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A METHODOLOGY TO IDENTIFY TRAFFIC CONDITION USING INTELLIGENT PROBE VEHICLES

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ABSTRACT

The traffic conditions of the arterial routes in addition to the whole network are vital monitoring criteria for the traffic management center in order to efficiently guide and administer the traffic networks. The main objective of this work is to establish a general methodology to identify different traffic conditions in the traffic network using intelligent probe vehicles. For this purpose we utilized Internet Protocol probe cars (IPCar) in Yokohama and Nagoya cities. Yokohama and Nagoya IPCar projects use different type of vehicles consisting of taxis and buses.

INTRODUCTION

The main objective of this work is to establish a general methodology to identify the different traffic conditions in the network using intelligent probe vehicles. The traffic conditions of the arterial routes as well as the whole network are vital monitoring criteria for traffic management centers in order to efficiently guide and administer the traffic networks. There have been large ranges of traffic monitoring equipments being utilized to observe traffic situation. Several intelligent vehicle-highway system demonstration projects are currently assessing the feasibility of using probe vehicles to collect real-time traffic data for advanced traffic management and information systems. However, most of the developed probe algorithm might be suffered from the cost of data transmission due to the richness of the probe information or the high frequency of data acquisition. There could be some efficient strategies to minimize the transmission cost if one be able to identify traffic conditions such as ‘congested’ or ‘free-flow’ from the time-space trajectory of probe vehicles. For instance, we may select only the ‘congested’ record to be transmitted from a probe vehicle to the data center, when one is interested to observe the traffic congestion conditions.

The aim of this project is to explore feasible real time application of Internet Protocol probe cars (IPCar) date either as a stand alone data source or with other data sources such as detector counts and automatic vehicle identification (AVI) travel time. The initial focus of this work is to establish a general methodology to identify the different traffic conditions in the traffic network using intelligent probe vehicles and would later extend it to provide other information such as traffic volume and consequently emission level. Traffic conditions heritably have dynamic nature. Therefore, this study utilized the extended arterial routes and links in order to capture traffic condition alterations and more specifically shockwave generations and dispersions under different traffic conditions. For this purpose sets of data capturing a wide range of information were collected using IPCars in Yokohama and Nagoya cities. A sophisticated and innovative method has been developed and employed to cleanse the IPCar data and searches for trip ends. Then this data is used together with the shape of vehicles trajectories to classify and distinguish different traffic condition patterns.

IPCAR SYSTEM

The Yokohama IPCar project uses 179 vehicles consisting of 140 taxis and 39 buses. The experiment ran for 11 days in December 2001 while the Nagoya IPCar consisting of 47 taxis ran for two days. The IPCar system is equipped with a GPS and a data logger. GPS collects position data at regular intervals. However, the IPCar system does not store the vehicle position at regular intervals. Instead it logs the state of events as either short stop (SS) or short trip (ST) (see Figure 1). The definition of a short stop is when the vehicle speed drops below 3 km/h. When the vehicle speed increases above 3 km/h, the event is considered as a short trip. In other words, instead of a time based data logging, the equipment is an event based data logging. So every time the event changes from SS to ST and vice versa, the GPS position and time stamp are recorded plus the event flag (eg. SS or ST). This approach reduces the amount of data stored and therefore less data transmission, without sacrificing the quality of the data (Horiguchi, 2002). Note that there is a maximum time limit of 30 seconds for a ST event in case of Yokohama IPCar and a maximum distance of 300 meters in case of Nagoya IPCar. Therefore, if a probe vehicle is moving for 2 minutes, four consecutive ST events will be recorded. However, there is no time limit for SS event. These event records are temporary buffered in the on-board equipment and transmitted by the polling request from the IPCar data centre. The interval of transmission is normally 1-5 minutes. In addition, the IPCar system records other parallel events information such as the status of the left and right blinkers, the hazard light and the parking brake (see Figure 1).

There are instances where data are not recorded ie. contains gaps. This could be due to communication or GPS errors. GPS errors might occur when a probe vehicle passes under an infrastructure such as tunnel, or when in the vicinity of elevated structures, the so called "urban canyon". Gap could also occur when the engine is switched off because no data will be recorded.

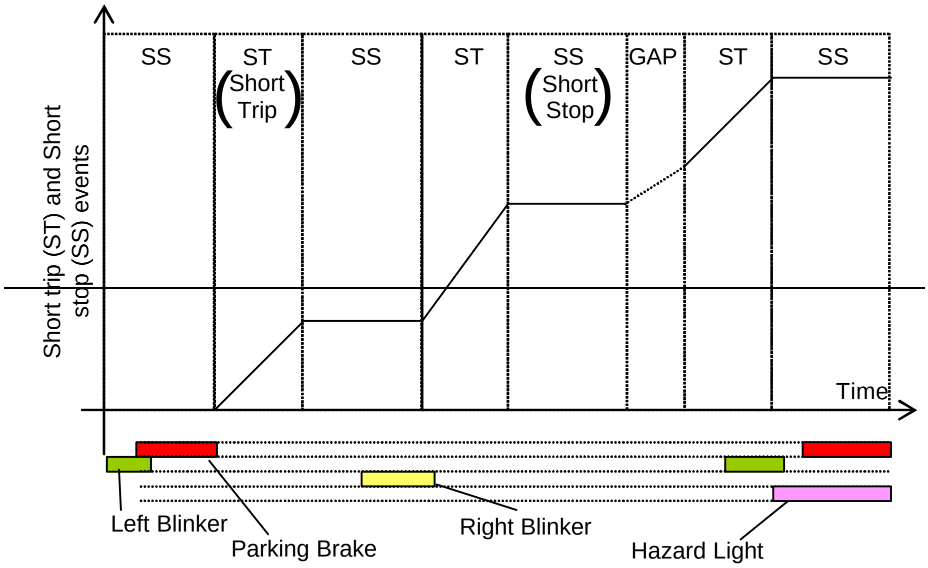


Figure 1 Data collected by the IP Car system

DATA CLEANSING

Before the probe data can be employed to distinguish traffic patterns, the data needs to be cleansed because probe data is a continuous trajectory (see Figure 2) and also there are gaps in the data. Therefore, the data cleansing process for the OD analysis is to cut the "continuous" trajectories into trip ends by detecting the following events.

- Gap with parking brake event,
- Long gap,
- Gap with unrealistic speed,
- Long stop,
- Short stop with hazard light, and
- U-turn.

The data cleansing process starts by considering gaps in the data in step 1 to step 3. It then searches for stops which are trip ends in steps 4 to 6. Details of each step are explained in reference 2.

Figure 2 Continuous trajectory of one probe vehicle including gaps

EVENT ANALYSIS

General Concept

As discussed in preceding sections, the outcome of the data cleansing for each IPCar is a series of origin to destination trip which could happen during free or alternatively congested flow. On the other hand each trip itself consists of a sequence of ST and SS. Therefore, it would be very valuable to investigate the sequence of these ST and SS, in order to distinguish different patterns of these sequences under diverse traffic conditions.

A typical trajectory of an IPCar trip which consists of several sequences of ST and SS is demonstrated in Figure 3. It shows that for instance, a long ST with relatively high speed might follow by a short SS which is in a magnitude of a red time at a typical intersection. Conversely, a long SS follow by a short ST could be a representative of proceed of an IPCar in the congested flow. However, merely considering the speed of ST may lead to unrealistic interpretation of traffic flow condition due to the fact that the average observed speed in urban area is less than 60km/hr. Therefore, the following three characteristics are selected in order to more accurately distinguish different traffic regimes.

1. ST duration in second
2. SS duration in second
3. Adjusted speed (Average speed over the period of one sequence of ST and SS).

This average speed is calculated by dividing the distance during a ST to the total time passed during that ST and its subsequent SS as it is demonstrated in Figure 3 by blue and pink arrows.

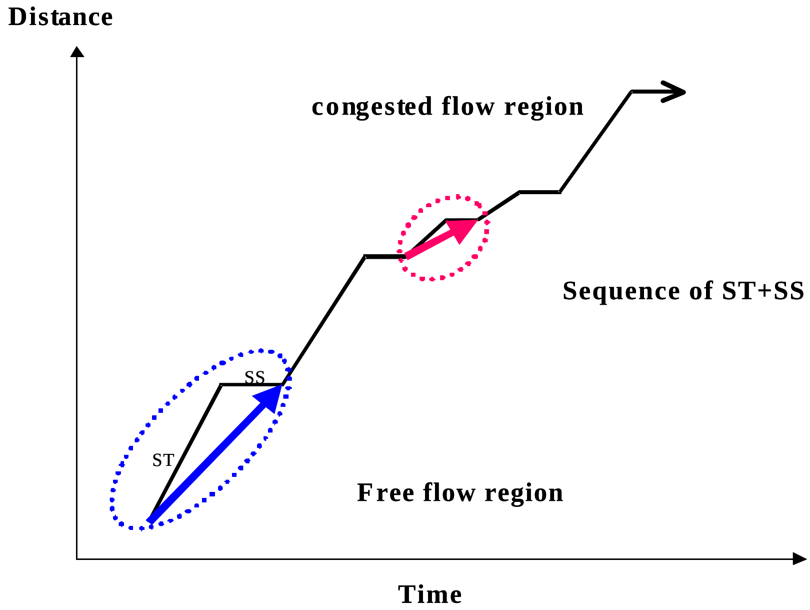


Figure 3 A typical time space trajectory of an IPCar

Traffic Pattern Classification

In this research, an extensive observation was carried out in one of the main arterial at Nagoya city (Fushimi-Sakae arterial) in order to have a better understanding of the event sequence. According to this observation periods of the day that have congested or free flows are established. Consequently, the sequence analysis of IPCars is divided to congestion and non-congestion periods and the result is shown in Figure 4. As expected it exhibits that the duration of ST is longer during non-congested periods and the maximum speed of IPCars is less than 70km/hr. In addition, high speed takes place with short durations. Nevertheless, sequence of ST and SS would be a much better representative of the traffic conditions as discussed earlier. Figures 5 and 6 demonstrate the subsequent ST and SS of IPCar number 12 at Nagoya for an aggregated period of one day divided for congested and non-congested time respectively. Each point on these contours shows the density or the probability that one ST and its following SS with specific characteristic occurs. Additionally, Figure 5 clearly illustrates two completely distinguished patterns. One with SS less than 40 second and the other with SS longer than 40 second and ST speed of higher magnitude. On the other hand Figure 6 suggests that longer SS and shorter ST distance (distance travelled by an IPCar during ST) happens during congested flow while shorter SS duration and longer ST distance occurs during free flow. These various patterns evidently demonstrate different driving characteristics resulted from diverse traffic conditions. To have enhanced understanding and to clarify and classify these various traffic patterns further analysis has been carried out utilizing more aggregated IPCar data for Yokohama and Nagoya. Some of the results are shown in Figures 7-a and 7-b.

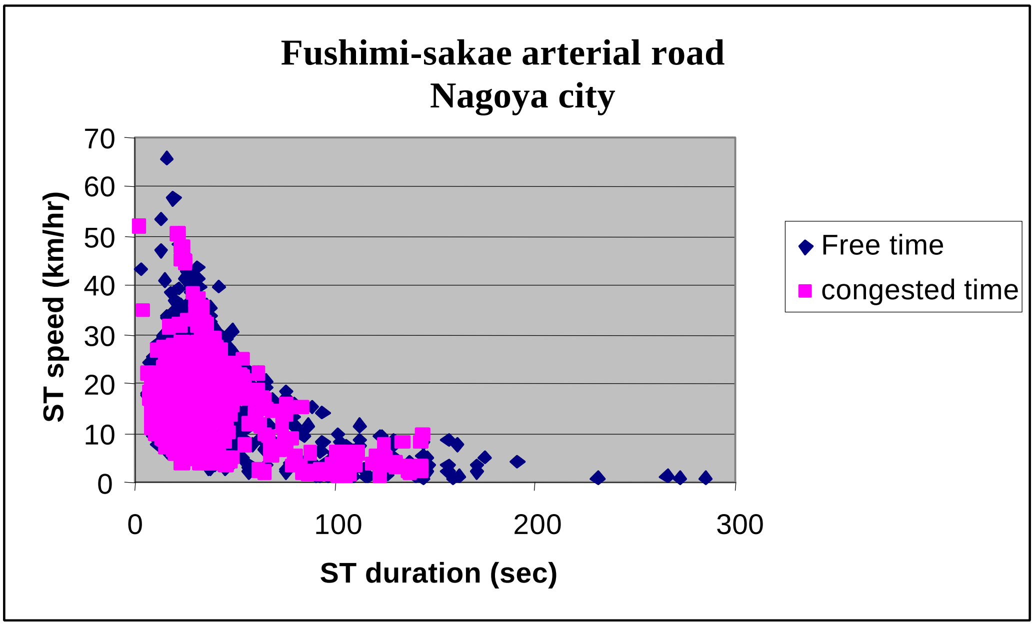


Figure 4 Preliminary analysis of IPCars in Nagoya

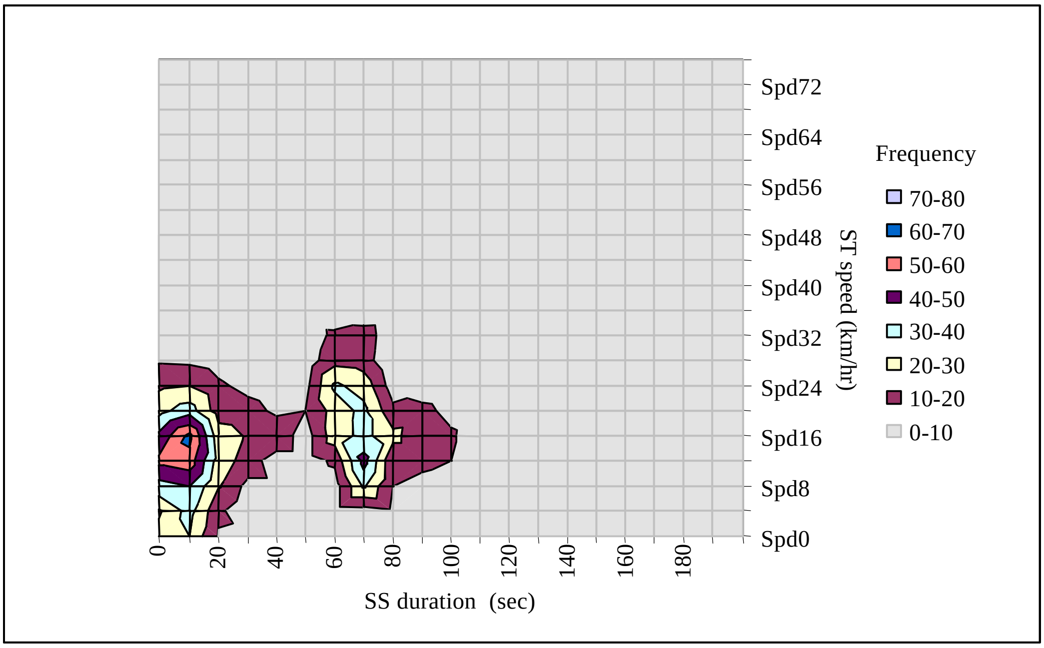
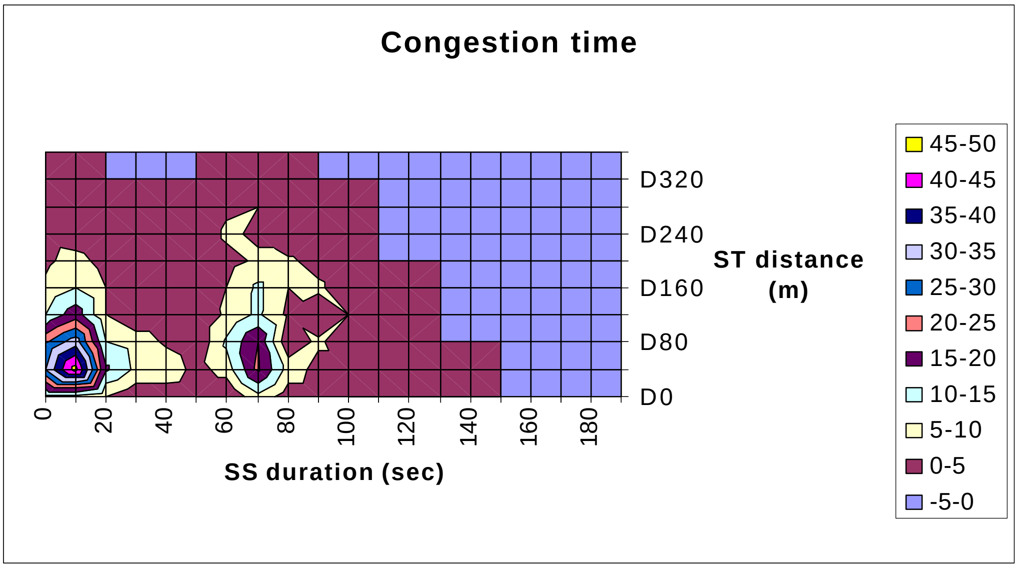


Figure 5 Contour of IPCar number 12 for one day, aggregated data



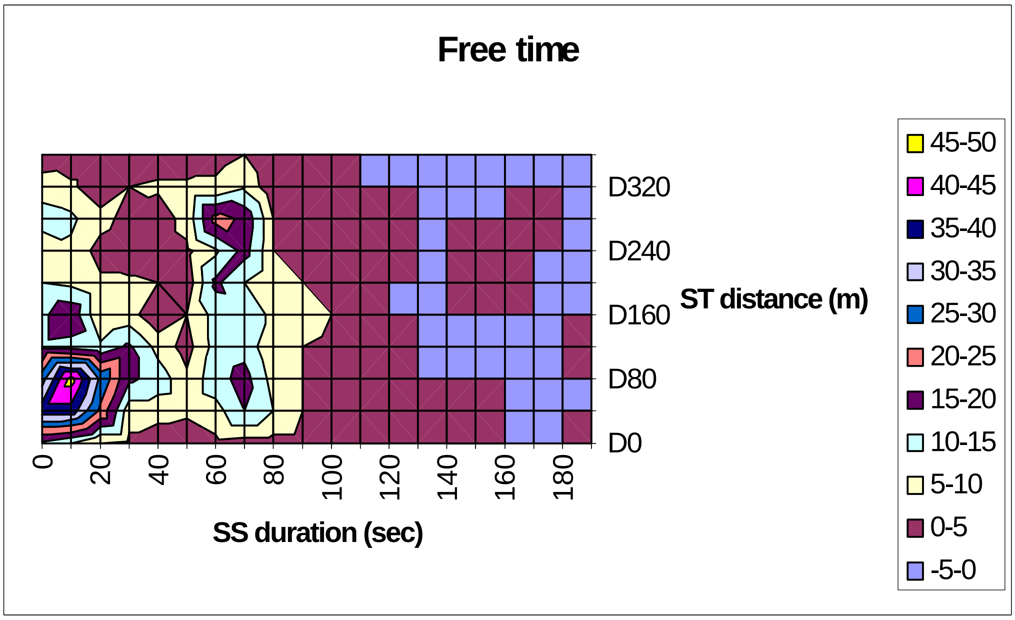


Figure 6 Contour of IPCar number 12during one day for congested and free flow conditions

Figures 7-a and 7-b show five IPCars aggregated data running in Yokohama. Moreover, this analysis is represented in different time of the day to capture potential diversity among morning peak, off peak and afternoon peak traffic regimes.

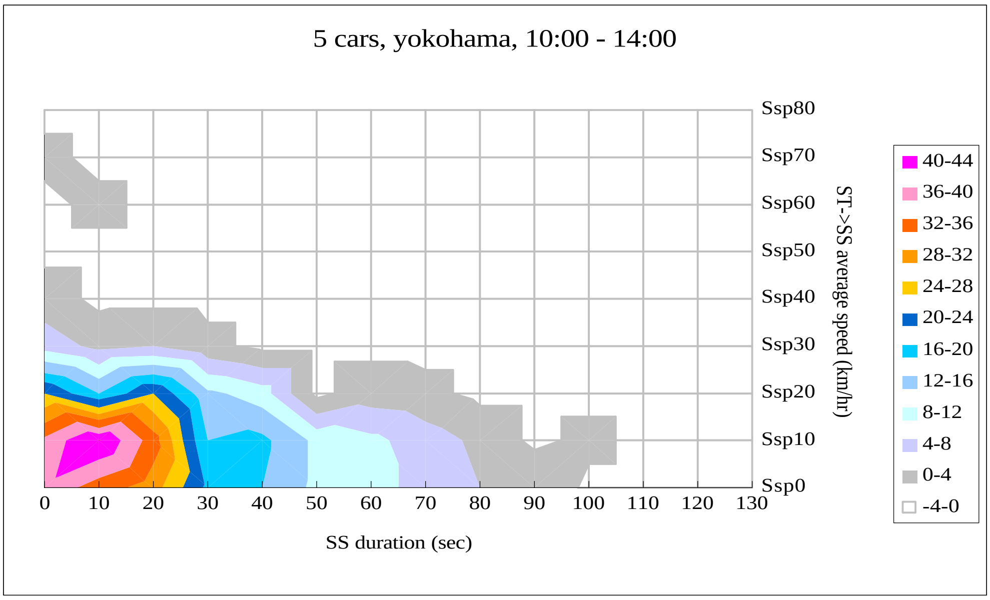


Figure 7-a Contour of five IPCars during 10:00 am to 2:00pm in Yokohama

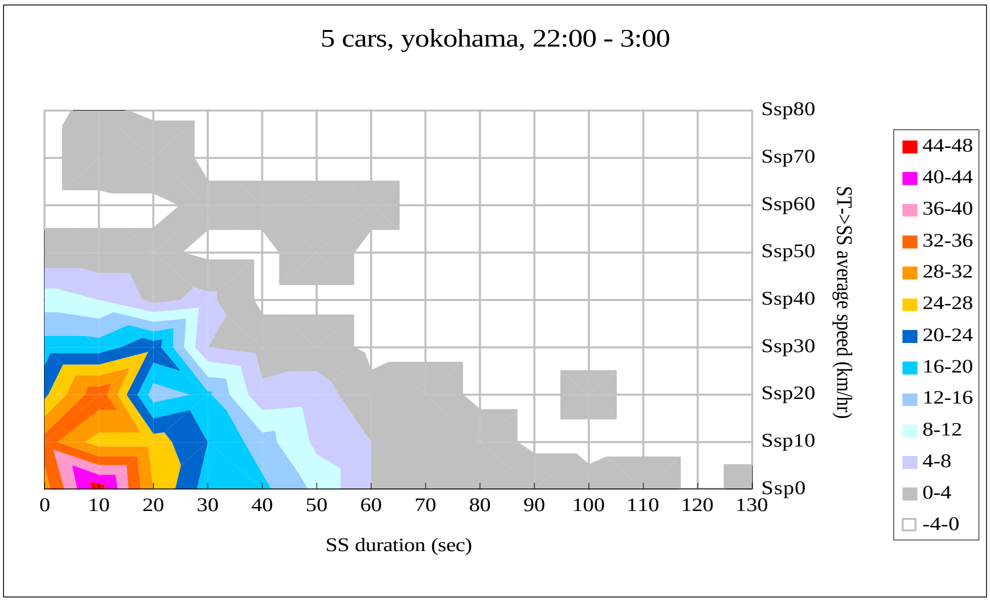


Figure 7-b Contour of five IPCars during 10:00 pm to 3:00am in Yokohama

These contours together with those data acquired from trial in Nagoya led us to establish the following five traffic patterns which might happen under various traffic conditions. Figure 8 schematically summarized these five patterns:

i. A1 with the adjusted speed of less than 20km/hr and grater than 2/3D (D is the ST distance in meter) and SS duration less than 30 sec. A representative of this pattern would be the pink area in Figure 7-a.

ii. A2 with the adjusted speed of less than 20km/hr and less than 2/3D (D is the ST distance in meter) and SS duration less than 30 sec. This pattern is frequently identified during congested traffic conditions. A representative of this pattern would be the yellow area in Figure 7-a.

iii. B1 with adjusted speed less than 20km/hr and SS grater than 30sec and less than 60 sec. This pattern also mostly occurs in traffic congestions. A representative of this pattern would be the light green and blue area in Figure 7-a.

iv. B2 with adjusted speed less than 20km/hr and SS grater than 60sec. This pattern frequently observed during congestion, however, less often it is observed under free flow condition as well. A representative of this pattern would be the grey area in Figure 7-a.

v. C with adjusted speed bigger than 20km/hr. This pattern solely represents the free flow condition.

According to the above classification, A1 and A2 represent short distance travel, for instance the advancement of an IPCar in stop and going movements during congestion at a traffic queue whereas B1 and B2 represent long distance travel with the same adjusted speed. Nevertheless, a tree analysis has been carried out in consideration of Figure 5 in order to better clarify which pattern correctly represents congested and free flow conditions. In this analysis each IPCar trajectory is mapped to a series of pattern A or B. Pattern A consists of a pair of ST and SS with the SS duration less than 50sec and Pattern B with SS longer than 50 sec (e.g. AABBABAABBAAA···). It is performed in three depth level as shown in Figure 9.

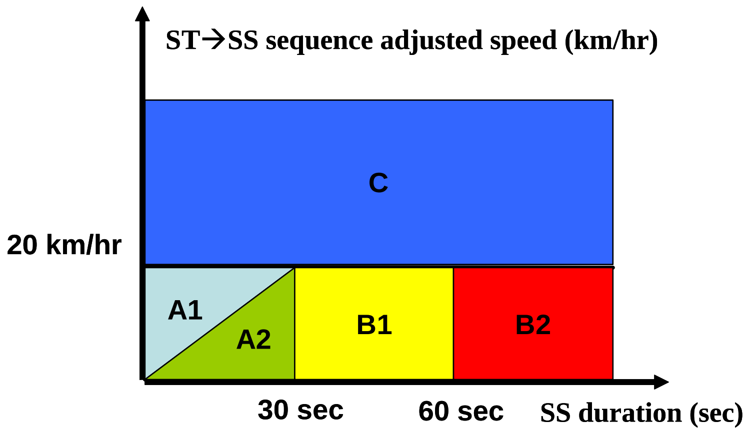


Figure 8 Summary of five distinguished traffic patterns

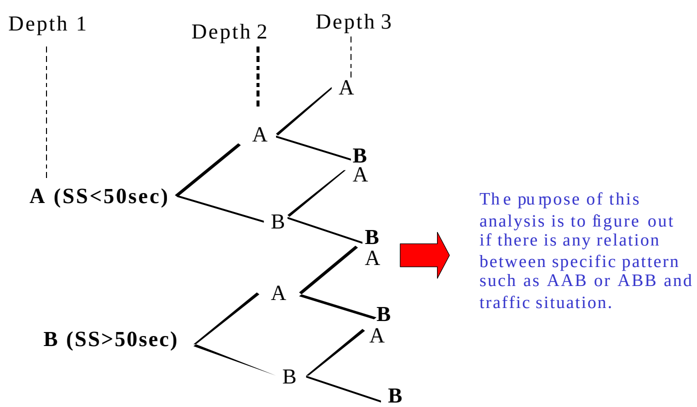


Figure 9 Frequency analysis using tree probability in three depths

The expected output of this tree analysis would guide to the probability of event sequences. For instance what would be the probability of AA or AB (e.g. P(AA) > P(AB)). Results are shown in Figure 10. It showed that P(AA) > P(AB), P(AAA) > P(AAB), P(ABA) > P(ABB).

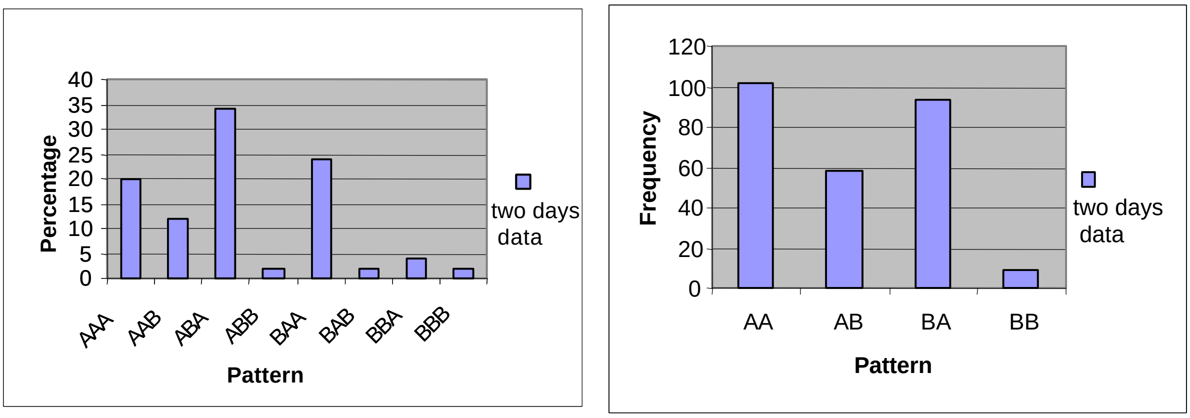


Figure 10 Frequency analysis using tree probability analysis

In addition, each IPCar trajectory map can be compared with five distinguished patterns (i.e. A1, A2, B1, B2, and C). Figure 11 illustrates the couple of the trajectories of IPCar number 1082 at Nagoya. The left hand side figure shows that the two sequence of pattern C, which represents a free flow regime, is changed to pattern B2 and then A2 and A1 by reduction of IPCar speed and transition to congested traffic condition. In contrast, the right hand side figure is the representative of a fairly free flow condition which observed at 1:00am. This analysis based on the extensive investigation on the IPCars trajectories of Nagoya and Yokohama confirmed that five recognized patterns are fairly capable of identifying the traffic condition and changing between traffic regimes. Further application of pattern analysis has been completed to minimize the amount of memory and time needed to transfer data to centre from an IPCar onboard equipments. Nonetheless, is not explained here due to space limitation.

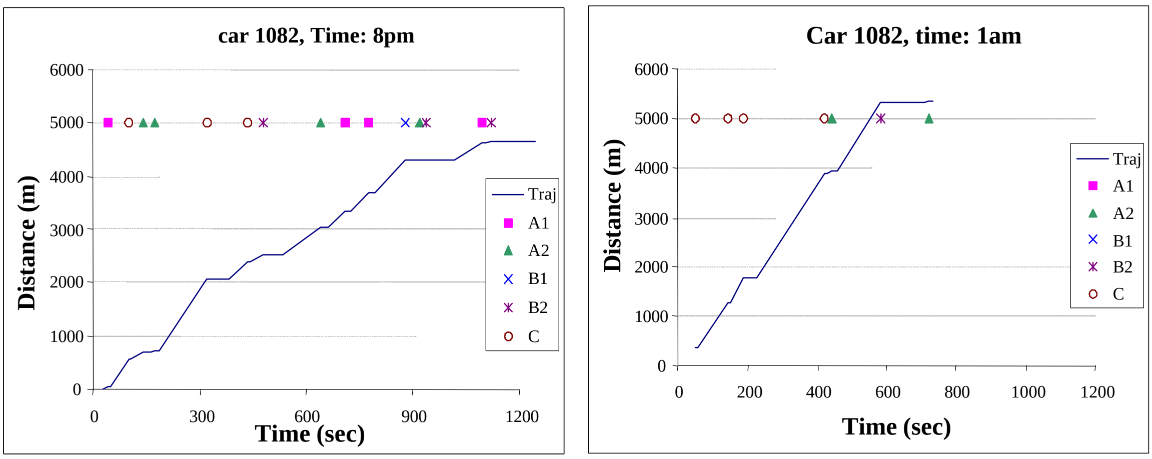


Figure 11 Trajectory analysis against mapped patterns

CONCLUSIONS

In this study a general methodology to identify different traffic conditions in the traffic network utilizing intelligent probe vehicles was introduced. For this purpose IPCars running in Yokohama and Nagoya cities were employed. A sophisticated and innovative method was developed and employed to cleanse the IPCar data and searches for trip ends. This data then was used with the shape of vehicles trajectories to classify and distinguish different traffic condition patterns. Five discrete patterns namely A1, A2, B1, B2 and C are introduced based on ST and SS contours and probability analysis. Further careful analysis of mapped trajectory of IPcar together with the proposed five patterns showed that these patterns can be applied to identify different traffic pattern during an IPCar trip. This analysis and patterns can be further utilized toward the minimization of data transactions between IPCar and the data center.

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