Improving moving jam detection performance with V2I communication

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ABSTRACT

Dynamax is a road side based system using the SPECIALIST control algorithm and inductive loops. Dynamax field tests showed that moving jams can be effectively resolved by dynamic speed measures [1,5]. This paper focuses on Dynamax In Car, which extends the road side infrastructure with a V2I cooperative approach. V2I cooperation is used to detect an emerging jam earlier and more accurately, so that a smaller speed measure can be set to resolve it and larger moving jams can be resolved within the available road length. The detection performance is analyzed through simulation and found to improve already with a very low penetration rate. An additional road side detection system is also analyzed that is independent of the penetration rate and provides the best detection performance.

Keywords: Safety and traffic management, Speed advice, Moving jam detection

1. INTRODUCTION

Moving jams are traffic jams that move with a more or less constant speed in upstream direction. Moving jams are often triggered in congested traffic, cause significant travel time delays and occur regularly on certain motorways, like the A12 and A15 in the Netherlands (Figure 1). They usually emerge at a bottleneck location, travel long distances and disappear at a next major intersection.

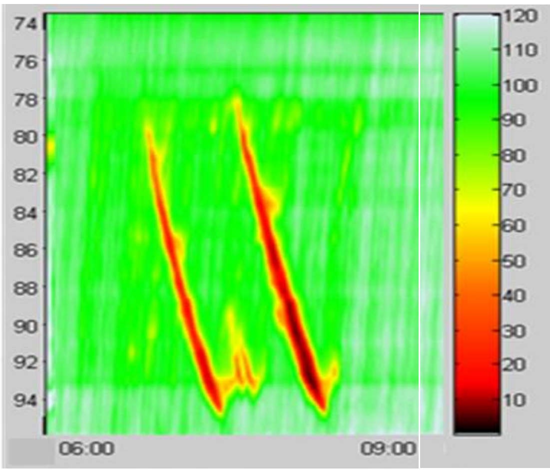

Figure 1. Time space plot of moving jams travelling 16 km on the A15 motorway in the Netherlands. Speed (color) in km/h.

In the earlier Dynamax project [1], a system based on the SPECIALIST control algorithm [8] was field tested on the A12 motorway that reduced the emerging moving jams by setting dynamic speed measures [1,5]. This was achieved by reducing the maximum speed limit upstream of the moving traffic jam to reduce the inflow into the traffic jam. If the traffic measure is set early, accurately and under the right traffic conditions, then the moving jam resolves. The field test showed that the algorithm triggered several times per day, successfully resolved 77% of the moving jams when it triggered, and improved total delays on average by 35 vehicle loss hours.

The system made use of the existing variable speed limit signs and induction loops every 500m of the motorway. The loop detectors had to be adapted to provide a speed measure every 10 seconds as input to the control algorithm.

The field test also showed possibilities for improvements. Jams could only be detected once they passed a loop detector and the length and speed of the jam cannot be detected accurately from the first loop detection only. Detection inaccuracies and delays resulted in delays in the activation of speed measures or in the decision to take no action because the moving jam could not be resolved within the length of the available road segment.

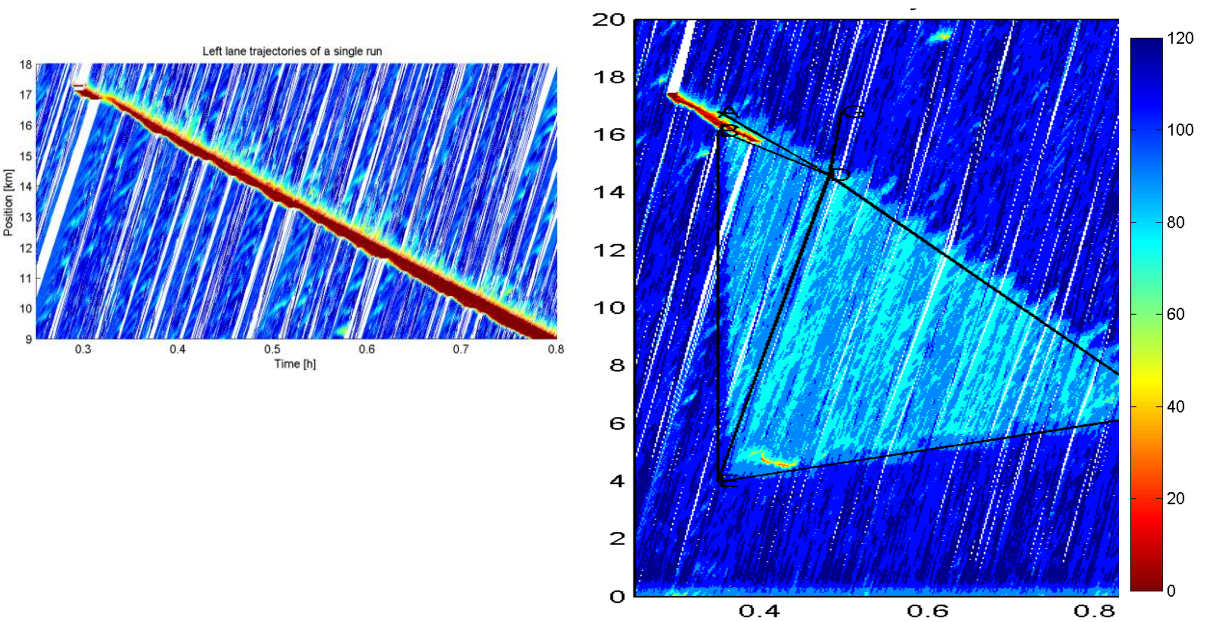

Figure 2: Dynamax speed limit control. Reference situation (left) and Dynamax (right – scaled to the location of the reference situation)

This field test and earlier off-line data analysis [7] lead to the hypothesis that if an emerging jam can be detected earlier and more accurately, then a smaller speed measure can be set to resolve it and larger moving jams can be resolved within the available road length.

In [2] Floating Car Data (FCD) is used to detect moving jams in a vehicle to vehicle (V2V) system concept, and without any road side traffic information. A penetration rate of equipped vehicles of 3% was found to be sufficient for reliable jam detection on a time scale of 5 to 10 minutes, which is beyond the focus here. In [3] a similar V2V concept is analyzed for urban traffic jam detection and it is estimated that 50% of the jams can be detected with 10% penetration rate within 45 seconds. To improve the jam detection performance in the Dynamax concept, the detection time of several minutes need to be improved in more than 50% of the jams. A penetration rate of 10% of equipped vehicles may not be realized in the next few years. Dynamax In Car exploits the V2I cooperation to improve the existing road side infrastructure with vehicle data. This paper analyses the potential detection performance and required penetration rate of equipped vehicles.

2. DYNAMAX IN CAR SYSTEM CONCEPTS FOR MOVING JAM DETECTION

The Dynamax In Car system concept extends the Dynamax system in two ways. Floating car data is fused with the existing loop data to improve the detection of moving jams. The dynamic speed measures on the matrix signs are also provided as in-vehicle speed advice to increase the driver's compliancy to those speed limits. This paper addresses the detection improvements. Figure 3 shows the possible concepts of the Dynamax In Car system.

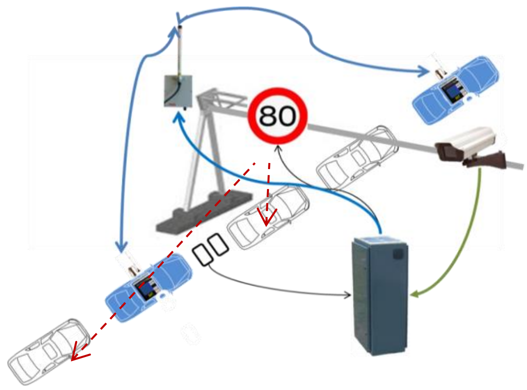

Figure 3: Dynamax In Car system concepts using gantries with loop detectors, matrix signs, video cameras, communication for floating car data and in-vehicle speed advice

2.1 In-vehicle systems

Vehicles can be equipped with in-vehicle or nomadic devices that provide communication, vehicle position and speed data, and a display to present the dynamic speed advice to the driver. The vehicle position and speed information is sent to the road side controller as floating car data (FCD). The control algorithm at the road side requires FCD updates every 10 sec, which is feasible with 3.5G cellular network communication or with ITS G5 802.11p WiFi communication. It can be expected that a minimum penetration rate of equipped vehicles (PEV) is required to improve moving jam detection.

2.2 Road side trajectory data

An alternative to collect vehicle data without the need for a minimum penetration rate of equipped vehicles is to use additional road side sensors that provide trajectory data of individual vehicles. Video Based Monitoring (VBM) is an example of such a vehicle tracking system that is successfully used for moving jam detections [4]. VBM provides position and speed data much more accurately than FCD, at 10 Hz and for all vehicles in the camera covered area. Here the VBM data is aggregated and only used at the sample rate of the fusion and control algorithms of 0.1 Hz.

2.3 Data Fusion

The data fusion algorithm is based on the Adaptive Smoothing Method (ASM) for loop data [8], which is extended in [9] to handle data from different data sources. The original ASM filter was designed for processing single data source and reconstruct missing spatiotemporal traffic data, - if necessary - at a higher sampling rate with smaller time and location discretization steps. The reconstruction is based on the simple assumption that the information propagates forwards in free flow (with the free flow speed) and backwards in congestion (with the jam propagation speed). The extension in [9] allows for the fusion of various data sources with different spatial and temporal sampling rates, different measurement delays, and different measurement accuracies.

For the Dynamax in car system the data from the detector loops, equipped vehicles, and VBM was fused with this method into a common space-time grid. The data of the most accurate source is actually used for any particular cell, where data from VBM is assumed to be most accurate, and FCD to be more accurate then loop detector data. In addition the data fusion algorithm was extended with a module that converted the various measured traffic quantities (loops: speed and flow, FCD: position and speed, VBM: speed, flow and density) into a full set of traffic state variables (speed, flow and density) as input to the SPECIALIST algorithm.

3. SIMULATION AND EVALUATION ENVIRONMENT

The system concepts are evaluated in the VISSIM simulation environment. A 20 km long motorway with a speed limit of 120 km/h is modeled. Gantries with loop detectors and variable speed limit signs are positioned at every 500 m (as in Figure 2). VBM is installed in the zone where moving jams start between location 16 – 18 km. After 17 minutes simulation time a moving jam is created by temporarily reducing the speed limit to 0 km/h over 300m. The start of the 300m area is varied between loop detector locations at 17.0 and 17.5 km to ensure that jams occur at different distances to the loop detectors in different simulation runs.

Nine scenarios are defined for the different system concepts in Table 1. The baseline scenario does not use any detection or control (Figure 2 left). Dynamax uses the loops and variable speed limit signs (Figure 2 right). The other scenarios are Dynamax in car concepts with a penetration rate of equipped vehicles (PEV), with VBM or both. All equipped vehicles provide floating car data (FCD) and receive in-vehicle speed advices.

Table 1: Simulation scenarios

Scenario Name	Loop detectors and variable speed limit signs	PEV for FCD (section 2.1)	VBM location (section 2.2)
Baseline	-	-	-
Dynamax	every 500 m	-	-
+% FCD	every 500 m	1%, 5%, 25%	-
+VBM	every 500 m	-	16 – 18 km
+VBM +%FCD	every 500m	1%, 5%, 25%	16 – 18 km

3.1 Individual detection systems

Figure 4 shows the simulated output from the individual detection systems. All detectors provide output with a 10 second update rate. Loop detectors provide a speed measure in vertical cells of 500m. Additionally FCD and VBM also give individual vehicle speeds. In Figure 4 the top right plot shows speed points from trajectories of the equipped vehicles. The density of measurements increases for 25% PEV (Figure 4 bottom right). VBM provides speed measures from all vehicles in the VBM covered zone only .

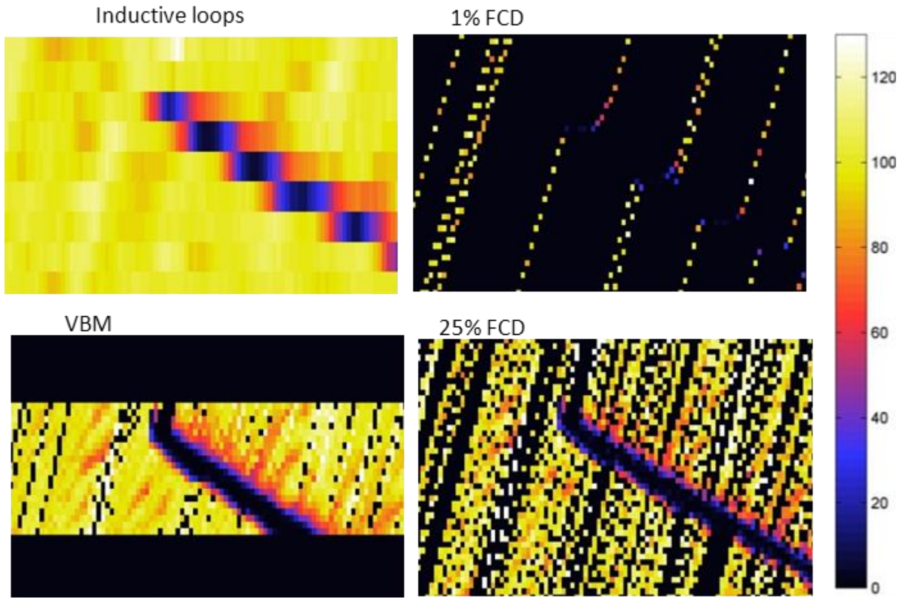

Figure 4. Simulated output from different detectors in time space plots when a moving jams occurs: 0.2 – 0.45 hour simulated time (horizontal axis), road locations 15 – 19 km including the zone covered by VBM (vertical axis), speeds in km/h (color).

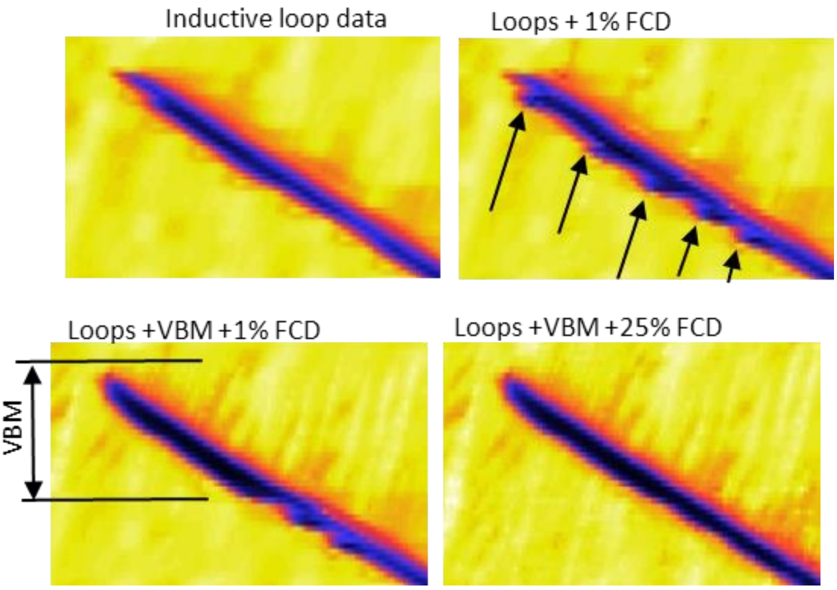

Figure 5: Speed estimates resulting from data fusion of the output from Figure 4 for different scenarios. Arrows in the upper right show the locations where equipped vehicles enter the moving jam. VBM only covers location 16 – 18 km.

3.2. Data fusion

The output data from the individual detectors is fused at the road side into a single input to the control algorithm. Figure 5 shows the output after fusion of the detections from Figure 4. The fusion algorithm refines the cell size compared to the loop detectors (c.f. top left of figure 5 with top left of Figure 4). Nevertheless, the jam length from the loop detections is still smaller than the detections from VBM or FCD. The jam tail is detected more accurately when the FCD vehicles enter the jam (Figure 5 top right).

4. MOVING JAM DETECTION PERFORMANCE

The performance of jam detection can be measured by three indicators; the detection delay, the accuracy of the jam tail location and the accuracy of the jam length. The detection delay is the time delay between the start of a jam and the first detection. The tail front of a jam is defined as the most upstream location where vehicle speeds drop below 40 km/h.

Figure 6 shows the vehicle trajectories of a particular simulation run when the jam emerges. The markers show the time and location of the first jam detection for the different scenarios. In this run, the scenario of Dynamax in car with a penetration rate of 25% vehicles the jam is first detected after 40 seconds. The scenarios with lower penetration rates and VBM detects it 10 or 20 seconds after that. The maximum accuracy is determined by the granularity of the data fusion using a cell size of 100m and 10 seconds, which causes the detections to be reported in the first next cell in the jam. Note that Dynamax using only the loop data detects the jam only after more than 2 minutes.

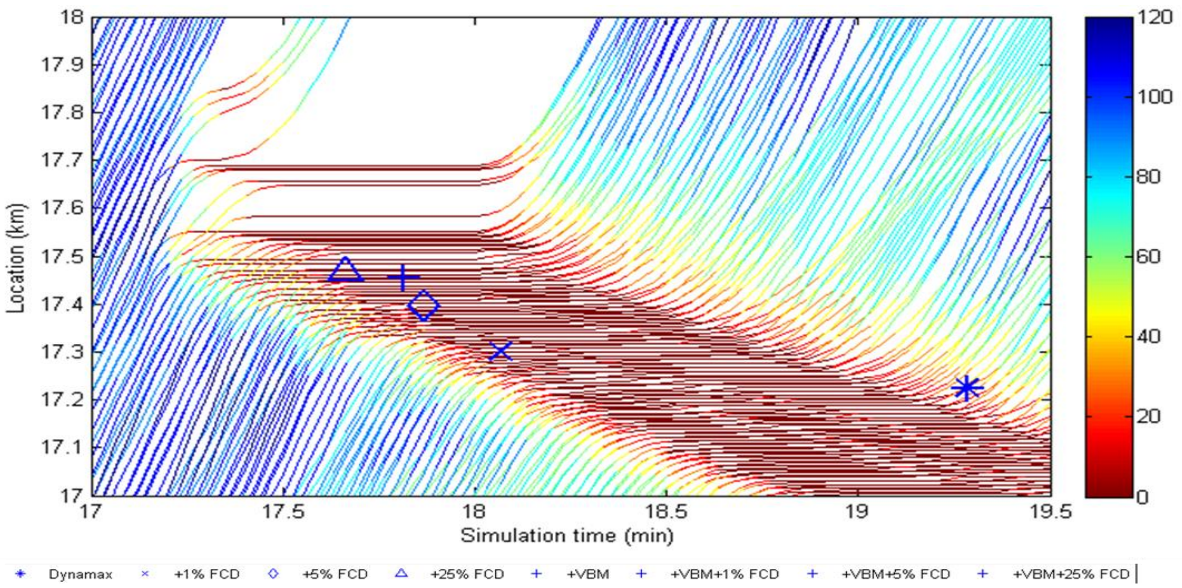

Figure 6: First detections of the jam tail for simulation run #8 in the time space plot of simulated vehicle trajectories. Color indicates the vehicle speed in km/h.

Figure 7 plots the detection performance for all scenarios averaged over the simulation runs. The detection delay of Dynamax is reduced by Dynamax in car by more than 1.5 minutes due to the floating car or VBM data, and the jam tail location accuracy improves by 1 or two cells of 100m. Fusing the loop data from Dynamax with as little as 1% floating car data already improves the jam detection because the floating car data provides more accurate data on the jam tail location (cf. Figure 5).

Upon first detection, the jam has not fully grown and the initial jam length estimates are much smaller. The low average values (less than 100m) indicate that in many runs no jam length could be estimated, which occurs most for Dynamax, and also for Dynamax in car without VBM data. The VBM data enables a better initial estimate of 100m which corresponds well to Figure 5.

The dashed lines in Figure 7 show the worst case values in any of the simulation runs. The variations in detection delay and location accuracy are much larger for Dynamax than for the Dynamax in car scenarios. This is important because smaller variations will result in smaller errors in control and smaller variations in the speed measures.

The performance improves with higher penetration rates. With 25% of equipped vehicles, the performance is as good as with VBM data. VBM provides data that is comparable to floating car data acquired from all passing vehicles. Hence the VBM scenarios perform best and are independent of the penetration rate of floating car data.

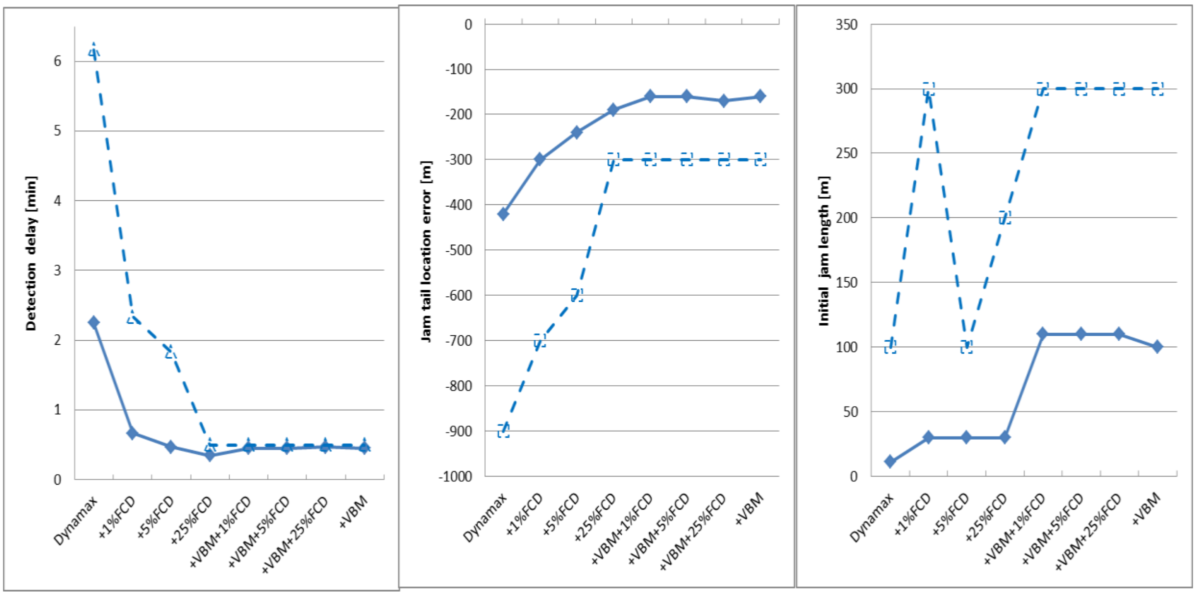

Figure 7: Delay, tail location error and jam length upon first detection of moving jams. Average values (solid) and worst case (dashed) performance per scenario.

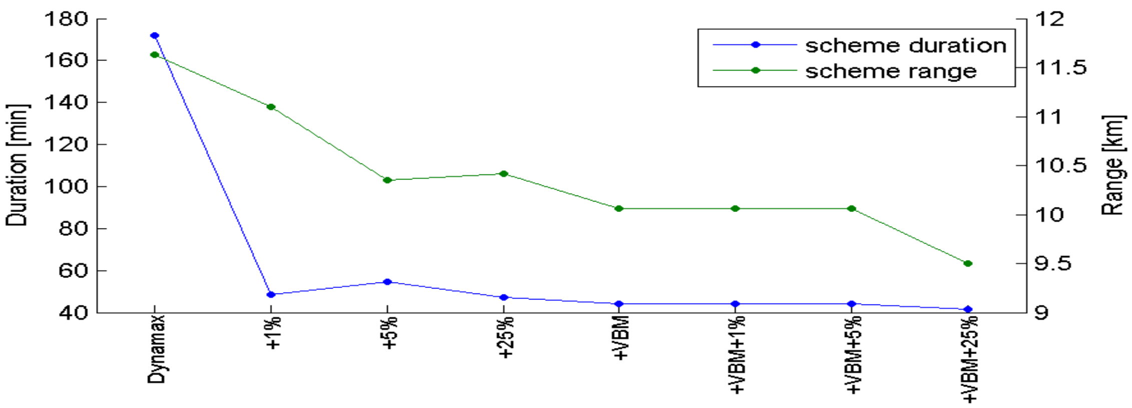

Figure 9: Average control scheme duration and ranges.

5. IMPACT ON MOVING JAM CONTROL

The SPECIALIST control activates immediately upon detection of a moving jam. The control algorithm calculates a control scheme, which is a scheme for the range and duration of the speed measures over time (Figure 2 right). The detected size of a jam has a significant effect on the required range and duration of the speed measure to resolve the jam. Figure 9 shows that the control schemes could indeed be reduced for the Dynamax In Car scenarios and with increased penetration rates of equipped vehicles.

It should be noted though that the control algorithm was tuned for each scenario, to compensate for the detection performance. The detection performance criteria cannot be directly related to the scheme duration or range. The algorithm was also tuned for an anticipated higher compliance to the speed measures for drivers with equipped cars, which enables slightly smaller schemes for higher penetration rates.

6. CONCLUSIONS

The performance of moving jam detection of the Dynamax In Car concept is evaluated through simulation and compared to the Dynamax concept and the baseline situation. Two approaches for the Dynamax In Car concept are considered to extend the road side infrastructure of Dynamax; in-vehicle systems to provide floating car data (FCD) and a new road side detection system that tracks vehicles and provide similar data.

The detection performance of Dynamax can be improved in all Dynamax In Car concepts. When using equipped vehicles, a penetration rate of 1% can already reduce the average detection delay by 1.5 minutes to 40 seconds and improve the accuracy of the jam tail front and jam length detections. Performance improves with higher penetration rates. At a penetration rate of 25%, detection delay has reduced to 30 seconds and the accuracy of the tail front by 200 m on average. More important is that the variation of detection performance strongly decreases with the penetration rate, providing more reliable input to the control algorithm.

In the alternative concept a new road side detection system is added that tracks all vehicles and provides data similar to floating car data as if all vehicles would be equipped. Detection performance is comparable or better than with a penetration of 25% equipped vehicles. This concept is independent of the penetration rate and provides a good solution for early deployment when the penetration rate is still below 25%. The cost benefit analysis for additional road side equipment or equipping vehicles is beyond the scope of this paper.

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