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Locating roadworks sites via detecting change in lateral positions of traffic signs measured relative to the ego-car

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Abstract

Roadworks can be hazardous for both road workers and road users. Even with state-of-the-art safety measures in place, serious accidents do happen there, particularly when drivers do not heed roadwork signs and speed limits. Crashes at roadworks that involve killed or seriously injured (KSI) casualties account for about 2% of all KSI crashes in developed countries, even though the roadworks are normally well-signaled and are also marked in quick-reaction road/traffic maps. These media provide several means for the drivers – and for the on-board advanced driving assistance systems (ADAS) helping them – to duly detect roadworks. In the paper, an approach based on statistical inference is presented for detecting roadwork zones. The approach takes into account the engineering regulations and practice concerning setting up temporary road configurations near and along roadworks. Such configurations often involve narrower traffic lanes and traffic signs installed closer to traffic. The approach detects change in – among other type of collected data – the lateral positions of the traffic signs measured relative to the ego-car along the road. In a practical implementation, the traffic sign detection and recognition, the lateral distance measurement and the data recording are carried out by some traffic sign recognition (TSR) system. The traffic sign data is seen as a realization of a marked Poisson process and the minimum description length (MDL) principle – set to work in the form of Page-Hinkley change detectors – is applied for detecting roadworks.

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1. Introduction

Roadworks can be hazardous for both road workers and road users. Even with state-of-the-art safety measures in place, serious accidents do happen near and along roadwork sites. Some instructive statistical data on accidents which had happened near and along roadwork zones are presented in Section 2. The data presented there underline the criticality of this road safety issue and suggest that any meaningful support given to the drivers in this regard could potentially save human lives.

Herein, a statistical inference approach is presented for detecting roadwork zones on roads, more specifically for detecting roadwork zones on motorways. The approach is closely related to the one proposed by Fazekas et al. (2016) for detecting transitions between topographical road environments based on traffic sign location and type data. The change detection task pursued there was chosen as an easy-to-verify test case for the approach (i.e., using traffic sign data as input for change detection) and the methodology (i.e., the application of the minimum description length principle), but was not practical enough to be implemented as a function for advanced driver assistance systems (ADAS).

A more practical task, which is more suitable for implementation as an ADAS function, was addressed by Fazekas et al. (2017). The same approach and methodology was applied as described above, but in this case for urban road environment detection. A straightforward implementation approach was proposed that would involve the enhancement of a traffic sign recognition (TSR) system with a minor additional functionality. Thereby turning it into a low-cost surrogate for a comprehensive vision-based road environment understanding and recognition system.

The present task, that is the detection of roadwork sites in an automatic manner, also has the potential to be converted into an ADAS function. The method presented here takes into account the road safety regulations and the engineering practices concerning setting up temporary road configurations near and along roadworks. Such configurations often involve narrower traffic lanes and traffic signs installed closer to the traffic, as well as repeated warning and speed limit signs placed at regular intervals along the road, especially when longer stretches of roads are affected by the construction or maintenance work.

Over the last few months, a car-based traffic sign data collection was carried out along the motorways. The data concerning the stretches of motorway affected by roadworks and their vicinity were used in the work presented herein. The details of the data collection procedure are given in Section 4.

The proposed method detects change in the spatial frequency of the traffic signs installed along the road and in their type probabilities, as well as change in their lateral positions which is measured from the midline of the current lane. Empirical spatial distributions of the traffic signs and their lateral distances from the actual traffic lane – on stretches of motorway in normal use, as well as on stretches along roadwork zones – are computed based on the data measured and logged during the data collection trips.

The traffic sign data is seen as a realization of a marked Poisson process and the minimum description length (MDL) principle – set to work in the form of Page-Hinkley change detectors (PHCDs) – is applied for detecting change in the spatial frequency of the traffic signs along the road, as well as in their lateral positions. The necessary mathematical background is summarized in Section 3. In Section 5, the output signals of three differently tuned PHCDs are shown for a particular roadwork zone. In Section 6, conclusions are given.

2. Roadwork sites and traffic safety

Although negotiating road work zones – particularly if they occur in large numbers along a route, or include longer stretches of road – is frustrating for vehicle drivers, the presence of roadwork zones are concomitants of the standard and responsible road maintenance. Conducting road construction or maintenance work in traffic is hazardous for the workers toiling at the site, but it poses serious dangers also for drivers. For the reasons given above, the transportation planners responsible for planning and managing roadwork zones try to improve the road safety and keep up the close to normal vehicle mobility by

- making road work projects as concise in time as possible,
- better informing drivers about the roadworks ahead, e.g., by installing appropriate warning signs and variable message signs (see Fig. 2),

- suggesting alternate routes,
- making sure that the warning signs are placed sufficiently close to the actual work zone so that drivers do not forget about the problem, and
- repeating the traffic signs along the effected stretch of road, so as to remind the drivers of the roadworks.

For related traffic engineering and measurement issues, see FGSV (2015). The roadwork zone – shown in Fig. 1 – on a motorway in Germany exemplifies such a good engineering practice.

Fig. 1. A roadwork site on a motorway.

Despite the above intentions and actions, there are still too many people killed or seriously injured (KSI) near roadwork sites. According to recent statistics, drivers endure far more fatalities than members of work zone crews, see Karr (2000) for details. In their paper, Weijermars and Spittje (2008) report that in developed countries crashes at roadworks that involve KSI casualties account for about 2% of all KSI crashes.

Fig. 2. Some of the typical road signs – including a variable message sign – placed usually near roadwork sites.

This is a relatively high percentage if one considers that the roadworks are normally well-signaled in the developed countries and are marked in quick-reaction road/traffic maps. These media provide several means for the drivers, as well as for the on-board ADAS helping them to duly detect roadworks.

2.1. Detection of roadwork zones by smart cars

The automatic detection of roadwork zones was a hot topic in the news last year in conjunction with self-driving cars and ADAS functions. Here we refer to two recent pieces of news in this regard: the first one was about an accident that involved a high-tech production car, while the second one was about a major ongoing project that tests – among other ADAS functions – the function responsible for automatic detection of roadworks sites. The strong media coverage of these topics seem to confirm the importance of the application area targeted herein.

The accident happened to a high-tech production car fitted with an auto-steering function and to its driver who was somewhat abusing this smart function. Left to its own devices – i.e., not receiving control input from the human driver – the car was following the lane markings which had been left visible ahead of roadworks, then it crashed into a highway barrier separating the construction site from the road. The accident was reported in a Mail Online article (2017). A video footage of the crash is also available from the web-page. The evolving debate on whether the auto-steering function of the car worked properly or not can be traced by following the links in Autoblog (2017).

An initiative for large scale testing of the ADAS function responsible for automatic detection of roadworks sites was announced by a car manufacturer investing in smart car technology and reported in a Daily Mail article (2016). A fleet of about one hundred connected and autonomous vehicles is to be trialed on public roads over the coming years. The trials will include a system – called roadwork assist (RA) – that is able to navigate through roadworks.

The RA system is able to recognize cones and barriers and assist drivers through roadworks. Initial tests will involve vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies that will allow cars to talk to each other and to the traffic signs, overhead gantries and traffic lights. The RA to be tested uses a forward-facing intelligent stereo camera to generate a 3D view of the road and recognize cones and barriers placed near and along roadworks. The system will sense when the host car is approaching the roadworks and will plan an ideal path through the construction sites and contraflows. It will also inform the driver that the road is narrowing ahead.

3. Mathematical background

A convenient model for describing traffic sign data is a marked point process. A point process is customarily given by an increasing sequence of time points, say T_n, However, the traffic signs that appear one after the other along a route and are better described in space coordinates rather than in time coordinates. For this reason, the path-length was chosen to characterize the point process corresponding to traffic sign data.

The points of a point process may be labeled with marks. A marked point process then can be formalized as a pair (T_n, ρ_n), where ρ_n is the mark. For instance, in a log of traffic signs taken during a car-based data collection trip – in the present case, along motorways with roadwork sites on them – a traffic sign location may carry a label stating the lateral distance of the traffic sign measured from the midline of the actual lane. In many practical cases that involve marked point processes, the marked Poisson processes have proved convenient and flexible. Although the Poisson process is a continuous-time (or continuous space) model, in the algorithm presented here its discrete space approximation was applied.

The problem of detecting abrupt changes in the dynamics of stochastic signals that occur in a wide range of applications has been extensively discussed in the literature. Initially, the change detection within independent and identically distributed random data was the main target of research. This effort led to the well-known Page-Hinkley change detector (PHCD), see Page (1954), Hinkley (1971), Lorden (1971). The PHCD was later adopted and analyzed also for dependent data, see Fazekas et al. (2016) for references.

The most important performance criteria for a change detector are its average run length between false alarms – which translates to false alarm rate – and the expected delay in detection.

The basic idea of the MDL approach is to choose between models for describing data on the basis of the minimum code-length by which one can encode the data relying on these models. The advantage of the MDL methodology is its enormous flexibility, e.g., the widely used PHCD can be interpreted as a procedure relying on this approach.

Assume that we have a sequence of observations ξ_1,..., ξ_N, which is composed of two parts. The first part of the sequence is an independent identically distributed (iid) sequence of random variables taking discrete values according to a particular probability law, while the rest of the sequence (i.e., the second part) is generated according to another probability law.

The problem is then to estimate the time – or in our case the location – of the change between the two probability laws from the observed data in real-time.

An MDL approach to solve this problem is as follows. Choose an arbitrary time – or in our case location (e.g., along a route) – τ, and assuming that this is where the transition between the probability laws takes place, encode the observed data optimally using the hypotheses concerning the data generating mechanism.

Based on standard results of information theory, the overall optimal code-length $L_N(\tau)$ of the observed data in an asymptotic sense and allowing block coding is

$$L_N(\tau) = \sum_{n=1}^{\tau-1} -\log p(\xi_n, \theta_0) + \sum_{n=\tau}^{N} -\log p(\xi_n, \theta_1) \quad . \tag{1}$$

Following the MDL principle, the estimator of the transition location is obtained by minimizing the overall assumedly optimal code-length – given in (1) – in τ.

A heuristic procedure for minimizing L_N in real-time is attained by identifying the location – along the route – after which L_N has a definite upward trend. After reformulating this feature of L_N, a sequence is derived that is typically 0 before the true change-point, and typically increasing after that. For details of the illation see Fazekas et al. (2016). The derived sequence is the output of the well-known PHCD when the detector is applied to detecting the change in the parameter of the probability law.

The formula for discrete location approximation of a marked Poisson process – derived in the paper cited above – is included here with a slight modification. This modified version was used for producing the results and the diagrams appearing in Subsection 5.1. In the cited paper, only one mark was attached to each observation, while two independent marks were used for each in the present application. This is reflected in the form of the encoding score in (2), where the last two terms correspond to the two independent marks ρ_n and ρ_n'.

In the application presented herein, the first mark corresponds to the type of each traffic sign, while the second one to its lateral distance from the car.

The approximation was obtained by assuming an inhomogeneous iid sequence of random variables with binomial distribution, taking values 1 and 0, with probabilities θ_i and $1-\theta_i$, respectively, where i is the sequential number of the model (e.g., in the application presented herein, i=0 identifies road sections in normal use, while i=1 identifies road sections affected by roadworks).

The difference of the optimal code-lengths encoding an observation – called encoding score – using the two probability laws is

$$\Delta L(j) = -\xi_j \cdot \log\frac{\theta_0}{\theta_1} - \left(1-\xi_j\right) \cdot \log\frac{1-\theta_0}{1-\theta_1} - \sum_{k=1}^{m} \xi_j \cdot \zeta_{j,k} \cdot \log\frac{p_{0,k}}{p_{1,k}} - \sum_{k=1}^{r} \xi_j \cdot \zeta'_{j,k} \cdot \log\frac{p'_{0,k}}{p'_{1,k}} \quad . \tag{2}$$

With the above encoding score, one can proceed by computing the overall optimal code-length. It is done by applying the PHCD to find the estimator of the change-point. See algorithmic details in the paper cited above. As an illustration, the outputs of differently tuned PHCDs – used in this case for detecting the same roadwork zone that occurred after a long stretch of motorway in normal use – are shown in Figs. 5 - 7.

4. Traffic sign data collection from roadwork zones on motorways

4.1. The traffic sign data collection procedure

A car-based traffic sign data collection was carried out by the authors and by technical support staff along the motorways in Hungary and Germany in 2015. The total distance covered was about 3000 km. The traffic sign data from stretches of motorways affected by roadworks and from their vicinity were gathered specifically for this study.

During these trips, 19 roadwork zones on motorways were recorded. Only the speed limit signs – in the range of 

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– and the triangular warning signs –  , , etc. – were logged. The motivation for this choice was that these traffic signs were targeted and recognized by many the state-of-art TSR systems at the time.

The data collection personnel for each trip consisted of three persons: a driver and two data entry assistants. The traffic sign data was manually logged by the data entry assistants. A tablet-based Android app was adopted for data input and trajectory data collection. Two copies of the app – running on different tablets – were used for entering the traffic sign data. For measuring the lateral distances between the car and the traffic signs appearing on either side of the road, two compact laser distance meters were placed on tripods within the car. One of data entry assistants took distance measurements with one of the devices in respect of the traffic signs installed on the right, while the other device was used by the other assistant for the signs appearing on the left. The measured lateral distances were then entered manually. A forward viewing camera was installed onto the windscreen to record the road and its surroundings in time-lapse mode for post-trip data verification purposes.

4.2. Empirical distributions of the lateral positions of traffic signs

According to roadworks planning and management regulations, the warning and the speed limit signs are placed ahead and along roadwork zones in a manner that guarantees road safety, see e.g., DPR (2014). The regulations set out both the longitudinal and the lateral placement of signs. In Figs. 3 and 4, the lateral sign positions – relative to the current lane – in roadwork zones and over normal road stretches are compared in an aggregated way and via examples.

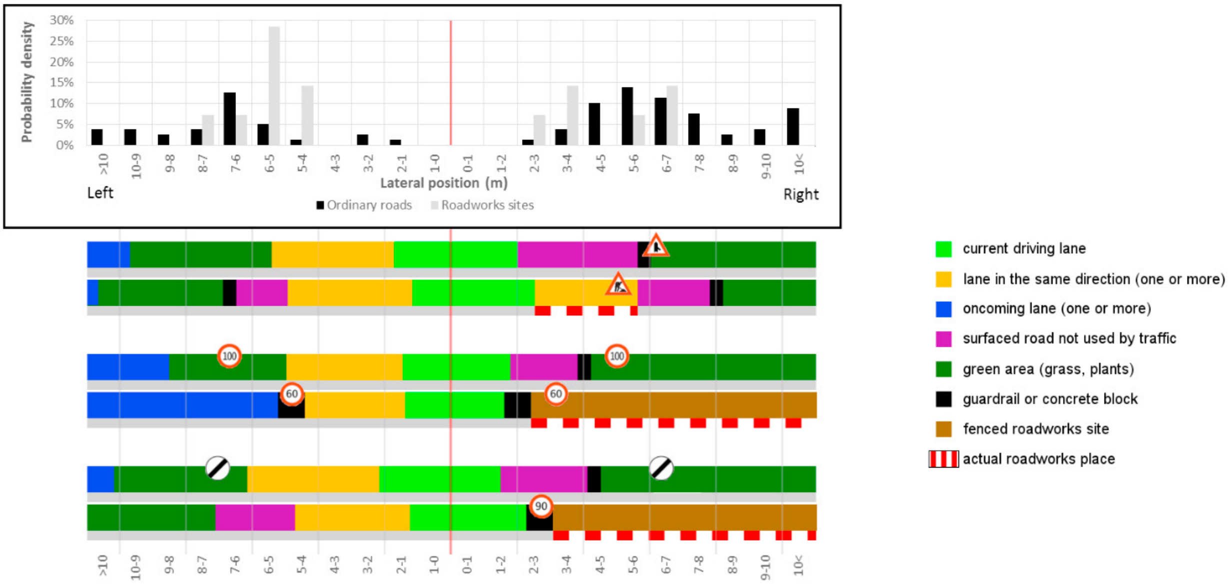

Fig. 3. Empirical probability distributions of the lateral sign positions – measured from the ego-car that was driven in the nearside lane – on motorways. The distribution marked gray is calculated for those motorway stretches, which were not worked upon, while the one marked black is for those roadworks zones, where the nearside lane was left open for the traffic. Below, lane arrangements for six sign locations are given: three are locations where the motorways were in normal use and the other three correspond to roadwork zones on the same motorways.

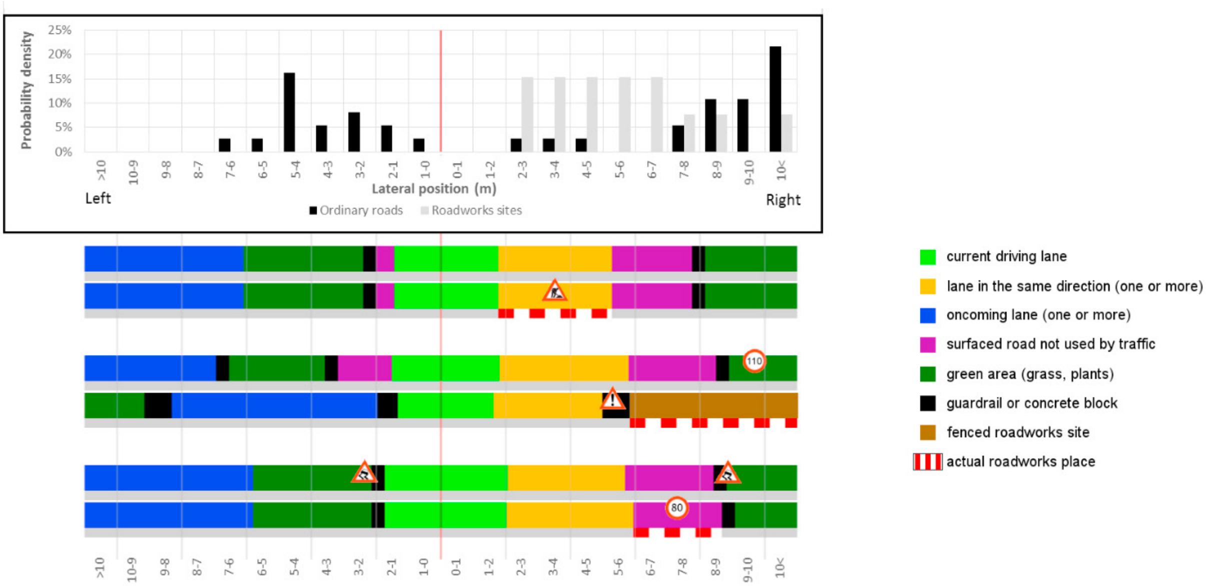

Fig. 4. Empirical probability distributions of the lateral sign positions – measured from the ego-car that was driven in the overtaking lane – on motorways. The distribution marked gray is calculated for those motorway stretches, which were not worked upon, while the one marked black is for those roadworks zones, where the overtaking lane was left open for the traffic. Below, lane arrangements for six sign locations are given: three are locations where the motorways were in normal use and the other three correspond to roadwork zones on the same motorways.

In Figs. 3 and 4, below the respective empirical probability distributions, pairs of lane arrangements are shown. Each pair exemplifies two road locations: one in normal use and the other affected by roadworks. These locations were close to each other on the same motorway. The lateral distances in the figures were measured from the current lane, more precisely from the center of the ego-car. In the figures, the probability distributions of lateral sign positions are shown for cases when the ego-car was driven in the original nearside and in the original overtaking lane, respectively.

5. Detecting the change in traffic sign type, location and lateral position data

In Figs. 5 - 7, the outputs of three differently tuned PHCDs are shown for one of the road locations considered in Fig. 3. The gray regions in the figures mark the ground truth location of the roadwork zone. The traffic sign locations along the route that were actually used for the tuning the detectors are marked with small red/orange triangles on the horizontal axes in the figures. According to our traffic sign data, the probability of a traffic sign considered in data collection – as specified in Subsection 4.1. – occurring on the right over a 50 m stretch of road in case of motorway in normal use, was θ_0= 0.13, while the respective probability for roadwork zones – on motorways – was θ_1= 0.15.

In case of Fig. 5, the PHCD was tuned to these probabilities and to the two empirical distributions shown in Fig. 3.

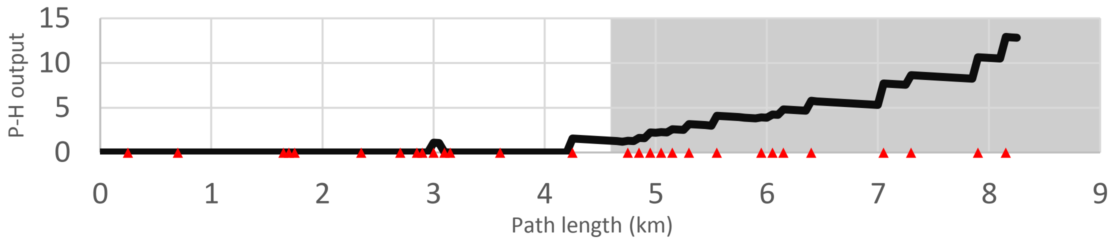

Fig. 5. The output of the PHCD for nearside lane. The detector was tuned to the two spatial frequencies of the recorded traffic signs and to the empirical distributions of their lateral positions. The small red triangles mark the locations of the recorded traffic signs.

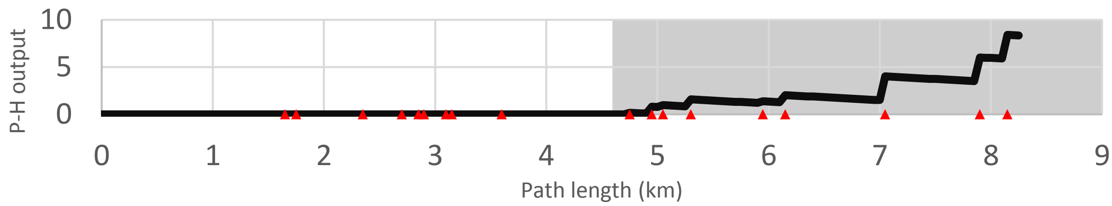

Fig. 6. The output of the PHCD for the nearside lane. The detector was tuned in this case to the two spatial frequencies of speed limit signs and to the empirical distributions of lateral positions of the signs. The locations of the speed limit signs – recorded along the route – are marked with small red triangles on the horizontal axis.

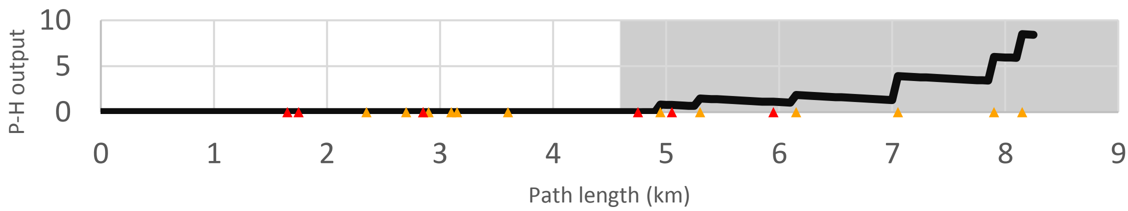

Fig. 7. The output of the PHCD for nearside lane. The detector was tuned as in Fig. 6, but also the speed limit class probabilities – see in the text – were considered. The locations of speed limit signs 50 to 80 km/h and 90 to 120 km/h are marked with orange and red triangles, respectively.

The probability of a speed limit sign – with 50 km/h to 120 km/h speed limit indicated on it – occurring on the right over a 50 m stretch of road in case of motorway in normal use was θ_0= 0.08, while the respective probability for roadwork zones was θ_1= 0.10 . In case of Fig. 6, the detector was tuned to these probabilities and to the empirical distributions given in Fig. 3. Among the speed limit signs, the group with limits ranging from 50 km/h to 80 km/h appeared with probability $p'_{0,1}$= 0.65 in case of motorway in normal use, and with $p'_{1,1}$= 0.69 for roadwork zones. While the group of speed limit signs with limits from 90 km/h to 120 km/h appeared with probability $p'_{0,2}$= 0.35 in case of motorway in normal use, and with $p'_{1,2}$= 0.31 for roadwork zones. In case of Fig. 7, the detector was tuned to these probabilities and to the probabilities θ_0 and θ_1 given above, as well as to the empirical distributions in Fig. 3.

For the roadwork zone considered in Figs. 5 - 7, the roadworks detection functions properly: each PHCD produces the expected upward trend in its output signal within a few hundred meters from the true start of the roadwork zone. Similar detector behavior was encountered for most of the roadwork zones recorded in our traffic sign logs. However, we did not compute the performance criteria – mentioned in Section 3 – for the PHCDs due to the small number of cases. Whether one considers the aforementioned distance lags of few hundred meters each acceptable or not, depends on the concrete smart car application in mind. However, to achieve faster detections with shorter distance lags, one needs to rely on signs that are placed at shorter intervals near/along roadworks, e.g., ’s.

6. Conclusions

A statistical inference method was presented for detecting roadwork zones on motorways. It detects change in spatial frequency of traffic signs along the road, as well as in their lateral positions. The sign data is seen as a realization of an inhomogeneous marked Poisson process, and the MDL principle is applied for detecting change. To illustrate the working of the detector, change locations indicated by three differently tuned PHCDs were compared to the ground truth. An practical implementation should rely on the TSR function of a smart car. It could be considered a low-cost surrogate of a vision-based comprehensive road and road environment understanding system. In order to achieve faster and more reliable detection of the roadwork zones, the occurrences of the banded warning sign (i.e.,) should be also considered. These signs were not logged during the data collection trips as many TSR systems did not recognize these signs at the time; however, since then this deficiency has been overcome in some TSR systems. Furthermore, the collection of traffic sign data for the purpose should be international and the relevant national data model should be used in the change detectors. Future work should include analysis of roadwork zones on other road types, as well.

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