Effect of rainfall on travel time and travel demand

Edward Chung
Laboratory of Traffic Facilities, Swiss Federal Institute of Technology (EPFL), CH-1015 Lausanne
edward@iis.u-tokyo.ac.jp

Osamu Ohtani
Nihon University, Tokyo, Japan
ohtani_osamu@trpt.cst.nihon-u.ac.jp

Masao Kuwahara
Institute of Industrial Research, University of Tokyo, Japan
kuwahara@iis.u-tokyo.ac.jp

Abstract

There is an increasing demand from both the transport authorities and road users to have travel time information for 1 to 2 hours ahead allowing users to plan their trip in advance, allowing them to choose the departure time, mode and route. However, accuracy of travel time prediction decreases with the prediction time horizon. Drivers tend to reduce their speed and keeping a longer headway when raining, which affects the lane capacity. Therefore, a more accurate travel time prediction model can be developed if the effect of rain on travel demand and travel time can be established. This paper sets out to determine the impact of rain on daily trips recorded at Tokyo Metropolitan Expressway (MEX) and the effect of rain on travel time. Rainfall data monitored by the Japan Meteorological Agency's meso-scale network of weather stations are used.

Introduction

With over 11 million VICS (Vehicle Information Communication System) in-vehicle navigation units which provides real time travel information such as travel time and location of accidents, sold in Japan, there is no question that travel information is a highly demanded service. An informed traveller has the ability to choose alternative route, time of departure and mode to minimise his/her travel cost if travel information such as travel time can be predicted accurately prior to making the trip. Hence it has the potential of resulting in the spatial dispersion of traffic, thereby maximising the utilisation of transport system.

The Tokyo Metropolitan Expressway (MEX) conducted an online survey and posed the question whether it is useful to have travel time information for on-route and pre-trip[1]. Each question received 845 responses and 92% and 98% of the participants agreed that it is good to have travel time information on-route and pre-trip respectively[2]. The results clearly demonstrate that drivers rate pre-trip travel time information above on-route travel time information. As the prediction time horizon is larger for pre-trip than for on-route application, a higher degree of error is expected from this application.

Especially for pre-trip information, it would improve the accuracy of travel time prediction if the effect of rain on travel demand and travel time can be established. Hence it may be possible to include weather forecast information as a variable of the travel time prediction model. This paper sets out to determine the effect of rain on travel demand and travel time. The first half of this paper discusses the impact of rain on the number of trips recorded at MEX and the later half investigates the effect of rain on travel time on MEX Route 3 in the inbound direction.

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

Study Area

The 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[3]. 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. 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.

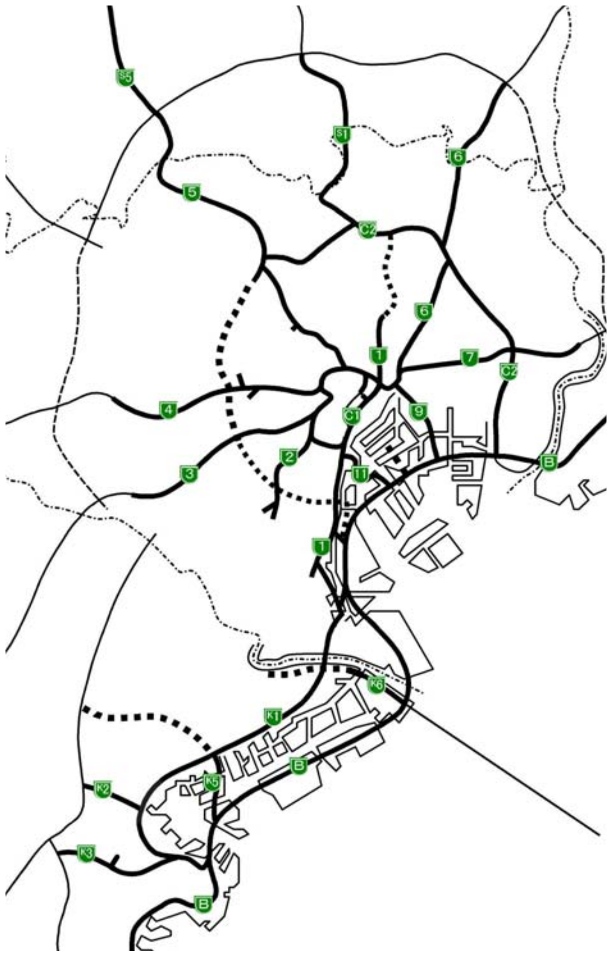

Fig. 2. Tokyo Metropolitan Expressway (MEX) Network

Travel Demand on MEX[5]

Although there are about 10 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 10 weather stations because rain observed at 1 station is not necessarily 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 Fig. 1were 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 Fig. 3). 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% (see Table I). 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.

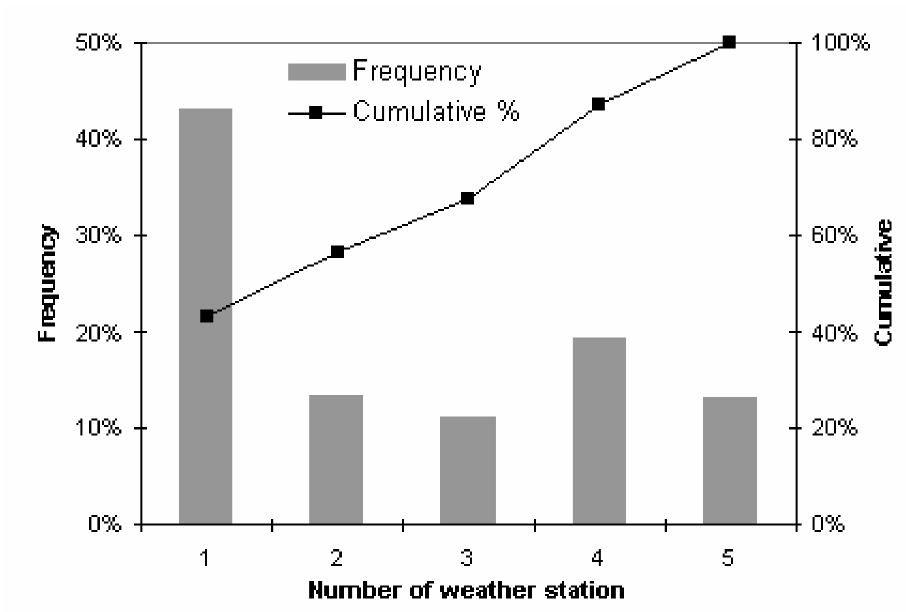

Fig. 3. Frequency of weather stations recording rainfall when rain is recorded in Tokyo weather stations

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. 4 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. 5 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. 6) 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%)[3]. 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.

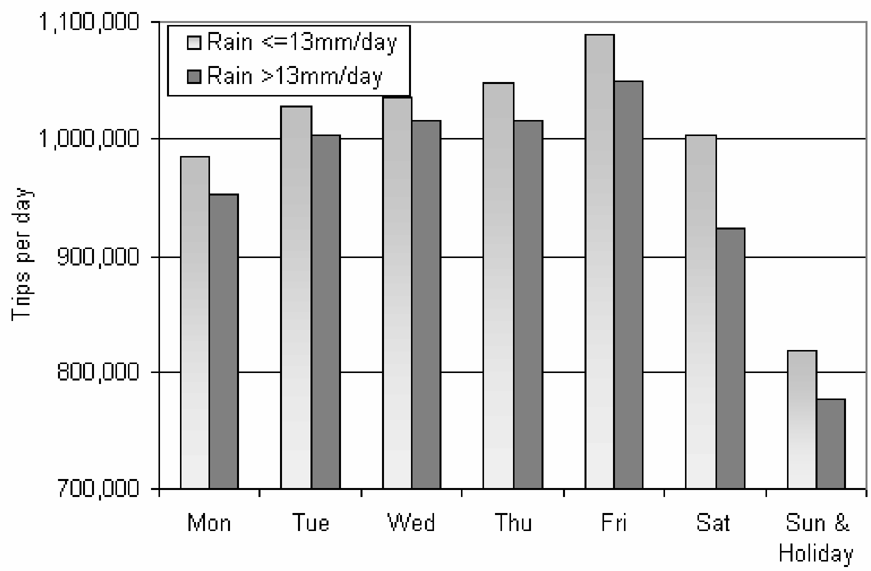

Fig. 4. Average number of trips made during rainy and non rainy days

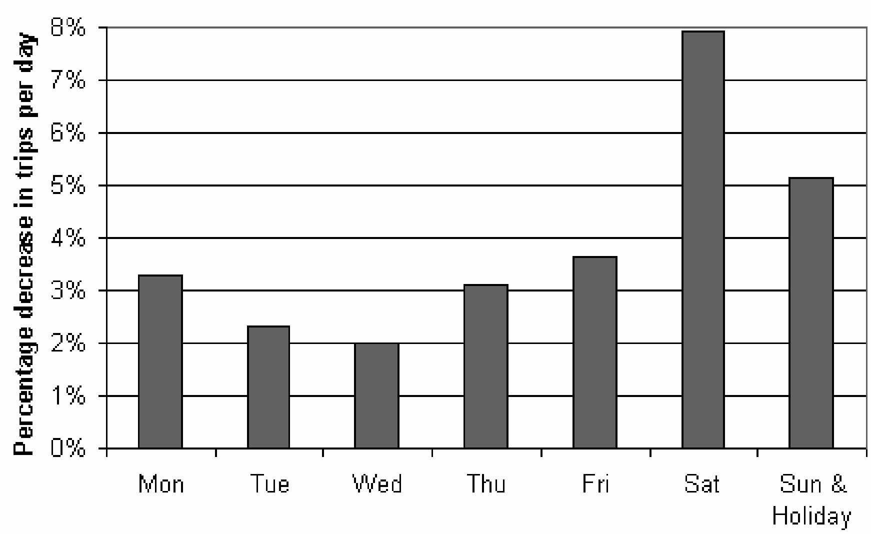

Fig. 5. Percentage decrease in daily trips during rainy days by day group (rain threshold > 13 mm/day)

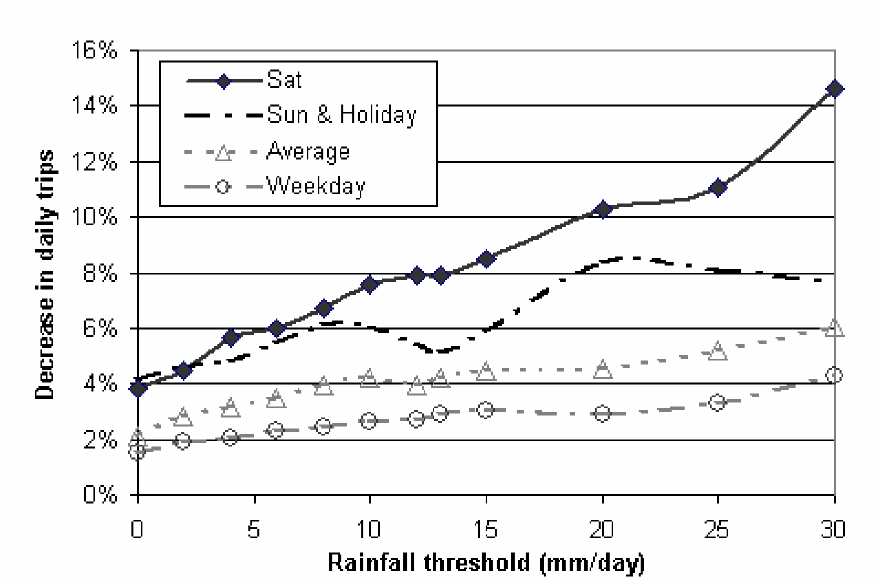

Fig. 6. Sensitivity analysis of rainfall threshold in determining the effect of rain on daily trips demand

Travel Time On Route 3

The route selected for the study is the inbound section of Route 3 of MEX. The length of route is approximately 12km. This route is a part of the network of Tokyo Metropolitan Expressways, which connects many intercity highways to the circular route of Tokyo Metropolitan Expressway. The selected route has two lanes per direction. There are three on ramps and three off ramps between the entry and exit points of the route for which this travel time prediction is made. All the routes of Tokyo Metropolitan Expressway are equipped with ultrasonic detectors which are approximately 300m apart. Historical travel time record shows that travel time on this route varies from 9 minutes in free flow condition to 70 minutes in severe congestion.

There are 40 detectors on inbound section of Route no. 3 of Tokyo metropolitan expressway. For this research, detector data from August 1998 to June 2000 was used to calculate instantaneous travel time i.e. summing of travel time information derived from velocity measurements at different sections of route simultaneously and density i.e. summing of flow (veh/5 minute) divided by vehicle speed measured at different sections of the route.

Each year, more than 13,000 accidents are recorded on MEX, together with a further 13000 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[4]. Depending on the type and location of accidents, the degree of interruption to traffic flow indirectly affects travel time. Therefore, days with accidents recorded during the analysis period are excluded. There is no electronic record of other incidents such as vehicle breakdowns and are therefore not excluded from the data.

Chung [2] classified travel time pattern on the same route and found that found that travel time profiles on weekdays are very different from the travel time profiles on the weekends. Further on weekends even travel time profile of Saturdays is totally different from Sundays. In the AM period the travel time pattern could be grouped in weekday, Saturday and Sunday (including holiday). Chung[2] also found that there is more scatter in the PM period and it does not show a strong grouping as in the AM period. Based on the above findings, this study uses only weekday data for AM period from 6 to 11 am.

Travel time is affected by traffic condition downstream. To ensure that the travel time comparison for rainy and non rainy conditions is carried out for similar condition, route density is used as a proxy for measuring traffic condition. It is clear that density without some form of weighting to include spatial effect of bottlenecks is not optimal but nevertheless an unweighted raw density is a satisfactory proxy.

CHAID Analysis

CHAID (Chi-squared Automatic Interaction Detector) analysis is applied to the above data set compiled above. CHAID technique constructs non binary tree using chi-squared statistics to identify the optimal splits. The alpha value for splitting node is set at 0.01 with travel time as the target and rainfall and density as predictors.

The results show that for low density, implying free flow condition, there is no significant difference in travel time between rainy and non rainy condition. However, at high density travel time difference between the 2 conditions range between 4.4 to 6.3% and is highly significant at 99% confidence (see Table II). This finding can be explained with the outcome of Ohtani[6] research indicating that free flow speed decreases 5-15 km/h and lane capacity decreases 6-10% during rainy condition depending on the amount of rainfall.

For the purpose of this study, the traffic condition has been made to be as similar as possible to reduce other exogenous factor. However, what is the change in travel time that can be expected during rainy condition? Firstly, result from the first part of this paper indicated that travel demand is slightly less during rainy days. In contrast, the free speed and lance capacity decreases[6], indicating a compensating effect. Finally, Chung et al.[5] found that accident rate during rainy days is higher than non rainy days. Overall we can therefore expect a higher travel time but the degree of difference depend on the change in demand, free flow speed, lane capacity and occurrence of accident.

TABLE II
AVERAGE TRAVEL TIME FOR RAINY AND NON RAINY CONDITION FROM CHAID ANALYSIS

Density (veh on route)	Not raining		Raining		Difference
	Travel time (min)	Sample size	Travel time (min)	Sample size	
838-966	20.4	4071	21.7	333	6.3%
966-1083	24.7	4106	25.8	302	4.8%
1083-1191	28.9	4100	30.2	340	4.4%
1191-1310	33.5	4045	35.1	360	4.5%

Conclusion

This paper aims to investigate the effects of rainfall on travel demand and travel time. The analyses show that travel demand decreases for rainy days, and especially during the weekend, when the sensitivity to rainfall is higher. Analysis of travel time under similar traffic density revealed that travel time is higher for high density (i.e. high traffic flow) and not significant at low density (i.e. low traffic flow) for rainy period. Taking other factors into account such as accident rate, free flow speed and lane capacity during rainy days into account, higher travel time can be expected especially for higher traffic flow condition.

Acknowledgment

The authors would like to thank MEPC for providing the traffic and accident data, and the Japan Weather Association for making the AMeDAS weather data available for this research.

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