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Effect of Rain on Travel Demand and Traffic Accidents

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***Abstract*— This paper studies the effect of rain on travel demand measured on the Tokyo Metropolitan Expressway (MEX). Rainfall data monitored by the Japan Meteorological Agency's meso-scale network of weather stations are used. This study found that travel demand decreases during rainy days and, in particular, larger reductions occur over the weekend. The effect of rainfall on the number of accidents recorded on 10 routes on the MEX is also analysed. Statistical testing shows that the average frequency of accidents, during periods of rainfall, is significantly different from the average frequency at other times.**

I. Introduction

Traffic performance during fine weather conditions, such as free flow speed, capacity and saturation flow rate, has been extensively researched. Traffic management measures, such as traffic signals and speed limits, are mostly optimised for good operating conditions. However, the causal relationship between weather and traffic performance is less researched, partly because of lack of disaggregate weather information. Anecdotal evidence suggests that traffic performance, such as free flow speed, deteriorates with poor weather conditions. This suggests that traffic control, such as traffic signal control parameters and speed limits, may need to take account of weather effects.

Does rain affect travel demand? Is there a significant difference between accident rates during fine and rainy weather conditions? This paper attempts to address these questions using meso-scale weather data and numbers of trips and accidents recorded on the Tokyo Metropolitan Expressway (MEX).

The following sections describe the weather data used and the study area in greater detail. This is followed with an overview of the analysis into the effects of rain on travel demand and accident rates on the MEX.

II. Weather Data

The Japan Meteorological Agency (JMA) operates a meso-scale observation network called AMeDAS (Automated Meteorological Data Acquisition System) of over 1300 observation stations with an average spacing of 17km. All stations monitor hourly precipitation, and more than 800 monitor air temperature, wind direction/speed and sunshine hours. In Tokyo, there are an average of 258 days (71%) per year with no rain, 49 days (13.5%) with ≤ 3 hours rain, and 58 days (15.5%) and > 3 hours rain. Rainfall data measured at 5 weather stations close to the study area, from April 1998 to March 2004, are used. The weather stations - Setagaya, Nerima, Shinkiba, Tokyo and Haneda are indicated in Fig. 1.

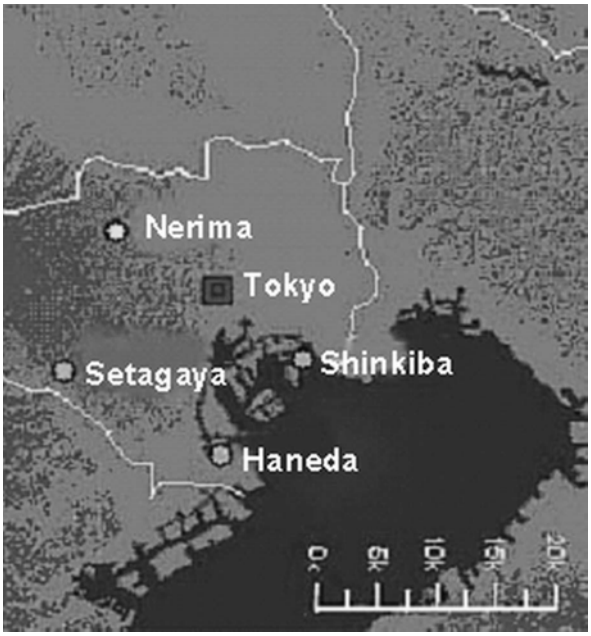

Fig. 1. Location of weather stations near central Tokyo

III. Study Area

The study area chosen for this study is the Tokyo Metropolitan Expressway (MEX). MEX serves as the major arteries of the Tokyo Metropolitan Area, carrying a daily average volume of 1.14 million vehicles over a total length of 283 km (see Fig. 2). MEX carries approximately 28% of all arterial vehicle traffic in the Tokyo Metropolitan Area and approximately 35% of its cargo volume[1]. A flat rate toll of 700 yen (approx. US$7) is charged for passenger cars using MEX, yielding an average daily revenue of over US$7 million.

Six years of daily trip volumes over the whole network, from 1st April 1998 to 31st March 2004, are available.

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During this period, 3 new routes were completed. Bay Shore Route (B) was in service from 2001 and a year later Central Circular Route (C2) and Kawasaki Route 6 (K6) came into service. From an overall network perspective, these 3 routes did not increase the total volume of trips recorded on the network. If anything, there was a slight decrease in total trips over the last 3 years.

Fig. 2. Tokyo Metropolitan Expressway (MEX) Network

IV. Travel Demand on MEX

Although there are about 5 weather stations in the vicinity of the area served by MEX, only the Tokyo weather station located in centre of Tokyo is used. It is difficult to use weather information from all 5 weather stations because rain observed at 1 station is not necessary observed at all other stations. However, when the total daily rainfall increases, there is a greater tendency for rainfall also to be recorded at other stations.

To demonstrate this point, daily rainfall records at 5 weather stations shown in Figure 1 were compared. If a 'rainy day' is defined as a day on which any rainfall is recorded at the Tokyo station, then 29% of days would by classed as 'rainy days' (see Table I). However, if the daily rainfall threshold is set at >5, >10 and >13 mm of rainfall per day, the percentage of time rainfall is observed at the Tokyo weather station drops significantly to between 6 and 7%. Therefore, using a higher rainfall threshold improves the robustness of using Tokyo as a proxy for weather stations across the whole MEX network. This study defines 13 mm of rainfall per day, recorded at the Tokyo weather station, as a 'rainy day'. According to this definition, there are 216 *rainy days* over the 6 year period i.e. the equivalent of 9.9% of the year.

TABLE I
PERCENTAGE OF WEATHER STATIONS RECORDED RAINFALL WHEN RAIN IS RECORDED IN TOKYO WEATHER STATION

No. of stations	Daily rainfall threshold (mm/day)			
	>0	>5	>10	>13
1	29%	7%	7%	6%
2	8%	30%	30%	31%
3	8%	9%	9%	8%
4	24%	36%	37%	38%
5	31%	18%	17%	16%

Daily trips are grouped by day of the week into 7 categories, where *Sunday* also includes any public holidays.

Fig. 3 shows the number of trips per day for rainy and non-rainy days. It is interesting to note that daily demand increases from Monday to Friday and decreases on Saturday and Sunday. Comparing the difference in weekdays and weekend daily trips for rainy and non-rainy day, it is clear from Fig. 4 that there is a smaller decrease in daily trips on weekdays (average of 2.9%) than on weekends (7.9% for Saturday and 5.2% for Sunday). In other words, Saturday is most sensitive to weather conditions, followed by Sunday.

Sensitivity analysis on the setting of the daily rainfall threshold was carried out. From the results (see Fig. 5) it can be concluded that weekdays are less sensitive than weekends. However, the sensitivity for Saturday trip to daily rainfall threshold is high and varies from 6% to 14% for threshold ranging from 5 mm/day to 30 mm/day.

Given that 86% of the trips on weekdays are *work* or *business related,* and involve a less flexible itinerary, it is not surprising that the reduction in travel demand on these days is small. Only 11.8% of the trips on weekdays are for shopping or recreational purposes. A higher percentage of shopping and recreational trips are made during the weekend, which explains the higher percentage decrease in demand, especially on Saturdays (down 7.9%).

In terms of revenue, on average a rainy day would reduce tolls by US$200,000 on a weekday, US$550,000 on a Saturday and US$300,000 on a Sunday. Whether trips not made on rainy days are postponed or cancelled altogether is yet to be analysed. Also this analysis did not take into account the time of day that the rain occurred. For example raining from midnight to early morning may have less effect on travel demand.

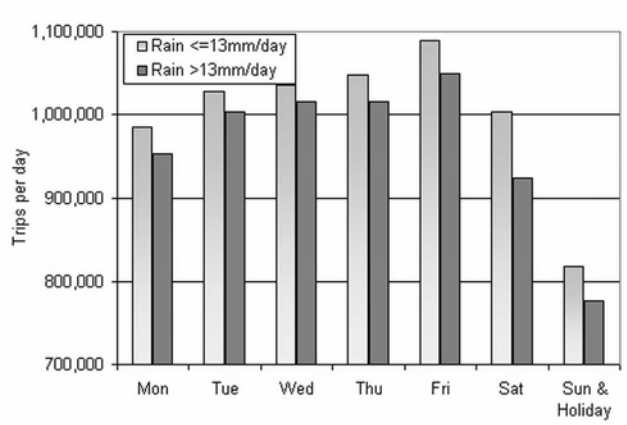

Fig. 3. Average number of trips made during rainy and non rainy days

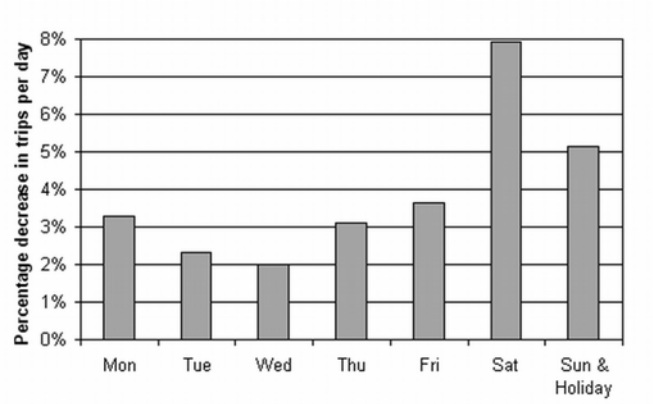

Fig. 4. Percentage decrease in daily trips during rainy days by day group (rain threshold > 13 mm/day)

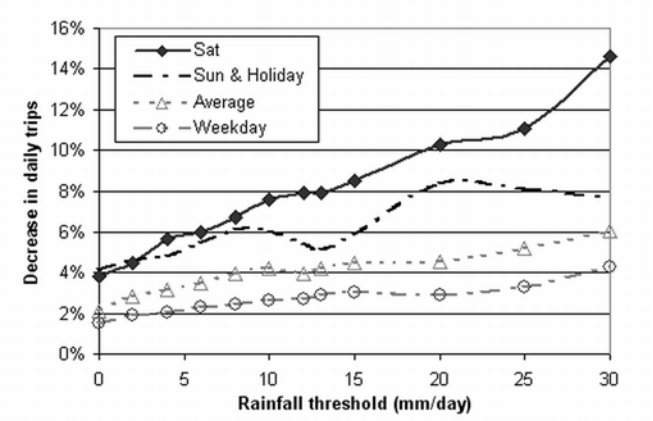

Fig. 5. Sensitivity analysis of rainfall threshold in determining the effect of rain on daily trips demand

V. ACCIDENTS ON MEX

Each year, more than 13,000 accidents are recorded on MEX, together with a further 13,000 vehicle breakdowns and 31,000 instances of items falling from vehicles. Therefore it should come as no surprise that Metropolitan Expressway Public Cooperation (MEPC) attributes 12% of the cause of congestion to accidents[2].

Do accidents occur more frequently on weekdays than on the weekends? Using accident records from April 1998 to March 2004, and dividing the days of week into the same 7 day groups as used above, the analysis found that more accidents occur on Saturdays and Sundays than on any other days (see Fig. 6). This accident pattern is directly opposed to the pattern of trip volumes, suggesting that weekend drivers may be less familiar with the expressway and with driving than weekday drivers. This may be accentuated in Tokyo where only 36% of the motorised journey to work is by car and 60.4% by public transport[3].

Even after considering trip length, that is converting accident rate to accidents per 1 million kilometre (see Fig. 7), weekend drivers are still at higher risk than weekday drivers.

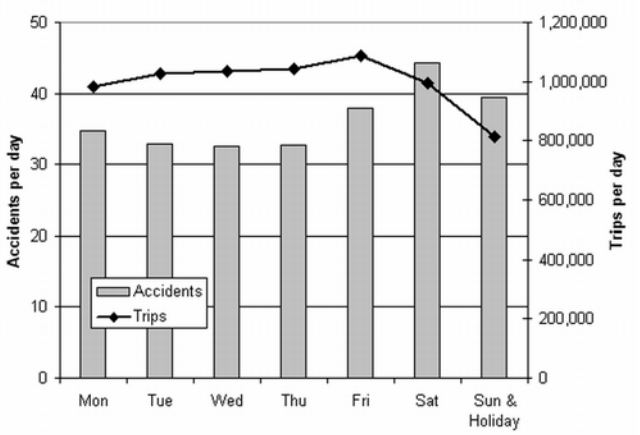

Fig. 6. Accidents and trips per day by day of week recorded on MEX over 6 years

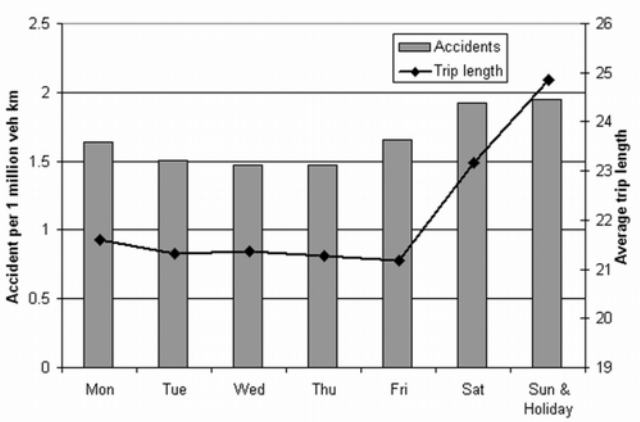

Fig. 7. Accidents per 1 million vehicle kilometer and average trip length for different day of week

Next, the study investigated whether there are more accidents on rainy days. Using accident records from 10 selected routes listed in Table II and hourly rainfall from the corresponding weather stations, accident levels on wet and dry days were compared.

In total, there were 3431 hours of recorded rainfall over the 6 year period. This is equivalent to 0.27% of the hours. With regards to accidents on the 10 routes, 42,041 and 5,700 accidents were recorded during hours with no rain and with rain respectively. An itemisation of accidents during hours

with rain is shown in Fig. 8. It is clear that the average frequency of accidents during rainy hours (1.5 accidents/hr) is significantly different from the average frequency at other times (0.85 accidents/hr). T-test also showed that the difference in average frequency of accidents during hours with no rain and with rain is significant at 95% confidence interval.

TABLE II
SELECTED ROUTES AND CORRESPONDING WEATHER STATIONS FOR ACCIDENTS ANALYSIS

Route	Station
C1, 6, 7	Tokyo
1	Haneda
2, 3, 4	Setagaya
5	Nerima
9, 11	Shinkiba

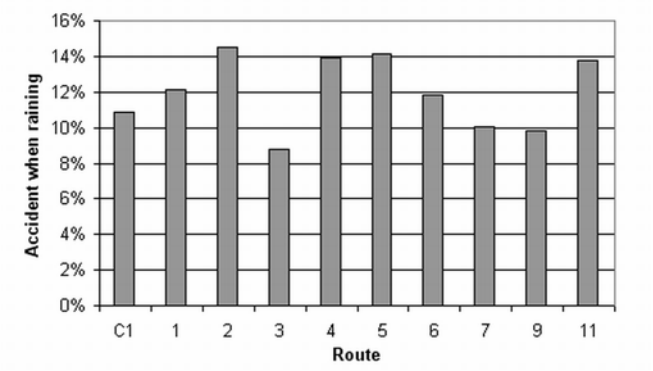

Fig. 8. Percentage of accidents occurred during rain

VI. CONCLUSION

This paper aims to investigate the effects of rainfall on travel demand and accidents. The analyses show that travel demand decreases for rainy days, and especially during the weekend, when the sensitivity to rainfall is higher.

Analysis of accident records revealed that accident rates on weekends are higher than on weekdays, suggesting that weekend drivers may be less familiar with the expressway and with driving than weekday drivers.

With ITS, speed limit and warning messages displayed on VMS which only apply under wet conditions can be integrated with meteorological stations, to reduce the number and severity of accidents.

MEPC patrol cars patrol the network 12 or more time per day, with the same number of patrol cars. While accidents cannot be predicted, it is clear that there are more accidents on weekend and during rainy condition. Therefore scheduling more patrol cars to assist in clearing accidents quickly during these periods could also reduce congestion.

ACKNOWLEDGMENT

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REFERENCES

[1] Metropolitan Expressway Public Cooperation, *Networking People, City and Daily Life* http://www2.mex.go.jp/profile/guide_english/

[2] Metropolitan Expressway Public Cooperation, *Traffic Congestion Countermeasures on Metropolitan Expressways.* http://www2.mex.go.jp/profile/guide_english/

[3] Tokyo Metropolitan Region Transport Planning Council. *Tokyo Metropolitan Region Person Trip Survey*, 1998.