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AN ASSESSMENT OF A TRAFFIC SURVEILLANCE TOOL BY USING LOOP, RADAR AND VIDEO DETECTORS

This paper presents an assessment of a real-time motorway traffic surveillance tool RENAISSANCE by using data collected from traffic detectors of various types including Video Image Processing (VIP), Ultrasonic Radar (UR) and Induction Loops. The results have shown RENAISSANCE to perform well in estimating flows and speeds over homogeneous motorway sections, whilst little difference was observed in its performance in relation to the involved detector types. The viability of video image processing (VIP) technology for motorway traffic surveillance has been demonstrated and VIP was found useful for supporting the traffic state estimation even under difficult weather conditions such as a snowstorm at night.

OCENA URZĄDZEŃ NADZORU RUCHU ZA POMOCĄ PĘTLI, RADARÓW I CZUJNIKÓW WIDEO

Referat przedstawia ocenę narzędzia do nadzoru autostrad w czasie rzeczywistym RENAISSANCE za pomocą danych zebranych z detektorów ruchu drogowego rozmaitego typu w tym przetwarzanie obrazów video (VIP), radarów ultradźwiękowych (UR) i pętli indukcyjnych. Wyniki pokazały, że RENAISSANCE działał dobrze w zakresie szacowania przepływów i prędkości na jednorodnych odcinkach dróg, lecz zaobserwowano pewne niewielkie różnice w jego działaniu stosunku do użytych typów detektorów. Zademonstrowano przydatność przetwarzania obrazów video (VIP) do nadzorowania ruchu na autostradzie. VIP okazał się również użyteczny w zakresie wspomagania oceny ruchu nawet w trudnych warunkach pogodowych, takich jak śnieżyca w nocy.

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1. INTRODUCTION

Large-scale motorway networks are usually equipped with a number of measurement devices of various kinds (loops, video sensors, radar, etc.) which deliver real-time information about the current traffic conditions in corresponding locations. Traffic surveillance applications are usually used to utilise the limited number of traffic detection devices available on a road network in order to estimate the currant traffic status over all parts of the considered network. Early applications of traffic state estimation were designed for short motorway stretches with lengths below 2 km and relatively simple modeling process (e.g. [1], [2], [3], [4] and [5]). Later approaches used more comprehensive dynamic traffic flow models which opened the way to the consideration of longer motorway stretches (2 ~ 4 km) (e.g. [6], [7] and [8]).

One of the aims of the European Project **RHYTHM** (IST-2000-29427) was to investigate the utilisation of various traffic detection technologies for traffic surveillance applications. With the support of **RHYTHM,** the **RE**al-time motorway Network tr**A**ff**I**c State Surveill**ANCE (RENAISSANCE)** tool [9, 10 and 11] has been developed to address several traffic surveillance tasks including traffic state estimation, short-term traffic state prediction, travel time estimation and prediction, and queue tail/head/length estimation and prediction. The functional architecture of RENAISSANCE is shown in Fig.1. The highlighted central block represents the main body of RENAISSANCE including its various functional modules. The external inputs to RENAISSANCE include real-time traffic measurements (flow and mean speed or occupancy) and, possibly, incident reports from the operators in the traffic control centre, while the outputs of RENAISSANCE correspond to its various functionalities. Through its integrated graphical user interface (GUI), RENAISSANCE provides the users with quite a few options in order for the traffic surveillance tasks to be performed according to the specific user needs.

The main state-of-the-art features of RENAISSANCE are:

- RENAISSANCE is a generic tool that is applicable in real time for motorway networks of arbitrary size, topology, and characteristics, based on any suitable traffic detector configuration.
- RENAISSANCE is able to handle real-time measurements collected via a variety of traffic detectors including induction loops, radar detectors, video sensors, or any combination of those.
- On the basis of on-line model parameter estimation, RENAISSANCE is self-adaptable to changing external conditions (weather and light conditions, percentage of trucks, speed limits, etc.) or abnormal events (e.g. traffic incidents).

This paper presents an assessment of the performance of RENAISSANCE with the consideration of possible impacts of various lengths of the involved test stretches and various types of utilized measurement data.

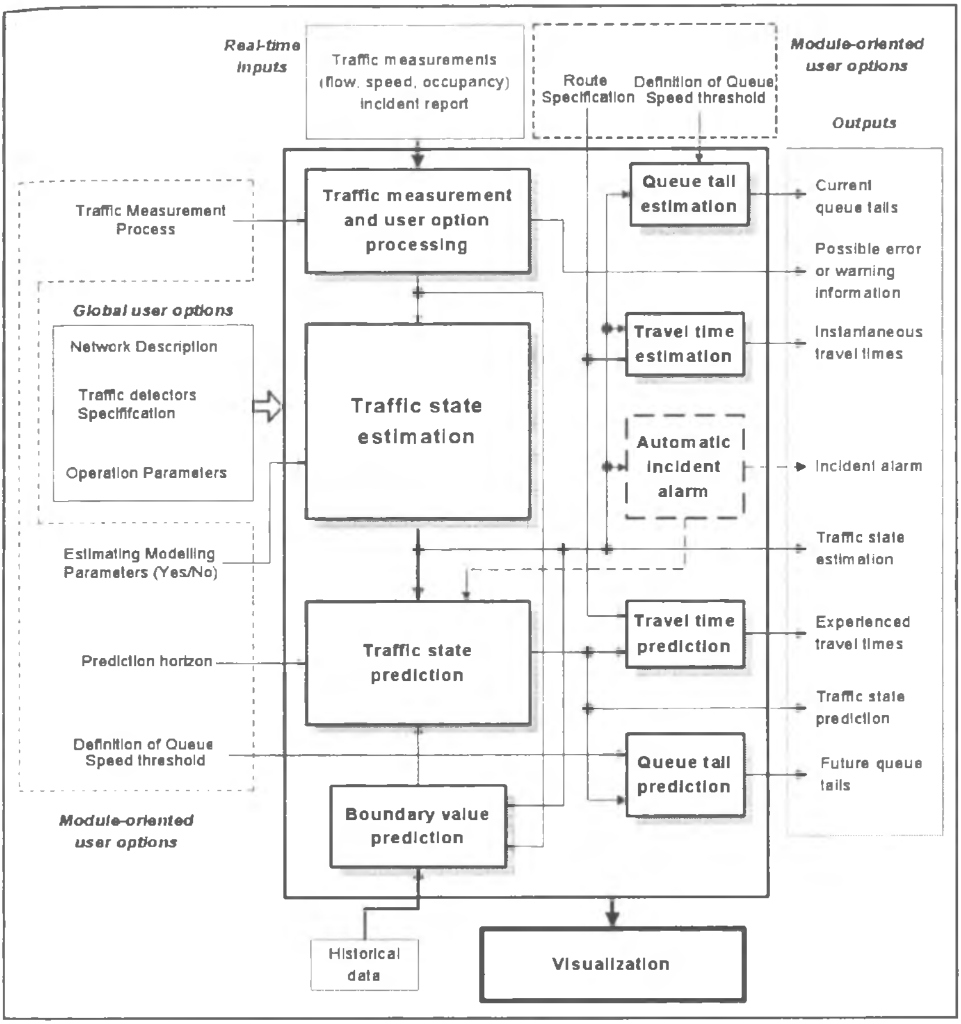

Fig.1. Functionalities of RENAISSANCE [12]

2. EXPERIMENTATL DESIGN

A test site at the A92 motorway in the North of Munich, Germany was used for demonstration and evaluation activities within the RHYTHM project. The site is about 7Km long and stretches southbound between the motorway interchange AD_Flughafen and AK_Neufahrn. Beside the already available traffic detectors (3 induction loops and 6 ultrasonic radars), up to 7 video cameras with video image processing detection technology (VIP) were installed on the site. In order to enable a cross comparison between the various traffic detection technologies, the video detectors (VIP) had to be installed at locations coincide with that of induction loops and ultrasonic radars. The site map and the corresponding detector configuration are presented in Fig.2.

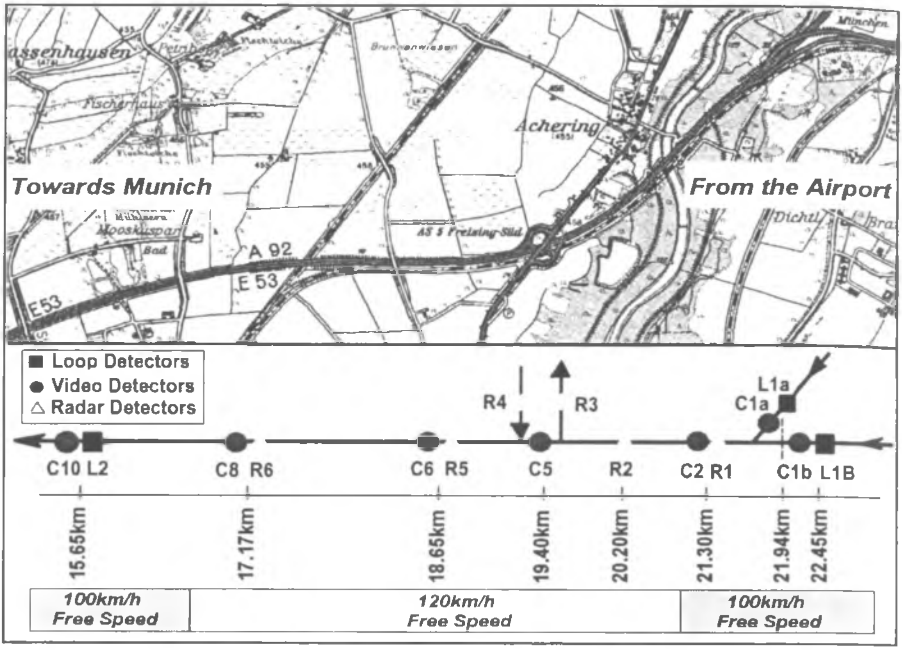

Fig.2. The A92 test site near Munich, Germany and the positions of the various traffic detectors which were made available to the RENAISSANCE evaluation.

Following a careful assessment to the free speed levels at several locations, the test site was found to be non-homogenous. Low free speed levels (100km/h) were observed at the beginning and end sections, whilst high levels (120km/h) were observed in the middle. A combination of topological factors (merging section upstream and major diversion downstream) and control measure (variable speed limit signs installed on several gantries on the site) have contributed to the site being non-homogenous. Although RENAISSANCE is able to deal with a non-homogenous site by dividing it into a set of homogenous links, a decision was taken to consider the site as one homogenous stretch to reduce the fidelity of setup and enable the undertaking of various test scenarios. As a result, some bias between the RENAISSANCE estimations and real measurements was expected for the locations within the stretch when RENAISSANCE is fed with measurement data only from the detectors at the most upstream and downstream of the stretch.

The evaluation had targeted situations where congestion was observed, however, the recent expansion of the A92 to a three lanes motorway made traffic congestion less frequent and reduced number of days that benefit the evaluation. Additionally, detectors reliability was an issue as the data collection try to target periods where all types of available traffic detectors were working properly. Out of a four-month survey period dedicated to the evaluation only seven days were able to be considered.

To assess the RENAISSANCE performance, several evaluation scenarios (EV) were undertaken. They were:

- **[EV1]**: In this scenario, the measurements from *loops* L1a, L1b, and L2 as well as *radars* R3 and R4 were used to feed RENAISSANCE whilst the measurements from *video sensor* C6 were used for assessment.
- **[EV2]**: In this scenario, the measurements from *video sensors* C1a, C1b and C10 as well as *radars* R3 and R4 were used to feed RENAISSANCE whilst the measurements from *video sensor* C6 were used for assessment.
- **[EV3]**: In this scenario, the measurements from *radar* R1, R3, R4 and R6 were used to feed RENAISSANCE whilst measurements from *radar* R5 were used for assessment.
- **[EV4]**: In this scenario, the measurements from *video sensors* C2 and C8 as well as *radars* R3 and R4 were used to feed RENAISSANCE whilst measurements from *video sensor* C6 were used for assessment.
- **[EV5]**: In this scenario, the measurements from *video sensors* C1a, C1b and C8 as well as *radars* R3 and R4 were used to feed RENAISSANCE whilst measurements from *video sensor* C6 were used for assessment.
- **[EV6]**: In this scenario, *measurements from a mix of different detector types* including C1a, C1b, C2, R2, R3, R4, R6 and L2 were used to feed RENAISSANCE whilst measurements from both *video sensor* C6 and *radar* R5 were used for assessment.

The above test scenarios enabled RENAISSANCE to be assessed under a variety of setups and circumstances related to the detector types and covered stretch lengths. A comparison between the evaluation results under scenarios EV1 and EV2 allowed the assessment of video detection against induction loops, while scenarios EV3 and EV4 enabled the assessment of video detection against radars. A comparison between scenarios EV2, EV4 and EV5 enabled the assessment of RENAISSANCE with respect to the different lengths of stretches. The aim of test scenario EV6 was to examine the performance of RENAISSANCE when it operates simultaneously with traffic measurements of various types. Using measurement data from seven days and considering the six scenarios for each day, some 42 RENAISSANCE runs were made, which produced a large database for the analyses.

The analyses followed a plan in which a set of assessment indicators were developed with clear definitions of success to meet the evaluation objectives. Mainly, the mean square error MSE and the relative mean square error RMSE between the estimated and observed values of a specific traffic parameter (e.g. flow or speed at a specific location) were used as indicators to measure RENAISSANCE performance. A time interval of 10 minute was used to calculate a single value of the MSE and RMSE and later the average and standard deviations of the MSE and RMSE were calculated over the whole survey period.

3. ASSESSMENT RESULTS

The conducted data analysis showed that RENAISSANCE performs well in tracking the flow and speed changes over the time. On average, the MSE and RMSE criteria over the whole survey period were lower than the pre-defined errors' thresholds (i.e. successful). The averages and standard-deviations of the MSE and RMSE related to the estimated flow and speed are presented in Table 1.

Table 1

The average and standard deviation of the MSE and RMSE related to the estimated flow and speed for various length of motorway stretch

Test Scenario	Parameter	MSE			RMSE		
		Mean	STD	Within the success level %	Mean %	STD %	Within the success level %
EV2 (6.8km)	Flow (Veh/h)	375.603	210.59	97.7	26.93	47.70	80.40
EV4 (4.2km)	Flow (Veh/h)	388.23	219.34	96.8	29.36	43.45	74.73
EV5 (5.4km)	Flow (Veh/h)	367.86	203.3	97.9	27.09	44.14	80.00
EV2 (6.8km)	Speed (Km/h)	12.72	8.21	98.88	12.87	43.30	96.08
EV4 (4.2km)	Speed (Km/h)	6.70	4.73	99.63	5.80	6.40	97.96
EV5 (5.4km)	Speed (Km/h)	6.67	4.48	99.69	5.80	6.58	98.33

It is interesting to notice in Fig.3 that a snowstorm was present between 4:00 and 6:30, during which a resulting decrease of the free speed was identified. In this testing, RENAISSANCE also showed its ability in tracking changes in mean speeds and flows. In particular, at the end of the snowstorm the traffic flow dropped sharply for a short time period, while the speed rose from less than 100km/h to nearly 120km/h. Clearly, both dynamic processes were well tracked by RENAISSANCE.

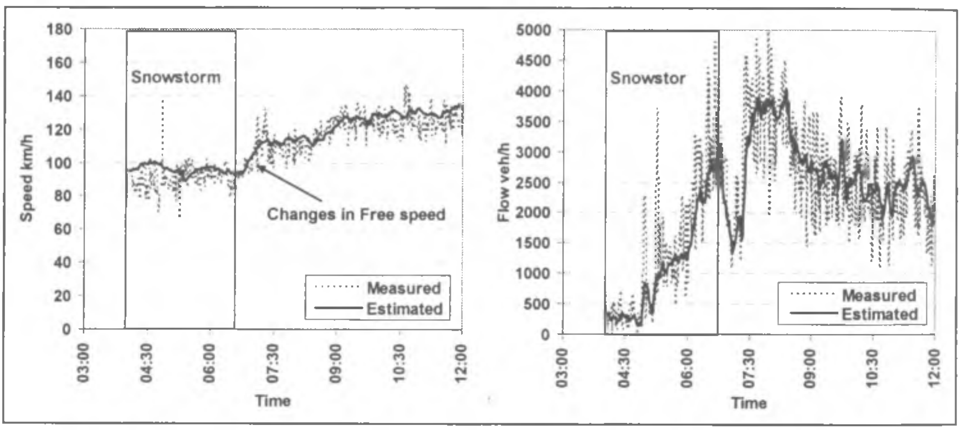

Fig.3. The real measurements and the estimated flow and speed for one survey day

The external measurement data input is indispensable to the RENAISSANCE operation. Hence, it was expected that when incident/accident occurred, the estimation would suffer from errors unless the detectors at the boundaries were able to detect the impact of that incident/accident. (An example is presented in Fig.4). However, no traffic surveillance tool can be free from such performance limitation. In addition, when measurement data suffered from bias (either due to detector errors or due to a non-homogenous stretch) then some estimation errors were also expected, (an example is presented in Fig.5). Interestingly, such features could be used to check detectors errors or identify the special characteristics of various links within a large road network, which adds another benefit to the use of RENAISSANCE.

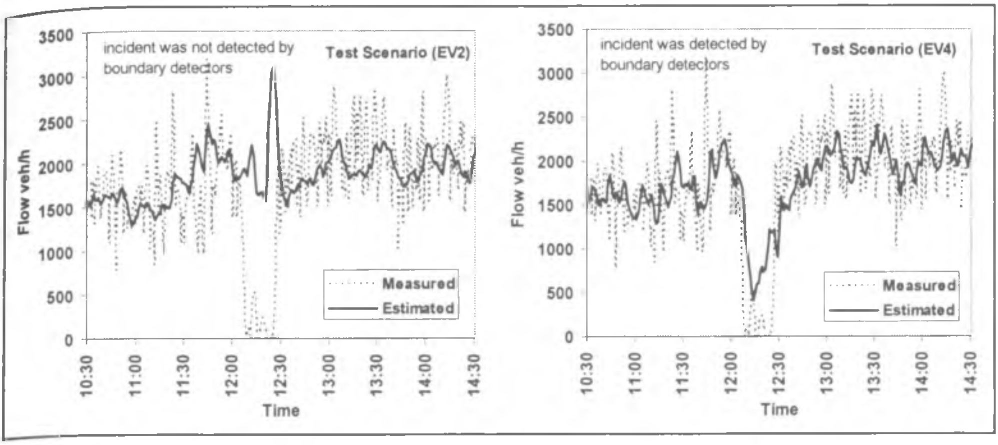

Fig.4. The estimated flow and speed of two test scenarios showing the importance of detecting an incident by boundary detectors

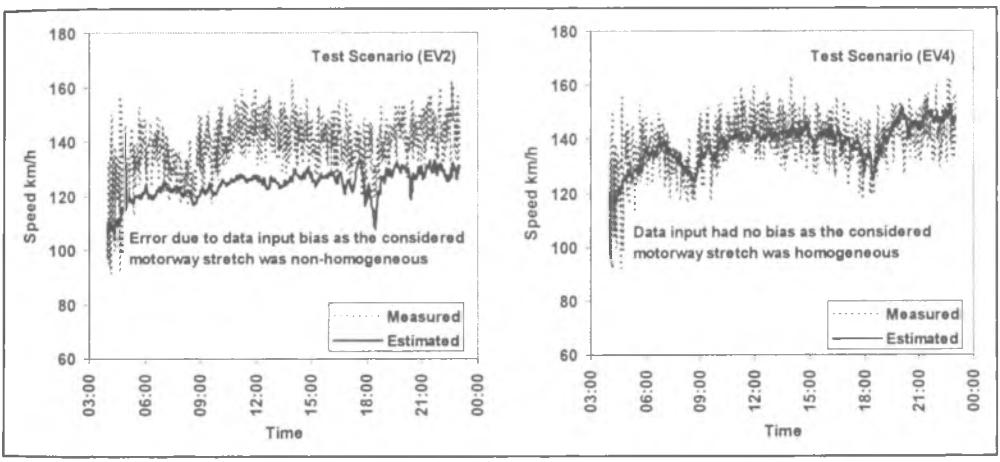

Fig.5. The estimated speed of two test scenarios showing the impact of data bias on the estimation accuracy

An issue of importance is the estimation of shockwave propagation following the instigation of an incident/accident. Although RENAISSANCE is able to track the speed drop correctly at several incidents, time lag was observed between the measured speed drop and the RENAISSANCE estimation under some other incidents (See Fig.6). A close investigation revealed that this was an indirect effect of the mechanism of on-line estimation of the modelling parameters. RENAISSANCE estimates the modelling parameters (i.e. free speed, capacity, critical density, etc.) every time step for each link of the road network considered. The estimated modelling parameters are then assigned to all road segments of the related link. When an incident occurres close to a downstream boundary and results in rapid and significant changes to the characteristics of traffic, the modelling parameter estimator will react and assign the new changes to segments within the link resulting in estimating fast shockwave propagation compared to the one observed. Similarly, if a shockwave was moving downstream (this is less common but could happen when slow moving group of tracks cross the observed link), then the RENAISSANCE would report slower speed propagation. In addition to the consideration of a shorter links, changing the setting of modelling parameter estimator could reduce the error for such incidence. However, a compromise setting has to be chosen to give the best over all performance to RENAISSANCE. The feature of on-line modelling parameter has more benefit than disbenefit to the performance of RENAISSANCE as it was found to be able to cope with daily events of regular congestion significantly better when utilising on-line estimation of the modelling parameter [13, 14].

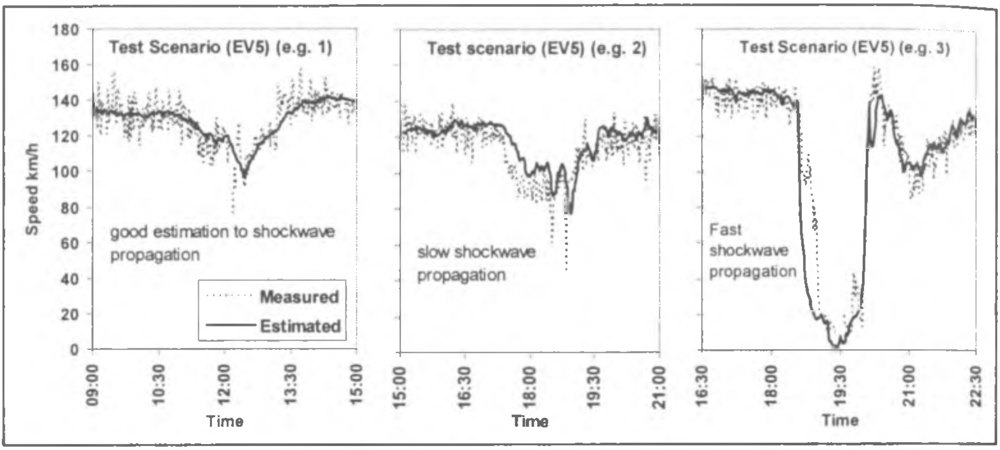

Fig.6. Three examples of events which showed different results of estimating shockwave propagation

The assessment also aimed to compare possible impacts of traffic measurements of various types on the RENAISSANCE performance. The comparison between test scenarios EV1 and EV2 revealed little difference in the performance of RENAISSANCE with regard to the use of loops or video sensors. A similar conclusion was derived on the basis of the comparison between EV2 and EV3. The corresponding MSE and RMSE criteria for flow and speed estimation are presented in Table 2. Whilst all detection types used in this assessment (i.e. loops, radars and VIP's) were found to be viable for traffic surveillance application, reliability and usability for other type of applications have to be considered when network managers decide on which type to install. Over the demonstration period VIP was found to be the most reliable, though this has to be put within the prospective of equipment work life expectancy as both loops and radars were of an older system. The demonstration has also shown that VIP could be used under some conditions that could be considered very challenging such as snowstorm, fog, rains. Clearly, there are many features which would make VIP very attractive to network managers. However, the question remained unanswered with regard to estimated figures of maintenance cost and life span for such system (long-term experience is required to address these issues).

Table 2

The average and standard deviation of the MSE and RMSE related to the estimated flow and speed for various types of traffic detectors

Test Scenario	Parameter	MSE			RMSE		
		Mean	STD	Within the success level %	Mean %	STD %	Within the success level %
EV1 (Loop)	Flow (Veh/h)	361.86	186.46	98.54	25.59	43.02	80.94
EV2 (VIP)	Flow (Veh/h	375.603	210.59	97.7	26.93	47.70	80.40
EV3 (Radar)	Flow (Veh/h)	333.33	194.64	99.06	26.77	36.28	83.80
EV4 (VIP)	Flow (Veh/h)	388.23	219.34	96.8	29.36	43.45	74.73
EV1 (Loop)	Speed (Km/h)	14.31	9.39	98.62	16.12	60.65	98.20
EV2 (VIP)	Speed (Km/h)	12.72	8.21	98.88	12.87	43.30	96.08
EV3 (Radar)	Speed (Km/h)	6.02	4.32	99.72	5.66	7.28	98.58
EV4 (VIP)	Speed (Km/h)	6.70	4.73	99.63	5.80	6.40	97.96

4. CONCLUSIONS

This paper has presented some results from the evaluation of a state-of-the-art motorway traffic surveillance tool RENAISSANCE that was recently developed with the support of an European project. Several test scenarios were utilized to test the RENAISSANCE performance at a test site and the RENAISSANCE has shown good performance in tracking both flows and speeds if the monitored road section is homogeneous. RENAISSANCE proved to be capable of dealing with various types of measurement data simultaneously and able to cope with real-time motorway traffic surveillance tasks over a motorway stretch with the considered detector spacing up to 7 km. Also, dynamic changes in traffic condition due to e.g. weather conditions or build-up of congestions create no problems for RENAISSANCE.

As a data driven algorithm, input from boundary detectors proved to be critical for producing accurate results. Unless incidents have been detected by input detectors, accuracy will drop considerably. Similarly, if detectors produced biased output then accuracy will also drop. However, this systematic limitation applies not only to RENAISSANCE, but to all known traffic estimation models.

One of the advanced features of RENAISSANCE was the on-line estimation of modelling traffic parameters (i.e. free speed, critical density, capacity, etc.) for each link of the monitored motorway stretch. However at some special and infrequent type of incidences, the estimation of shockwave propagation could suffer from some time lag error as an indirect effect of the mechanism of on-line parameters estimation. Non-the-less, such technique has more benefit than disbenefit to the performance of RENAISSANCE as it enabled the tool to track dynamic changes of traffic conditions.

Finally, little difference was observed in the performance of RENAISSANCE in relation to the use of loops, radars, or video sensors. However, the viability of video detectors for traffic management has been demonstrated and they were found to be usable even under difficult weather condition such as snowstorms.

5. ACKNOWLEDGMENTS

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