ABSTRACT
Cooperative systems use wireless communications between vehicles to enhance the road traffic safety and the efficiency of transports. The wireless technology enables a plethora of new applications which complement already existing intelligent transport systems (ITS) applications. Today, hazard goods transports through tunnels can be identified by cameras reading the hazard identification plates (i.e., ADR plates). However, this system is not sufficient in all situations and the safety can be greatly enhanced by introducing wireless communications, which will be shown in this article. Two important measures for enhanced tunnel safety are surveillance systems for tracking the dangerous goods through the tunnel and limitations to the type and amount of dangerous goods allowed at any given time. This paper gives an overview of the current state-of-the-art systems for tracking dangerous goods in tunnels and continues with detailing a cooperative tunnel management application realized through cooperative systems developed within the European project SMARTFREIGHT. Cooperative systems are based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, which increases quality, reliability, and "time horizon" of information. CVIS (Cooperative Vehicle-Infrastructure Systems) was a European research project financed by the European Commission. Within CVIS the CVIS Reference Execution Platform was developed which is the key European research platform for testing of cooperative systems. In the SMARTFREIGHT project the CVIS Reference Execution Platform was used as a basis to develop and test new innovative applications to support freight distribution.

INTRODUCTION
Transport of dangerous goods is an area where monitoring and control is of great interest to authorities, especially in urban areas where the density of both traffic and people is high, and also in tunnels where any emergency handling can be extremely challenging. The transport of hazardous materials on roads are governed under ADR [1], which is the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR is abbreviated from French Accord européen relatif au transport international des marchandises Dangereuses par Route). One important requirement in ADR is that transport units carrying dangerous goods shall display two rectangular orange-coloured plates, one at the front and one at the rear of the vehicle. Figure 1 shows an example of such an ADR plate. On the ADR plate the upper number is the hazard identification number (HIN) and the lower number identifies the substances. The substance is identified with a UN number from the United Nations (UN) Recommendations on the Transport of Dangerous Goods. In the shown example HIN is 80, which denotes hazard of corrosivity. If the HIN number is prefixed by the letter "X", this indicates that the carried substance will react dangerously with water. The UN designation is always a four-digit number,
in this case the UN number is 1789, which denotes hydrochloric acid.

Current systems for surveillance of tunnels typically employ camera equipment for the monitoring task. The pictures from these cameras can then be transferred to an associated traffic management centre, where operators can manually assess the current situation. The pictures can also be fed into advanced image processing solutions for automatic reading and decoding. By employing optical character recognition (OCR) technologies both the license plates and the associated ADR plates can be read. Such automatic vehicle identification requires careful mounting of the cameras for proper viewing angle to the plates. Therefore such OCR based reading will typically be restricted to some fixed locations where space is available for correct mounting of the cameras.

The OCR technology has its drawbacks such as blurry images in bad weather conditions (heavy snowfall/rainfall and fog) and it also requires manually supervision to handle unreadable plates. By introducing cooperative systems based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications the safety in for example tunnels could be enhanced and the supervision could be automated. The wireless technology is not influenced by a bad weather situation to the same extent as cameras. The required technologies for wireless communication is already in place, and several research projects have orchestrated systems based on the concept of cooperative systems for the benefit for freight transport. Cooperative systems enables more efficient applications for enhanced traffic safety.

**COOPERATIVE SYSTEMS**

In cooperative systems road operators, infrastructure, vehicles, drivers and other road users, cooperate to achieve safe and efficient journeys by using wireless communications. Cooperative systems use V2V and V2I communications, enabling the different users to exchange information about their status and environment. The information communicated can be safety related, such as emergency braking or slippery road conditions, or more focused on traffic efficiency, such as congestions, roadworks, and dynamic route advices. In effect this communication increases quality, reliability, and the "time horizon" of information. V2V and V2I communication can be implemented by using wireless local area network (WLAN) techniques optimized for vehicular environments. Several standard-developing organizations, including IEEE, ISO, and ETSI, have harmonized the use of radio frequencies around 5.9 GHz for safety and efficiency applications.
This type of omni-directional communication enables V2V and V2I communication ranges of typically 500 meters (line-of-sight). In addition to this WLAN based communication technology, several cooperative system services also require ubiquitous Internet connectivity. This can be enabled by using existing infrastructure for cellular communication (GPRS/UMTS), but in areas where suitable roadside infrastructure exists this can be augmented by using V2I Internet access routers.

CVIS (Cooperative Vehicle-Infrastructure Systems) [2] was a European research project financed by the European Commission. Within the CVIS project the CVIS Reference Execution Platform was developed to enable V2V and V2I communication. This is an open platform made available to interested stakeholders for testing and development of cooperative systems. Figure 2 shows the realized CVIS Reference Execution Platform. In addition to the communication facilities the reference platform also include facilities for positioning. The positioning is GNSS/GPS based and also features an inertial platform for both added accuracy and dead reckoning support. In addition the reference platform provides a runtime environment for applications. This runtime environment is based on the OSGi specifications and facilitates on-the-fly installation, deployment and provisioning of applications.

In the SMARTFREIGHT [3] project the CVIS Reference Execution Platform was used as a basis to develop and test new innovative applications to support freight distribution. The SMARTFREIGHT project also incorporated the concept of intelligent cargo. Intelligent cargo uses radio-frequency identification (RFID) tags to identify cargo units. The RFID tags enables wireless readout of the identity and associated data of cargo and can be enhanced by embedding ICT (Information and Communication Technology) processing capabilities on the on-cargo tags. The result is called intelligent cargo, defined as cargo that is self-aware, context-aware and connected. The use of smart tags on individual cargo units enables continuous tracking and surveillance of the goods. The smart tag used in the SMARTFREIGHT project is shown in Figure 3. This tag includes, in addition to ICT processing capabilities, an acceleration sensor, a temperature sensor, and several positioning sensors. The 3-axis acceleration sensor enables tilt and shock detection, while the temperature sensor can be set to detect temperature peaks above...
or below pre-set limits. The on-cargo unit communicate directly with the vehicle, using the standardized CEN DSRC protocol for communication. CEN DSRC, running at 5.8GHz, is a commonly used standard for electronic toll collection (ETC) and road user charging (RUC). It was chosen for this application due to its excellent power saving properties, which is important for prolonging the battery lifetime of the tags.

COOPERATIVE TUNNEL MANAGEMENT

Within the SMARTFREIGHT project a new cooperative application for the surveillance and tracking of dangerous goods was developed. This application, Cooperative Tunnel Management, enables each dangerous goods carrying vehicle to receive individual and time-specific admissions to tunnels. The application also continuously monitors the "content" of dangerous goods in the tunnel. The tunnel restrictions can be based on both vehicle properties and the amount and type of dangerous goods. By combining the concepts of cooperative systems and intelligent cargo the vehicle itself knows any associated dangerous goods codes (ADR code), and depending on the city policy it can be obliged to report its position, and even its planned route, to a traffic management centre. For the specific case of dangerous goods in tunnels not only tracking might be desired, but also means to limit the number of concurrent vehicles with dangerous goods. When detailed information on the cargo is available a limit can also be set for the total amount (weight/volume) of dangerous goods, or even prohibit certain combinations to be concurrently in the tunnel. These limits can be dynamic based on the time-of-day or traffic situation.

Figure 4 outlines the Cooperative Tunnel Management implementation from SMARTFREIGHT. In Figure 4a the roadside equipment (RSE) ensures V2I communication coverage to vehicles approaching the tunnel. The blue polygon is designated as the approach area. The red polygon is a holding area for vehicles, while the green line denotes a possible bypass road for vehicles not allowed to enter the tunnel. The tunnel management implementation has multiple components allowing for a distributed implementation. A tunnel (or a set of tunnels) is owned by a tunnel coordinator application. The RSE will broadcast service announcements to the vehicles. In the service announcements there is a uniform resource identifier (URI) to the tunnel coordinator. Vehicles with the tunnel application installed on their on-board equipment (OBE) will process the tunnel service announcement from the RSE. Based on the URI the in-vehicle application will query the tunnel coordinator for the tunnel access policy. This policy contains information about the road network around the tunnel, approach area, holding area, by-pass roads and goods restrictions that apply to the tunnel. After the policy is loaded and validated, the in-vehicle
application will start to track the position of the vehicle in relation to the defined approach area. When the vehicle is entering the approach area, the in-vehicle application will send an access request to the tunnel coordinator. This request contains the goods properties relevant to the access policy. The tunnel coordinator will then, based on current tunnel occupancy and access policies, evaluate the request. There are three possible outcomes of this evaluation: Access granted (proceed), access permanently denied (use bypass), or access temporarily denied (hold and wait in holding area). The result of this evaluation is sent as a response to the vehicle and communicated to the driver through an in-vehicle human machine interface (HMI). Figure 4b shows the message exchange. Figure 5 shows the HMI used in SMARTFREIGHT project. If the result of the evaluation is that the vehicle is temporarily denied, the vehicle is put into an access queue by the tunnel coordinator. All access requests in the access queue are re-evaluated whenever a vehicle exits the tunnel. If this re-evaluation results in an access grant the vehicle is notified. This queue concept can easily be extended to prioritize certain vehicles. The vehicle will, based on the geographical boundaries described in the tunnel policy, always inform the tunnel coordinator when it enters or leaves the tunnel. The tunnel coordinator will therefore have an up-to-date list of the content of dangerous goods inside the tunnel. This status can, if required, be forwarded automatically to a central traffic management system. In case of an accident authorized emergency services can query the tunnel coordinator for an updated list of dangerous goods.

Figure 4. Tunnel management implementation from SMARTFREIGHT, (a) a sketch over the tunnel area, and (b) the message exchange between vehicle and RSE.
COOPERATIVE FREIGHT APPLICATIONS

The cooperative tunnel management application is only one example of a plethora of new applications enabled by cooperative systems. Several other promising applications have also been developed. The philosophy behind the cooperative tunnel management can be extended to other areas such as urban freight transport. For example, a better control of freight transports with dangerous goods could be enforced when it is passing by a city, but also route guidance to avoid places where an accident could have disastrous consequences to a water catchment.

More and more cities are implementing low emission zones or green areas, where only certain

Figure 5. In-vehicle HMI for Cooperative Tunnel Management application.

Figure 6. Controlled areas of the transport network (from SMARTFREIGHT).
types of low emission vehicles are allowed. Other examples of such controlled areas are
areas/roads where vehicle weight or size limits apply, or where access is restricted for some
types of goods. Figure 6 outlines such a scheme.

The green and red areas are controlled areas where specific access control rules apply. The
access to controlled areas depends on the individual characteristics of the vehicle. The
characteristics consist of static vehicle information like vehicle class, vehicle physical
dimensions and emission class, but also dynamic information such as vehicle weight, axle load,
and also type and amount of cargo. To implement this scheme the city (or any local area
responsible entity) needs to define an access policy for each area. This access policy can then be
used to compute individual access rights for the vehicles. The computation of the access rights
can be done in three different ways:

1. Centralized access control. The request for access together with the vehicle
characteristics is communicated to a central processing entity. The central processing
entity then sends individualized access rights to each vehicle.

2. Access control distributed to RSE. The vehicle directly sends access requests to RSE
using V2I communication. The access control application, residing in the RSE or an
associated area controller, processes the request and sends response over the same
communication link.

3. Access control distributed to OBE. The vehicle will receive the relevant access policies
through available ICT infrastructure. The computation of the access rights is done by the
vehicles OBE.

In each case the final outcome is communicated to the driver through a suitable HMI. In Figure 6
the green dots at the edges of the transport network are RSE stations. Even in the case of
centralized access control these RSE stations are useful for notifying approaching vehicles,
through V2I communication, about the existence of controlled areas. This is especially useful for
inter-city freight vehicles when entering a new city. The outlined scheme for controlled areas can
further be enhanced by including additional properties such as access rules depending on the
time-of-day, or access rules that are dynamic based on the actual traffic situation. Also the access
policy can be linked to a booking system for loading bays, and only allow access to vehicles
with a suitable booking. Such a scheme coupled with holding areas at the outskirts of the city has
the potential to greatly reduce the problem of circulating vehicles and will therefore contribute to
maintaining an optimum traffic flow. The scheme can also be coupled to the previous described
tunnel management application such that the transport of dangerous goods is restricted to certain
routes or time slots.

In many areas, especially in urban areas, the efficiency of freight distribution is hampered by the
limited existence of suitable loading/unloading bays. The limited number of loading bays often
results in circulating vehicles waiting for their turn and illegal on-street parking. The ultimate
results are increased traffic congestion, increased local pollution and CO2-emissions. These
inefficiencies also affect the operational costs of the freight operators and the reliability of their
services. One measure to overcome these inefficiencies is by implementing a booking system for
loading/unloading bays. A booking can either be done by the driver itself directly to the traffic
management centre, or on behalf of the driver by an associated freight distribution management
centre. The CVIS project demonstrated booking of loading bays using cooperative systems as
part of the London Freight Trial. Integrating the concept of intelligent cargo with the concept of
cooperative systems enables a booking scheme where the booking procedure automatically takes
into account the destination and type of cargo. It is trivial to extend such a booking scheme to also handle booking of parking spaces.

**CONCLUSIONS**

Cooperative systems realized through V2V and V2I communications will enhance road traffic safety and efficiency on many levels and enable a plethora of new applications to be implemented on a common in-vehicle unit. The benefits from cooperative systems have been demonstrated in several R&D projects during the last years. The technologies are already in place and can easily be extended to support various enforcement requirements. Cooperative systems have great potential for enhancing the operational efficiency of freight logistics, which is required since freight transports are increasing every year. For example, chauffeurs from foreign countries could easily, using cooperative applications, receive information in their own mother tongue and many simple mistakes due to bad language knowledge could be avoided.

In this article a specific cooperative application, Cooperative Tunnel Management, targeting tunnel safety was detailed. The basic functionality of the Cooperative Tunnel Management such as admission control and dangerous goods tracking, can be extended and additional functionality and automation can be achieved when incorporating the concepts of intelligent cargo. The described implementation of Cooperative Tunnel Management uses a distributed approach, which makes it highly scalable, and the smart in-vehicle units (OBE) enables easy dissemination of individualised advices and directions to the drivers. A distributed approach is also possible when implementing a citywide access control regime. In general the concept of cooperative systems supports both distributed approaches and centralized approaches. The choice depends on the actual case, including organizational and legal considerations.

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**REFERENCES**

