SKYTOLL

Automatic Incident Detection

Design, build up, finance and
operation of the Electronic Monitoring
and Toll Collection System

CONTENTS

INTRODUCTION OF SKYTOLL, A.S.

HISTORY AND SUCCESSFUL PROJECTS

SkyToll, a.s. was established in 2008 by a group of technological and financial investors for the purpose of participating in an open tender for provision of the electronic toll collection service in the Slovak Republic.

The National Motorway Company (NDS) is responsible for development and maintenance of the road network in Slovakia as well as for collection of payments for its use. In 2008 NDS decided to develop an electronic toll system on motorways, expressways and 1st class roads for lorries with the maximum permissible weight over 3.5 tons and buses. The project objective was to increase the efficiency of collection of fees for road use and the success rate of toll collection using cutting edge technological solutions (replacement of the existing system of motorway stickers for these categories of vehicles). SkyToll, a.s. won the open tender and on 13 January 2009 concluded the contract with NDS, under which SkyToll committed to design, build and for 13 years of the system operation to provide complex services of electronic toll collection on the specified road sections in Slovakia.

In less than 12 months SkyToll developed a customer service network, necessary infrastructure, implemented information systems and formed an expert team, which provided for the ETC system development and commissioning of the service as such. Since 1 January 2010 SkyToll has administered one of the most cutting edge ETC systems and currently Slovakia is in the group of global leaders in the ETC area. At the system start-up the specified road sections included almost 2400 km of motorways, expressways and selected 1st class roads. After several expansions the system now covers 17,762 km of roads (all motorways, expressways and 1st, 2nd and 3rd class roads). This system uses the satellite GPS-GSM technology, which provides maximum flexibility in expansion of the toll road network within the Slovak Republic. The satellite technology is used to determine the distance driven on the specified road sections by means of the On-Board Unit (OBU). The OBUs used in the Slovak Republic include all three key technologies for international cooperation: GNSS (standardised satellite technology), GSM/GPRS (interoperable network for data transmission) and DSRC (for enforcement interoperability for satellite as well as for conventional microwave systems). The OBU transmits data of the location into the central system through channels of the GSM-GPRS mobile network. The central system informs the toll calculation on the basis of data and it will issue an invoice for the vehicle owner.

The Slovak ETC system is ready for integration with other European systems in the greater area of the European Electronic Toll Service. As a result the Slovak Republic meets all the conditions to offer relevant experience with implementation of the European directives 2004/52/EC and 2009/750/EC on interoperability of the ETC systems in Europe.

CERTIFIED MANAGEMENT SYSTEM SKQS ISO 27001

SkyToll considers it very important to deal with the issue of data security and personal data protection. Therefore, the company introduced the Information Security Management System according to ISO 27001 and received a certificate for this system.

PROFESSIONAL EXPERIENCE AND COMPETENCIES

In the implementation of its projects SkyToll obtained extensive professional experience, which can be applied for the successful execution of the project of electronic toll collection as a compensation for damage caused to the federal roads by vehicles having the permissible weight exceeding 3.5 tons.

Complex solution provider:

SkyToll designed the complex service of electronic toll collection, built and integrated system domains and service organization, defined efficient operational processes and operates the complex service of electronic toll collection in Slovakia.

Strong experience and successful implementation:

Fast and cost efficient implementation of the electronic toll collection system is possible to achieve in case of having the know-how and the broad experience from successful implementation and efficient operation of a toll collection system. SkyToll offers the experience starting from legislation, complex setup of the solution and guaranties for the delivery including financing and successful and efficient operation.

Commercial and technological operation:

SkyToll operates all of the services and components including toll collection, customer services, enforcement services, OBU distribution and maintenance, IT administration and operation (monitoring centre, technological support and maintenance).

Optimized operational processes:

The Back-office, the Points of Sale and the Call Center are designed to meet the customers' needs and expectations of customers. All the services covering customer registration, customer data changes, the OBU handover to the customer and its collection from the customer, receiving payments, providing information, receiving of claims are under one roof and ready for communication in several languages, thus being extremely convenient for transit transport drivers.

Expert consulting and project financing:

Besides the complex technological delivery, SkyToll is able, based on its experience with financing of the big European projects, to secure financing for the whole project as well as for the toll system operation itself during the period of repayment of the investment by the government.

Research, development and innovation:

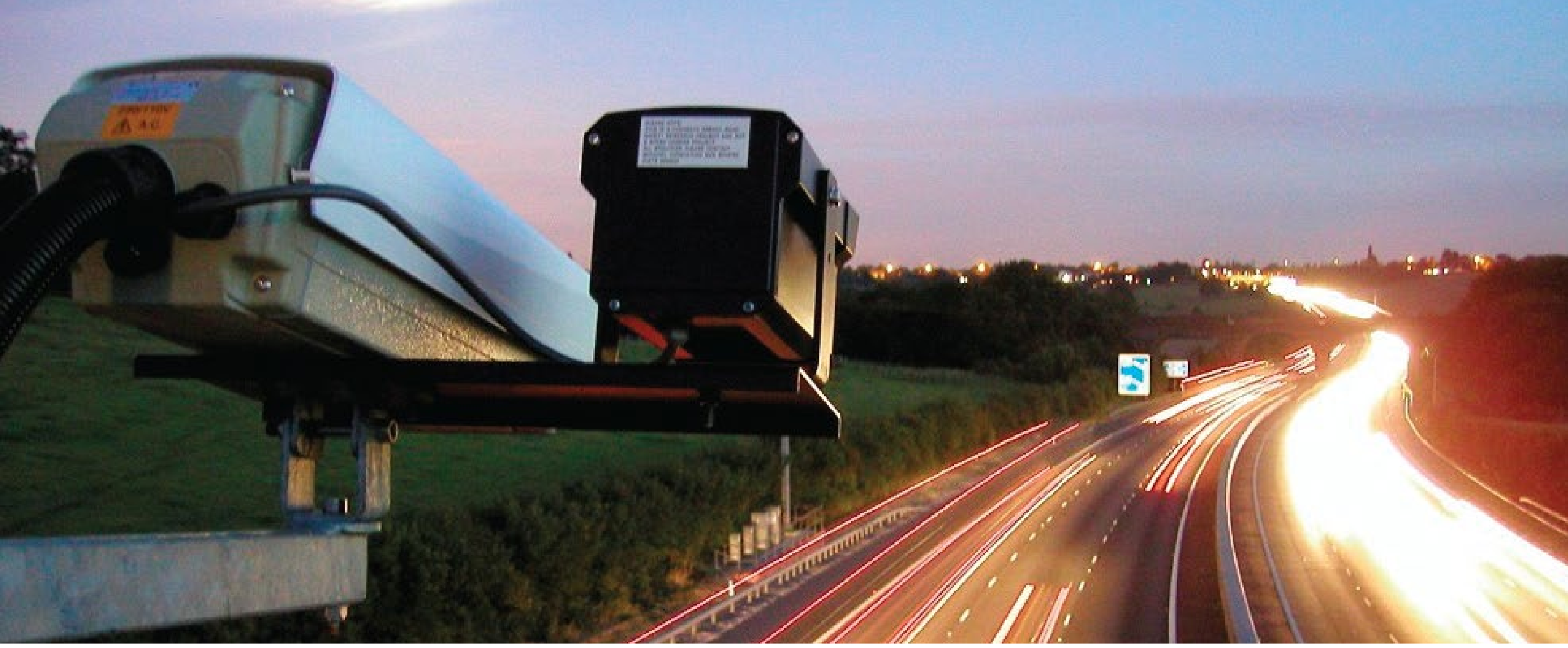
Thanks to the complex technological platform SkyToll has also the competence to provide the suggestions for further enhancement of the system and for development, delivery and operation of additional solutions and new services.

In-house product portfolio for delivering E2E solution:

SkyToll as a solution provider creates the effective end-to-end solution based on the components from its own portfolio. Already today it utilises the unique combination of technologies that represent the basis for the information traffic systems of the future. The application thereof erases the boundary between the present and the future.

Beneficial cooperation:

SkyToll is a strong partner with experience from implementation and management of real projects. In its design for provision of an integrated service for the Russian ETC project, SkyToll offers long-term partnership and cooperation, consultation and support for ongoing optimisation of the whole service of electronic toll collection as well as for implementation of development requirements for the system or the business.



INTRODUCTION

Technology used for the traffic monitoring became mature enough and affordable so that the wide deployment is possible recent years. The core capability of the Automatic Incident Detection (AID) System is to combine information from the exploited equipment to produce impeachable evidence of the detected incident at the output. It also implies that the system is closely related to laws in the target country. The system is then able to substantially reduce the number of most dangerous traffic rules violations. Traffic rules infringements made by drivers are fined using the automated system, which produces and sends a printed (hard copy) documentation of the driving offence to car owner's mailbox.

In the next section, we firstly summarize technology enablers exploited for the proposed automatic incident detection system. Then more details will be added to each technology domain. Having described all necessary building blocks the whole system will be specified as well as the example violation detection and evidence creation. Ease of use and flexibility during new site configuration is demonstrated in the last section.

TECHNOLOGY BACKGROUND

Each technology itself has been introduced relatively long time ago, however until now they were exploited separately with non-negligible interaction with human operator required. The AID system developed by Skytoll is focusing a set of the, unfortunately very common, traffic rules violations. The system gets the input data from

- ANPR (a.k.a. ALPR) camera – automated name (license) plate recognition module: provides the recognized LPN of the vehicle
- Speed measurement module: provides certified measurement of the vehicle speed
- Context camera
  - Video analysis module: vehicle motion tracking and subsequent motion analysis,
  - Context picture selection module: provides pictures for the incident evidence
- Dynamic weighing module: provides vehicle weight measurement

according to selected violations that are to be detected at the given site. Next few subsections are describing the contributing technologies in more detailed level.

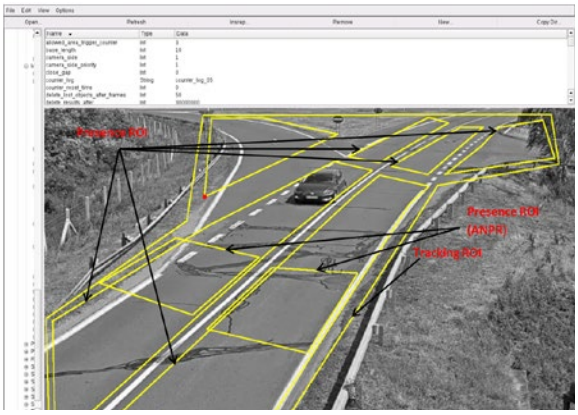


Figure 1: Tracking and Allowed Area ROIs

Figure 2: Motion Tracking

MOTION TRACKING & ANALYSIS

Monitoring camera is focused on the area where the potential incidents are to be detected. The area consists of static scene (background + other geographically fixed objects like traffic signs, semaphores etc.) and moving objects (typically vehicles). According to given set of traffic rules infringement to be detected, number of polygons is designed within this focused area during the site configuration process. These polygons define so called region of interests (ROIs). The motion analysis software recognizes several basic types of ROIs: tracking (intensive video processing required for moving object tracking), presence monitoring (only presence of the object is evaluated over time) and other (i.e. brightness is evaluated within this specified area). The example of ROIs plotted in the real scene viewed from the monitoring camera using the operator GUI can be seen at the Figure 1, where all ROIs of various types are drawn with yellow lines.

Motion tracking algorithm then keeps track of the vehicle within given ROI. It produces all outputs needed for subsequent motion analysis. The vehicles, or better moving objects, are tracked using the so called templates – estimated raw shape of the vehicle, rather than just moving pixels blob. It helps to track even partially overlapping objects (see Figure 2).

Having tracked precisely the vehicle, one can easily evaluate the direction and potential deviations from allowed course. The sequence of detected vehicle presences in the ROIs (corresponds to the coarse vehicle track) can be checked against the set of series to be detected and any match produces an event which is further processed in the system. Vehicle stop time (no move) within given ROI can be also easily evaluated. In other words, motion analysis gives us a variety of generic tools created upon its basic building blocks enabling detection of a large number of various incidents based on the inputs provided by the motion tracking module. The system, due to its modularity, is very flexible and can be easily augmented by almost arbitrary detecting rule.

SPEED MEASUREMENT

The speed can be measured through several principles. Every target country has its own legal requirements sometimes even the concrete technology must be allowed. Usually the requirements for the speed measurement are defined through the measurement accuracy – typically the error must be less than ±3 km/h (for speeds less than 100 km/h) and less than ±3 % (for speeds higher or equal than 100 km/h). The decision about suitable technology should be done individually for the given site; usually the Doppler radar is sufficient for spot speed enforcement and, furthermore, such solution can be easily integrated with ANPR camera lowering thus the number of installed components. Skytolls' AID system can integrate equipment using any of following technology.

- Spot speed measurement
    - Doppler principle based radars – standard equipment evaluating the speed based on the Doppler principle, i.e. on the changed wavelength of the reflected radio signal from the

approaching (or going away) vehicle. The speed is proportional to the wavelength change.

  - LIDAR – measures almost continuously the vehicle distance by sending set of laser impulses (at the speed of light) and receiving the reflected ones. The receiver then just calculates speed having the travelled distance within known time interval.
  - Inductive loops – loops are placed at fixed distance and the time interval is measured between two vehicle detection timestamps at these loops. Again, the travelled distance and the time delta required for speed evaluation are known.

- Segment average speed measurement – requires two measurement stations with perfectly synchronized (time) ANPR cameras. Speed is evaluated from known distance between stations (vehicle detection locations) and the difference between two detection timestamps.

ANPR

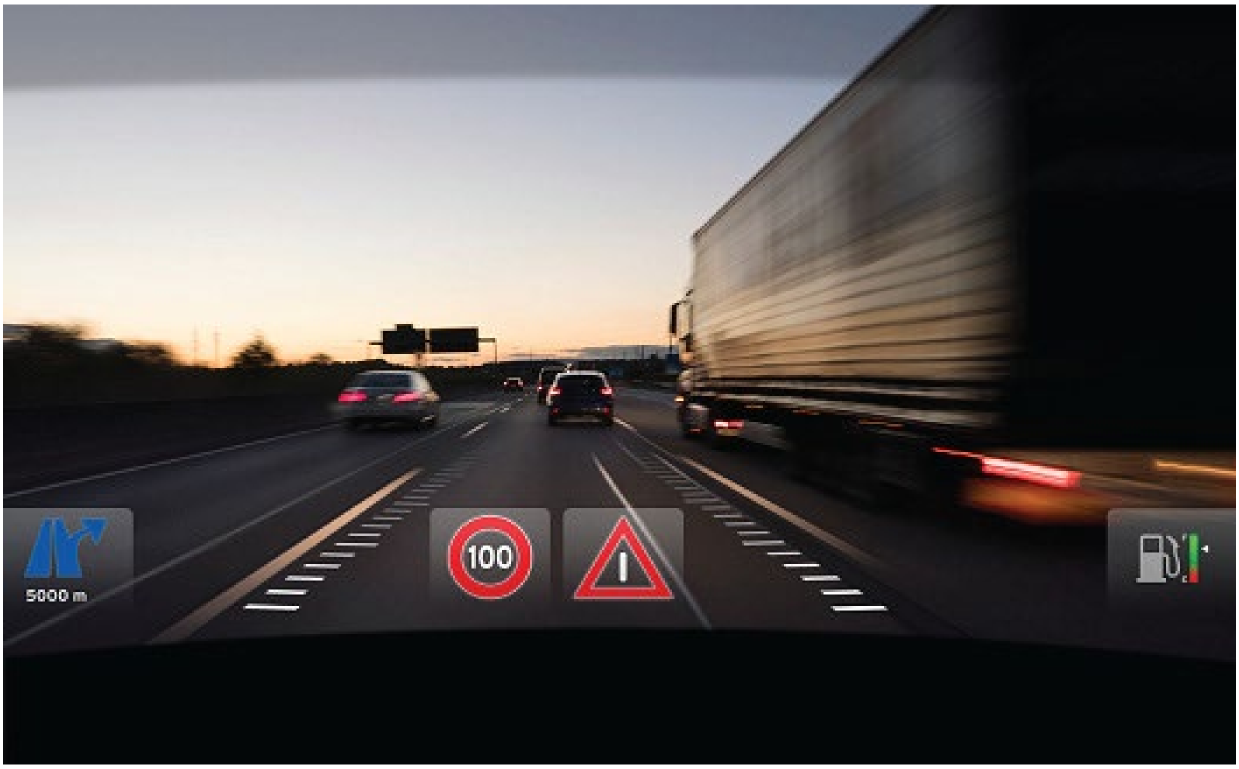
ANPR camera is typically a standalone component that has often infrared strobe integrated in the camera case. Processing unit at the camera is able to continuously monitor focused area and when it is triggered (internally from the own motion detection algorithm or externally from e.g. the inductive loop or laser trigger) it searches for the LPN in the picture and subsequently performs an OCR (Optical Character Recognition) on the found object. This is done many times for the whole sequence of pictures and the best result is sent to the output. ANPR cameras have rich configuration options including the priority list for the specific country character sets, etc.

DYNAMIC WEIGHING (WEIGH-IN-MOTION)

Weigh-in-Motion (WIM) stations are probably the most expensive part of the AID system. It requires installation of several (the more the better weighing accuracy) inductive loops and weighing sensors directly into the road surface. Moreover there are some requirements on the road surface quality, and regular checks and recalibrations (can be automated) are also needed.

Although the price of the system, including the installation and maintenance expenses, is relatively high it was proven that the payback period is less than one year. There are basically two principles – widely used piezoelectric and minor optoelectric (exploiting the measurable deformation of optical fibers installed in the road surface). Skytoll's AID exploits the mature piezoelectric principle based best-in-class technology. There can be various configurations installed depending on the target application.

Weighing for enforcement purposes must have at least accuracy class A(5) or B+(7). The measurement of weight load can be done per wheel, axle and overall vehicle (gross) without any traffic flow disturbances (i.e. at normal travelling speeds).



APPLICATION TO AUTOMATIC INCIDENT DETECTION

GENERAL SCHEME

Figure 3 depicts the general scheme of the AID system architecture. It contains the site equipment supplemented by the AID Controller. Its function is to receive data from all components and mainly put them all together (information pairing) so that the output can be used as the traffic rules infringement evidence. There can be number of sites with various configurations of installed components. The configuration will differ according to violation detection requirement for given location.

Data from AID Controllers in specific format (including e.g. encryption) are gathered at the concentrator which provides an interface to the back office system – Traffic Infringement BackOffice (TIBO). Here all data are stored in a safe way and required incident documentation can be generated using e.g. the system GUI (Graphical User Interface). TIBO is connected to other country wide registers which provides necessary information about the vehicle owner so that he/she can be fined. Optionally, other registers can be also connected through the interface adaptor to get the complete picture about the given vehicle.

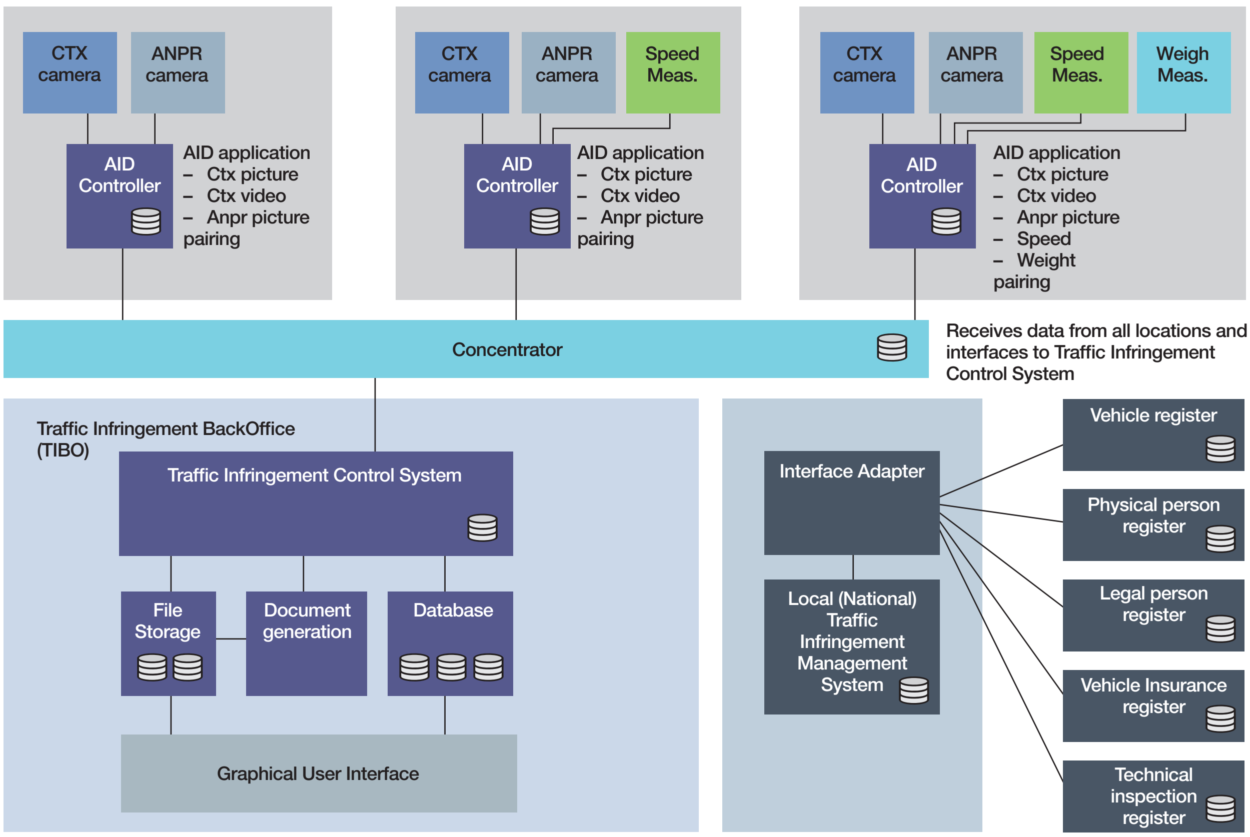


Figure 3: Architecture of Automatic Incident Detection system

LEGAL MATTERS

As it was mentioned above the most challenging task of AID system is to pair the information from components in such way that unimpeachable evidence of the traffic violations can be build. Apparently the most important entry in the pairing process is the detection or capture timestamp. However ambiguities often generate a need for other supplementing rules that help to pair the right data automatically.

Every video material (pictures, short video sequence, etc.) has to be equipped with data that specifies in a unique way:

- Where the picture or video has been captured (location – GPS coordinates)
- When the picture or video has been captured (precise UTC timestamp synchronized from back office)
- Which component has generated the video material (serial number)

Furthermore the video material attached to the evidence documentation should contain the matching parts – e.g., the video frame sequence shall contain the context picture, LPN visible by naked eye at the context picture or video shall be the same as

from the ANPR, ANPR focus area shall overlap with the context camera focus area.

EXAMPLES OF INCIDENT DETECTIONS

Stop sign crossing

In this case we are interested in detecting whether a vehicle stops inside an area delimited by the dedicated ROI. The MA analyses the path of the object and make some extra checks trying to properly detect the stopped vehicles and to avoid false detections. Normally the MA is configured so that a stopped vehicle event requires a template to be tracked for a predefined amount of time (e.g. 1 second) on the same position in order to be classified as stopped. It is also possible to define that the template is to be considered as stopped even if it moves inside a predefine pixel range (hysteresis). This is useful because, sometimes even though a vehicle being tracked is stopped, due to noise or other spurious events the template related to that object moves a little. Figure 4 shows an example of stopped vehicle detection by MA. Incident documentation (video and context picture) is further supplemented with the picture from the ANPR camera with recognized LPN.

Figure 4: Stopped vehicle detected (top right corner)

Figure 5: Traffic light ROIs

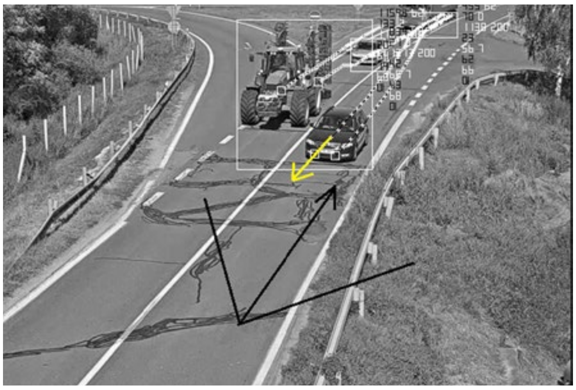


Figure 6: Wrong way (direction) detection

RED LIGHT VIOLATION

This can be considered as an extension of the stopped vehicle detection as it is further conditioned by the detected red light on the traffic light or semaphore. It means that vehicle must be stopped when the red light is on. Context/monitoring camera must either see on the semaphore or the control signals from the semaphores have to be available. In the first case, the special ROI is defined where the red and green lights is placed on the image (Figure 5) and the ROI brightness is being evaluated to decide whether the red light is on or not. This is another input for the MA algorithm.

NO STOPPING SIGN CHECK

Monitoring of the vehicles where the stopping is prohibited, typically through installed "no stopping" traffic sign, is an inverse task to those mentioned above. Nevertheless the same MA tool is used however with different rule defined – vehicle cannot stop in this ROI for more than specified time interval (given by local traffic rules).

WRONG WAY OR REVERSING

As the vehicle move direction is being tracked it can be always compared to the predefined allowed direction at given place.

Figure 6 shows the situation when the allowed direction is given by the black cone oriented with black arrow – the solid line is on the road, so no car is expected to go in yellow arrow direction. This is the most apparent example – the opposite direction.

U TURN AND FORBIDDEN TURN CROSSING

The sequence of detected vehicle presences in the ROIs (corresponds to the coarse vehicle track) can be checked against the set of series to be detected.

Figure 7 and Figure 11 present wrong turn detected at the test site (Note: this turns are of course allowed in the reality, but for the test purposes they were considered as prohibited.) U-turn can be detected, e.g., by searching for the sequence starting at the ROI #2 and ending at the ROI #5.

Figure 7: Wrong turn detections- detection based on sequence starting with ROI #4 and ending with ROI #1 (4..1, left), detection based on sequence starting with ROI #0 and ending with ROI #4 (0..4, right)

Figure 8: Wrong turn detection, sequence starting with ROI #3 and ending with #4Incident Detection system

SOLID LINE CROSSING

Crossing of the solid line can be detected via two ways/ two MA tools – either using the direction evaluation or ROI sequence analysis.

RAILROAD CROSSING

Railroad is typically equipped either with traffic light or at least with the special traffic sign demanding vehicle to stop. This allows to use almost the same setup as for the red light violation – ROI is defined where the vehicle is required to be stopped when the railroad red lights are on or when the stop sign is installed.

OVERWEIGHT

The vehicle overweight can be monitored almost seamlessly without disrupting the traffic continuity. The weighing can be done with sufficient accuracy at normal traffic speeds (about 90km/h). Weigh-In-Motion system for such required accuracies is equipped with at least two inductive loops and two in line piezoelectric sensors build-in the road surface. This allows measuring the vehicle speed from the inductive loops data as the important factor for the weight evaluation.

FORBIDDEN HEAVY WEIGHT VEHICLES SIGN CROSSING

This incident can be detected using the accurate dynamic weights in connection with the motion tracking & analysis. Weighted vehicle is being tracked (e.g.,) and forbidden move is detected whenever given ROI polygon presence sequence is matched.

HIGH AND LOW SPEED MONITORING

Site must be equipped with the speed measurement device. Typically the Doppler radar is sufficient for two lanes (one approaching and one go away lane) roads. It provides accurate measurement and furthermore it's often integrated with ANPR camera.

Figure 9: Solid Line Crossing, detected by the sequence 1..0 (left) or using the driving direction evaluation (right)

ID	Violation	ANPR	Context Camera Motion Analysis	Context Camera Video	Context Camera Picture	Weigh-In-Motion	Speed Measur.
1	Solid line crossing	✓	✓	✓	✓		
2	High and Low speed monitoring	✓		✓	✓		✓
3	Red light ("Stop" sign) crossing	✓	✓	✓	✓		
4	U Turn/reversing	✓	✓	✓	✓		
5	"No Stopping" sign check	✓	✓	✓	✓		
6	Railroad crossing	✓	✓	✓	✓		
7	Overweight	✓		✓	✓	✓	
8	Forbidden turn crossing	✓	✓	✓	✓		
9	Forbidden heavy weight vehicles sign crossing	✓		✓	✓	✓	

Figure 10: Required technology for example violations to be detected and well documented

SITE CONFIGURATION

As soon as the HW required for given set of violations to be detected is installed (having in mind the set of rules mentioned in previous sections), the site SW needs to be configured and calibrated. The most crucial part of the setting is the configuration of the motion analysis algorithm. This process can be very simple with Skytoll's AID system. The operator performing the site configuration has a simple GUI at disposal, where all required ROIs can be designed directly on the viewed scene as it is demonstrated in Figure 11.

When all ROIs are drawn manually, one gets the ROI set like at the Figure 1. Zone design is, of course, closely related to the concrete situation. Most of other settings can be let at their default values as it is comes from the system provider.

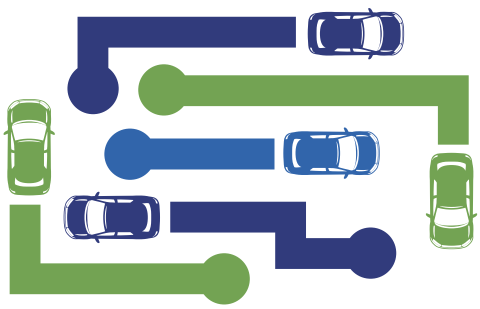
Figure 11: Steps for drawing a new polygon –Creating a new polygon (top left), Setting the name (top right), drawing all sides of the polygon except for the last (bottom left), closing the polygon (bottom right)

AIRBORNE TRAFFIC MONITORING

Airborne monitoring overcomes the limitations of traditional traffic data collection methods. This is particularly possible thanks to the high mobility of the solution and the ability to record data across large areas. Due to the use of unmanned vehicles - drones, it is possible to deploy the monitoring system immediately to the point of actual need. Air data are automated and their outputs can be shared on-line, allowing the client to perform an immediate hit, e.g. in case of a traffic violation

FUNCTIONALITY OF AIRBORNE TRAFFIC

- speed measurement, detection of exceeding the speed limit
- monitoring the compliance with mandatory and prohibitory traffic signs
- detection of passage on red light on crossings and intersections
- traffic density monitoring
- monitoring the compliance with traffic lanes
- distance measurement between cars
- classification of vehicles and monitoring of LPNs



ADVANTAGES OF AIRBORNE

- fast deployment
- extensive coverage
- fully mobile system
- without the need to build a fixed infrastructure
- hidden monitoring system

CONCLUSION

The benefits of AID system are clear – one can expect a drop in amount of traffic rules violations not only at monitored sites, but also in the whole monitored area (town, country, etc.) as the drivers are continuously being brought up with AID system. Reduction of traffic accidents is a natural consequence. Secondary, however equally pleasant, effect is more money paid by fined drivers that can be used for any useful reasons, e.g. further invested into better road infrastructure. Furthermore variety of new violations can be added only through the SW adjustment.

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