IMPROVING ROAD AND TUNNEL SAFETY VIA INCIDENT MANAGEMENT: IMPLEMENTING A VIDEO IMAGE PROCESSING SYSTEM

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ABSTRACT

Today, increasing traffic volume and complexity has created a need for more optimised & improved ITS technology, highly automatic incident management systems in particular.

Facts & figures such as ‘more than 200.000 people killed each year in traffic’, ‘At least 10 people have been killed and several others injured by a fire in the Gotthard Tunnel’, … and also the need for more security result in more investments into safer roads and better control of the traffic on highways in general. Traffic managers are looking for effective incident management because this can save countless commuter hours, hectolitres of fuel, and thousands of euros. Effective incident management completely depends on fast incident detection and fast incident verification. While video detection handles both traffic data collection and automatic incident detection, its incident detection shows a high detection rate, a short time to detect, a fast incident verification and a low false alarm rate. These characteristics make video extremely useful for reaching incident management goals such as fast & effective intervention or secondary incident prevention.

This paper discusses the wide range of capabilities and some of the limitations of video image processing for incident detection as Traficon have experienced it over the past 20 years. A basic methodology will be discussed highlighting the key parameters for implementing a video image processing system. This paper also will give you a head start on what video detection, as ITS technology, will bring in the next decade. Detailed case studies of AID systems in the tunnels of Slovenia, Austria, Germany serve as an illustration of these features.

INTRODUCTION

Traffic Managers worldwide are faced with an increasing demand for state-of-the-art intelligent traffic systems: both for statistics purposes as for safety issues. Fast-developing urban regions have a need for information on traffic streams, to take well-founded decisions regarding new road infrastructure and changes to the existing infrastructure. Traffic congestion and secondary accidents are now costing thousands of lives and billions of euros every year. Therefore, traffic managers need an effective incident management system. The time delay to detect and verify an incident seems to be the crucial factor for effective incident management. Every minute lost heightens the risk of having another accident and drastically increases the time to clear the accident.

Traditionally, loops and CCTV cameras provide ample information to direct traffic flows and assemble statistics. But their information is limited, and increasing traffic volume and complexity has created a need for more optimised systems; highly automatic incident management systems in particular.

We believe that improved ITS technology such as incident detection systems could lead to a significant reduction in both frequency and cost of accidents. Some observations gathered from several studies support this point of view. First, between 20% and 30% of all accidents on freeways are caused by preceding (primary) incidents. Secondly, far more than 50% of the secondary accidents occur within 10 min of the first incident. In many cases, they are caused by minor primary accidents and could have been avoided if unprepared approaching drivers
could be warned in time. Third, studies show that more vehicle hours of delay result from traffic jams caused by accidents rather than from regular daily traffic jams. While video detection handles both traffic data collection and automatic incident detection, its incident detection shows a high detection rate, a short time to detect, a fast incident verification and a low false alarm rate. These characteristics make video extremely useful for reaching incident management goals such as fast & effective intervention or secondary incident prevention.

**Basic functions of incident management**

The basic functions of Advanced Transportation Management Systems (ATMS) are traffic monitoring, incident detection, incident verification, driver information and incident clearing. Traffic monitoring, setting appropriate speeds and ramp metering can keep the traffic rolling at a level close to or even above the maximum capacity. This will avoid or delay the recurring congestion and its potential secondary effects. The time needed to detect an incident is of utmost importance. It is only starting from this moment that other activities such as incident verification, driver information, alternative routings and removal activities can start. Incident verification is necessary to decide upon the appropriate corrective actions and on the ways to inform the driver. The fast and efficient information of drivers approaching an accident zone will decrease the number of secondary accidents and also decrease the traffic load in this zone. This can be done by VMS panels, radio, Internet, etc. Finally the necessary manpower and material must be available on the spot as soon as possible to clear the accident and to restore normal flow. These five factors are the key elements for efficient incident handling.

**Traffic monitoring, Prevention (1)**

By setting appropriate speeds and a good controlled ramp metering, one can keep the traffic flow at a level close to or even above the maximum capacity. This will avoid or delay the recurring congestion and its potential secondary effects.

![Figures 1 & 2:](image)

The installation on the Luxembourg highways with video traffic monitoring connected with Variable Message Signs every 1.5 km has proven to be very effective.

**Incident detection, time to detect (2)**

Incident detection can be seen as a crucial component of the overall incident management process. It is clear that an incident has to be detected and verified before any other incident management actions can be taken (such as incident verification, driver information, alternative routings and removal activities). To guarantee the success of any incident management process, it is critical that incidents are detected as soon as they have occurred. Timely and accurate incident management becomes more important when we consider the negative effects of not clearing an incident as quickly as possible. A delay in detecting an incident can cause long queues and traffic congestion, which, in turn, are the primary cause of secondary accidents.
Incident verification (3)
When an incident is detected, it is necessary to decide upon the appropriate corrective actions and on the ways to inform the driver. The use of video cameras is normally the fastest way to see what must be done. One can use a specific CCTV system combined with Automatic Incident Detection using the video of these cameras.

Driver information (4)
The fast and efficient information that drivers approaching an accident zone receive, will decrease the number of secondary accidents and also decrease the traffic load in this zone. This can be done by VMS panels, radio, Internet, etc.

Incident clearing (5)
Finally the necessary manpower and material must be available on the spot as soon as possible to clear the accident and to restore normal flow.

These five factors are the key elements for efficient incident handling. Video detection is by far the best method to perform the three first tasks so that the full incident management can be executed at best.

WIDE AREA VIDEO CONTROL: AUTOMATIC INCIDENT DETECTION

Video detection has now been available commercially for several years and is gaining acceptance as a more effective technology than conventional inductive loop-based technology. Why?

BASIC FACTS
Incident detection using video image processing has several distinct advantages over inductive loop-based technology (Blosseville, Morin, and Locegnies 1993). Inductive loops only are capable of gathering traffic flow data at a point. Video image technology can provide this as well as information about traffic flow at a higher level. It can measure travel times, average speed, and detect stalled or stopped vehicles within the detection zone. It has been successfully used to accurately detect shoulder incidents (Blosseville, Morin, Locegnies 1993).

Wide area video detection for direct automatic incident detection is based on real time analysis of the images of cameras that cover the whole road that has to be monitored. This analysis will detect all abnormalities of the traffic such as stopped vehicles, inverse direction drivers, slow vehicles, fallen objects, traffic jams, etc. An average installation will have cameras installed along the road at distances between 250 and 400m, for tunnels best results are obtained with distances between 70 and 100m. Since there is full coverage, all incidents can be verified immediately. This detection method is mostly used in tunnels, on bridges and on roads with heavy traffic and regular traffic jams and accidents. Figure 3 illustrates a real life, video detection example.
When direct video detection is not possible due to budgetary restrictions, a good compromise is to use indirect incident detection based on wide area zone monitoring. The indirect approach covers zones up to 100 metres. Cameras are mounted every 500 to 1,000 metres. The parameters monitored are the average space speed, the variations of these speeds and the zone occupancy. These data can be used to calculate the expected travel time and its evolution. Tests performed with systems based on the space speed show a fast detection of incidents between cameras (less than 2 minutes) and a high detection rate (more than 90%). Typical installations have cameras at a distance of 500 to 1,000 metres and visually cover most of the highway that has to be monitored. An important side feature of this detection method is the good performance of the time to destination or travel time measurement both in normal traffic and congestion situations. Indirect video incident detection can also be used as a stand-alone installation that will directly activate VMS panels to warn the drivers of upcoming traffic jams. This method already showed very good results for mobile installations that have to guard road works informing the drivers in real time about the situation of the road ahead (See figure 8).

Another advantage of this method is that it can be combined with CCTV systems with pan-tilt and zoom that have a good homing system. The automatic incident detection will detect the incident and automatically show the image of the camera concerned to the operator, who can then verify the incident and start the appropriate actions.

USE OF CLOSED CIRCUIT TELEVISION CAMERAS (CCTV)

The NTCIP proposed standard for center-to-center communication describes the function of cameras as a help for the traffic management system

- Verify the existence of traffic congestion reports
- Determine what assistance may be needed by the incident
- Monitor the progress of incidents, construction and special events
- Determine when the residual congestion from an incident is cleared
- Provide visual images to the public as to the state of the highway
- Determine what type of Emergency Services are needed to be dispatched

All these functions can be combined with an Automatic Incident Detection system. This will result in an integrated video traffic monitoring system with optimal results for safety.
WHAT IS THE CRUCIAL FACTOR FOR EFFECTIVE INCIDENT MANAGEMENT?

An effective incident management completely depends on fast incident detection and fast incident verification! Every minute lost heightens the risk of having another accident and drastically increases the time to clear the accident.

Classic incident detection systems based on loop data and incident detection algorithms have normally a time to detect of 5 minutes or more with a detection rate of about 85%. After this detection one still has to verify what has happened. These delays will greatly influence the impact of the incident. Out of incident simulation models, we can see that the impact of detection and verification time of incidents during heavy traffic has a strong influence on the amount of vehicles involved and the time to clear the traffic jam. The following calculations and accompanying figures are partly based on data from the ARRB Research Report 327 ‘Effective Incident Detection and Management on Freeways’ by Chung, E. and Rosalion, N. (1999).

Table 1: Summary of the waiting and clearing time of an incident with or without a fast incident detection & verification system

<table>
<thead>
<tr>
<th>Traffic restart at</th>
<th>Without fast system (16min)</th>
<th>With fast system (2 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clearing time</td>
<td>Waiting time</td>
</tr>
<tr>
<td>100% of full cap.</td>
<td>77 min to clear</td>
<td>1505 hours</td>
</tr>
<tr>
<td>90% of full cap.</td>
<td>93 min to clear</td>
<td>1676 hours</td>
</tr>
</tbody>
</table>

This means that in this example without looking at shock waves and other effects, the direct impact of 14 minutes delay in verifying will multiply the number of involved vehicles by factor 4 and thus also multiply by 4 the risk of secondary accidents. The economic impact (total time lost due to the accident) is even five times larger. All these effects will grow practically exponentially if the road is nearing saturation when the accident occurs.

Figure 4: Incident Clearance with/without a fast incident detection & verification system.
Video detection is a direct wide area detection method. ‘Direct’ means that it is not a question of calculating if an incident could have occurred, but a direct detection on the image of any abnormality in the traffic situation. As such, the VIP/I or Traficon’s incident detection module is able to detect all major incidents within seconds: stopped vehicles, wrong way drivers, queues, slow moving vehicles, fallen objects, … This short time to detect and fast incident verification can seriously reduce the impact of the incident and prevent secondary accidents.

An example of how an AID system helped preventing a major disaster is the bus accident in the Ekeberg tunnel (Oslo, Norway). In 1995, Traficon equipped this tunnel with 63 cameras. The Ekeberg Tunnel is about 1500 metres long, has three lanes in each of the two tubes, and the amount of traffic on a weekday is 76.000 vehicles a day. Although it is fairly unusual for a bus to catch fire inside a tunnel, this happened in the Ekeberg Tunnel in August 1996. Because the driver had difficulty opening the front door, as the emergency exit did not function, he was not able to get out of the bus immediately. Luckily the video based incident detection system had already given a ‘stopped vehicle’ alarm three minutes before the bus driver was able to activate the local push button alarm himself. The tunnel was already closed and the alarm lights were flashing informing the drivers concerning this incident.

**Figures 5 & 6:** The video based incident detection system gave the alarm 3 minutes before the bus driver had activated the local push button alarm. The tunnel was already closed, the alarm lights were flashing and no other cars were involved.

Another example is the **Tunnel de Foix** in France

**Figure 7:** Since the beginning of February 2001, the tunnel of Foix (Ariège - France) is open. With its 2160 metres it constitutes one of the longest tunnels on the French national road network. Right from the beginning, at the time of the risk survey, the commission of security asked for the installation of an incident detection system because of the passage of vehicles transporting dangerous goods.
OTHER VIDEO IMAGE PROCESSING FUNCTIONS

Besides monitoring stopped vehicles, there are lots of other events that should be monitored and informed to the traffic managers.

1. **Queue monitoring**

The early detection of queues is very important because this will allow the traffic manager to inform the road user of upcoming traffic jams in time, this to prevent queue tail accidents.

2. **Road works monitoring**

Road works can lead to very dangerous situations because the traffic jams they generate are not expected by regular road users, as a consequence resulting in many accidents. Using video detection and VMS panels that can be mounted on a temporary basis have proven to lower the accident rate by more than 70%!

![Figure 8: Road works along the E313, Belgium.](image)

3. **Inverse direction**

Another important application that can be performed by video is the monitoring of roads and tunnels for inverse direction. This application is especially useful at the entrances and exits of highways.

4. **Fallen objects**

Wide area automatic video monitoring allows the detection of fallen objects (e.g. something that comes down from a trailer), this information can be used to warn the driver in the area and to program the removal within the shortest time possible.

5. **Pedestrians**

Recently the city of Los Angeles installed 35 Smart pedestrian warnings based on video detection. The system was developed by the Los Angeles Department of Transportation and tested over more than one year. It uses a video camera to detect pedestrians entering the crosswalk. A controller then activates a flashing light on a mast arm above the crossing. The effect was that 72% of the warned motorists stopped when the light flashed, whereas without the system only 25% did. In L.A. only 7% of the incidents involve pedestrians but they account for 40% of the traffic fatalities.
Figure 9: In L.A., a video camera is used to detect pedestrians crossing the street. Approaching motorists are then warned by a flashing light.

6. Fire and smoke

It is also possible to detect other effects of incidents such as smoke and fire. This approach is mainly used inside tunnels. The main problems with this kind of measurements are that they also need full coverage, they nearly always come with an important delay and that they are subject to a higher degree of false alarms. The following table illustrates how long it takes before smoke or flames become visible after a vehicle has stopped in a tunnel. It is clear that if the stopped vehicle can be directly detected in 12 seconds and verified in a few seconds, this will have superior results.

Evolution of Fires of Vehicles in and around Tunnels:

Table 2: Evolution of Fires of Vehicles in and around Tunnels (Data are from Escota, France).

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Stopped Vehicle</th>
<th>Visible Smoke</th>
<th>First Visible Flames</th>
<th>Global Fire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>0 min</td>
<td>3 min</td>
<td>5 min</td>
<td>8 min</td>
</tr>
<tr>
<td>Van</td>
<td>0 min</td>
<td>5 min</td>
<td>8 min</td>
<td>15 min</td>
</tr>
<tr>
<td>Lorries engine fire (2%)</td>
<td>0 min</td>
<td>Fast</td>
<td>fast</td>
<td>fast</td>
</tr>
<tr>
<td>Lorries brake fire (98%)</td>
<td>0 min</td>
<td>10 min</td>
<td>12 min</td>
<td>20 min</td>
</tr>
</tbody>
</table>

Even if most fire and smoke is detected first by detecting the stopped vehicle it is also possible to detect direct smoke and even flames using video detection.

7. Stopping vehicles or left objects (Homeland Security)

The immediate detection and monitoring of vehicles stopping in suspect zones such as bridges can be a major source of information for detecting dangerous situations, similar for the detection of fallen or left objects on roads and bridges.
IMPORTANT CONSIDERATIONS

Detection rate
The detection rate and the time to detect are generally considered the most important factors in an incident detection system. But besides these it is very important to consider also the false detections and the overall life reliability of the system.

False detections
The number of false detections must be limited in order to avoid that the system will become fully useless. Many people still use the false detection rate (number of false detections over the number of real detections). This factor is dependent on the number of real incidents. We feel a better definition for an incident detection system should be based on the number of false detections per Km lane per day. This can also be split up over different types of events one wants to be informed of.

False detection cost
Using video detection an eventual false detection can be cleared instantly by the informed traffic manager. This is a major saving of costs over other systems where one either has to go on site or has to use a pan and tilt camera to search, locate and verify the incident.

Reliability
In general all of the road detection systems have a much higher reliability than in road systems, they normally have also a much shorter time to repair. Some customers have also preferred to install fully redundant systems such as the Öresund tunnel between Sweden and Denmark. In this tunnel the cameras are at a distance of 60 meter when testing the system we found out that all stopped vehicles were detected by 3 cameras. Since they had also split up the system between pair and impair cameras, this resulted in a system with nearly 100% on time.

Figure 10: Fully redundant system in the Öresund Tunnel
CONCLUSIONS

The actual state of the art makes it now possible to have fully automatic video based incident detection covering both the main road and the hard shoulder. The direct incident detection systems based on video images cover the entire highway and will provide the fastest way (10 seconds) to detect the incidents. They show the highest detection rate with the lowest false alarm rate and also the lowest false alarm cost.

Available data support our claim that using video signals for detecting traffic data and incidents is the most reliable and cost-effective solution currently available. A full coverage, video incident detection system on a busy highway has an economic payback period of less than 6 months, this even without taking into account the number of lives saved or the ecological impact.

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