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Cooperative Traffic Management System Using V2X Data

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Abstract
The spread of CVs (connected vehicles) equipped with DSRC/IEEE 802.11p based technology is progressing. These CVs broadcast V2X data such as position and speed of the own to the surroundings for the purpose of safe driving support to prevent a collision. This V2X data also has big potential as new traffic information that conventional vehicle detectors could not provide. We have been tackling R&D to enable smoothing traffic flow and reducing CO_2 emitted from vehicles by advancement of traffic control using V2X data. In this paper, we focus on the traffic jam phenomenon and we would explain the summary of the traffic diagnosis system utilizing V2X data to detect unusual traffic events and to identify the cause of traffic jam such as overflow from right-turn-lane. In addition, we show the test result of traffic diagnosis system using data observed from real fields.

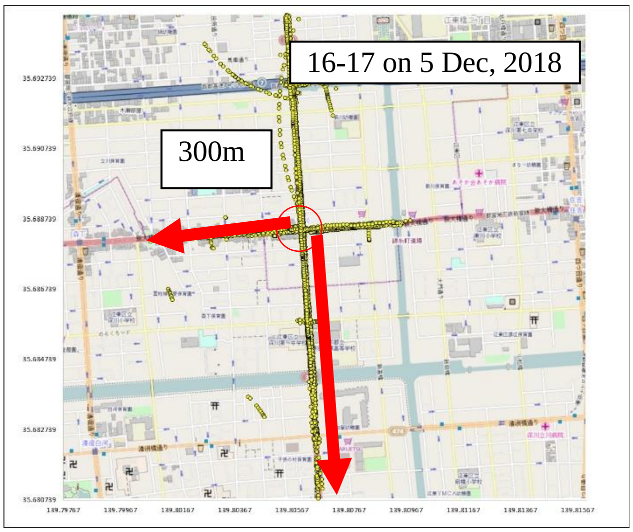
Keywords:
V2X, Traffic Control

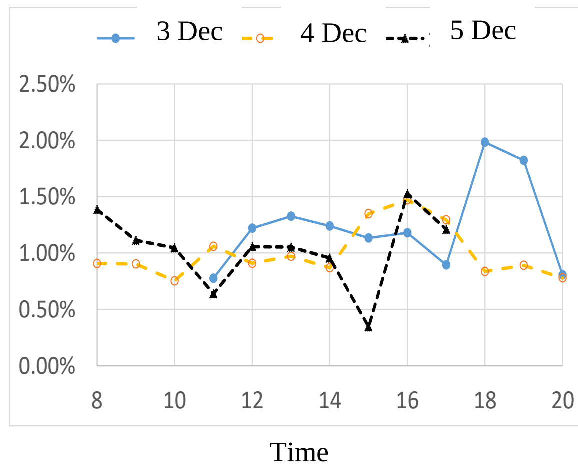
Background

"The Traffic Flow Control System Working Group" of UTMS society of Japan have been tackling R&D to enable smoothing traffic flow and reducing CO2 emitted from vehicles by advanced traffic control using probe data collected directly from vehicles via wireless communication. In late years, DSSS[1] (Driving Safety Support Systems) utilizing DSRC/IEEE 802.11p based technology for V2I communication have developed toward zero traffic accident fatalities in Japan. As a result of big efforts, "Right Turn Collision Prevention Support System", "Right Turn Predestination Collision Prevention Support System" and "Traffic Signal Oversight Prevention System" were put into practical use in 2015 and those systems are operating at more than 90 intersections across 8 prefectures at the end of FY 2019 in Japan. Currently, several car models are on the market and those are traveling nationwide. In the near future road traffic environment that these cooperative systems spread, vehicles and roadside units are strongly connected by wireless communication everywhere, and it is expected to be able to collect V2X data such as the position and the travel speed of the vehicle broadcasted in real time directly from these CVs equipped with wireless communication units. Therefore, we are studying to utilize this V2X data as new traffic information for traffic management.

Features of V2X Data

The CVs broadcast their own vehicle information to neighbouring vehicles and other communicators through wireless communication. This V2X data contains dynamic information of travel position, travel speed and driver operation (brakes, accelerator, steering wheel operation) other than static vehicle attribute information such as ID and car types. In EU, ETSI developed CAM (Cooperative Awareness Message) [2] for safety driving support systems related to V2V applications. In US, SAE developed BSM (Basic Safety Message) [3] as well. On the other hand, in Japan, the communication band of the 760MHz was assigned for exclusive use of ITS. And V2V message like CAM in EU and BSM in US has been developed [4]. This V2X data is broadcasted every 100ms period. And it has the communication coverage of several hundred meters. Figure1 shows an example of communication area and current mixed ratio of CVs in real field in Japan. It shows that average number ratio of CVs was 1.08% on the test field at the end of 2018.





Plots of V2X Data that RSU Received
(© Openstreetmap contributors)

Average Ratio of CVs on Southbound

Figure1 Communication Area and Ratio of CVs at Kikukawa intersection in Tokyo

What We Can Collect from V2X Data

By analysing V2X data, it is possible to track changes in vehicle behaviour in detail. As the most likely event, there is a possibility that traffic congestion can be detected from information on where vehicle travel speed drop occurs. In addition, it is expected to be used for detecting any unusual traffic events. Figure2 illustrates the relationship between the traffic signal light status the traveling trajectory of the vehicle based on the time, position, and speed information stored in the V2X data. If the vehicle does not depart even if the departure wave of green signal arrives, it can be said that there is a high possibility that a traffic event that is blocking the flow of the vehicle other than the red signal has occurred.

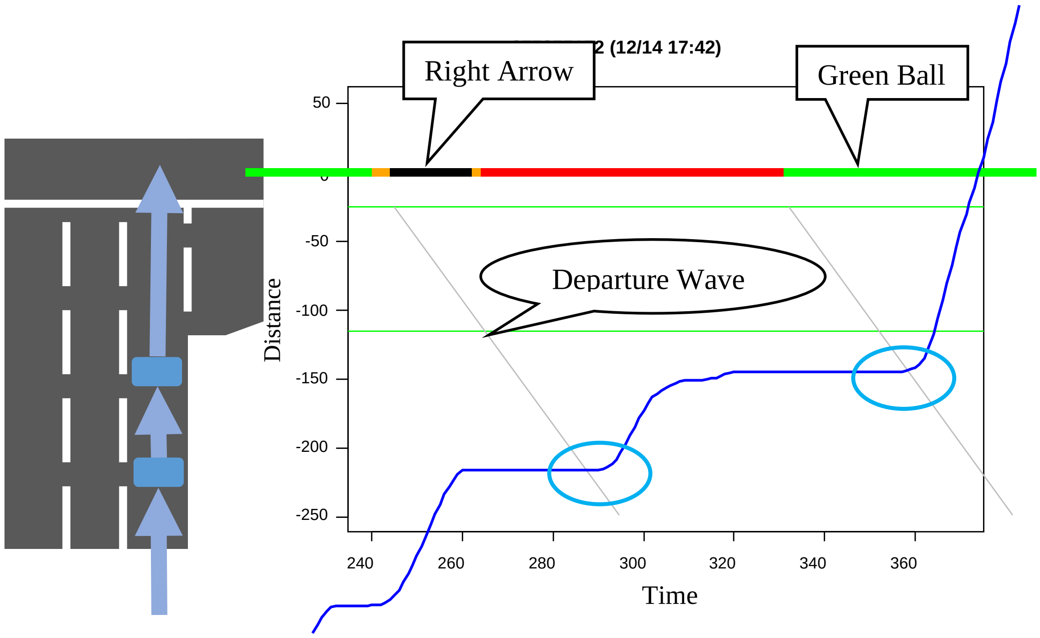


Figure2 Vehicle trajectory Analysis from V2X Data

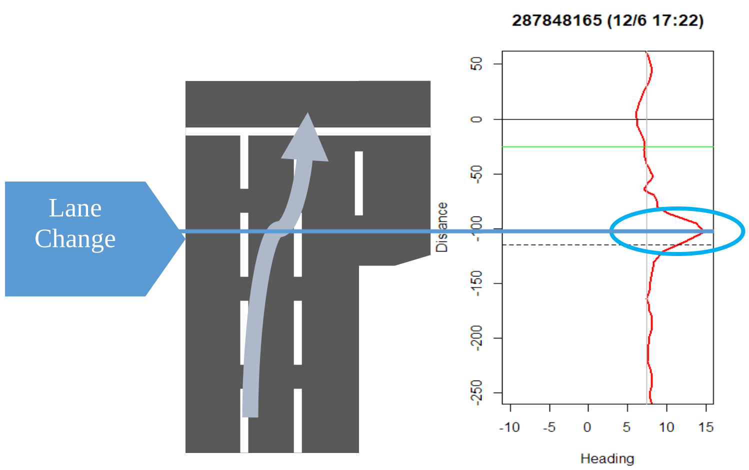


Figure3 Vehicle Heading Analysis from V2X Data

On the other hand, Figure3 shows a change in the vehicle heading direction stored in the V2X data when the lane change is executed, and it is considered that the lane change behaviour can be easily detected from the V2X data. For example, if lane changes are concentrated at a specific location on the road compared to normal traffic environments, it is likely that there is an obstacle such as a fallen object or a broken vehicle at that location.

Use Cases Utilizing V2X Data

As mentioned earlier, it is expected to detect traffic events automatically from V2X data. Table 1 shows proposed use cases for advanced traffic signal control utilizing probe data that we have been researching.

Table1 Use Cases Utilizing V2X Data

<table>
<tr><th>Class</th><th colspan="2">Use Case Name</th><th>Outlines</th><th>Status</th></tr>
<tr><td rowspan="4">Off-Line</td><td rowspan="2">Traffic Condition Indicator</td><td>Intersection</td><td>Speed, Stop Position, Queue, Branching rate</td><td rowspan="4">Under Development</td></tr>
<tr><td>Network</td><td>OD, Travel Route, Travel Time</td></tr>
<tr><td colspan="2">Benefit Indicator</td><td>Quantifying investment benefits of signal control systems</td></tr>
<tr><td colspan="2">Signal Control Performance Diagnosis</td><td>Efficiency: Excess or deficiency of green time
Safety: Speed violation, Occurrence of dilemma zone entry, Occurrence of signal violation etc.</td></tr>
<tr><td rowspan="2">On-Line</td><td colspan="2">Less Vehicle Detector Signal Control</td><td>Replacing vehicle detectors with V2X data from CVs</td><td rowspan="2">Under Field Tests</td></tr>
<tr><td colspan="2">Traffic Flow Diagnosis</td><td>Identifying causes of jam such as overflow, downstream blocking, turn-lane-spillover, etc.
Event detection such as accidents</td></tr>
</table>

Use cases are classified into two categories. One is for offline operation support, such as automated signal control performance evaluation. The other is for online traffic signal control to respond to traffic changes dynamically. One of typical online use case is “Traffic Flow Diagnosis” that is aiming to reflect diagnosis results on signal control by identifying causes of traffic jam such as downstream blockage and overflow from right-turn-lane, as well as detecting occurrence of unusual traffic events such as falling objects and broken cars. According to the results of an experiment [5] conducted in 2015 to detect jam cause by overflow from right-turn lane from right-turn vehicle behaviour analysis, the average detection delay time was 15'53 under the conditions of 0.81% mixed ratio of CVs. Delay time was a big challenge. Because it is important to quickly respond to a traffic event for traffic signal control. In order to reduce this detection delay time, we are tackling to analyse the behaviour of straight-ahead vehicles affected by overflow from right-turn lane. This is because the absolute number of straight-ahead vehicles is much larger than that of right-turn vehicles.

Field Test Results

We carried out a field test of extracting the characteristics of the straight-ahead vehicle behaviour at an intersection (Koto-Dori, Aichi Prefecture) where traffic jams often occurred due to overflow from right-turn lane. We recorded traffic situation video with 2 video cameras for two months from December 2017 to January 2018, and accumulated V2X data every 1 second from CVs traveling at the intersection. Figure 4 shows the outline of the intersection.

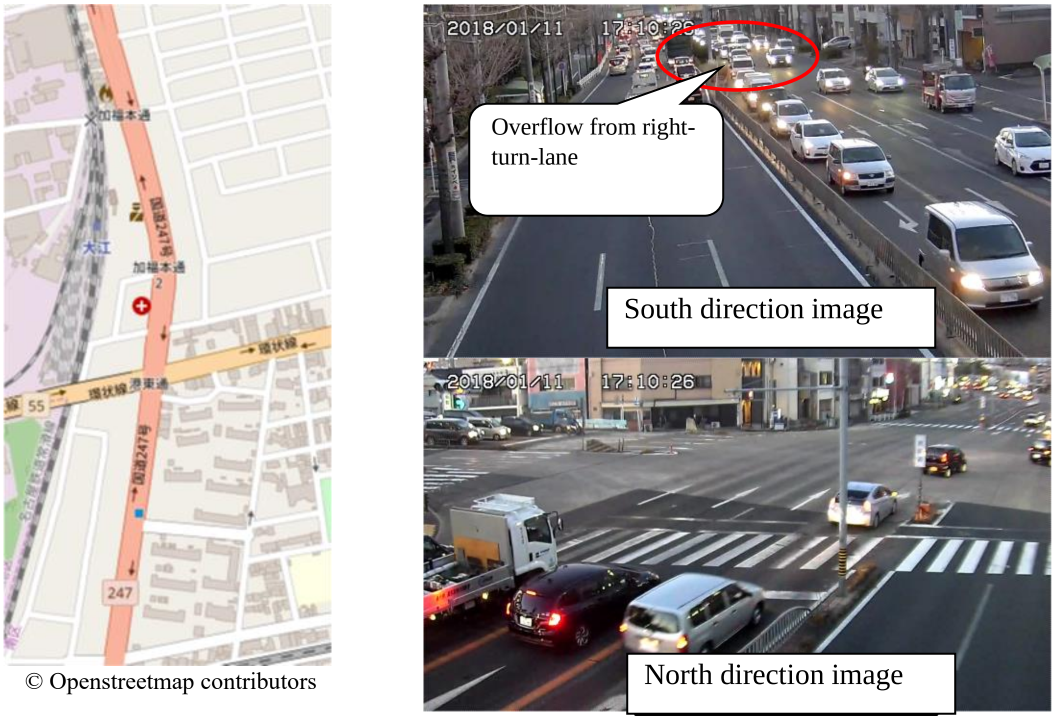


Figure4 The Intersection used for the field test

We assumed the following 4 patterns as the behavior of straight-ahead vehicles when an overflow from right-turn lane occurred, and extracted the number of CVs corresponding to each behavior pattern from the recorded video and the accumulated V2X data. Table 2 shows the extraction results.

① Stop due to direct impact of overflow from right-turn lane
- Stop in front of the right-turn lane
- Restart in synchronization with the departure wave from the right-turn arrow signal

② Slowdown upstream from the right-turn lane, accelerate after passing the right-turn lane start position (Overflow occurrence point)
- Slowdown upstream
- Accelerate after passing overflow occurrence point

③ Change lane to left lane in front of right-turn lane
- Vehicle heading direction fluctuate

④ Change lane to right lane after passing overflow occurrence point
- Vehicle heading direction fluctuate

Table2 Numbers of straight-ahead CVs affected by overflow from right-turn lane

Classifications	16:00-17:00	17:00-18:00	18:00-19:00	Total
Total number of straight-ahead CVs passed during a right-turn overflow event	34	117	78	229
①Stop at right-lane jam	1	15	5	21
②Slowdown in upstream	3	21	25	49
③Left lane change	1	0	2	3
④Right lane change	0	5	1	6

Table 2 shows that the number of lane change behaviors of CVs that avoided the overflow from right-turn lane was small. In addition, regarding the slowdown in upstream, which many target behaviors were observed, no correlation was found between the presence or absence of an overflow from right-turn lane and the speed change. Figure 5 shows the relationship between the overflow from right-turn lane event occurrence and the average vehicle speed change.

Based on the above analysis results, we propose a diagnostic model that determines that "occurrence of overflow from right-turn lane event" when the following vehicle behavior is detected.

1) Stop in front of the right-turn-lane and start when the departure wave from the right-turn-arrow signal arrives.
2) Stop again before the stop line
3) The distance between 1) and 2) is above a certain level

As a result of applying the diagnostic model to the accumulated V2X data, the model was able to detect all 21 straight-ahead vehicles that stopped at the right-turn congestion extracted from the recorded video. In addition, 2113 straight-ahead vehicles that passed during the time when the right-turn overflow event did not occur, only 4 were mistakenly detected as a vehicle stopped under overflow from right-turn lane event (false rate: 0.19%). From this result, it is considered that our diagnostic model could detect the overflow from right-turn lane with high accuracy.

Next, the event detection rate and the detection delay time were evaluated from the recorded video for all the scenes in which the overflow from right-turn-lane continued for 3 signal cycles or more. Table 3 shows the comparison between the result based on only the data of the right-turn vehicles and that based on the data of both the right-turn vehicles and the straight-ahead vehicles. By using the data of both right-turn vehicles and straight-ahead vehicles, the detection rate of overflow from right-turn lane event improved from 27% to 45%, and the average detection delay time also improved by 20% from 15’ 12” to 12’ 7”. Currently, the CVs are increasing year by year, and further improvement is expected.

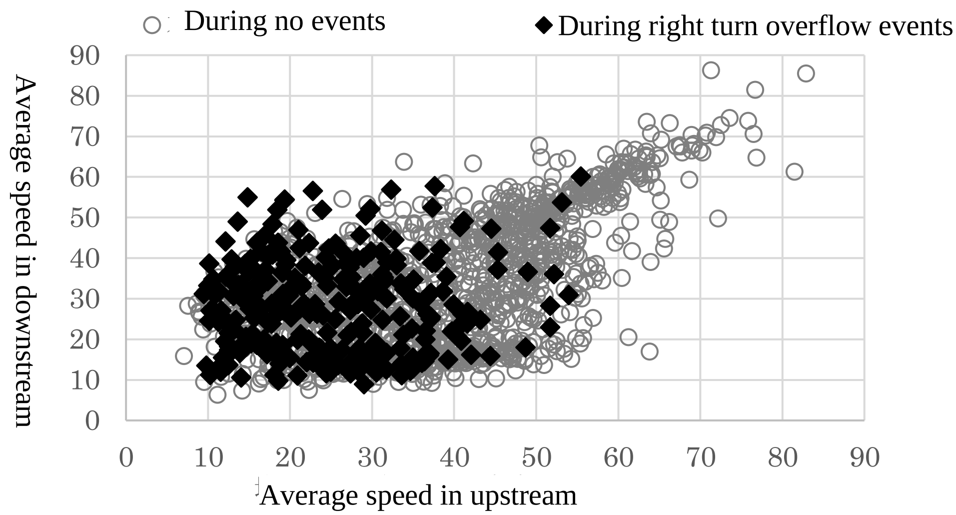


Figure5 Relation between speed and overflow events

Table3 Detection Rate and Detection Delay Time

Target Vehicles	Detection Rate		Detection Delay Time		
	Num.	%	Average	Max	Min
Right-turn-vehicles Only	17/64	27	15’ 20”	36’ 9”	1’ 21”
Right-turn-vehicles & straight-ahead-vehicles	29/64	45	12’ 7”	36’ 9”	4”

Conclusion

CVs broadcasting V2X data have been spreading. We believe that V2X data has big potential as new traffic information that conventional vehicle detector could not provide. We carried out a field test to evaluate traffic diagnosis system using V2X data to detect the occurrence of events that interfere with traffic such as overflow from right-turn-lane. And the test results showed the potential of traffic diagnosis system to smoothen traffic flow and reduce CO_2 emitted from vehicles.

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