the route. This implies stable

Fig.2 NL Tree Structure for Dept. Time & Route Change

route choice is desirable. However, commuters who change their route get less exposure towards flood risk. Portion of route being under 100cm and deeper-than-100cm flood risk reduce as much as by up to 9.41% and 5.88%, respectively.

Table 3. Commute Behaviour Outcome

| Adjustment | Avg. Chang | e in Arrival Time | (in min.) |
|---------------|------------|-------------------|-----------|
| - | Light | Moderate | Heavy |
| Dept. time | +8.65 | +14.29 | +28.61 |
| Route | +12.31 | +18.63 | +34.29 |
| Dept. & route | +7.16 | +12.38 | +26.38 |
| No adj. | +11.42 | +19.07 | +38.01 |

5. Conclusion

Commute behaviour adjustment involving only route change does not generate arrival time outcome as good as behaviour adjustments that involve departure time change. However, route change does increase avoidance towards flood risk and modelling result also stresses how exposure to flood risk shapes route change decision. With this regard, traffic management policy oriented at improving travel welfare and network level of service cannot be separated from flood prevention policy. This policy is currently integrated in JMA's land use policy. However, although the basis for actions does exist, the infamous problem that causes flood risk remains recurring issue is the lack of enforcing power in its implementation. This research does not suggest enactment of new policy, rather, it amplifies the necessity of strict implementation of any policies related to land use control currently present.

This research provides wider array of analysis in travel behaviour-weather related topics with tropical region setting and focus on private motorised mode, which has been unavailable. Improvement can be made by using objective travel data, e.g. from GPS record data.



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| Explanatory Variables | Ught Rain | | | Moderate Rain | | | Heavy Rain | | |
|---|----------------------|----------------------|-----------------------|----------------------|----------------------|-------------------|----------------------|----------------------|------------------|
| | Upper Lv. | Lower Lv.: 2 | 2 nd Route | Upper Lv. | Lower Lv.: 2 | M Route | Upper Lv. | Lower Lv.: 2 | M Route |
| | 2 nd dep. | 2 nd dep. | routine dep. | 2 nd dep. | 2 ^m dep. | routine dep. | 2 rd dep. | 2 nd dep. | routine dep. |
| route length (km) | | -1.149** (-2.063) | | | -0.798* | | | -2.250 (-1.644) | |
| %noute under 30cm flood risk | | -2.688** (-3.344) | | | -1.268** (-2.93) | | | -1.915 | |
| %noute under 100cm flood risk | | -1.069 (-1.804) | | | -2.177 (-2.347) | | | -1.103*** | |
| %noute under 100cm+ flood risk | | -1.672* (-1.946) | | | -0.551** (-2.667) | | | -1.118*** | |
| rain impact1: %com. duration increase | 2.205** (3.659) | | | 2.167*** (4.194) | | | 2.018*** (4.762) | | |
| rain impact2: % congestion Increase | 2,489*** | | | 2.472*** (4.535) | | | 2.025*** | | |
| mode dummy (1 = motorcycle) | 1.424 (0.956) | 0.478" (2.061) | 0.945 | 0.462 (0.636) | 1.462 (1.636) | 1.515 (0.764) | -0.056 (-0.089) | 1.185 (1.165) | 1.526 (0.797) |
| gap work start - nutine arrv. time | 2.029** | | | 2.004*** | | | 0.803*** | | |
| age dummy (1 = up to 35 years old) | 1.455" (1.978) | 2.641* (1.962) | 2.766* (1.966) | 0.068 (1.043) | 1.907 (1.638) | 1.831 (1.703) | 1.056 (1.577) | 1.226 (1.102) | 1.230 (1.115) |
| monthly income1 dummy (1 = 450-900US\$) | 3.989 (1.745) | 2.349 (0.261) | 2.901 (1.363) | 2.029 (1.041) | 0.401 (1.851) | 0.862 (0.892) | 3.871 (1.223) | 1.517 (0.902) | 1.565 (1.402) |
| monthly income2 dummy (1 = higher than 900USS) | 1.263* (1.982) | 0.879 (1.317) | 1.085 (0.686) | 2.068° (1.998) | 2.126 (1.462) | 2.830 (1.486) | 1.766 (1.097) | 0.267 (1.345) | 0.958 (1.354) |
| feetble schedule dummy (1 = yes) | -1.521** (-3.285) | | | -2.384** | | | -0.905" (-2.068) | | |
| residence length (years) | | 1.346* (2.074) | 1.482* (1.972) | | 0.243* (1.968) | 0.272* (1.952) | | 1.846 (1.385) | 1.810 (1.178) |
| work length (years) | | 4.717 (1.635) | 5.006 (0.673) | | 4.214 (1.429) | 4,869 (0.980) | | 3.520 (1.053) | 3.553 (1.405) |
| pre-trip traffic info access dummy (1 = intensive) | 1.954 (0.979) | 1.730 (1.130) | 1.135 (0.899) | 1,048 (1,074) | 1.791 (0.975) | 1.597 (1.021) | 1.076 (1.119) | 2.385 (1.122) | 2.131 (1.122) |
| en-route traffic info access dummy (1 = intensive) | 2.009 (1.671) | 1.042 (1.040) | 2.448 (1.844) | 1.363 (1.723) | 1.724 (0.491) | 1.763 (1.497) | 1.140 (1.521) | 1.205 (1.119) | 1.971 (1.318) |
| weather info access dummy {1 = intensive} | -1.934 (-1.094) | -0.072 (-0.528) | -0.500 (-0.617) | 0.096 (0.157) | 0.338 (0.903) | 0.396 (0.940) | 0.218 (0.347) | 0.226 (0.030) | 0.127 (0.029) |
| Intercept | 3.132 (2.953) | -2.056 (-0.628) | -2.979 (-0.684) | -1.274 (-1.553) | 2.588 (1.797) | 2.951 (0.771) | -3.281 (-1.389) | 2.965 (1.318) | 3.212 (1.819) |
| IV 2 ^{rel} departure time (change d | departure) | 0.561* | | 0.485 | | | 0.501* | | |
| IV routine departure time (no di change) | eparture | 0.429** | | 0.424 | | | 0.453 | | |
| No. of observation | | 296 | | 291 | | | 285 | | |
| Log likelihood | | -265.620 | | -216.020 | | | -161,940 | | |
| Log likelhood chi-sq | | 133.780 (p | = 2.3666e-09) | 368.590 (p.= < | < 2.22e-16) | | 457.190 (p.= < | :2.22e-16) | |
| McFadden R-sqrd | | 0.201 | | 0.360 | | | 0.485 | | |
| Sig. level: *= 0.05; **= 0.01 | 1: *** = 0.001. | t-test value in | parentheses | | | | | | |

Appendix: Output of NL model