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Exploration of OptaSense Road System as a data source for AID algorithms

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(minor textual corrections have been applied on May 5)

Content

1 Executive summary

1.1 Site description

The OptaSense solution targets the northbound (A9R) and the southbound direction of the (A9L) A9, for longitudes between km 51.8 (Beverwijk) and km 69.5 (Alkmaar). It utilizes a fiber that resides in the right shoulder of the A9R. Hence the distance between the fiber and the lanes carrying road traffic on the A9R is smaller than the distance to the lanes on the A9L. Therefore it is expected that the derived speeds and congestion alerts for the A9R will be of a higher quality than those derived for the A9L.

The system was physically installed on September 28, 2021 and calibrated by OptaSense in the subsequent months. The first meaningful results have been available since December 9, 2020, but at that time OptaSense was still in the process of further calibrating the system. After a few rounds of inspections and feedback on the part of Rijkswaterstaat, starting January 21, 2021 the final calibration of the system has been available. A slight adjustment has been applied as of March 4, 2021.

The BeMobile Floating Car Data provide an excellent source for an off-line assessment of the OptaSense data. As of February 3, 2021, FCD data are no longer available. The MTM AID status data and the Individual loop data (IVP) provide additional data sources to compare against. But these data are limited to specific longitudes. This leaves a time window of only a few weeks where both FCD and OptaSense data are fully available, which is too short. Therefore mainly MTM data have been used as a reference.

Another complication is that due to the Covid situation the number of congestion events in the studyperiod has been very low. As of January 23 a curfew applies after 21:00.

1.2 Results for the A9L

The OptaSense data on the A9L were extensively studied but the correlation between the OptaSense speeds and congestion indicators for the A9L and the occurrence of traffic events logged by the MTM system has been quite weak.

Congestion events reported in the MTM system are often barely visible in the OptaSense speed map, while the same speed map frequently reports slow traffic in periods where the MTM system reports no incidents.

Even a very severe congestion event on February 1 that lasted over 3 hours and spread over the full length of the A9L is only partially visible in the OptaSense speed map.

Attempts have been made by OptaSense to tweak the system for improved detection quality but in the end the conclusion must be that for the A9L the system has little added value.

1.3 Results for the A9R

For the A9R the results are much more promising. Congestion events detected in the MTM system were usually reproduced in OptaSense system.

There are however a number of concerns:

- The congestion events are usually reproduced with a considerable delay. This delay typically is between 1 and 10 minutes;
- For each justified congestion alarm there are many congestion alarms that do not correspond to detected congestion events by the MTM system. In many cases these alarms are restricted to a small area or a short period;
- The observed speed seems to be correlated with the traffic volume. In periods with low traffic volumes, for example during the night, the system reports low speeds much more frequently than plausible;
- For at least one location the system is adversely affected by traffic at the service area that is located there (Twaalfmaat fuel station, parking and restaurant).

Given these concerns, transferring the FCD-based AID solution as evaluated earlier to a fiber optics based solution without changing the underlying logic is not advised. For the application of AID it would simply generate too many false alarms and probably also respond with too much delay.

1.4 Possible adaptations

1.4.1 Filtering of congestion alerts

The problem of false alerts can be addressed by filtering the congestion alerts. In this case an AID is only generated when in a specific time-space contour *multiple* independent congestion alarms are detected. This is to prevent that a single faulty observation can trigger an AID.

In a way this is similar to the AID algorithm based on FCD data. Also in this case an AID is only triggered after a first observed slow vehicle, is followed by at least one extra observation originating from a different vehicle.

FCD measurements contain a so-called "uuid" that uniquely identifies the device that generates the measurements. This makes it easy to separate between independent measurements. OptaSense speeddata are reported per chunk and 10 second time slot and cannot be traced back to individual vehicles. Therefore if a heavy vehicle on service road nearby triggers a number congestion alarms that are false from the viewpoint of managing traffic om the A9, it is difficult for the system to conclude that these multiple alarms have a common cause.

Requiring congestion alarms to be confirmed before triggering an AID is an effective manner to reduce false congestion alarms but also leads to an increase of the response time.

1.4.2 Gradual improvement

There are a number of parameters that OptaSense applies to transform raw data into speed estimates and congestion alerts. OptaSense has tuned the system to obtain the optimal tradeoff between the sensitivity of the system for slow vehicles and suppressing noise that could lead to erroneous results.

The ever recurring problem is that slow vehicles are less visible to the system because these cause less vibrations, while detecting slow speeds is the main interest of the system in the current application.

Results have shown that tuning of the system has resulted in quite large differences in behavior. Although the current state of the system is considered to be the best achievable result, there is always the possibility of further improvements.

1.4.3 Geofencing

Some locations have much more incidental reports of congestion than others. Where these locations coincide with known sources of interference, it might be a good strategy to exclude these, or at least make the system less sensitive locally. A good candidate for this would be the longitudes in the area of the Twaalfmaat rest area.

1.4.4 Data fusion

For the A9R the alerts generated by MTM where usually overlapped by alerts of the OptaSense system, which is a good thing However the OptaSense system also generates many false alarms. It might therefore be a good idea to combine the OptaSense system with complementary detection system, like FCD.

1.4.5 Interpretation of the underlying waterfall data

The raw OptaSense data can be visualized as a so called Waterfall plot (see Figure 1). The mechanism that OptaSense uses to derive speed estimates and congestion alerts from these is not known in detail. However it is known that the congestion alerts were derived from the speed estimates, which in turn should be considered as the best available estimates of the average speed.

For AID detection not so much the average speed is relevant, but the presence of slow vehicles. Therefore it is conceivable that the congestion indicator can be improved upon, by creating an algorithm that is based on the raw data rather than the speed estimates.

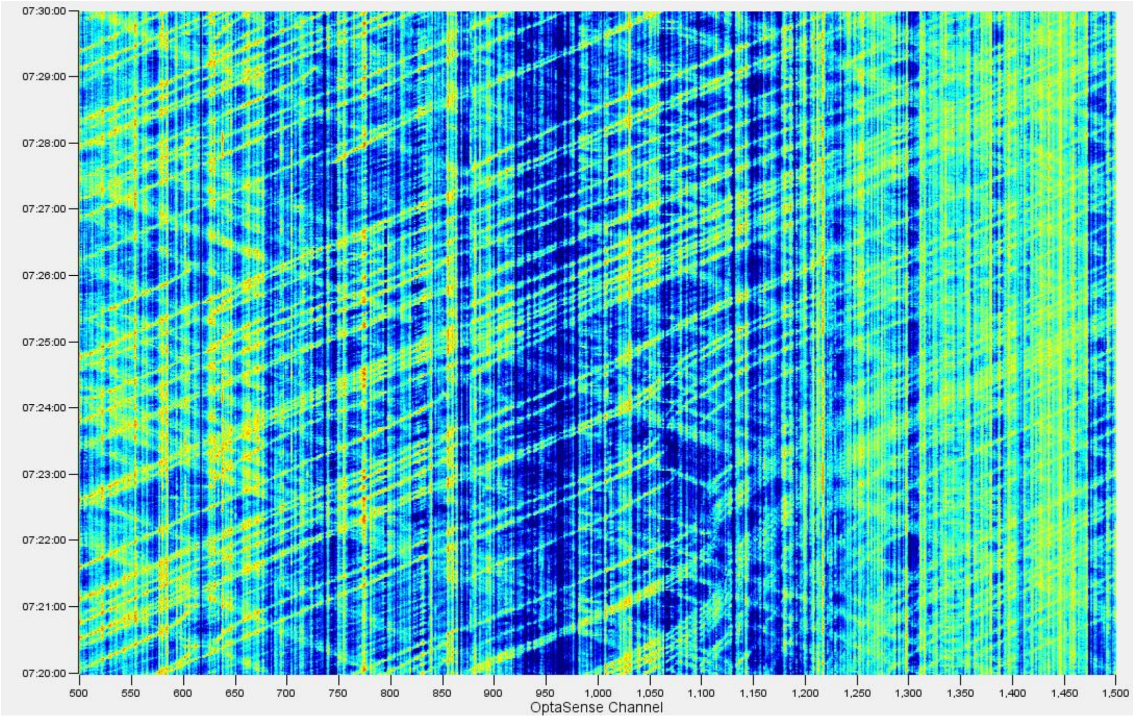


Figure 1: *Waterfall plot. Time is plotted on the vertical axis and ranges from GMT 07:20- 07:30 on 29 Jan 2021. This is local time 08:20-08:30. On the horizontal axis the channels are plotted. Colors indicate the amount of vibrations detected. The channels 1050-1150 correspond to longitudinal positions km 61.450 – 62.390.*

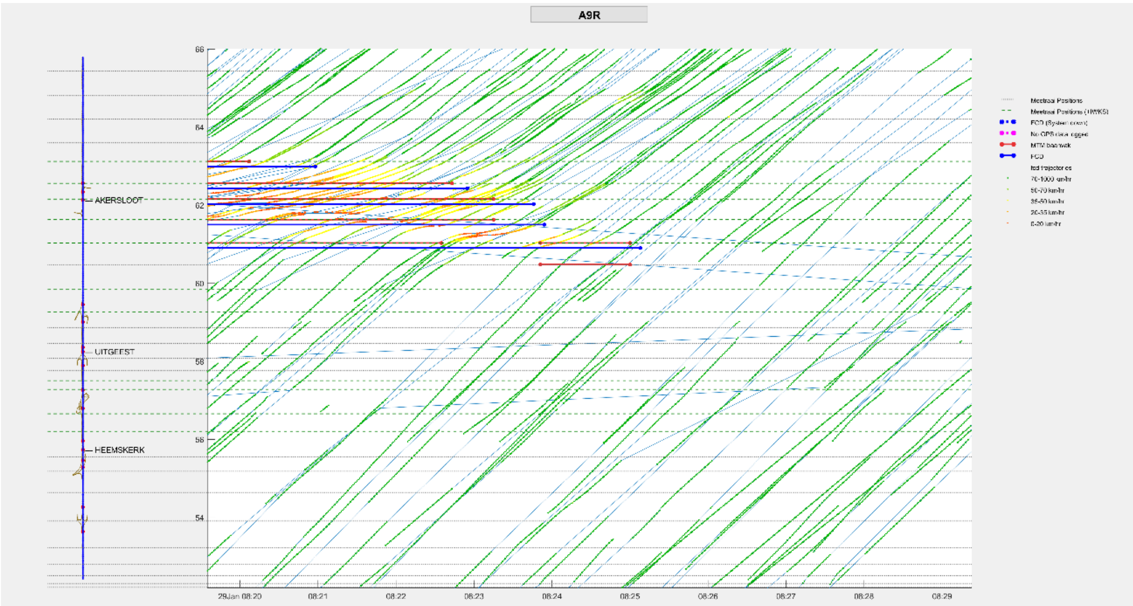


Figure 2: *Corresponding plot of the fcdview viewing tool. Time is plotted on the horizontal axis, longitude is plotted on the vertical axis. Sloping lines correspond to FCD trajectories. Horizontal lines correspond to MTM AID's (red) and FCD based AID (blue).*

2 Introduction

2.1 About the project

As of November 1 2020, Rijkswaterstaat has contracted OptaSense to deliver traffic data based on the “OptaSense Road System” solution. This product utilizes an existing fiber optic data cable that is embedded in the right shoulder of the A9.

Typically fiber-optic cables contain multiple optical fibers that can be used for data transmission independently, and in most cases only a part of the optical fibers in a cable are in use. The OptaSense solution utilizes an unused optical fiber. At one end this fiber must be terminated with a passive component called a “fiber termination point” (T). The other end is connected to a so called “interrogator unit” (IU) . The maximum allowable length of the fiber is 40 kilometer. Each interrogator is connected to a “processing server” (PS), and a processing server can accommodate two interrogator units.

Given these components, different configurations can be built. See for example Table 1.

Table 1: *Configuration possibilities*

Hardware Configuration	**Theoretical Monitoring Capability**
1 PS, 1 IU, 1 fiber in a single shoulder of the road	Allows traffic monitoring in both directions for a maximum stretch of 40 kilometers, directly upstream or downstream of the location of the IU. On the far side (relative to the shoulder) the monitoring quality might be bad.
1 PS, 2 IU, 2 fibers in both shoulders of the road, both fibers in parallel direction	Allows traffic monitoring of a maximum stretch of 40 kilometers, directly upstream or downstream of the location of the IU.
1 PS, 2 IU, 2 fibers in one shoulder at departing in opposite directions	Allows traffic monitoring of a maximum stretch of 80 kilometers, (40 upstream and 40 downstream relative to the location of the IU’s). On the far side (relative to the shoulder) the monitoring quality might be bad.

Each configuration collects traffic data at relatively low costs. Traffic on all lanes is monitored simultaneously and in theory it should be possible to monitor traffic in both directions with each configuration, although fibers in both shoulders allow for a better overall monitoring quality. The system reports 1 minute averages of speeds for “chunks” with a typical length of 50 meters. The estimates are updated each 10 seconds.

The main question addressed in the current project is if an Automated Incident Detection can be operated that is entirely based on the data provided by OptaSense Road System. The current project has a limited scale and can therefore only explore this option.

2.2 Site description

The OptaSense solution targets the northbound (A9R) and the southbound direction (A9L) of the A9, for longitudes between km 51.8 (Beverwijk) and km 69.5 (Alkmaar). It utilizes a fiber that resides in the right shoulder of the A9R (this corresponds to the first hardware variant in Table 1). Hence the distance between the fiber and the lanes carrying road traffic on the A9R is much smaller than the distance to the lanes on the A9L. For this reason it is expected that the derived speeds and congestion alerts for the A9R will be of a higher quality than those derived for the A9L.

2.3 Calibration and availability of the OptaSense system

The system was physically installed on September 28, 2021 and calibrated by OptaSense in the subsequent months. The first meaningful results have become available on December 9, 2020, but at that time OptaSense was still in the process of further calibrating the system. After a few rounds of inspection and feedback, starting January 21, 2021 the final calibration of the system has been available. A slight adjustment has been applied as of March 4, 2021. Appendix 7 contains a diary of configuration changes.

2.4 Reference data

The BeMobile Floating Car Data provide an excellent source for an off-line assessment of the OptaSense data. The MTM AID status data and the Individual loop data (IVP) provide additional data sources to compare against. But these data are limited to specific longitudes. As of February 3, 2021, FCD data are no longer available. This leaves a time window of only a few weeks where both FCD and OptaSense data are fully available.

2.5 Covid 19

Another complication is that due to the Covid situation the number of congestion events in the study period has been very low. As of January 23 a curfew applies after 21:00.

3 Assessment approach

3.1 Considering AID status in isolation

When an AID outcome is assessed for a specific combination of longitude and time-instant, 4 options exist, depending on the traffic state (congested or not) and the detection status (incident detected or not). The outcome of an AID algorithm can be wrong in two ways: failing to detect an existing congested state (false negative) or falsely detecting congestion (false positive). When developing an AID method one seeks to simultaneously minimize both types of error.

Any investigation into the suitability of an AID algorithm is required to look into both types of error.

A complicating factor is that the distinction between congested state and free flowing traffic is a gradual one. Also, depending on its parameters an AID algorithm may or may not characterize a specific situation as an incident, which makes the distinction somewhat arbitrary.

3.2 Considering AID status as a function of time and space

Also, congestion events are not limited to a single location and time instant but always span a time- and longitude interval. When this is taken into consideration an AID detection is usually not assessed as 100% right or wrong but rather as "early" or "late" or "too much upstream" or "too much downstream".

3.3 Considering the AID status from a practical point of view

The main objective of AID is to prevent accidents by warning upcoming traffic for congestion. When assessing the quality of an AID solution one would ideally like to express to which extent an AID algorithm contributes to this.

The highest risk for accidents exists when a driver arrives at the upstream end of a congestion. AID will be effective if a high proportion of drivers confronted with congestion is alerted for this in a timely manner. In this context "timely" means that at the moment of the warning the headway to the congestion should be between 500 and 1000 meters. Warnings given to late obviously have no use, but warnings given to early have the adverse effect that future warnings might be ignored.

Therefore the utility of each AID algorithm can be summarized as the accuracy with which it predicts the upstream end of a congestion.

With this in mind visualizations should be interpreted and quantitative results should be analyzed.

3.4 Visual exploration of the results

The sole method of exploration in the current study is that of visual inspection. A quantitative analysis of the results would have been more objective but is not feasible due to lack of reference data, scarcity of congestion events, calibration changes that have been made to the OptaSense system during the studyperiod and budget constraints.

The results of the exploration are presented in chapter 4.

3.5 Software used for visualization

To visualize the OptaSense data the “fcdview” application was extended with the option to display OptaSense data. The fcdview displays traffic data as a function of time (x-axis) and longitude (y-axis). The color is used to display the speed or congestion status.

In the same plot other data sources can be shown such as:

- Floating Car data (FCD) trajectories;
- Observations created with double inductive loops. These observations are available for each separate lane at specific longitudes. Each data point consists of a longitude, lane, time stamp, recorded vehicle length and recorded vehicle speed;
- Log files of the Motorway Traffic Management system. These log files contain the full history of the text-content of the “Matrix SIgnaalgevers” (MSI’s) that was shown on the portals above the A9;
- Also from the MTM log file, the history of the AID status for each MTM portal is available. This AID status is usually derived from loop detectors at the portal itself and the next downstream set of loop detectors.

4 Exploration and Verification of OptaSense data

4.1 Introduction

An indispensable step in the exploration of a new data source like OptaSense is to visually inspect the data so that a proper intuition is developed about the information that is contained in the data. The inspection process itself generates a multitude of graphs. Part of these were presented and discussed in separate screencasts that have been published on a weekly basis during the project. See section 4.2 for this.

The fiber used for detection is located in the right shoulder of the northbound side of the A9 (indicated as the A9R). An important finding of the initial inspection is that congestion events on the south bound side of the A9 (the A9L), although technically monitored by the OptaSense system, go largely undetected while on other occasions the system reports unlikely spells of slow or missing traffic. Given the unfavorable location of the A9L relative to the fiber this is not an entirely unexpected result. The remainder of the exploration mainly focuses on the A9R.

As noted in section 3.1 the exploration should look into two types of error:

- *Falsely detecting a congestion event.* To get insight into this phenomenon section 4.3 visualizes the congestion status as reported by the OptaSense system for each week in the study period, together with the MTM AID status. This gives insight in how often OptaSense data indicate incidents outside periods covered by MTM AID events;
- *Failing to detect a congestion event.* Section 4.4 enumerates and visualizes all congestion events on the A9R in the study period. The raw OptaSense speed data for these periods were subsequently inspected.

4.2 Screencasts

The “fcdview” software was used to create periodic updates that were published as screencasts. Each screencast is a presentation with a duration between 2 and 15 minutes. The table below lists these presentations in chronological order.

Published on www.modelit.nl as:	**Archived as:**
screencast1.mkv	20201116_screencast1.mkv
screencast2.mkv	20201116_screencast2.mkv
exploreOptaSense.mkv	20201227_exploreOptaSense.mkv
exploreOptaSense2.mkv	20210106_exploreOptaSense2.mkv
A9R_jan15.mkv	20210121_A9R_jan15.mkv
northbound.mkv	20210121_northbound.mkv
southbound.mkv	20210121_southbound.mkv
A9R_week04.mkv	20210201_A9R_week04.mkv
A9L_week5.mkv	20210209_A9L_week5.mkv
A9R_week5.mkv	20210209_A9R_week5.mkv
A9R_week6.mkv	20210215_A9R_week6.mkv
A9R_week7.mkv	20210222_A9R_week7.mkv
A9R_week8_9.mkv	20210309_A9R_week8_9.mkv

These presentations speak for themselves and will not be discussed separately in the current report.

4.3 Inspection of the OptaSense congestion indicator

The appendix "Appendix: congestion plots, OptaSense indicator" (8) contains a series of separate plots of the OptaSense congestion indicator, where each plot covers 1 week of data.

By zooming in on these plots one can compare the congestion indicator with the MTM AID status. When comparing the two one must bear in mind that the MTM AID typically is derived from two sets of inductive loop detectors spaced 300-500 m apart and reported at the most upstream longitude of the pair. The OptaSense system reports on chunks with a typical length of 50 m.

The OptaSense congestion indicator has in fact two levels, where level 1 should be interpreted as light congestion and level 2 as heavy congestion. For the current study we have only considered level 2. Inspecting all level 2 congestion alarms gives the number of false positives, also known as nuisance alarms. In summary these can be categorized as follows:

- Alarms that are seemingly caused by interference of traffic on a nearby road or service area;
- Alarms that occur in periods with very low traffic volumes. It seems that when traffic volumes are (very) low the system is prone to reporting slow speeds that are very unlikely given the nightly hour they are recorded;
- Isolated, short lived alarms without an obvious explanation.

If the OptaSense congestion indicator were to be deployed in an automated and unattended mode one of the challenges would be to implement a method that would filter out these unwanted alarms.

4.4 Inspection of congestion events

4.4.1 Congestion events recorded by MTM

To inspect to what extent congestion events are visible in the OptaSense data, all congestion events on the A9R after 1 January 2021 have been tracked down. For each event the time and space spanned by the event has been manually recorded. Events that span less than 3 minutes or less than 2 subsequent portals are ignored. This is to exclude the very light events. Also the events that occurred on 7 and 8 February have been ignored. Due to icy conditions the A9 has been barely accessible on these days, and conditions were not representative at all.

What remains is a total of 21 events. Each event is displayed in detail in the appendix "MTM Congestion events on A9R". Figure 3 shows all events as black verticals, followed by a sequential number that identifies the event. Table 2 provides date, time, duration (in minutes), downstream longitude and length (in km) for each event.

Due to the Covid related lockdown measures that still continue, congestion has been much less than normal for the time of year. Also the average duration of the events is much less than average. For example, the duration for 6 of the 21 events considered is less than 10 minutes.

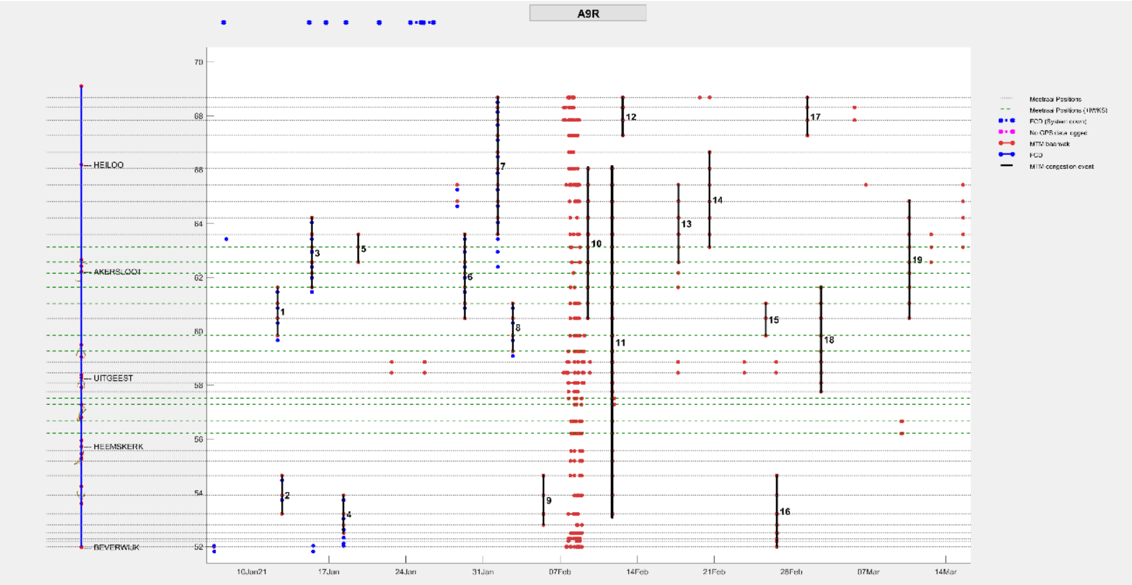


Figure 3: *Manual selection of MTM congestion events on the A9R in 2021.*

Table 2: *Manual selection of congestion events on the A9R in 2021*

Index	Date	Time	Duration (min)	Longitude (km)	Length (km)
1	12-01-2021	08:11	7	61.648	1.820
2	12-01-2021	17:50	7	54.654	1.448
3	15-01-2021	10:27	78	64.235	2.634
4	18-01-2021	08:02	23	53.924	1.419
5	19-01-2021	16:19	3	63.604	1.051
6	29-01-2021	08:04	21	63.620	3.161
7	01-02-2021	07:42	30	68.713	5.137
8	02-02-2021	16:36	12	61.044	1.791
9	05-02-2021	11:05	50	54.664	1.852
10	09-02-2021	11:40	115	66.101	5.645
11	11-02-2021	16:25	117	66.141	13.071
12	12-02-2021	15:42	79	68.706	1.459
13	17-02-2021	17:38	20	65.465	2.936
14	20-02-2021	13:12	40	66.676	3.561
15	25-02-2021	16:00	6	61.052	1.219
16	26-02-2021	15:38	71	54.664	2.684
17	01-03-2021	10:11	50	68.696	1.441
18	02-03-2021	15:51	43	61.674	3.942
19	10-03-2021	16:15	37	64.870	4.407

4.4.2 Congestion events: plots by event

A separate appendix "MTM Congestion events on A9R" contains visualizations of each separate congestion event in Figure 3 / Table 2. As an example Figure 4 shows a joint plot of the OptaSense speed data and the FCD/BeMobile AID status.

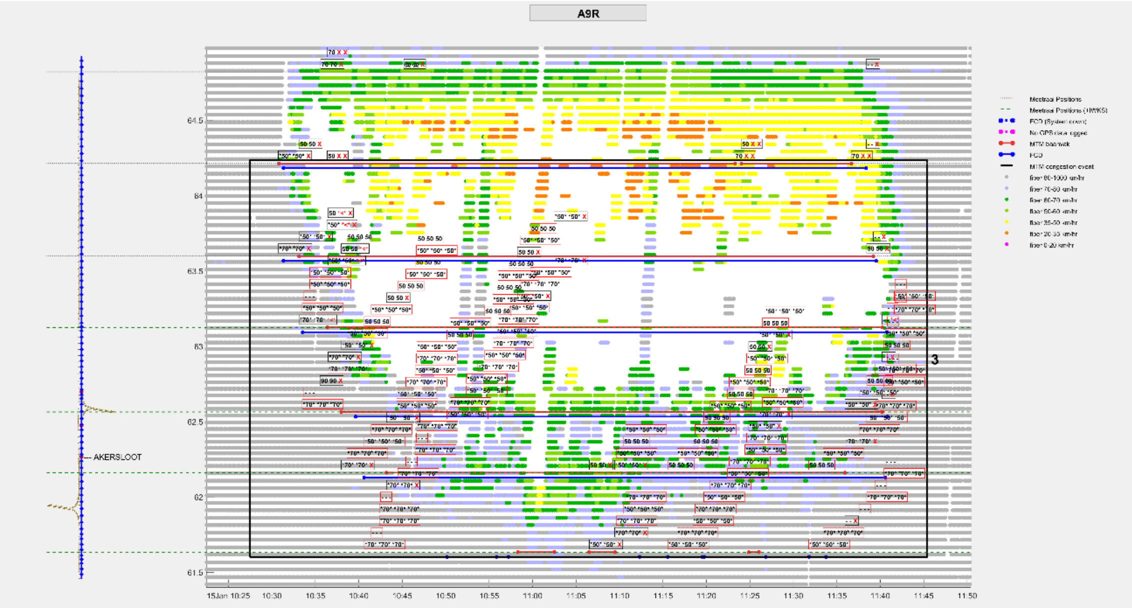


Figure 4: *Joint plot of OptaSense speed data and FCD/BeMobile AID status*

In this (and all other plots in the appendix) the OptaSense speeds are displayed as colored dots. As shown in the table below, 7 colors are used.

Speed range	Dot color
80 km and above	Grey
70-80 km/h	Light blue
60-70 km/h	Green
50-60 km/h	Light green
35-50 km/h	Yellow
20-35 km/h	Orange
0-20 km/h	Magenta
no traffic	white / no color

The signs that are shown on the portals above each lane are plotted as textboxes. The lower left corner of each textbox aligns with the longitude and time of the message. To prevent textboxes from overlapping in the plot, textboxes are shifted upward when needed.

The MTM congestion event index that refers back to Figure 3 / Table 2 is plotted in each plot to the right of the black square that indicates the time and longitude spanned by each congestion event. These squares were drawn manually based on the MTM AID detections that are visible as red lines in the plots. The boundaries of the plots are set to 5 minutes before and after the event and 200 and 750 meters upstream and downstream of each event.

4.4.3 *Congestion events: Summary of findings*

After inspecting the plots a number of general impression remain. These are:

- Congestion events with a short duration are not clearly visible in the OptaSense data. The main tell tale of these events seems to be that the recorded speed indicates "no traffic". Observations of slow traffic (35- 50 km/h, yellow) and very slow traffic (20-35 km/h, orange) that coincide with short-lived congestion events are rare;
- The status "no traffic" also frequently occurs outside of the area spanned by the congestion event;
- The plots show no observations of Stop-and-go traffic (0-20 km, magenta) at all;
- There seems to be a delay in detecting changes in average speed that varies from 1 to 10 minutes;
- Congestion events detected by MTM correlate with lower speeds recorded by the OptaSense system, meaning that in each MTM congestion event one sees reported speeds dropping below 70 km/h. But especially in short lived congestion events the reported speed is on average higher than one would expect;
- Congestion events with a longer duration are reproduced with a better quality. In these events one sees also that low and very low speeds are reported by the OptaSense system.

What does this mean for the applicability to AID?
Quoting section 3.3 "The main objective of AID is to prevent accidents by warning upcoming traffic for congestion. The highest risk for accidents exists when a driver arrives at the upstream end of a congestion. AID will be effective if a high proportion of drivers confronted with congestion is alerted for this in a timely manner. Therefore the use of each AID algorithm greatly depends on the accuracy with which it predicts the upstream end of a congestion, also referred to as the tail of the congestion."

In the case of the OptaSense data the general impression is that prolonged periods of slow traffic are correctly detected, but that in order to keep the false alarm rate to an acceptable level, measures would be needed that would probably go at the cost of an increased latency.

This means that if a congestion is more or less stationary and spans a period of several hours a high proportion of the upcoming traffic can be alerted in an adequate manner based on data collected with the OptaSense system. On the other hand, if a congestion is short-lived, or if the location of the tail of the congestion is moving fast and unpredictable, an algorithm based on the current OptaSense data does not trace the tail of the congestion sufficiently accurate to be useful for AID.

Can the results found in the current study period be extrapolated to the general case?
During the study period, 21 congestion events have been identified. If there were to be a near perfect correspondence between the MTM congestion

events and the detection of slow or absent traffic in the OptaSense system, these 21 congestion would have been sufficient justification to extrapolate such results. Given the variability of the outcomes this is now much harder.

Can the results be transferred to other locations?
When the traffic state transitions from free flowing to fully congested the OptaSense plots in the appendix "MTM Congestion events on A9R" typically show normal speeds initially and "no traffic detected" at the end. In between one would expect a number of observation of vehicles driving 35-50 km/h (displayed as yellow dots) or 20-35 km/h (displayed as orange dots). In many plots (for example plots 1,2,3,4 and 5) such a transition is not or barely visible.

The explanation for this is somewhat speculative. But could be as follows: The system relies on vibrations that reach the fiber optic cable that is used for monitoring. Weight and speed are assumed to be important factors that determine the amount of vibrations induced by a vehicle. Slowly moving vehicles risk not being detected by the system as their signal is weak in comparison with the background noise. Below a certain speed lighter vehicles like person cars might even be no longer detectable by the system. The plots indicate that for some locations this lower limit might be well above the threshold that one would normally use to decide whether or not the traffic is congested. In order to continue using the system for detecting congestion a number of options exist:

- Change the tuning of the system by increasing its sensitivity;
- Apply a higher speed threshold.

However there seems to be a delicate trade of between being able to detect slow vehicles on the one hand and eliminating the influence of interference and background noise on the other hand. The outcome of this trade of might very well vary from site to site. This would make the system less transferrable.

4.5 Summary of the results

Overlooking all results (screencasts [4.2], congestion status plots [4.3] and Congestion event plots [4.4]) the results are summarized in the subsections below.

4.5.1 Results for the A9L

The OptaSense data on the A9L were extensively studied but the correlation between the OptaSense speeds and congestion indicators for the A9L and the occurrence of traffic events logged by the MTM system was quite weak.

Congestion events reported in the MTM system are often barely visible in the OptaSense speed map, while the same speed map frequently reports slow traffic in periods where the MTM system reports no incidents.

This is best illustrated by showing a pair of plots based on FCD and OptaSense datasources for a particularly severe congestion event on February 1 that lasted over 3 hours and spread over the full length of the A9L. The FCD data show the congestion very clearly while the same congestion event is only partially visible in the OptaSense speed map.

Attempts have been made by the OptaSense team to tweak the system for improved detection quality but in the end the conclusion must be for the A9L the system has no added value.

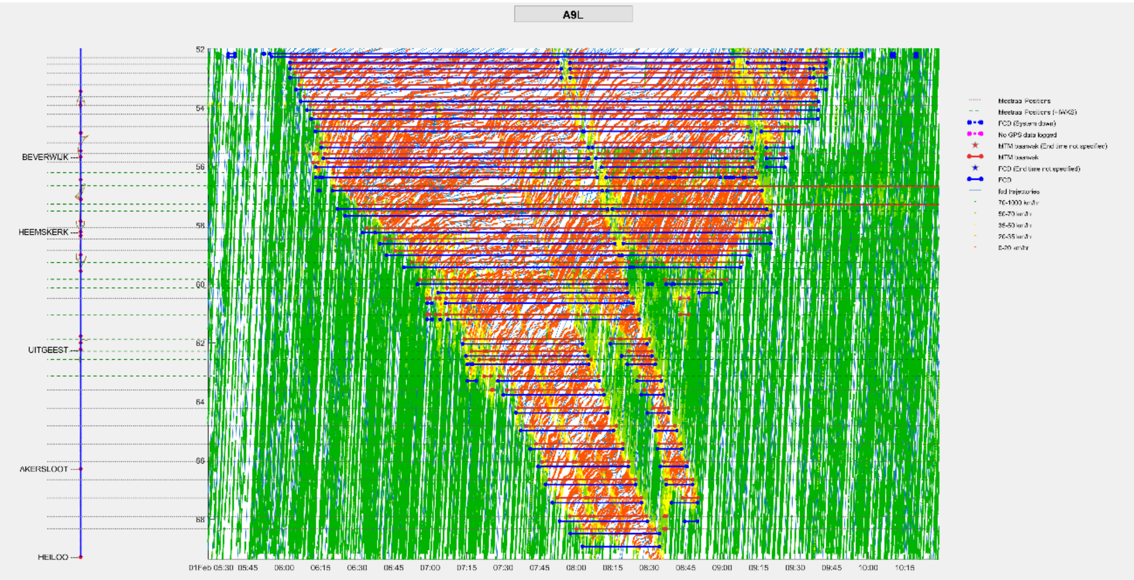


Figure 5: *FCD data for the A9L on 01 Feb 2021 for the period 05:30-10:30*

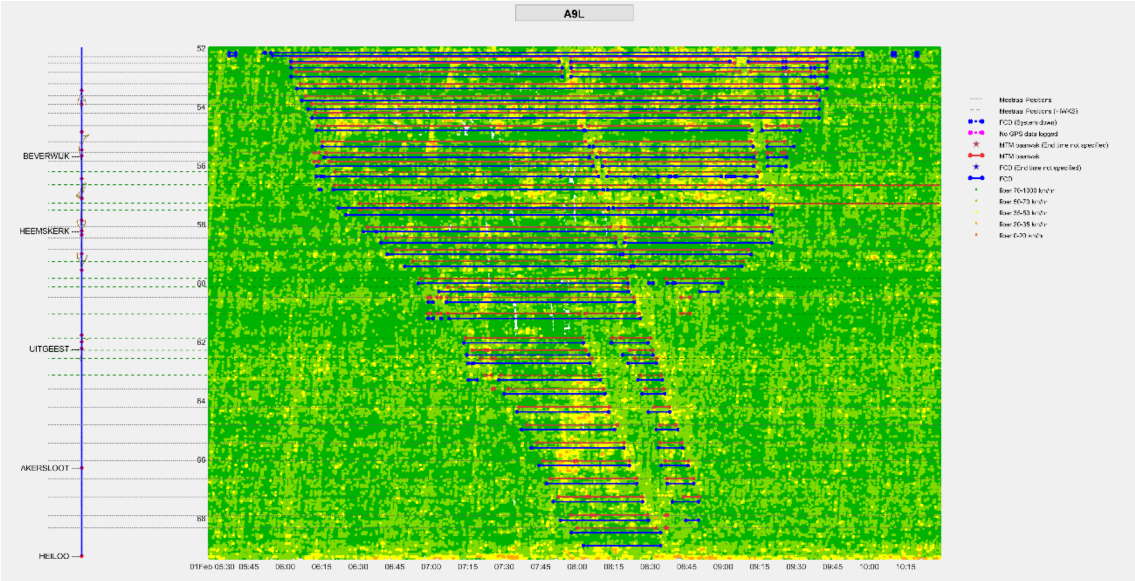


Figure 6: *Optasense speed data for the A9L on 01 Feb 2021 for the period 05:30-10:30*

4.5.2 Results for the A9R

For the A9R the results are much more promising. Congestion events detected in the MTM system are usually reproduced in OptaSense system. Figure 7 is a good example of this. The MTM data in the figure show an extensive congestion that in fact consists of 3 large congestion waves merged together. This is reproduced in the OptaSense speed data, although with a few minutes of delay.

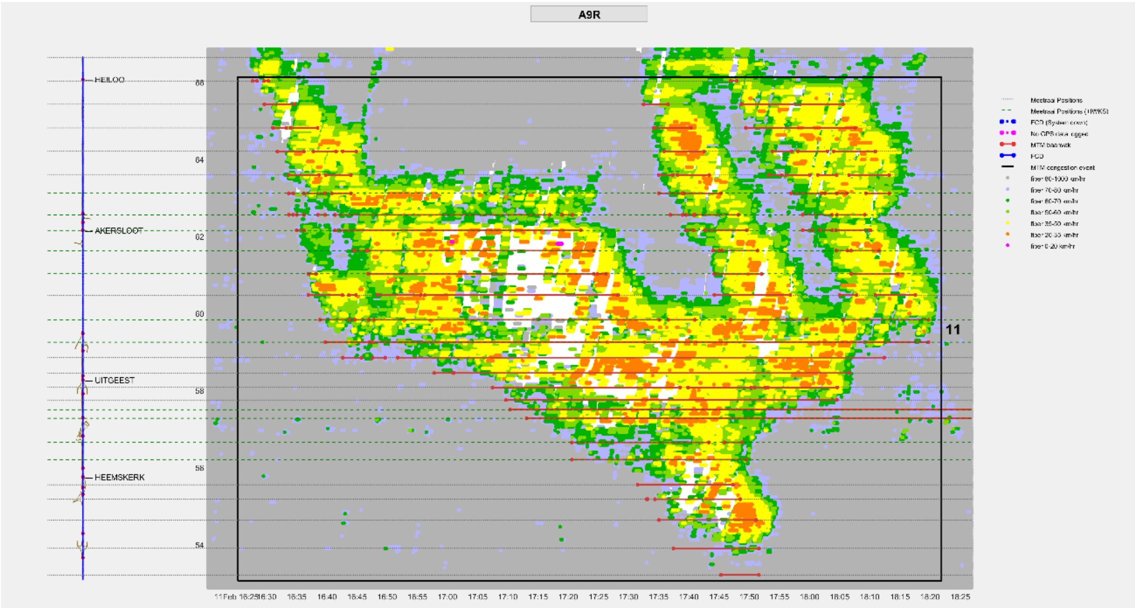


Figure 7: *OptaSense speed data for the A9R on 11 Feb 2021 for the period 16:30-18:30. Note that the emphasis in the plot is on speeds below 70 km/h. These are plotted with colors ranging from green to orange. Higher speeds are plotted in purple and grey.*

There are however a number of concerns:
- The congestion events are usually reproduced with a considerable delay. This delay typically is between 1 and 10 minutes;
- For each justified congestion alarm there are many congestion alarms that do not correspond to detected congestion events by the MTM system. In many cases these alarms are restricted to a small area or a short period;
- The observed speed seems to be correlated with the traffic volume. In periods with low traffic volumes, for example during the night, the system reports low speeds much more frequently than plausible;
- For at least one location the system is adversely affected by traffic at the service area that is located there (Twaalfmaat fuel station, parking and restaurant).

Given these concerns, transferring the FCD-based AID solution as evaluated earlier to a fiber optics based solution without changing the underlying logic is not feasible. For the application of AID it would simply generate too many false alarms and probably also respond with too much delay.

5 References

[1] Joe Ciorra, Graham Bruce (26/10/2016) OptaSense® Road System Interfaces Tech Note, (REF TDS-14-000096-ITN)

6 Appendix: Importing the OptaSense data

6.1 Introduction

OptaSense is a system that delivers traffic data based on analyzing signals that are sent through existing fiber data cables. In past months a trial project has been conducted on the A9 motorway. The objective of the trial is to assess if OptaSense data can be used to generate reliable Automated Incident Detection (AID) messages.

After the OptaSense system was installed the first step was to explore and verify the data. A first step in this process is to write code to import the OptaSense data and to convert the data to a format that allows further processing. This includes mapping the OptaSense data to the road network.

Before developing and evaluating methods that rely on this interpreted OptaSense data it is required that a number of tests are conducted. This is to prevent that future work needs redoing because of wrong assumptions about the data.

These steps are includes in the OptaSense import routines as developed for the current project.

6.2 Importing OptaSense data

6.2.1 Data

The format of the OptaSense data is described in the document "OptaSense® Road System Interfaces Tech Note" , see [1], locally stored as "OptaSense Road System Interfaces Tech Note.pdf"

The table below was taken from this document and describes the type of data that is available.

Type	Filename(s)	Data Resolution	Time Resolution	Approx. Size (per day)
Speed Data	*speedA_DATE.csv* *speedB_DATE.csv*	50 m	10 seconds	120 MB
Histogram Data	*histogramA_DATE.csv* *histogramB_DATE.csv*	500 m (default)	60 seconds	30 MB
Journey Times Data	*journeyTimesA_DATE.csv* *journeyTimesB_DATE.csv*	Time between adjacent junctions	10 seconds	3.5 MB
Queue Data	*QueueA_DATE.csv* *QueueB_DATE.csv*	50 m	10 seconds	24 MB
Congestion Data	*IncidentA_DATE.csv* *IncidentB_DATE.csv*	50 m	10 seconds	24 MB

Speed Data, Queue Data and Congestion Data are available as matrices, where rows correspond to time stamps and columns correspond to locations. The time stamps are listed in the first column using the format "dd/MM/yyyy HH:mm:ss" and represent UTC.

These data will be visualized in the “fcdview” application. Histogram Data and Journey Travel Time data will not be inspected at this moment.

6.2.2 Metadata

All relevant metadata is stored in the files:
“A9_Lookup_Table_A_L.csv”
(for datafiles stored in folder A, corresponding to A9L), and:
“A9_Lookup_Table_B_R.csv”
(for datafiles stored in folder B, corresponding to A9R).

In these files the following columns are relevant for direct exploration:

Road Latitude, Road Longitude	WGS coordinates that correspond to the central position of the indicated chunk. Each chunk has a length of about 50 meter.
Chunk Index	A (zero based) column reference that specifies the column that stores the Speed Data, Queue Data or Congestion Data. Because this is a zero based index and because the first column in the csv files is reserved for the time stamps chunk index = 0 means that the data for the first chunk are stored in column 2 of the csv file, the data for chunk 1 are stored in column 3, etcetera.

6.2.3 Mapping Lon-Lat pairs to hectometer

The location reference system that is universally used by Rijkswaterstaat is BPS (Bepalende Plaats Systematiek). This is a reference method that identifies locations using attributes. The dominant attributes that identify a location are:

- *Road Number*, an integer number that is unique for each main corridor;
- *Road Direction*, a letter “R” or “L”, where R corresponds with the direction of increasing longitude;
- *Longitudinal Position*, the travel distance between most upstream point and the specified location (offset by the longitude assigned to the upstream point);
- *Segment Letter*, if specified this any of a-z, in order to unambiguously identify locations on onramps ramps and connecting segments;
- *Lane type and Lane Number*. If required these attributes define the cross sectional position.

Although in reality road sections are 3D surfaces, the majority of the traffic models consider one dimension only, the longitude. This applies to the AID algorithms as well. In order for these models to deal with observations that refer to real world coordinates, the coordinates must be mapped to the linear coordinate system used by the model.

6.2.4 *Software module description*

For the current project the metadata provided by OptaSense has been mapped to longitudes using and the adhoc script "read_csv_opta.m" that in turn relies on a number of pre-existing utilities in the Modelit code base.

This process is only needed once for each new OptaSense configuration, and can be carried out off line. At some stage it might be required to implement equivalent functionality in the production environment. For this reason it is outlined in the sections below.

6.2.4.1 Module: read_csv_opta

Phase 1: Read csv files and store content in binary format

For this the module "read_csv_opta.m" is used. This module is locally stored in the folder "impuval\fcdeval".

The names of the csv files are typically:

{YYYYMMDD}_{datatype}Data{roadside}.csv

With:

YYYYMMDD	the date;
datatype	the type of data (speed, congestion or incident);
roadside	a letter that indicates the direction (A for A9L and B for A9R);

In phase 1 the following variables are read from the csv file:

Variables read	Description
ts (Tx1)	The first column of the csv file contains time stamps. These are denoted as ASCII text using the convention {dd/MM/yyyy HH:mm:ss} and represent UTC time stamps. They are read into a binary Matlab "datetime" variable, with the TimeZone property registered as "UTC".
data (TxL)	The remaining columns are stored as double, where missing values are transformed to NaN (Not a Number)
HM (Lx1)	A vector with longitudes that correspond to the columns of the "data" matrix. This vector is not read from the CSV file, but is based on the Excel file with metadata provided by OptaSense. The module that reads the metadata and computes longitudes is LonLatHM.m and is stored locally in the folder (impuval\fcdeval\iwks\).

For each csv file the above variables are saved in a (binary) file with the name:

{YYYYMMDD}_{datatype}Data{roadside}.mat

This completes phase 1 (csv file conversion)

Phase 2: Combine content of converted csv files in weekly archive

Although the converted csv files can be loaded into the "fcdview" program, it is more convenient to load the data 1 week at a time. For this purpose the script "read_csv_opta", after completing phase 1, automatically runs phase 2. In this phase data from 1 week, starting at Monday and ending on Sunday, are combined in a single archive.

Normally this should have no effect on the data. The exception is if the "HM" vector somehow changes during the week. This may happen if the OptaSense configuration is changed. In this case the weekly HM vector is computed as the union of the daily HM vectors, and any missing cells in the "data" matrix are filled with a NaN (Not a Number) value.

6.2.4.2 Module LonLatHM

The module LonLatHM is locally stored in the folder impuval\fcdeval\iwks. Its objective is to:

- read the metadata files provided by OptaSense (see table below);
- combine these data into a single table;
- expand this table with a column "Side" that stores the road direction ("R" or "L") ;
- expand this table with a column "HM" that stores the longitude that corresponds to the WGS Latitude-Longitude pair provided by OptaSense.

File (Locally stored in)	**Content**	**Road side**
A9_Lookup_Table_B.csv (fcd2018\optasense)	Defines the mapping from chunk index (sequential number starting at 0) to WGS Latitude-Longitude pair	A9 R (northbound)
A9_Lookup_Table_B.csv (fcd2018\optasense)		A9 L (southbound)

The substantial part is the mapping of the WGS coordinates to a longitude on the A9. For this, the module LonLat2HM relies on 3 commands, as explained in the table below.

Matlab code	**Description**
	[Initial state] The input consists of an Nx2 matrix "WGS" with the WGS coordinates that need to be mapped, and the parameter "roadside" (R or L) that indicates the road side.
`nw=` `fetchNetwork(roadside)`	Load NWB network from disk. The network data is stored in a TRIP workspace. The TRIP application may be used to visualize and manipulate the

	network. The module "fetchnetwork" loads the workspace-data from disk and removes all but the network data. The remaining variable is a structure "nw". This structure holds two fields: nw +----svnet (segmentVector) +----dbfnet (Table)
`[longPos,segmentIndex,Xprj,Yprj, segLen]= xy2long(nw.svnet,RD(:,1), RD(:,2));`	The method "xy2long" is used to map RD coordinates to the segmentVector "nw.svnet". xy2long is part of the segmentVector toolbox.
`HM= assignHM(longPos,segmentIndex, segLen,nw.dbfnet);`	The module assignHM is used to compute a proportion from "longPos" and "segLen". Using this proportion, the initial longitude, and the length of an NWB segment, the longitude of the projected point is computed.
	[Final state] Output vector "HM" (Nx1) has been computed

7 Appendix: Diary of configuration changes and updates

This appendix contains a table that logs all events known by the author of this report that affect the OptaSense system. Only personnel of OptaSense is capable of making changes to the system. There is no strict protocol to communicate these changes. Usually changes are communicated orally or by email. The table below was reconstructed from looking at the data, notes and emails.

Date	**Event**
30-10-2020	Hardware has been installed in the traffic center in Velsen. A meeting has been held where Optasense has demonstrated the system to Rijkswaterstaat. In the days prior to the meeting Optasense personnel has visited a number of locations across the A9 traject to construct a set of reference data that will be used to calibrate the location map for the system. This is done by dropping heavy objects at various locations. The pulses that are created in the process are used in the calibration.
9-12-2020	Data has been calibrated with respect to position. Reported speeds and congestion status need further calibration.
10-12-2020	Technical acceptance test. A checklist that insures the system operates correct from a technical viewpoint is completed.
15-12-2020 13:00	Update in calibration of speeds.
28-12-2020 12:00 - 1-1-2021 01:00	Gap in data, or data not downloaded from server.
21-1-2021	Update in calibration of speeds, described as “Improve the sensitivity on both carriageways. This has the benefit of increasing the car-weighting of the average speeds and improving the low-speed detection rate”. Although the change is announced for 21/01, the effect is visible as of 20/01
4-3-2021 17:00	Update in calibration of speeds, described as: “we have modified a couple of settings on the 3rd March which should have the effect of reducing the averaging time on the speed measurements, and therefore making it more reactive than the current configuration”.

8 Appendix: congestion plots, OptaSense indicator

8.1 Background

When an AID outcome is assessed for a specific combination of longitude and time-instant, 4 options exist, depending on the traffic state (congested or not) and the detection status (incident detected or not). The outcome of an AID algorithm can be wrong in two ways: failing to detect an existing congested state (false negative) or falsely detecting congestion (false positive).

The current appendix gives insight in the second type of error by plotting the congestion status generated by the OptaSense system.

8.2 Approach

This appendix contains plots of the OptaSense congestion indicator, together with the MTM AID indicator (plotted as a red line) and the FCD congestion indicator (plotted as a blue line, if present). Each plot covers 1 week of data and the full stretch of the A9R or A9L.

The red dots represent the longitude-timestamp combinations for which the congestion indicator has vale “2”. The yellow dots represent the longitude-timestamp combinations for which the congestion indicator has vale “1”.

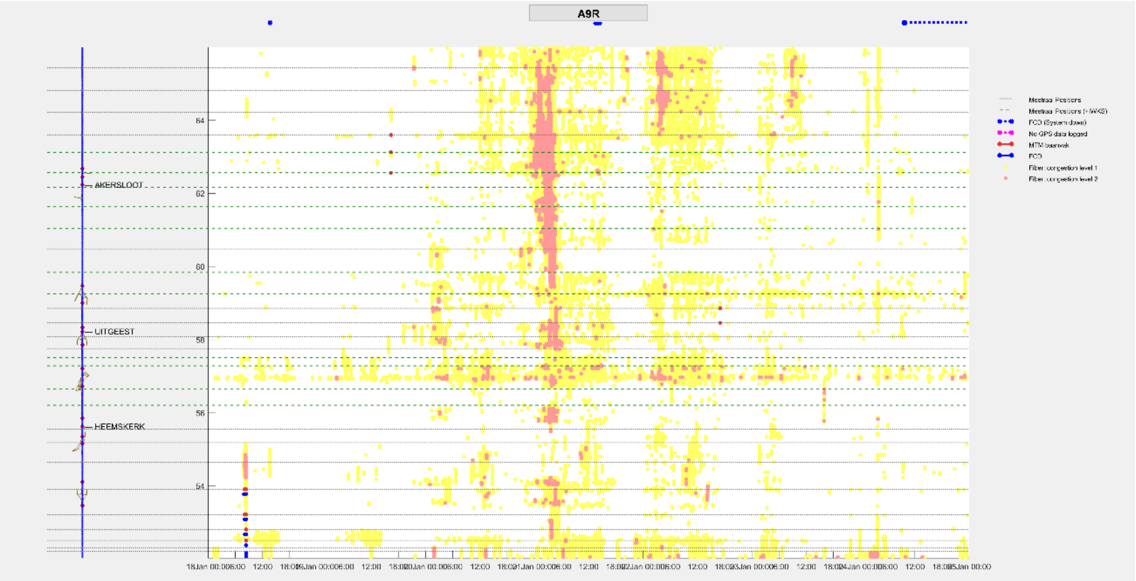
8.3 Findings

The findings are discussed in the main report.

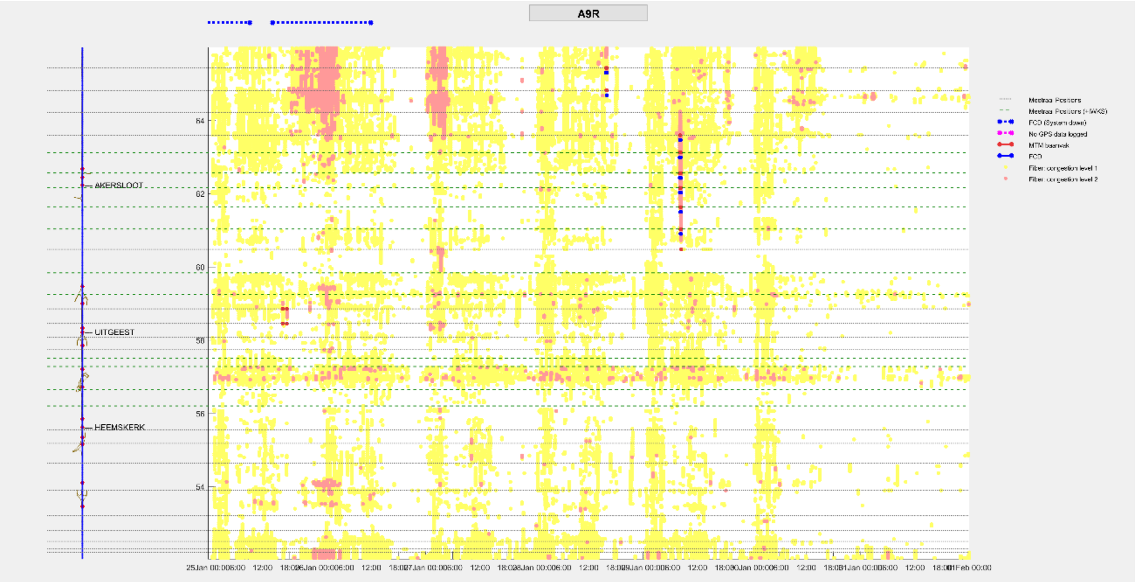
8.4 A9 North (A9R)

For the A9R all congestion status data are shown, starting week 3, 2021. Note that an important calibration update has been applied on January 21 (Thursday week 3), and a minor update has been applied on March 4 (Thursday week 9).

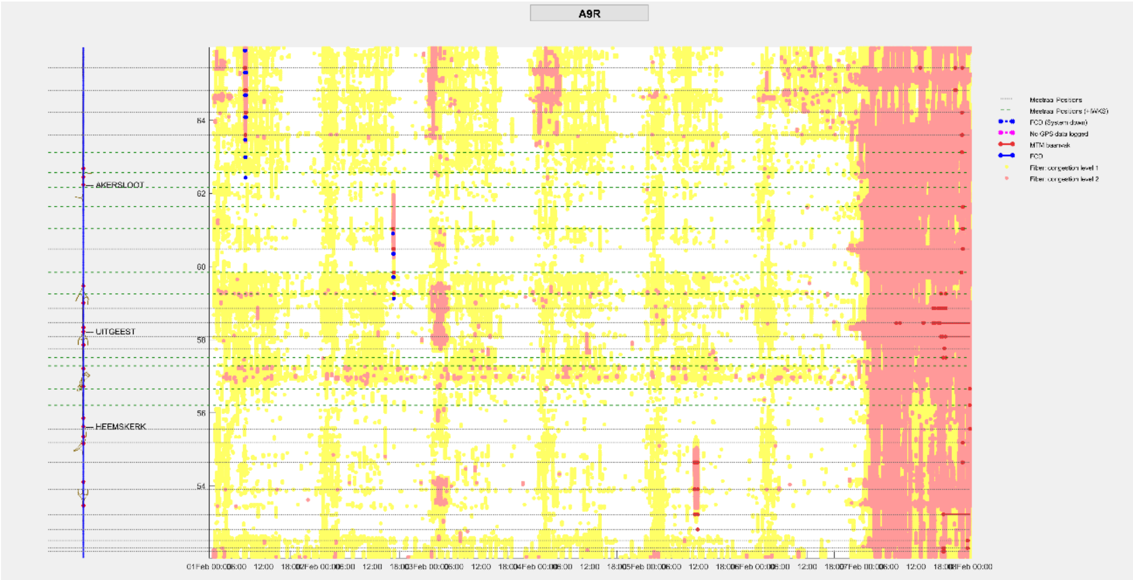
8.4.1 *2021, A9R, Week 3*



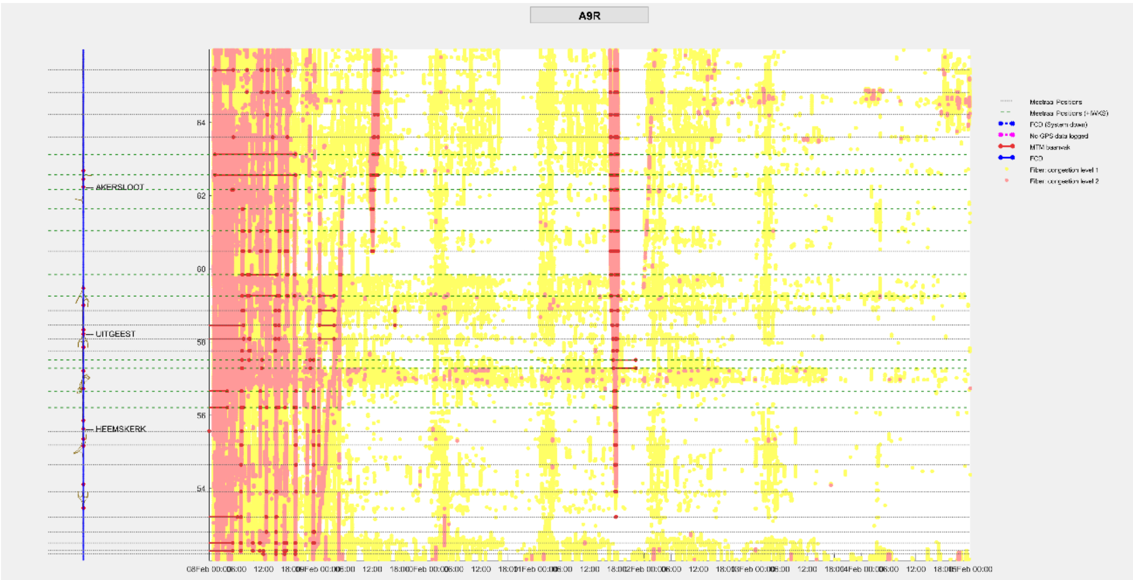
8.4.2 *2021, A9R, Week 4*



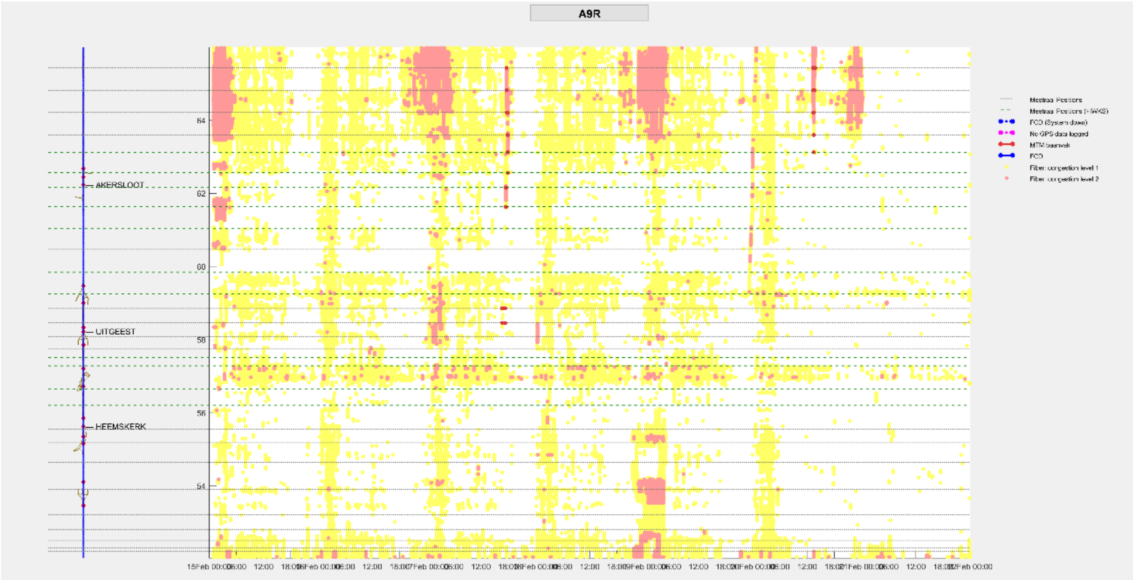
8.4.3 2021, A9R, Week 5



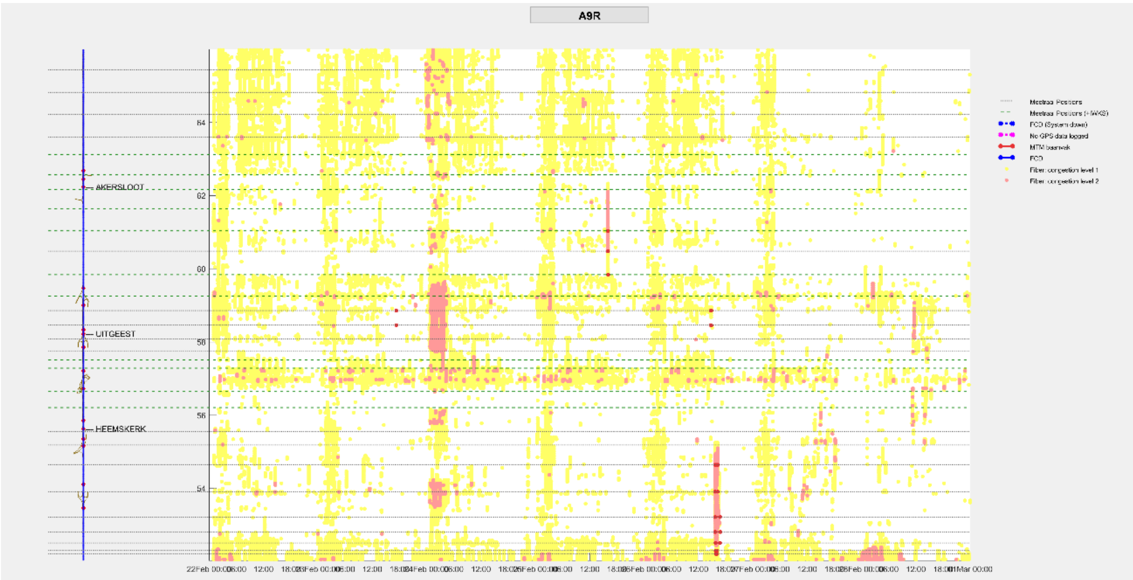
8.4.4 2021, A9R, Week 6



8.4.5 2021, A9R, Week 7



8.4.6 2021, A9R, Week 8



8.4.7 2021, A9R, Week 9

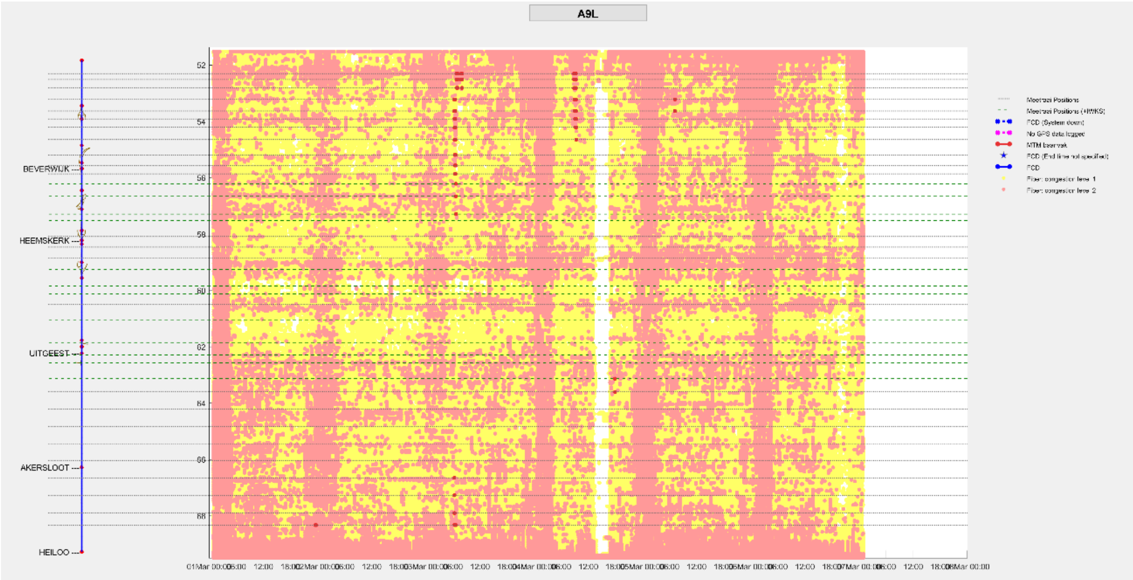
8.5 A9 South (A9L)

For the A9L only a few representative samples of the congestion status data are shown.

8.5.1 2021, A9L, Week 5

8.5.2 2021, A9L, Week 6

8.5.3 2021, A9L, Week 9



9 Appendix: MTM Congestion events on A9R

Due to the size of the images contained in it the appendix “Appendix: MTM Congestion events on A9R” is attached as a separate document.