

# A PROPOSAL OF DELAY ESTIMATION METHOD AT A BOTTLENECK WITH HYPOTHETICAL TRAFFIC DEMAND USING VEHICLE DETECTOR DATA

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Comprehensive traffic management measures are essential to alleviate the traffic congestion during the Olympic games. In this paper, we proposed methodologies to estimate the total delay with hypothetical traffic demand, and to separate the effects of Traffic System Management (TSM) and Traffic Demand Management (TDM) separately based on the vehicle detector data. Then we applied the methodologies at a bottleneck on the Tokyo Metropolitan Expressways (MEX) as a case study, and compared the periods during the Tokyo 2020 Olympic games and before the Olympic games. The results for the case study suggested that TSM was efficient for reducing onramp traffic demands, which will further contribute to the total delay reductions at merging bottlenecks.

**Keywords:** Total Delay, Traffic Demand Estimation, Traffic System Management, Traffic Demand Management, Tokyo 2020 Olympic games

## 1. INTRODUCTION

### 1.1 Background

Tokyo 2020 Summer Olympics was held from 23rd July to 8th August 2021 in Tokyo, Japan. In Tokyo, the traffic volume is usually high from July to

early September, and during the Olympic games it would further increase due to the increased volume of the Olympic-related vehicles. It was expected that without any measures, expressway congestion would be about twice as high as the situation in 2019, and localized congestion will occur around the venues and on neighboring routes (Tokyo 2020 Traffic and Transport Technical Consideration Meeting, 2019). Furthermore, as the number of distribution vehicles and general vehicles is also expected to increase, it is essential to implement comprehensive traffic management measures in order to achieve both safe and smooth transportation for the Olympic games, and stable urban activities including logistics.

In order to alleviate the traffic congestion during games time, Tokyo Metropolitan Government promoted the traffic management that composed of Transportation Demand Management (TDM), Traffic System Management (TSM) and Public Transport Management, and Toll Rate Setting on Metropolitan Expressway etc. (Tokyo Metropolitan Government, 2022), where the TSM duration for the Tokyo 2020 Olympics was from 19<sup>th</sup> July, 2021 to 9<sup>th</sup> August, 2021.

## 1.2 Traffic System Management (TSM)

Traffic system management (TSM) refers to the initiatives to maintain smooth traffic flow (mainly during peak hours) and alleviate the temporal and spatial concentration of traffic demand according to the road situation, even overall traffic volume has been reduced by TDM (Bureau of Olympic and Paralympic Games Tokyo 2020 Preparation, 2019). With that purpose, TSM measures are applied dynamically on expressways and general roads based on the conditions of regular and irregular times.

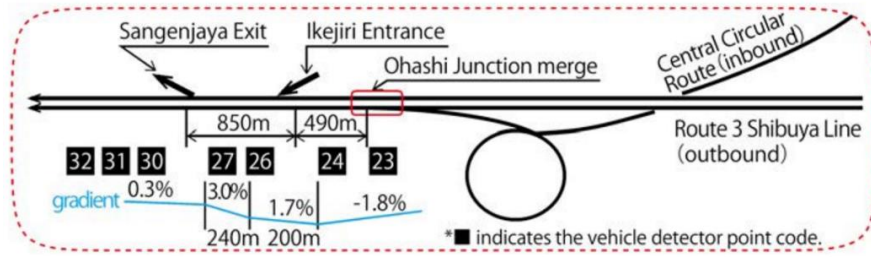
In this study, we aim to propose methodologies to estimate the total delay with hypothetical traffic demand, and to separate the effects of TSM and TDM

separately based on the vehicle detector data. The data used in this study was provided by Tokyo Metropolitan Government including various types of transport and traffic related data during the Tokyo 2020 Olympic games.

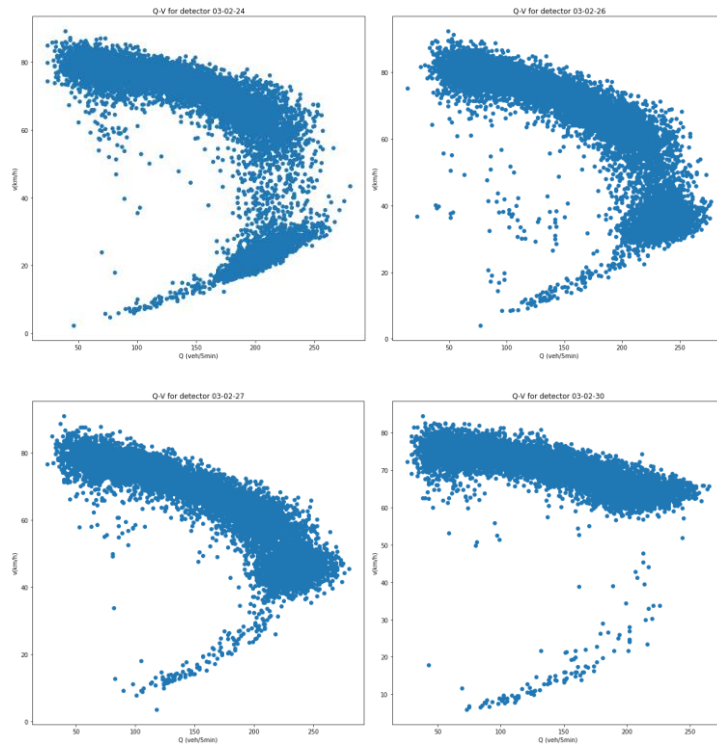
## 2. STUDY AREA

Bottlenecks are defined as locations where the capacity provided is insufficient to meet the demand over a given period of time (Wada et al., 2020). When flow breakdown occurs at one bottleneck section, congestion forms at the upstream section, and reduction of vehicle speeds can be observed; meanwhile, vehicles at the downstream section remain uncongested flow conditions.

In this study, one representative bottleneck on Route 3 Shibuya Line Outbound was selected for detailed analyses. Fig. 1 shows the schematic diagram of the bottleneck (Yamaguchi et al., 2016). Fundamental diagram  $Q$ - $v$  relationships were utilized for determining the bottleneck location. The  $Q$ - $v$  fundamental diagrams for detectors 24, 26, 27 and 30 were plotted in Fig. 2. It can be observed that large amount of points is concentrated in the congestion region for detector 24 (section number 9), in the transition region for detectors 26 and 27 (section number 10), but free flow region for detector 30 (section number 11). Therefore, we can conclude that bottleneck locations between Ikejiri Entrance and Sangenjaya Exit, and this bottleneck was chosen for further analyses.



**Fig. 1** bottleneck location of Route 3 Shibuya line outbound  
(Yamaguchi et al., 2016)



**Fig. 2**  $Q$ - $v$  fundamental diagrams for detectors 24, 26, 27 and 30

### 3. METHODOLOGY

#### 3.1 Total Delay calculation

In order to calculate total delay, in this study, we assumed that the uncongested speed is 60 km/h; and if the vehicle travel speed is greater than 60 km/h, we assumed no delay occurs. In addition, we assumed congestion occurs if the vehicle travel speed is less than 40 km/h (MEX company Limited, 2021). An example time-space

diagram for vehicles arriving at the bottleneck section is shown in Fig. 3.

From the section detector data, we can obtain the information including traffic volume  $Q_{ij}$ , average section speed  $v_{ij}$ , and ‘Congestion Level’. Then, the ‘Standard Travel Time’  $T_{stij}$  is obtained by dividing the section length  $L_j$  by the uncongested speed of 60 km/h; and the ‘Real Travel Time’  $T_{rij}$  is obtained by dividing the section length  $L_j$  by the average section speed  $v_{ij}$ .

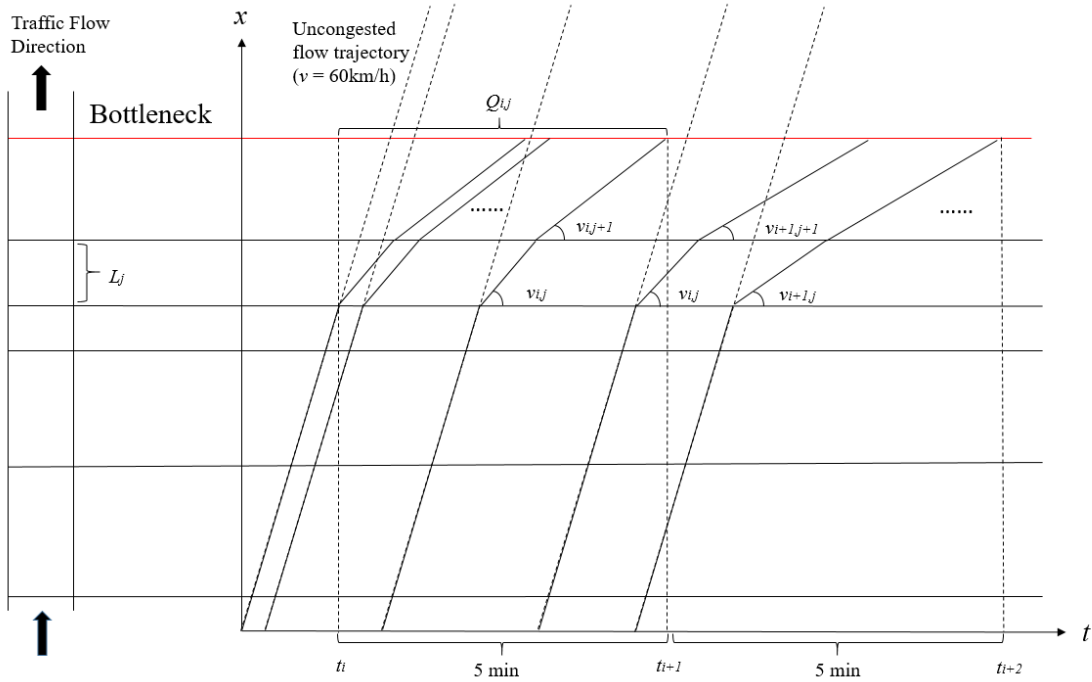


Fig. 3 Time-space diagram for delay calculation

In addition, the congestion events were determined according to the following rules:

- Data whose ‘Congestion Level’ is ‘congested(R)’ or ‘mid-congested(Y)’.
- Data whose average section speed  $v_{ij}$  smaller than the congestion speed (i.e., 40 km/h) (even if its ‘Congestion Level’ is ‘uncongested flow (G)’).
- Duration of one congestion event should be at least 20 minutes.

Therefore, the total delay for one specific bottleneck during one congestion event can be calculated by the following Eq. (1):

$$\begin{aligned}
 & \text{Total Delay (TD)} \\
 & = \max\left(\sum_j \sum_i \left(\frac{L_j}{60} - \frac{L_j}{v_{ij}}\right) \times Q_{ij}, 0\right) \quad (1)
 \end{aligned}$$

$$= \max\left(\sum_j \sum_i (T_{rij} - T_{stij}) \times Q_{ij}, 0\right)$$

where:

$L_j$ : Length of the  $j^{\text{th}}$  section

$t_i$ :  $i^{\text{th}}$  5 min time point

$v_{ij}$ : 5-min average sectional speed of the  $j^{\text{th}}$  section during time interval  $[i, i+1)$

$Q_{ij}$ : 5-min traffic volume of the  $j^{\text{th}}$  section during time interval  $[i, i+1)$

$T_{stij}$ : Standard Travel Time of the  $j^{\text{th}}$  section during time interval  $[i, i+1)$

$T_{rij}$ : Real Travel Time of the  $j^{\text{th}}$  section during time interval  $[i, i+1)$

### 3.2 Traffic demand estimation

Traffic congestion occurs when traffic demand exceeds the bottleneck capacity. During uncongested flow period, traffic demand can be estimated using the traffic volume ( $Q$ ) information obtained from the detector data at bottleneck sections. However, when the bottleneck is activated, it is difficult to estimate traffic demand by traffic volume ( $Q$ ). Therefore, in this study, we approximated the traffic demand for bottleneck sections using the slope of imaginary cumulative arrive curves, as shown in Fig. 4. In Fig. 4, bottleneck is assumed at the downstream end. We can generate 'imaginary' arrival curve of the upstream section according to the method retrieved from the study by Otaka et al. (2004):

- a) Plot the departure curve  $D$  by using the traffic volume  $Q$  at the bottleneck.
- b) Measure the travel time  $T'_k$  between the upstream end and the downstream end bottleneck. Here, the travel time  $T'_k$  is equivalent to the 'Real Travel Time'  $T_r$  described in the previous subsection.
- c) Select one point  $D_k$  on  $D$ , horizontally shift it to the left (past) by  $T'_k$ , and obtain the point  $A'_k$  on the 'imaginary' arrival curve.
- d) Repeat steps b) and c) for all points on  $D$ , then the 'imaginary' arrival curve  $A'$  can be derived and the slope of it is estimated as the traffic demand for the bottleneck.

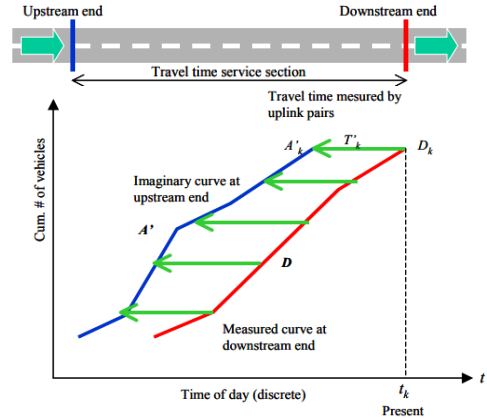


Fig. 4 Demand estimation using arrival curves  
(Otaka et al., 2004)

### 3.3 Separation of TDM and TSM effects

During Olympic period, traffic management (TM) measures, including both TDM and TSM, were implemented on the MEX network. Therefore, it is essential to separate the effects of TSM and TDM, after estimating the total delay and traffic demand reductions from the empirical data. However, TSM measures were dynamically applied according to the traffic conditions, as explained previously. The effects of TSM can only be estimated during its implementation days.

The on-ramp traffic volumes at Ikejiri entrance of the Route 3 outbound for the 1<sup>st</sup> week TSM implementation period were shown in Fig. 5. In Fig. 5, three cases of on-ramp traffic volumes were plotted including: 'without TM', 'only with TDM', and 'with TSM and TDM'. In this paper, we assumed that TSM only has the effect of onramp closure for the selected bottlenecks. From the detector data, we can obtain the onramp demands of cases 'without TM' and 'with TSM and TDM'. Then the days without the application of TSM during the Olympics periods were identified. The average onramp traffic demands were approximated as the onramp demand pattern

for ‘only with TDM’ case. Hence, the effect of the TSM on the traffic demands can be determined by the difference of the onramp traffic volumes for the cases ‘only with TDM’, and ‘with TSM and TDM’. In addition, the cumulative arrival and departure curve examples for the same three cases were plotted in Fig. 6. The area between the

cumulative arrival and departure curves for each case represents the total delay. The effect of the TSM on the total delays can be obtained by the area differences for the cases ‘only with TDM’, and ‘with TSM and TDM’.

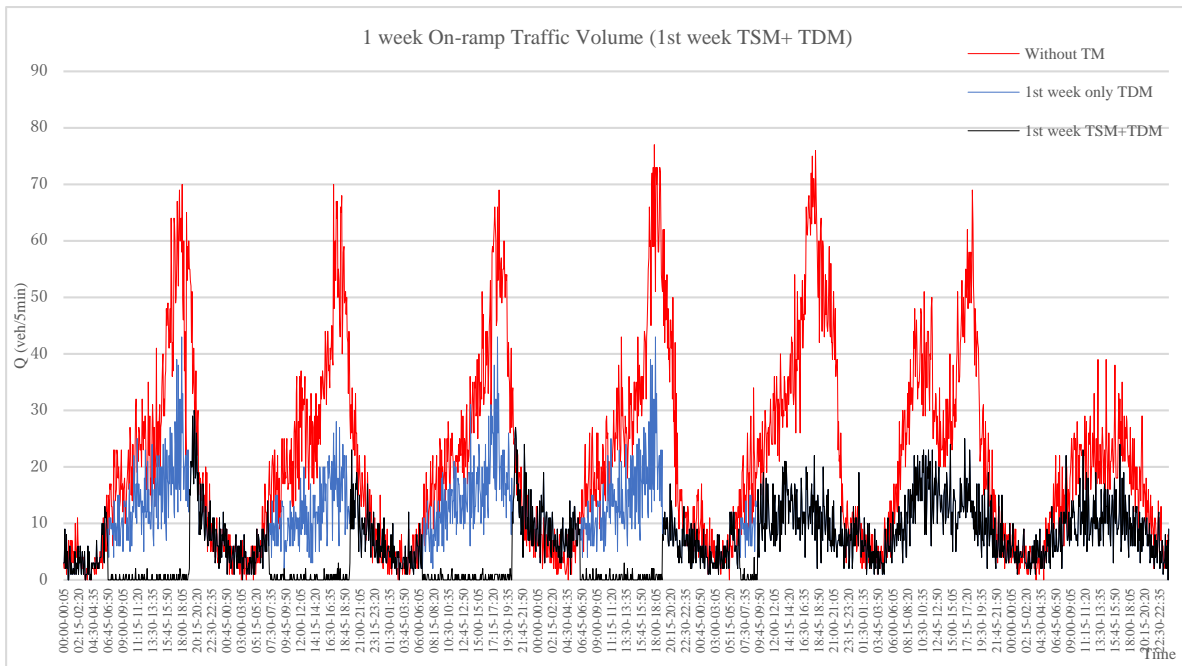


Fig. 5 On-ramp Traffic Volumes at Ikejiri entrance of the Route 3 outbound (1<sup>st</sup> week TSM)

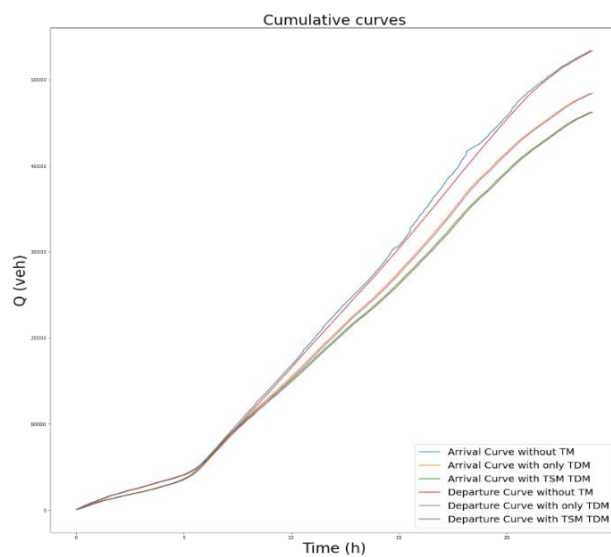


Fig. 6 Cumulative Arrival and Departure Curves under different TM measures

## 4. RESULTS AND DISCUSSIONS

### 4.1 Results

According to the methodologies described in the previous section, the results for traffic demands and total delays for 2020 and 2021 were shown in Fig. 7. In the figure, bar charts were applied for the total delay values, and line charts were utilized for the traffic demand values. Moreover, average values were taken for weekdays, and Sat. Sun. and holidays during 3 periods: TM period, just before TM period in 2021, and in 2020. The details are provided in Table 1. The reduction percentages were also obtained compared to the periods in 2021 before TM, and in 2020.

In addition, we applied the proposed methodologies to estimate the effects of TSM at Route 3 outbound. The results for the traffic demand reductions were obtained in Table 2. Furthermore, average values were taken for weekdays, and Sat. Sun. and holidays for 3 cases: ‘without TM’, ‘only with TDM’, and ‘with TSM and TDM’. The details are provided in Fig. 8 and 9. Last but not least, Table 3 gives the result for the reduction effects of TDM ( $\Delta_{od}$ ) and TSM ( $\Delta_{ds}$ ) on the total delays.

### 4.2 Discussions

From Table 1, we can observe that during TM period, the total delay reductions were more significant compared to the traffic demand reductions. The total delay reductions for Sat. Sun. and Holidays during the TM period before were about 97% in 2021 before TM, and 93 % in 2020. For weekdays, the total delay reductions for the two cases were about 87%. At the same time, the total demand reductions for Sat. Sun. and Holidays during the TM period were about 23% and 16%, respectively. For weekdays, the total demand reductions were roughly 8% and 10 %, respectively.

On the other hand, the effect of TSM for reducing onramp traffic demands compared to without TM for Sat., Sun. and holidays were about 18%, and for weekdays were about 27%. This reduction will further contribute to the total delay reductions at merging bottlenecks. Meanwhile, the effect of TSM for reducing total traffic demands for Sat., Sun. and holidays were approximately 2%, and for weekdays were about 3%. This is due to the assumption that only onramp closures were considered as TSM measures.

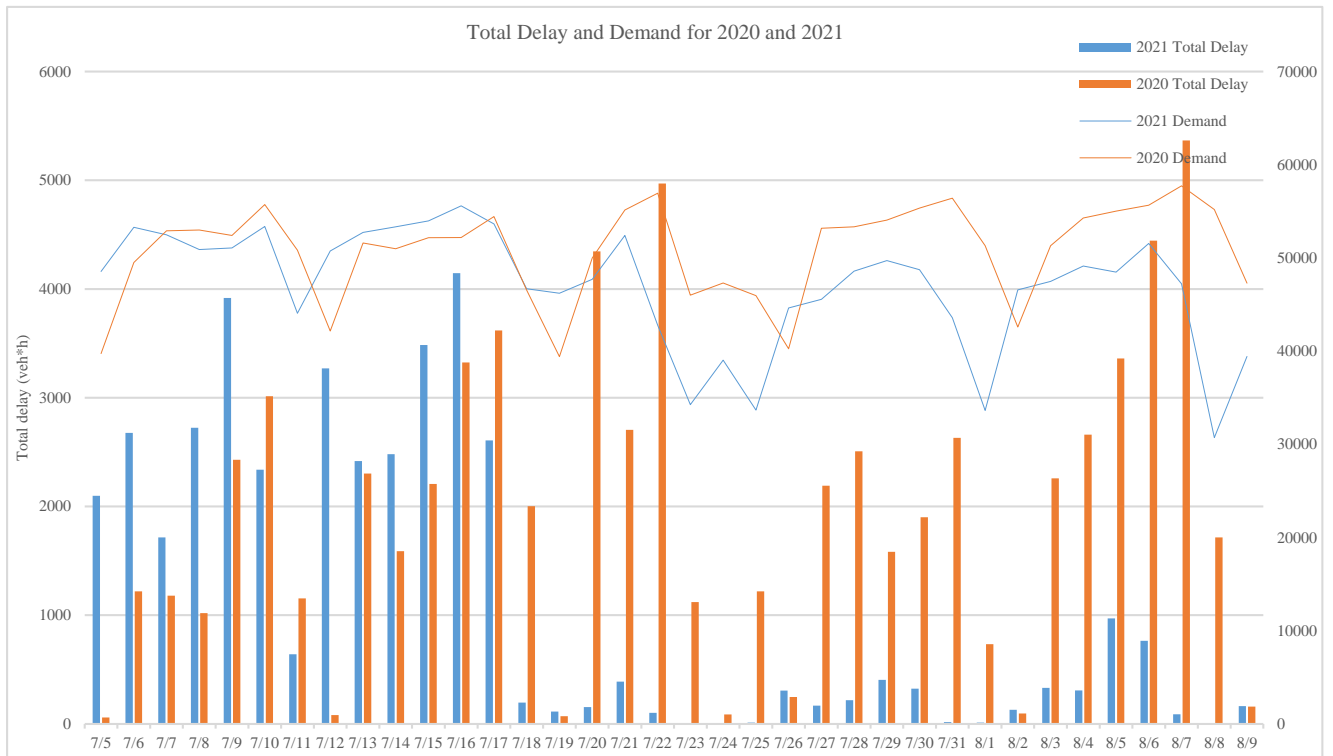


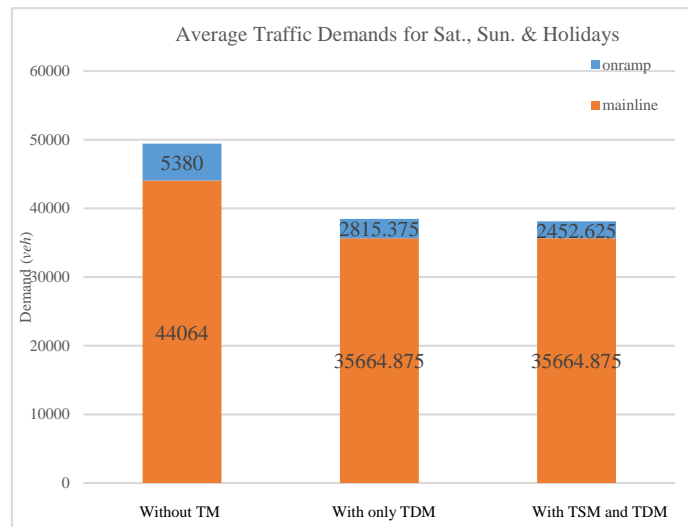
Fig. 7 Total Delay and Traffic Demand Results for 2020 and 2021

Table 1 Results for Traffic Demand, Total Delay and TM Reductions

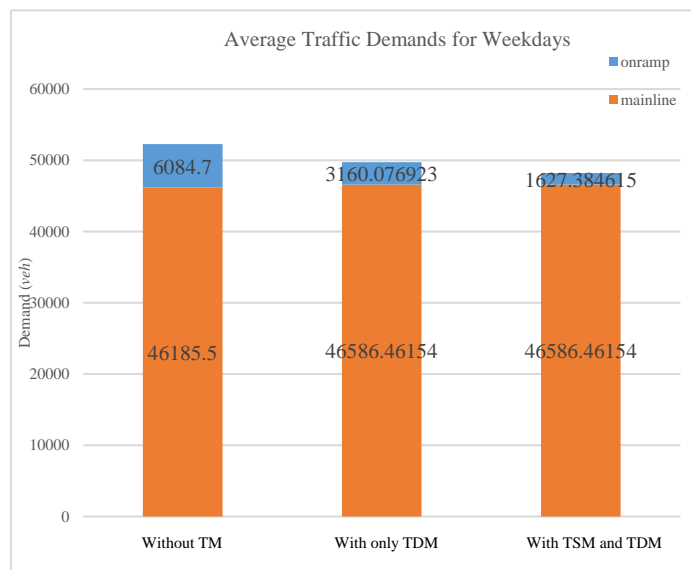
Traffic Demand	Day Type	TM period (veh)	2021 before TM (veh)	2020 (veh)	TM reductions compared to 2021 before TM (%)	TM reductions compared to 2020 (%)
	Sat., Sun. Holiday Ave.	38262.22	49444	45738.31	22.62	16.35
	Weekdays Ave.	48213.85	52270.2	53628.39	7.76	10.10
Total Delay	Day Type	TM period (veh*h)	2021 before TM (veh*h)	2020 (veh*h)	TM reductions compared to 2021 before TM (%)	TM reductions compared to 2020 (%)
	Sat., Sun. Holiday Ave.	44.96	1445.14	672.76	96.89	93.32
	Weekdays Ave.	352.25	2892.99	2731.69	87.82	87.11

**Table 2** Results for Traffic Demand and TSM Reductions

Demand type	Day type	Without TM (veh)	With only TDM (veh)	With TSM and TDM (veh)	TSM reductions compared to without TM (veh)	TSM reductions compared to without TM (%)
Onramp Demand	Sat., Sun. Holiday Ave.	5380.00	2815.38	2452.63	967.33	17.98
	Weekdays Ave.	6084.70	3160.08	1627.38	1660.42	27.28
Total Demand	Sat., Sun. Holiday Ave.	49444.00	38480.25	38262.22	967.33	1.96
	Weekdays Ave.	52270.20	49746.54	48213.85	1660.42	3.18



**Fig. 8** Average Traffic Demand for Sat., Sun. & Holidays



**Fig. 9** Average Traffic Demand for Weekdays

## 5. CONCLUSIONS

In this paper, we proposed methodologies to estimate the total delay with hypothetical traffic demand, and to separate the effects of TSM and TDM separately based on the vehicle detector data. We applied the methodologies at Route 3 outbound on the MEX network as a case study, and compared the periods during the Tokyo 2020 Olympic games and before the Olympic games.

Our analysis revealed that during TM period, due to the combined effect of TSM and TDM, the total delays were notably reduced for the selected bottleneck; even if no substantial decrease has been observed in the traffic demands. Additionally, we separated the effects of TSM and TDM, and found that the implementations of TSM were efficient for reducing onramp traffic demands, which will further contribute to the total delay reductions at merging bottlenecks.

In this research, only an example bottleneck was selected as a case study, and the relationship between the TSM durations and traffic demands was not investigated in details. Future research directions are to conduct more quantitative analyses, as well as perform network-wide evaluation of TSM. In addition, the day-by-day traffic dynamics during Olympics period will be investigated. Also, improvements for the TSM strategies will be proposed for future events.

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