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REAL TIME INFORMATION PROVISION BENEFIT MEASURED BY MACROSCOPIC FUNDAMENTAL DIAGRAM

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ABSTRACT

The existence of Macroscopic Fundamental Diagram (MFD), which relates space-mean density and flow, has been shown in urban networks under homogeneous traffic conditions. Since MFD represents the area-wide network traffic performances, studies on perimeter control strategies and an area traffic state estimation utilizing the MFD concept has been reported.

One of the key requirements for well-defined MFD is the homogeneity of the area-wide traffic condition with links of similar properties, which is not universally expected in real world. For the practical application of the MFD concept, several researchers have identified the influencing factors for network homogeneity. However, they did not explicitly take the impact of drivers' behaviour and information provision into account, which has a significant impact on simulation outputs.

This research aims to demonstrate the effect of dynamic information provision on network performance by employing the MFD as a measurement. A microscopic simulation, AIMSUN, is chosen as an experiment platform. By changing the ratio of en-route informed drivers and pre-trip informed drivers different scenarios are simulated in order to investigate how drivers' adaptation to the traffic congestion influences the network performance with respect to the MFD shape as well as other indicators, such as total travel time. This study confirmed the impact of information provision on the MFD shape, and addressed the usefulness of the MFD for measuring the dynamic information provision benefit.

Keywords: Macroscopic Fundamental Diagram, pre-trip information, en-route information, microscopic simulation, route choice

INTRODUCTION

The Macroscopic Fundamental Diagram (MFD) relates an aggregated mean density and flow of an area. Similarly to the conventional link-based fundamental diagram, the MFD represents area traffic states by defining the traffic throughput of an area at given density levels, and therefore can be used for the assessment of area traffic states. The idea of the MFD was first introduced by Godfrey (Godfrey, 1969), and its existence was verified in Geroliminis (2007) and Geroliminis and Daganzo (2008). The MFD was defined as the relationship between area 'production', the weighted average of flow of all links, and 'accumulation', the weighted average of density. The analysis results, from a microscopic simulation of San Francisco Business District (SFBD) and a field observation in downtown Yokohama, showed that well-defined MFD exists for homogeneously congested areas, while conventional flow-density relationships for individual links displayed highly scattered plots. Since such a crisp shape MFD represents the area-wide network traffic performances, studies on perimeter control strategies and an area traffic state estimation utilizing the MFD concept has been reported (Yoshii et al., 2010, Knoop et al., 2012, Horiguchi et al., 2010, Geroliminis, 2007, Daganzo, 2007).

The underlying assumption in these previous researches has been the homogeneity of the area-wide traffic condition with links of similar properties, which is not universally expected in the real world. Buisson and Ladier (2009) further investigated the MFD shape in heterogeneous environments. Based on the analyses, carried out using the real data set from a medium-sized city network in France, they figured out that network types and unusual events such as incidents have a strong impact on MFD shapes. In order to further clarify the necessary condition for well-defined MFD, Mazloumian et al. (2010) and Geroliminis and Sun (2011) have identified that the spatial distribution of link densities is the key factor for defining the MFD shape. The findings suggest that MFD can be applied for unevenly congested network if the network can be partitioned in homogeneous zones. Based on these finding, Ji and Geroliminis (2011) investigated the methodology of the network partitioning into compact shape zones, where well-defined MFD was expected and perimeter control can be applied based on the MFD concept.

These previous works have set remarkable milestones for practical applications of MFD. However, the analyses have been limited to a particular traffic condition, and the impact of other factors such as information provisions and drivers' behaviour has not been investigated. The impact of drivers' route choice on network performance under real-time information provision has been explored for decades (Emmerink et al., 1995, Mahmassani and Chen, 1991, Peeta et al., 2000, Sinuany-Stern et al., 1997, Stern et al., 1996). They confirmed that 1) pre-trip information and en-route information have a potential of improving network performance, and 2) identified the optimal market penetration rate in particular network settings based on some network performance measurements such as average travel time and total travel time. MFD also represents the network wide traffic performance, and therefore, the MFD shapes can be affected by different information types and/or drivers' route choice behaviours. Since most studies on MFD have been conducted in simulation environments, where drivers' route choice model plays a crucial role, it is worthwhile to investigate the impact of such a factor on MFD shapes.

This research aims to demonstrate the impact of dynamic traffic information on network performance by employing the MFD as a measurement. The work will contribute to 1) demonstrating the dynamic information provision benefit using the MFD and how it is related to the conventional indicators, and 2) highlighting the impact of route choice parameter settings in the MFD research. A microscopic simulation, AIMSUN, is selected as an experiment platform, where two types of drivers are introduced, en-route informed drivers and pre-trip informed drivers. En-route informed drivers, who are considered as equipped vehicle's drivers, can choose the best routes every update interval based on a route choice principle. Pre-trip informed drivers, who decide the best routes according to the information at the departure, never change the routes on the way. By changing the ratio of these drivers and route choice parameters, different scenarios are simulated in order to investigate how drivers' adaptation to the traffic congestion influences the network performance and how it appears in the MFD shape.

ROUTE CHOICE MODEL AND INFORMATION TYPES

The Route Choice Model

This study employs AIMSUN microscopic simulation model. AIMSUN is embedded with several different route choice models (Transport Simulation Systems). Logit type models are among the most popular route choice models. Based on discrete choice theory, Logit models assign a probability to each alternative path between each origin-destination. A well-known drawback of them is of an Independence of Irrelevant Alternatives (IIA), which refers to the inability of Logit function to distinguish between highly overlapping routes. In order to overcome this IIA problem, AIMSUN employs C-Logit model (Barceló and Casas, 2004), which is able to take the network topology into account and allows for alternative routes with little overlapping by introducing an index for the degree of overlapping in the utility term. The choice probability P_k of each alternative path k belonging to the available path set I is formulated as:

$$\boldsymbol{P_k = \frac{e^{\theta(V_k - CF_k)}}{\sum_{l \in I} e^{\theta(V_l - CF_l)}}} \tag{1}$$

Where V_i is the perceived utility for alternative path i, which is equal to the minus of the travel time of path i measured in hours. θ is the scale factor, which determines the drivers' sensitivity to the travel time difference among alternative paths. The term CF_k is denoted as 'commonality factor (CF)' of path k, which is proportional to the degree of overlapping of path k with other alternative paths. Thus, highly overlapped paths have a larger CF factor and therefore smaller utility with respect to similar paths. CF_k is calculated as follows:

$$\boldsymbol{CF_k = \beta \cdot ln \sum_{l \in I} \left(\frac{L_{lk}}{L_l^{1/2} L_k^{1/2}} \right)^{\gamma}} \tag{2}$$

Where L_{lk} is the length of sections shared by paths l and k, while L_i and L_k are the length of paths l and k respectively. Depending on the two factor parameters β and γ, the 'commonality factor' is weighted. Larger β means that the overlapping factor has greater importance with respect to the utility V_i; γ is a positive parameter, whose influence is smaller than β and which has the opposite effect; the smaller γ is, the more significant the overlapping factor is.

Pre-Trip Information and En-Route Information

In order to investigate the effect of drivers' adaptation to congestion, we introduce two types of drivers with different information, pre-trip informed drivers and en-route informed drivers. Pre-trip informed drivers are able to obtain the traffic information only at the network entrance and choose their routes based on the information at their departures. Once they leave the origin centroid, their routes are fixed and never be changed while their journey. En-route informed drivers are considered as equipped vehicle's drivers and capable to receive the latest traffic information every update interval i.e. 5 minutes, and search the preferred routes adaptively once the new information is available. By changing these drivers' ratio, the impact of drivers' adaptivity to congestion is investigated. In this study, en-route informed drivers' ratio = 0, 20, 40, 60, 80 and 100% are tested i.e. If the ratio is 80%, then 80% of the vehicles are dynamically informed and change their routes adaptively, and the remaining 20% are set as pre-trip informed drivers, whose routes are determined and fixed at their departures.

IMPACT OF DYNAMIC INFORMATION PROVISION

The Test Network

The test network imitates a Manhattan type network, which consists of 20 x 20 regular grids with entrance/exit links as shown in Figure 1. All intersections are signalised with the same setting, i.e. 90 seconds cycle with 0.5 green split. The network has two different geometries, an inner area and an outer area. The outer area consists of 3 lane links, whereas the inner area links are given 2 lanes in order to represent a CBD district with less capacity.

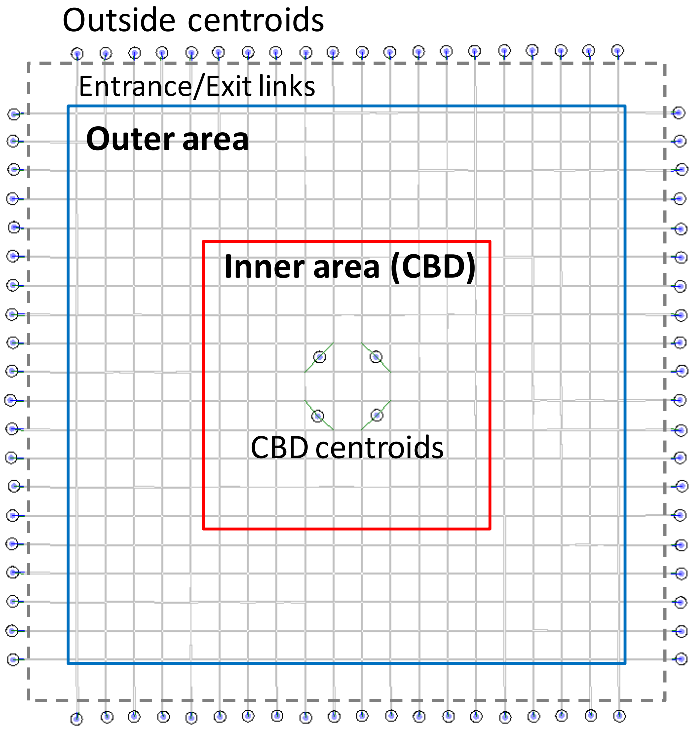

Figure 1 Test Network

Simulation Settings

Centroids, shown as blue dots in Figure 1, are set at entrance/exit links and the CBD area. All demand is coming from the outside. Figure 2 illustrates the demand profile generated from each origin centroid. Vehicles are loaded for 3 hours. In the beginning, each origin generates 400 veh/hour/origin in total, 75% of which coming into the CBD centroids and 25% going across the network to the opposite side. The demand increases during the first one hour up to 800 veh/hour/origin, and decreases after two hours time. The demand is determined so as not to have virtual queue outside of the network i.e. there is almost no waiting vehicle in entrance links. After 3 hours time, the simulation keep running without additional demand input in order to empty the network and to make sure all vehicles have finished their trips.

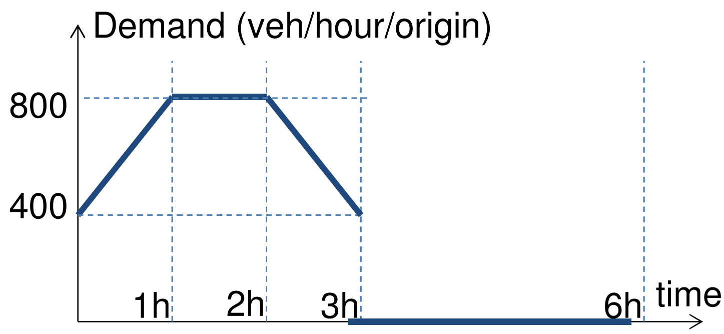

Figure 2 Demand Profile

With regard to the route choice parameters, this analysis selects the AIMSUN default setting, the scale factor $\theta = 100$, where most drivers choose the shorter route if the travel time difference is greater than 3 minutes, and $\gamma = 1$. Preferred β value is between minimum and maximum travel time of the paths measured in hours (Transport Simulation Systems). Considering the network size, $\beta = 0.5$ is selected in order to make sure that β is greater than the free flow travel time of all OD pairs.

The Macroscopic Fundamental Diagram

The simulation results are aggregated every 5 minutes. Simulation outputs include section flow and section density per lane. Then, area average flow q and density d are calculated according to the following definitions (Geroliminis and Daganzo, 2008) for every 5 minutes:

$$\boldsymbol{q} = \frac{\sum_i \boldsymbol{q}_i \boldsymbol{l}_i \boldsymbol{n}_i}{\sum_i \boldsymbol{l}_i \boldsymbol{n}_i} \tag{3}$$

$$\boldsymbol{d} = \frac{\sum_i \boldsymbol{d}_i \boldsymbol{l}_i \boldsymbol{n}_i}{\sum_i \boldsymbol{l}_i \boldsymbol{n}_i} \tag{4}$$

Where i denotes individual link i in the network. q_i is the average flow per lane of the link **i**, d_i is the traffic density per lane of link i, l_i is the length of link i and n_i is the number of lanes of link i. For drawing the MFD, only links in inner and outer area are considered, and the data from entrance and exit links is excluded. The MFD is obtained by taking scattered plot of the area average flow and the density.

Results of the MFD

Figure 3 shows the MFD for the first three hours (the demand loading period) from the whole network data with different ratios of en-route informed drivers. The diagrams show the maximum flow rate when the density is around 20-25 veh/km/lane regardless of the equipped vehicles' ratio, and then flow drop is observed in higher density regime.

The maximum flow is the lowest, 250 veh/h/lane, when every driver is only given the pre-trip information (0 % case), and the flow rate increases as the en-route informed drivers' ratio increases up to 40%. The maximum flow rate in 40% case is about 300 veh/h/lane, that is 20% improvement from the 0% case. When drivers can only access to the pre-trip information, their route choices are based on the traffic condition at their departure time, and the routes are fixed during their journey. Since the best option at the departure may no longer be the best when they actually use the routes, the pre-trip route choice can induce the demand concentration on some particular routes. On the other hand, the en-route information enables drivers to switch to better routes during the trip, which avoids the demand concentration and delays the onset of congestion. Therefore, the network is utilised better when the more drivers are dynamically informed, and the higher throughput is achieved.

Beyond 40% cases, no major improvement is found in terms of the maximum flow rate. However, when one looks at the congestion regime (density > 25%) in the diagrams, the flow rate drop is less significant for higher en-route informed ratio cases. The results suggest the effectiveness of information provision in avoiding the severe breakdown, and this effect is observable in MFD shapes.

These trends are observable from Figure 4, which summarises the maximum flow rate around the critical density (shaded area in Figure 3) for different adaptive drivers' ratio. As adaptive drivers increase, the more flow is achieved. However, no major improvement is found over 60%, rather 80% works slightly better than 100% case.

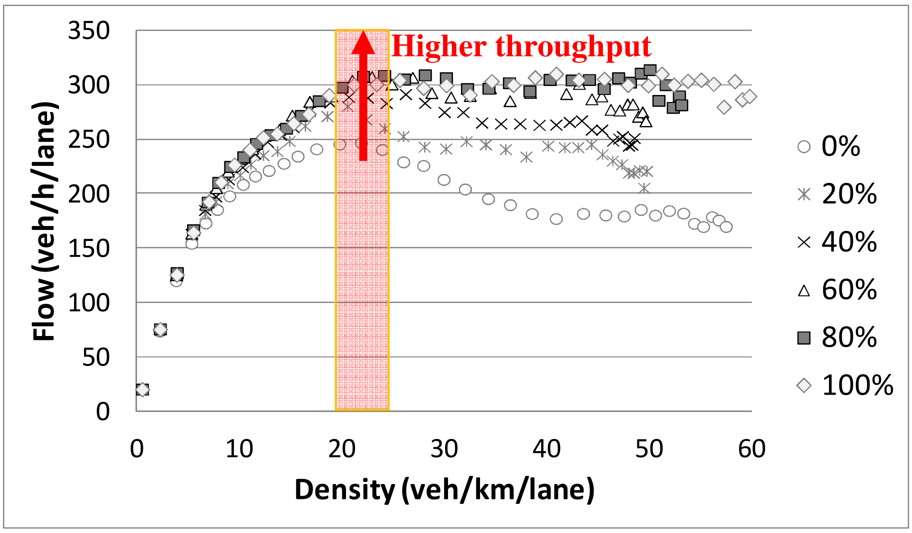

Figure 3 Whole Network MFD for Different En-Route Informed Drivers' Ratio (0, 20, 40, 60, 80 and 100%)

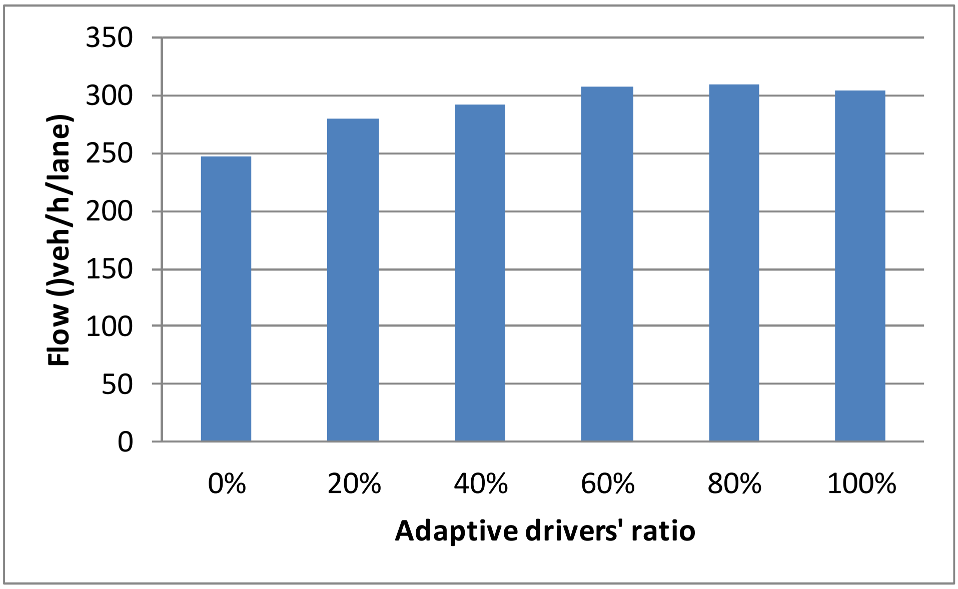

Figure 4 Maximum Flow Rate for Different En-Route Informed Drivers' Ratio (0, 20, 40, 60, 80 and 100%)

Comparison with the other indicators

Here, the system performance is measured from the different perspectives. Three indicators are introduced: Total travel time, total travel distance and average speed defined as below, respectively.

$$\boldsymbol{Total\ Travel\ Time} = \sum_{t}\sum_{i}\frac{\boldsymbol{l_i}}{\boldsymbol{v_i^t}}\boldsymbol{q_i^t n_i} \tag{5}$$

$$\boldsymbol{Total\ Travel\ Distance} = \sum_{t}\sum_{i}\boldsymbol{l_i q_i^t n_i} \tag{6}$$

$$\boldsymbol{Average\ Speed} = \frac{\boldsymbol{Total\ Trave\ Distance}}{\boldsymbol{Total\ Travel\ Time}} \tag{7}$$

Where v_i^t and q_i^t denote the average speed and flow per lane of link *i* during time step *t*, respectively.

Figure 5 compares the total travel time among different en-route informed drivers' ratio. It is calculated for whole simulation period (6 hours time) until every vehicle finishes the trip so that all the traffic's travel time is taken into account. The network performs better as the adaptive drivers increase up to 40%, whereas the graph shows the inverse trend over 60% cases. When there are too many drivers having access to dynamic information, they tend to keep switching their routes too much instead of reaching to the destinations, which causes non-optimum situation in terms of the system performance. In fact, the total travel distance calculated for the same period (Figure 6) shows monotonic increase as the adaptive drivers' ratio increases. These results suggest that drivers are experiencing longer travel distance as they get more adaptive to the congestion, which causes worse system performance in terms of the total travel time.

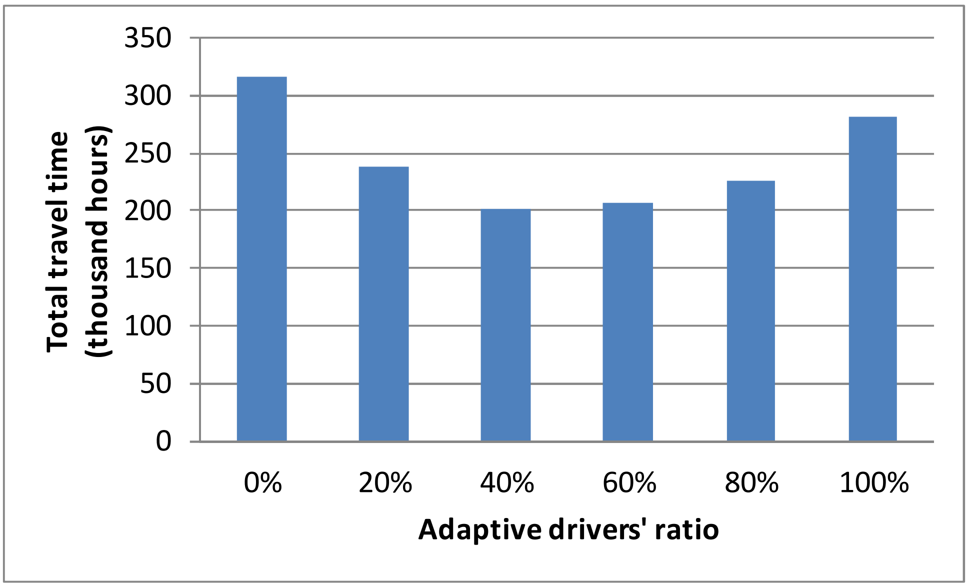

Figure 5 Total Travel Time for Different En-Route Informed Drivers' Ratio (0, 20, 40, 60, 80 and 100%)

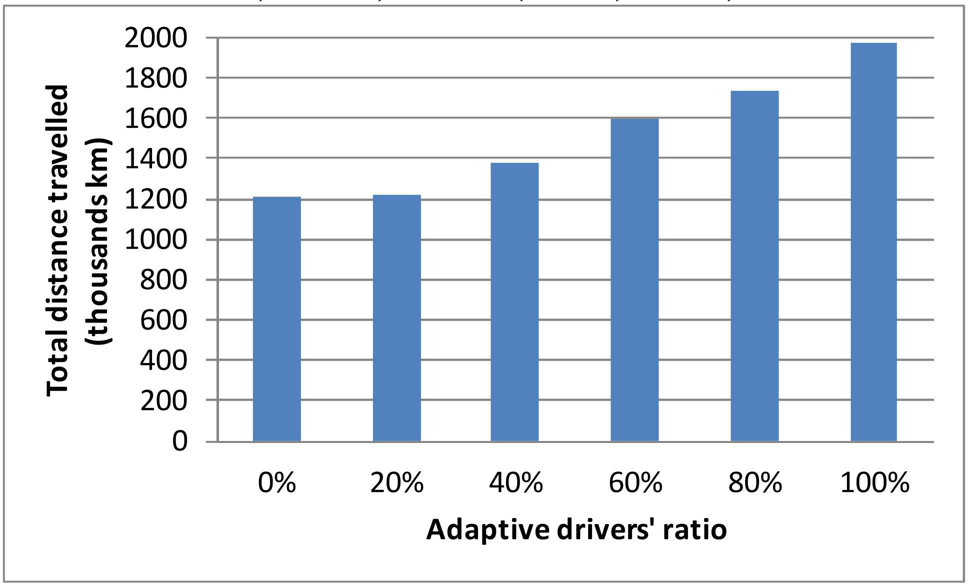

Figure 6 Total Travel Distance for Different En-Route Informed Drivers' Ratio (0, 20, 40, 60, 80 and 100%)

As in equation 7, the division of the total travel distance by the total travel time gives the average speed. Figure 7 shows the average speed comparison for different ratios of adaptive drivers. Figure 7 (a) compares the average speed during the loading period (the first three hours). The trend is consistent with the one of the total travel time, i.e., the better (higher) average speed is observed until the adaptive drivers' ratio reaches to 60%, and then the performance decreases for higher ratio cases.

However, when the system performs at its maximum throughput, that is, when the area density is around the critical (the shaded area in Figure 3), the average speed shows slightly different trend with the peak at 80% case (Figure 7 (b)), which agrees with the maximum flow rate comparison in Figure 4 measured from the MFD.

The MFD relates the area average density and the flow. As well known, the flow over the density is equivalent to the speed. Figure 4 compares the flow at the similar density level in the MFD, and therefore, is consistent with the average speed comparison in Figure 7 (b) calculated with equation 7. This confirms that the MFD captures the traffic congestion dynamics well and the result is not conflicting against the conventional indicator, the average speed around the critical density condition.

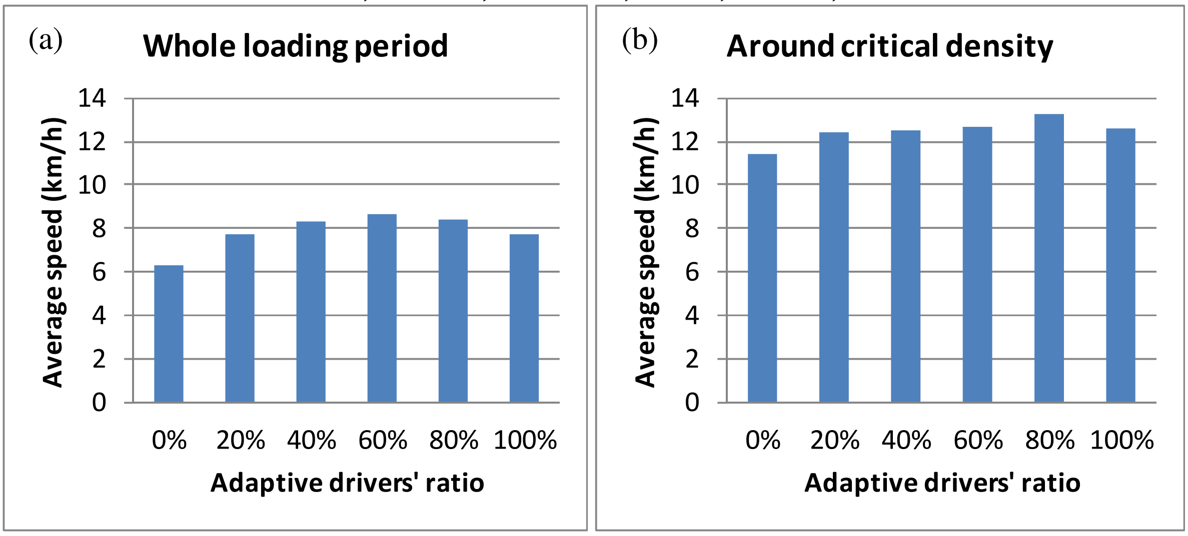

Figure 7 Average Speed for Different En-Route Informed Drivers' Ratio (0, 20, 40, 60, 80 and 100%) (a) during the loading period, (b) around the critical density

CONCLUSIONS

This research aims to analyse the impact of drivers' route choice behaviour on the network performance represented by the MFD and explored the relationships with other indicators. Two types of drivers with different information provisions are introduced. One is pre-trip informed drivers, who can choose their best routes only at the network entrance based on the traffic condition at their departure. The other is en-route informed drivers, who are informed of the latest traffic information every 5 minutes and are able to choose their best routes based on the updated information adaptively. The simulation analyses using a 20 x 20 grid network revealed the following:

1) The whole network MFD confirmed that drivers' route choice behaviour has an impact on network throughput. The more drivers are dynamically informed, the higher maximum throughput is observed in the whole network MFD.
2) The congestion regime of the whole network MFD shows the less drops and/or the recovery in the average flow as drivers become more adaptive to dynamic route choice. This result suggests that the traffic information has a potential to avoid a serious breakdown of system performance.
3) The MFD captures the dynamics of traffic congestion, whereas the conventional indicators, such as total travel time, evaluate the whole simulation period including different traffic conditions. Therefore, the trend from the MFD does not agree with the one from other indicators.
4) The average speed comparison during a particular period, when the system is performing at its maximum flow level, is consistent with the result from the MFD. This confirms the usefulness of the MFD for evaluating the information provision benefit in a targeted congestion regime.

Based on the above findings, the study confirmed that network performance is highly affected by the dynamic information provision and route choice behaviours as mentioned in earlier studies, and that the MFD is able to capture the impact of these factors for different traffic regimes. The information provision benefits identified here is not new. However, this work would contribute to giving a new perspective to this well-explored research area.

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