Impact of Loop Detector Distance and FCD Penetration Rate on Queue Tail Warning

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Abstract

The first part of the paper introduces the topic of growing interest in the traffic community about the relation between traffic data quality and the efficiency of traffic management. In the second part of the paper the topic is illustrated by presenting the results of a small study into the effect of different loop detector distances and FCD penetration rates on a queue tail warning system.

Keywords: Floating Car Data, Traffic Data Quality, Queue Tail Warning

1 Introduction

Generally speaking, more and more data is coming available. In a study from IBM [IBM11] it was stated that 90% of the data in the world of today has been created in the last two years alone. As a consequence, in just a few short years the challenge has shifted from 'if we only had the data' to 'how can we drive better intelligence from the data' [VMT00]. The growth in data also holds in the traffic world. Not only more data is coming available, but also different types of data from different sources, such as loop detector data, floating car data (FCD), GPS or GSM data, blue tooth data etc. Especially, floating car data is a rapid growing data source, fed by the recent growth of smartphones and smartphone GPS applications.

Dynamic traffic management and information is used by road operators in order to improve network utilization, safety or the environment. Examples are influencing the traffic flow by influencing speeds, lane use, route choice or merging operations by employing variable message signs (VMS), Dynamic Route Information Panels (DRIPs), ramp metering etc. In order to operate the measures, to generate traffic information and to choose the best suitable measure, traffic data are required.

Accurate, reliable, high quality traffic data are a prerequisite for effective traffic management and information services.

Each data type has its own characteristics and quality. The required quality for a dynamic traffic management (DTM) measure or traffic information service differs, depending on the type of measure or information needed. Some measures are more time critical than others, while also the required accuracy requirements may differ. However, good research to establish requirements for the quality of traffic data in relation to the intended traffic management goals is lacking, while more and more new traffic data is coming available and the demand for reliable traffic information is increasing. Therefore more research on this subject is needed.

If the requirements for traffic data can be determined accurately for certain traffic management applications, this will give new possibilities for better traffic management: It will lead to a better achievement of the traffic management goals with the same data, i.e. more efficient data use. Also, better requirements for data acquisition can be imposed to traffic data providers, which may lead to cost reduction when less detailed/accurate data is sufficient, or when data acquisition can be tuned better for better results. For example by choosing optimal monitoring locations. An advanced possibility to improve the performance of traffic management applications is to select dynamically the best algorithm and data processing technique for the current situation and available data.

In this paper, the relation between different resolution data of loop detectors and floating car data on the performance of a queue tail warning system is studied. The queue tail warning system is a widely applied system in the Netherlands that uses dynamic speed limits on overhead matrix signs to warn drivers for downstream congestion. The system now operates on data from (induction) loop detectors, which have been installed widely on the Dutch motorway network. However, for cost saving reasons, one is interested if the system can function well enough with less loop detectors or with the use of other data sources. A first investigation into this problem is presented in this paper.

2 Background

2.1 State-of-the-Art

An important development concerning collecting and distribution of traffic data in the Netherlands is the National Data Warehouse for Traffic Information (NDW). The NDW is the Dutch databank that collects, processes, stores and distributes all relevant traffic data to provide complete, reliable and up-to-the-minute information on the status of the main Dutch road network. Quality requirements have been defined by the NDW and imposed to traffic data suppliers. Currently, there are discussions about redefining the quality requirements, especially to differentiate them for different road types or traffic management applications, because the current quality requirements cannot always be met and will lead to high costs, as presented in [Fel12].

In [Klu12], a preliminary study was performed on the relation between inaccurate traffic data and route choice, which concluded that accurate traffic counts are important for route choice information in case both route alternatives are close to oversaturation. In [Tam11], a study was performed on the relation between data quality and dynamic traffic management. However, this research studied only the effect on the resulting information or traffic management measure, not the impact on the traffic system, and they concluded that more thorough research is needed on this. Also at European level it has been identified that there is a lack of common quality criteria for traffic data and services. The QUANTIS project [Öör10] aimed to provide preliminary insights into the issue. Also in the U.S. it is recognized that the matter of data quality has become more urgent in recent years by the increase of ITS applications and various travel information systems, as reported in the “Data Quality White Paper" from the Federal Highway Administration [Ahn08].

Concerning the use and comparison of induction loop data or FCD data, research had been done already for example in [Gaz71]. In this article, a new method is put forward for fusing heterogeneous and semantically different data from different traffic sensors. In [Lin07] they compared and used both induction loop data and FCD for traffic state estimation, and also performed a cost-benefit estimation.

2.2 Organizational Aspects of Data Monitoring

Finally, apart from the quantitative aspects, there are also organizational aspects concerned, because many different parties need to cooperate in order to get access to the different data sources, to define data format standards and to implement data processing algorithms. These include private parties who collect traffic data, such as navigation system providers and traffic light operators, and public parties like road operators and traffic management centres. It seems that while data fusion techniques have been developed since the seventies of the previous century [Lin09], still few of them have been implemented in practice. Probably the cause of this is both lacking of good data and organizational problems.

Furthermore, the current operating traffic management systems such as the queue tail warning system, have been developed many years ago and in the meantime the systems and algorithms have evolved to such a complexity that it is not easy to switch to another (more efficient) system. When the current situation would be totally blank without any monitoring system, one could design a much more efficient traffic management system then the current one. In order to make this switch now, high initial costs are needed and many organizational issues will need to be solved. As such, the Netherlands has to deal with the law of the handicap of a head start, being one of the countries with the most extensive and oldest traffic monitoring systems. In that sense, countries who don't have an extensive monitoring system yet have an advance to design new efficient traffic management systems using new data sources.

3 Algorithm for Queue Tail Warning

On the Dutch motorway network a queue tail warning system is applied (AID, Automatic Incident Detection), which has the aim to prevent (secondary) accidents at the tail of traffic jams by lowering the maximum speed for vehicles approaching the traffic jam. A side benefit is that it helps to solve congestion quicker, especially shockwaves, because it reduces the inflow to the queue. It does this by detecting a traffic jam (low speeds), and gradually lowering the maximum speed upstream of the traffic jam tail. The first sign where the traffic jam is measured shows 50 as maximum speed, the next sign upstream 50 with flashers and the next sign upstream 70 with flashers. The portals are placed at a distance of around 500 meters from each other. It uses the available loop detection monitoring system as input and portals with variable message signs that show the maximum speed to the drivers. The system is already operational since the seventies of the previous century and proved to have lowered the number of head-tail accidents due to traffic jams. Based on research in 1984 [Bos07], the number of accidents was lowered with 16% in total, 36% of secondary accidents and 19% less vehicles involved in accidents.

The algorithm is based on speed detection of individual passing vehicles. First, outliers are filtered (speeds higher than 200 km/h are removed and speed slower than 18 km/h are set to 18 km/h). The algorithm works on reversed speeds instead of speeds, because that responds faster to speed differences for small speeds [Kli11]. A weighted moving average is calculated of the reversed speeds to smooth out speed fluctuations, by weighting the current smoothed speed with the current measured speed with a certain factor. This factor is higher for the measured speed when the new measured speed is smaller than the smoothed average speed from when the new measured speed is larger; in this way the system responds faster to low measured speeds than to high measured speeds. The system is triggered to start when the smoothed average speed gets below 35 km/h on one of the lanes, based on at least n vehicles. In the current research, $n=3$ is chosen. The trigger to turn off is when the average speed on all lanes gets above 50 km/h. This last condition is chosen in order to prevent too frequent on-off behavior of the system. The algorithm is responsive and not predictive: it is activated after the congestion has arisen and turned off after the congestion has been solved.

Though the system has proven to be successful, it is complex and expensive for maintenance. It needs a high density loop detection monitoring system which is currently under investigation in the Netherlands for lower cost alternatives, as explained before. Also, in other countries there usually is a much less dense monitoring network available. This justifies the current research to the performance of the system for different detector densities and other data sources such as Floating Car Data.

3.1 Experiment with Real-World Data

In order to find out what the effect is of different resolutions of detector and FCD data on the queue tail warning system, calculations have been done with a detailed real-world dataset. The main questions were:

- Which detector distance is possible for a sufficient performance of the queue tail warning system?
- With which penetration rate of FCD is it possible to reach a comparable performance?
- Which improvement is possible for a combination of FCD and loop detectors?

3.2 Data

As a test dataset, empirical microscopic loop data from a densely used motorway in the U.K. is used. The data come from the Active Traffic Management section of the M42 motorway near Birmingham [Wil11]. This section has an unprecedented coverage of inductance loop detectors, with a nominal spacing of 100 m. During 2008/09, 16 consecutive detectors on the Northbound carriageway were enhanced so that, among other improvements, the full individual vehicle data of all vehicles driving through the 1-mile section were recorded. A dataset of 10 days (1st to 10th October 2008) was used for a motorway stretch of one kilometer which contained 10 detectors. The individual vehicle data include the passage time, speed, lane number, and length of each vehicle as it passes each of the sites. With this high resolution, one can track most individual vehicles through the section in most traffic conditions and thus in effect reconstruct their trajectories [Wil08]. As such, a floating car data set was constructed by interpolating the individual vehicle recordings between the detectors. The FCD data was subsequently generated by sampling the trajectories at a resolution of one Herz. During the 10 measured days, a sufficient amount of congestion and shockwaves occurred to test the AID algorithm.

3.3 Experiments

Since the goal of the queue tail warning algorithm (AID) is to prevent accidents when approaching the tail of the traffic jam, the performance of the system should ideally be tested in practice by counting the number of accidents over a long period of time. Since this is a long and unreliable process and doesn't allow for experimenting, the performance is checked by calculations in Matlab, using indicators that are related to the safety of the vehicles approaching a traffic jam. These are the time to detection of the traffic jam, the error in the estimated location of the tail of the traffic jam and the number of detected traffic jams. Time to detection is in this study defined as the difference between the first time of detection of the traffic jam (average speed < 35 km/h) in the baseline situation (100% FCD) and the situation under investigation. The error in the estimated location of the tail of the traffic jam is defined as the difference between the most upstream location of the detected traffic jam in the baseline and the situation under investigation. The number of detected traffic jams is defined as the number of times that the AID algorithm was triggered to go on (ones it is on, it needs to go off before it can be triggered to go on again). The idea behind these indicators is that the safety reduction is larger when there are less vehicles that approach a traffic jam without passing the lower speed warning of the system (or equivalently, when there are more vehicles warned by a lower speed limit).

To test the effect of the detector distance on the performance, several distances have been tested by leaving out the detector data of part of the detectors. Since the length of the measured motorway stretch is only 1 kilometer and contained 10 detectors, only a limited number of detector configurations were possible. The following detector distances have been used: 1000 m, 550 m, 385 m, 288 m, 192 m and 97 m.

Since the basic AID algorithm has been developed for loop detector data, it is as such only suitable for data measured at fixed locations. In order to be able to apply it with FCD data, some additions were needed to the algorithm. This has been done as follows: the FCD second-by-second data was interpolated at fixed locations, namely at every meter. The AID algorithm was now applied at each meter (as if there was a detector at every meter). Again at least three vehicle measurements are needed to trigger the system. In this way, the location of a vehicle driving with low speed can be detected very accurately, though with low penetration rates the time to detection of a queue could be long.

The penetration rate was varied by a random draw (uniform) of all measured vehicles and taking into account only the data of this selected set of vehicles. The following FCD penetration rates have been simulated: 0%, 1%, 2%, 10%, 50% and

100%.

Also combinations of FCD and loop detector data have been simulated. This was easily possible in the above explained algorithm, by applying the algorithm both for all vehicle measurements at the loop detector locations and for the set of FCD vehicles at every meter.

The baseline scenario is defined as the 100% FCD scenario. By using 100% FCD, the exact moment of all congestion occurrences and locations of the traffic jam tail have been determined. To determine the ground truth, the location and timing of commencement of the traffic jam tail was determined at every second and every meter as the most upstream location where the AID was triggered on.

4 Results

Results are shown in Figure 4, 5, and 6. Looking at the detection rate in Figure 4, a 100% penetration rate logically shows a detection rate of 100%, while loop detectors without FCD only detect up to 30%. Probably this high difference is caused by too much on-off behaviour with the high-resolution FCD. A penetration rate of 50% detects 60%-75% of the traffic jams.

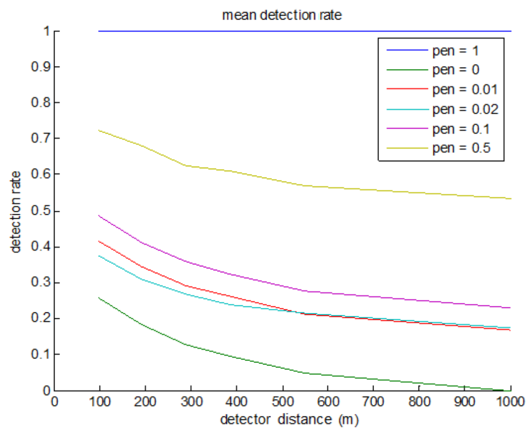

Figure 4. Mean detection rate for various detector distances and penetration rates of FCD vehicles

As shown in Figure 5, the time to detection varies from 10 seconds to 100 seconds without FCD, while with 50% FCD the detection time stays below 40 seconds. Also the location error benefits from FCD data. While with loop detectors the location error increases up to 250 meters, with the addition of 1% FCD this is reduced to 200 meters, and with 50% FCD it stays below 80 meters.

N.B. It seems strange that the time to detection goes down after 550 meters. This is probably a boundary effect because two detectors where used (one at the upstream boundary and one at the downstream boundary) which capture traffic jams better than one detector in the middle for the case of a detector distance of 550 meters.

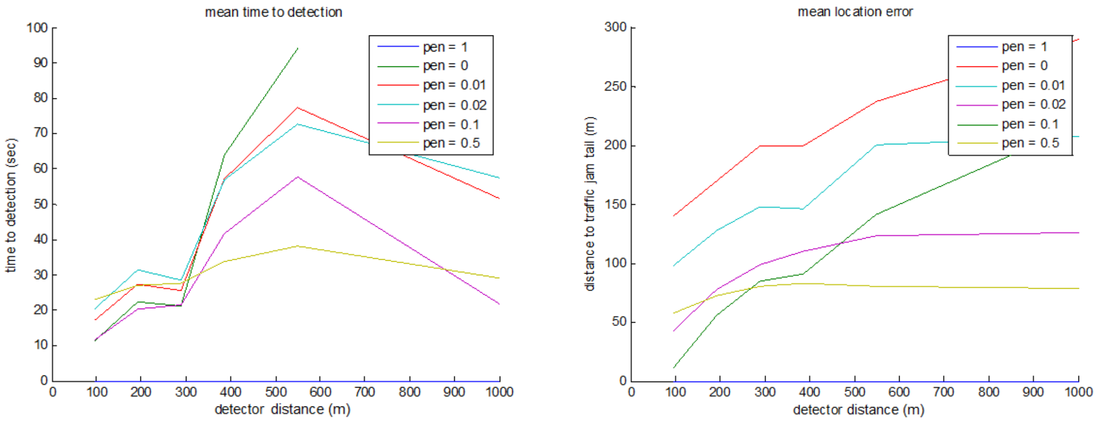

Figure 5. Mean time to detection and location error for various detector distances and penetration rates of FCD vehicles

5 Conclusions

Linking traffic data quality to efficiency of traffic management is an unexplored field; while more and more traffic data are coming available, not much is known about the needed data quality in order to reach the desired goals of traffic management. If the requirements for traffic data can be determined accurately for certain traffic management applications, this will give new possibilities for better traffic management: It will lead to a better achievement of the traffic management goals with the same data, i.e. more efficient data use, and cost reduction, for example when less detailed/accurate data can be sufficient. However, in order to achieve this in the current world of traffic management practitioners, a change of view is needed: start with what you want to achieve instead of what data you have.

Looking at the results of the data study to the effect of different loop detector distances and FCD penetration rates on a queue tail warning system, we can answer the research questions as follows:

The first question was which detector distance is possible for a sufficient performance of the queue tail warning system. Up to 300 meter detection distance, the performance seems to be reasonable: the detection time stays below 25 seconds and the location error below 200 meters. With larger detector distances, the time to detection and location error increases quickly.

The second question, with which penetration rate of FCD is it possible to reach a comparable performance, it can be concluded that the detection time and location error is already shorter with 1% FCD.

Thirdly, which improvement is possible for a combination of FCD and loop detectors? Looking at a detector distance of 500 meters, adding 1% FCD reduces both the detection time and the location error with 20%.

It has to be remarked though that the used indicators are related to the final aim, i.e. increasing traffic safety, but the exact relationship is not known.

6 Further Research

Further study is needed to determine the relation between the used indicators and the effect on traffic safety, i.e. the relation between the time to detection and location to the traffic jam tail in combination with reduced speed limits on the risk of traffic jam tail collisions. Options to study this are for example driving simulator studies, camera observation in practice or using surrogate safety measures in a traffic microsimulation study.

Also more accurate results could be achieved with a larger dataset. The presented results are based on data from a quite short road section and also influenced by the random draw of FCD vehicles. Furthermore it would be more realistic to use a larger set of real-world measured FCD on a longer track.

This research is part of a PhD research, which aims to address the problem of the relation between traffic data quality and traffic management/information in a broad perspective. Therefore, in future research quality requirements will be established for several traffic management and information applications and situations. This will be done both for time critical applications such as ACC, medium time critical applications such as queue length estimation for urban control and less time critical applications such as routing and network-wide traffic management. In order to be able to generalize the results, a general framework will be designed. Also the type of errors that occur in reality on different types of traffic data will be investigated, as well as statistical relations between different types of errors.

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