REQUIREMENTS FOR SPACE BORNE TRAFFIC MEASUREMENT BASED ON THE SATELLITE TERRASAR-X

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KEY WORDS: Space, Acquisition, Detection, SAR, Satellite, Real-time, Experiment, Requirements

ABSTRACT:

With new methods, strategies and systems of intelligent transport management the continuous increasing traffic has to be opposed to reduce its negative effects. The safety has to be improved and the number of casualties has to be reduced. Congestions should prevent for keeping emissions of noise and air pollution acceptable.
Basis of all innovative management strategies are reliable on traffic flow data. To improve the database significantly is the aim of a lot of current projects around the globe. The development of traffic counts, probe vehicle, and remote sensing are the most important topics in this context.
The Institute of Transport Research of the German Aerospace Certer (DLR) is developing a procedure to measure traffic flow parameters using the low earth orbit radar satellite TerraSAR-X. The SAR- sensor has some advantages over optical sensors: The procedure is independent of daylight or weather conditions and it is possible to detect cars and measure their speed in one and the same detection. But there are also some disadvantages because the processing of SAR-data is very complex and it is not possible to say if the requirements of modern intelligent transport management systems could be fulfilled by SAR-sensors systems. This paper shows a proposal how to define the requirements of intelligent transport systems (ITS) for satellite based traffic flow measurement.
For defining this requirements four different factors have to be analysed:

~ possible applications,
~ mathematical analysis,
~ applicable regulations and relevant laws, and
~ important user groups.

For analysing the applicable regulations not only national law and orders[1] will be account. It would be a system for cross boarder data collection (a low earth orbit satellite system is global available) and therefore international regulations[2 and 3] has to be analysed too. The global availability is one of the major advantages of such a space borne system.
Most of the individual parameters are depending on different applications. Therefore it is important to have a close look on these traffic applications. The share of the satellite system for each application has to be analysed.

1. CONTEXT

1.1 General Information

Today we are facing a continued increase in traffic volume, but the construction of new highway facilities in urban, intercity, and rural areas does not keep up. This situation has caused an increase of congestions, a higher accident rate, higher pollutant emissions and fuel consumptions throughout the industrialised world, as well as in developing countries.
Regarding the EU White Paper on Transport Policy for 2010, studies show that congestions in Europe today cause costs up to 0.5 percent of the European Gross Domestic Product (GDP). If nothing is done, the costs will increase up to 1 percent of the GDP (80 billion Euros) in 2010.
Another important point in the EU White Paper is the significant reduction of fatalities on European roads. In the year 2000 over 40.000 people were killed in road accidents and about 1.7 million were injured. The annual costs involved amount to 160 billion EUR. That is 2 percent of the European GDP.
In the face of this economic loss, the EU Commission has committed financial resources of 91 billion EUR to realise the absolute necessary basement of traffic infrastructure to open and to develop the area of the new states of the European Union. According to literature, a cost-effective method to reach high qualitative and quantitative targets in the field of traffic management is the application of information and communication technology (ICT).
The implementation of strategies that promote a better utilisation of the given transportation facilities, by using this ICT, has to be considered. These strategies are termed Intelligent Transportation Systems (ITS). A general definition of ITS can be as follows:
"Intelligent Transportation Systems include the application of advanced information processing (computers), communications, technologies and management strategies, in an integrated manner, to improve the safety, capacity and efficiency of the transportation system."

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[1] The Technical Supply Conditions or Roadside Stations (TLS), the Guideline for Traffic Computer Control Centres and Control Sub-Centres (MARZ). And the Open Communication Interface for Road Traffic Control Systems (OCIT)

[2] On the European level, no generally admitted standard exists at the moment. Therefore, various approaches are stated.

[3] E.g. the Manual for Design and Road Traffic Facilities (HBS) 2001, the ISO/OSI Reference Model or the NATO Standard Ground Moving Target Indicator (GMTI)

1.2 Acquisition of Traffic Parameters

Measuring methods, e.g. inductive loops, probe vehicle data (PVD), and space-borne traffic data collection, highlight different aspects of traffic. Measuring methods are limited either in spatial or temporal scope and, therefore, provide different types and qualities of data.
Nearly every sensor provides at least two of the characterising traffic flow parameters: density, traffic flow, and speed. The third parameter can be computed or estimated, for example by using fundamental diagrams. Concerning the measurement of speed there are an important definition: Speed can be measured at a local point with its mean value in time or along a street section with the mean value in space at one single moment.
For the acquisition of traffic parameters, various systems already exist. These systems will be discussed in short in order to distinguish them from space-borne remote sensing system which will be developed within this project.
The most common system is a local sensor. Local sensors, e.g. inductive loops, measure traffic flow and speeds at a given point on a road during a specified time interval, normally one hour. They focus on a fixed point, and, therefore, record information as a function of time only.
Non-radar based methods working with technical sensors like video cameras or laser sensors to collect traffic data are widely established in Germany. Yet, the traffic data is collected solely at fixed points. And as well, these systems, which are existent in Germany, are less widespread in other European countries.
With another concept, the PVD, traffic data is collected via vehicles which float within the traffic-flow. This data provides a good overview on traffic situation, but traffic flow and density are difficult to compute. Based on the gathered data, information about the actual traffic status of the appropriate section of road is derived.
Air borne and space borne measurement techniques provide snapshots of density and speed (see definition above) in an observed area. This observed area can be one street, like in air-borne traffic data collection, or a wide area with many streets, like in space-borne systems.

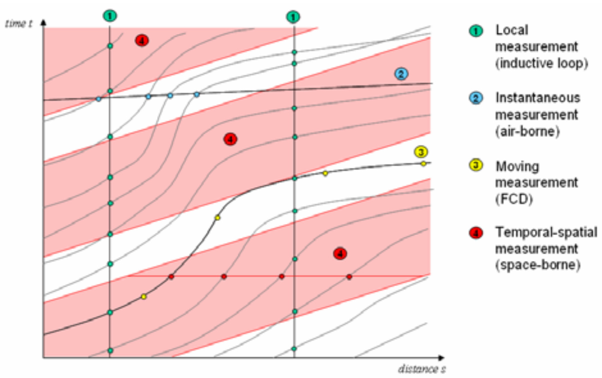

Figure 1. Distance-Time-Diagram of a group of vehicles

The Figure 1 shows the field of impact of every sensor type. The temporal and spatial differences become clear through this diagram. While PVD data is provided by several cars within the traffic flow, inductive loops remain at the same location and provide data of every passing vehicle. Air-borne traffic data collection provides snapshots of a specified street section. Space-borne traffic data collection observes several streets at a moment on a wide area.

1.3 Traffic Data Acquisition by Remote Sensing

Yet, because of the special requirements of collecting data from ground vehicle traffic (for example the fact that it is highly dynamic), there are high requirements on the sensor systems. On the other hand a high clock speed can only be achieved by synchronising various systems.
Despite these requirements, an economic operation of air borne and space borne traffic data acquisition systems seems to be realistic. With the project *space borne traffic data collection* (RAVE), the Institute for Transport Research has the intention to integrate the relevant satellite systems into the established transport system technologies. The aim is to extend the current database of data collected conventionally, e.g. through inductive loops, with wide-ranging collected data. Within the projects *TerraSAR-X data products for transport research* and *Space borne traffic data collection via radar* – TRAMRAD, the research required to reach this goal is carried out. It is intended to work out the transport relevance of the TerraSAR-X approach. Wide aerial collection of transport data is a method which is adequate to solve problems concerning transport data collection and which therefore influences security in road traffic and considerably improves individual mobility. The TerraSAR-X mission is based on a public private partnership between the German Ministry of Education and Science (BMBF), the German Aerospace Center (DLR) and the EADS Astrium GmbH. It aims on scientific and commercial applications. TerraSAR-X is a side-looking Synthetic Aperture Radar for remote sensing that provides a new class of high quality X-Band SAR products, due to its high resolution and the flexibility of the antenna. New experimental modes, like the Dual Receive Antenna (DRA) Mode, facilitate new applications, such as along track interferometry (ATI), i.e. ground moving target identification that is relevant to this document.
The experiments for traffic data acquisition will be done on base of the satellite system for TerraSAR-X. The experiments occur exclusively in rural and suburban areas on freeways, highways and arterials of transport. Therefore, it recognises some standards and legal frameworks that will be described. Because this is a cross-border system not only the German standards, like TLS, Guideline for Traffic Computer Control Centres and Control Sub-centres (MARZ) and Open Communication Interface for Road Traffic Control Systems (OCIT)[4] should be taken into account, but also European standards, as far as they are developed yet. Standards that may exist outside Europe, especially in the USA will be mentioned, but are beyond the scope of this paper and will not be described in detail.

2. AREAS OF APPLICATIONS

2.1 Traffic Management

Key applications for traffic management on freeways and rural highways are traffic monitoring and incident management. They are based on some fundamental services, such as Traffic

[4] Up to now the OCIT is designed for inner city traffic only. But in future it would be realistic to use it also for all types of traffic management technologies.

Data Collection, Historical Database, Vehicle Detection, Vehicle Classification and Weather Information.
A possible workflow within a traffic management system would be as follows: Professionals monitor events on major roadway corridors as they occur. Incident response teams can be alerted to hazardous conditions ahead. Delays can be predicted and alternate route information transmitted to motorists via message board.

Traffic Flow Management

The most important application in the field of traffic management is to harmonise the traffic flow. This means to keep the traffic flow stable for long periods in time and space.
For example high variations in speed and density will suppressed by variable speed limits. Such a strategy is helpful for reducing lags, incidents, or fatalities and keeps the road traffic safe.

Traffic Data Collection

Data collection is essential for any traffic engineering, planning, or operational activity. All of the below-mentioned applications are supported by this collection of traffic flow information. All tasks of advanced traffic management and traveller information systems can only be performed effectively on the basis of real-time, online traffic data.
However, a sustainable traffic management policy does not only require short-time data for instantaneous traffic control. There is also a need for long-run data.
The requirements of traffic management data depend on the application. They can support real-time operational strategies, off-line planning and administration, computation of measures of effectiveness[5], compilation of related statistics, and verification of proper sensor operation or research.
Generally, three basic parameters are utilised to characterise and manage highway traffic, flow rate q, speed v, and density k. Any of the following applications has its own requirements consisting of these parameters.

Ramp Metering

Regulating the ramp flow rate, so that the downstream mainline capacity is not exceeded, is the main objective of ramp metering. From this, it follows that the mainline traffic flow becomes more consistent and a vehicle moves at or near the optimum speed through the network.
Two options are available. Firstly, vehicles are stopped in front of the ramp or secondly they will be diverted. In case of an incident for example, upstream ramps could be highly limited or closed to reduce the number of vehicles involved in that incident. The vehicles could be diverted to downstream ramps that could act more flexibly and balance the situation. A further possibility is that the occupants of a vehicle could change their mode of transportation. The impact of an incident would be reduced. As mentioned above, ramp metering also serves to reduce turbulences in the merge influence area through dispersion of vehicle platoons.
For this application, very accurate data and high operational availability are necessary, as specified in the previous chapter. First of all, the application needs to know the point where the density changes. This is realised by using inductive loops. A more flexible solution is given by space-borne traffic surveillance. This system knows the density for particular sections exactly and can, therefore, react more flexible on the changing traffic flow. For this application, a high resolution is necessary, as every vehicle has to be detected separately.

Historical Traffic Flow Database

Developing a database on historical traffic flow data, will be advantageous for most traffic management applications. Historical data can be used for operations analysis, new constructions, safety planning, transport research and administrative services. Space-borne traffic flow data acquisition has the potential to enhance the quality of traffic data.

Vehicle Detection and Classification

Most of the traffic management and ITS applications depend on different classification accuracies. According to the Technical Supply Conditions for Roadside Stations (TLS), a car classification in at least two plus one categories can be implemented. A distinction can be made between passenger car-like and truck-like vehicles. A detection of the unknown vehicle type is important for the incident management. By means of edge detection, vehicles can be detected and classified. Vehicle detection is the basic requirement for vehicle classification and consequently for further services and applications.
Vehicle classification is important to assess influences on the traffic flow or for making road traffic safe. For example there are different general speed limits for trucks or passenger cars. Due to the combinations of different vehicle categories, differences in traffic flow and homogeneity of the traffic occur. Furthermore, the impact of trucks on the life cycle of the streets has to be considered. High truck ratio leads to a shorter life cycle of the pavement.

Emergency Management

Emergency management can be viewed as part of the incident management (incident verification on site, incident removal). Fast incident detection can reduce the time between the occurrence of a traffic accident and the notification, the so-called accident notification time. Reducing this accident notification time can in turn decrease the number of fatalities. The decrease of fatalities leads to economic benefits.
Emergency Management relies on detailed spatial information. Next to this information it is important to know how many cars are affected in an incident.
The extent of an accident can be detected by observing the vehicle flow speed and the density. In case of detecting an incident, the distinction between a full inhibit of the freeway or a marginal interference is important. The situation at the end of the traffic jam propagates with different speeds. The next detectable fact is the direction in which the vehicles are standing, and how large the clearance between waiting cars is. In case of different headings of the cars, an accident may be assumed.

2.2 Telematic Application

The following section gives a detailed overview of selected ITS applications. Either they belong to the categories mentioned above or extent these. They all receive information from lower services and applications to fulfil their tasks. They are partially interdependent on each other. ITS applications are not only

[5] Quantitative estimated measure indicating the performance of a transportation facility or service, HCM 2000.

telematics applications, although ITS always closely depends on telematics. Important application fields are transportation demand management (TDM), traveller information and individual route guidance.

Traveller Information

The advances in Intelligent Transportation Systems in the last years have resulted in improved traveller information. Most important characteristics of this information are the timeliness and the usefulness. Most precise information enables the driver to make better travel decisions.

Traveller Information Service can be seen as the most common service in the field of ITS applications. Information of any kind may reach the driver in many ways. The Traffic situation on a certain route or particular street, traffic incidents on a particular route, weather situation in the surrounding area, congestion warning, road or bridge closures, traffic flows, and effective evacuation routes are information that can be communicated directly to drivers via In-Vehicle Units (IVU), on electronic message signs or through radio broadcasts.

The decision which route to use or which means of transportation depends on the accuracy of the information provided. Therefore, a system with extensive information is required.

Trip Planing: Trip planning precedes route guidance and describes the pre-trip information of the traveller in view of a planned journey. Pre-trip information can include historical data, but also real-time traffic data to provide a most effective route planning. Pre-trip information in contrast to on-trip information, such as individual route guidance, aims at using multimodal transport, to distribute the demand.

Individual Route Guidance: Individual route guidance enables the driver to choose either a cost-effective or a time-effective guidance from the origin to the destination. Static or dynamic systems can provide information to the driver. An advantage of dynamic systems is the situation-based adaptation of the individual route, based on information of the freeway incident management, for example. Road works, accidents and congestions on the current route will be included in the route information and delays may thus be avoided.

3. LEGAL FRAMEWORK ON DATA ACQUISITION

3.1 Legal Frameworks

Acquisition of traffic data is subjected to many regulations regarding system architecture, functionality, interfaces, and protocols. Governments not only of most industrial countries, but throughout the developing countries as well, put a lot of effort in standardising traffic management systems. Thus a transparent market should be created, thereby providing more interchangeable products and more competition in the field of ITS applications. Furthermore, these guidelines aim to guarantee the greatest possible flexibility and extensibility for including the newest communication technologies and hardware devices. This will lead to a very cost efficient installation of traffic management facilities.

Within the scope of this experiment, European, as well as German standards in traffic management has to be considered. The government of the United States of America also supports efforts in standardising ITS applications and systems. The National Transportation Communications for ITS Protocol (NTCIP) is a well-established standard for modern traffic management applications. Because this experiment will be done primarily in Europe, a further analysis of this standard is not yet necessary, but it may become important in future research efforts.

German Standards

The German Ministry of Transportation, Building and Housing (BMVBW) is responsible for traffic data acquisition and traffic management facilities on German road facilities. Two standard guidelines on traffic data acquisition for rural road facilities exist, namely the TLS and the Guideline for Traffic Computer Control Centres and Control Sub-centres (MARZ).

For traffic management facilities in urban and suburban areas, the OCIT Developer Group (ODG) works on a standardisation of interfaces for traffic management systems, named Open Communication Interface for Road Traffic Control Systems. Leading German manufacturers of traffic management technology as well as representatives of local governments are members of this committee. This guarantees the success of these efforts.

The system works only in rural and suburban areas, on freeways, highways, and arterials; the TLS and the MARZ will play the most important role in this part. Nevertheless, the OCIT standard should be considered as an important guideline for arterial routes and intercity connections, which are appearing in rural, as well as in suburban areas.

Due to the federal nature of the German Republic, the task to operate traffic management systems in Germany is shared between the Federation and the individual States. While the Federation is responsible for the management of traffic between local entities, the states are responsible for local traffic management. A change of the political system is not to be expected; therefore, an interface connecting both systems would be desirable.

European Standards

The final EU-report on the Trans-European Transportation Network (TEN-T) from 1998 discusses inter alias the development of traffic management and guidance systems. It has already been mentioned that the quality and continuity of cross-border services have to be enhanced. The importance of the establishment of Intelligent Transportation Systems and Traffic Information Services has been proven, as it is a useful tool for efficiency improvement, road safety and the environment. Furthermore, the report recognises the activities on ITS infrastructure in particular EU-Member States. Nevertheless, until present, no European guideline on the technical framework of traffic management systems was created.

However, another effort involving the integration of ITS systems was started. On system level, differences will remain but on traffic centre level, network activities between individual countries have started. As a matter of fact, there are Euro-regional projects (e.g. CENTRICO, Netherlands) with standardised interfaces for cross-bordered traffic management. The interchange of traffic data collected on a national level was realised for co-ordinated traffic management. This is only an isolated case. A uniform guideline for system aspects and infrastructure aspects for ITS, has not been realised so far.

There exists a de facto technical committee in the European Committee for Electrotechnical Standardisation (CENELEC), the CEN/TC278, formerly known as Transport Expert Team (TET 278). Although, the technical committee works on standardisation in the field of road transport and traffic telematics, it has not yet created a standard regarding the technical infrastructure of ITS systems.

International Standards

As a standard for transport systems or road traffic there is just one important document on the international level: The Highway Capacity Manual. But there are important international standards on other relevant topics like e.g. communication.

Highway Capacity Manual: The Manual for Design of Road Traffic Facilities (HBS) 2001 was initiated by the German Road and Transportation Research Association (FGSV) in 2001. It is abutted on the revised version of the Highway Capacity Manual (HCM 2000) that was reissued by the Transportation Research Board (TRB) in 2000.

ISO/OSI Reference Model: In 1984, the International Standards Organisation (ISO) developed the so-called ISO/OSI Reference Model. It describes the connection and communication of open systems based on an abstract model of networking and a set of concrete protocols.
The networking system is divided into layers. Each layer has defined functionality and interfaces. Similar layers of corresponding systems logically communicate over standardised protocols in horizontal direction. The real communication between layers is vertical, except for the physical layer. Each layer communicates only with the layer immediately beneath it.
The main objective is to achieve an open system on a uniform platform. Thus, an easily upgradeable and adaptable system can be created. Consistent open system architectures generate more competition. This leads to a greater variety of products. Moreover, access to the data is possible in a simple way for public authorities, business partners, and research facilities.
NATO Standard: Ground Moving Target Indicator (GMTI)
For military purposes, the North Atlantic Treaty Organisation (NATO) Standardisation Agency (NSA) developed Standardisation Agreement (STANAG) 4607, called the NATO Ground Moving Target Indicator Format (GMTIF).

3.2 Geo-Referencing

When using remote sensing technologies for traffic data acquisition, a generally admitted framework to geo-reference the data has to be implemented. All previous methods included stationary sensors. Therefore, the data was clearly geo-referenced.
The automated methods themselves demand a clear geo-referencing. Because of their specific recording geometry and because of the topographic irregularities of the earth surface remote sensing data have geometric distortions.
An according integration and intersection of the traffic data, which should be acquired extensively by space borne remote sensing requires a standardised system connection and integration of projection parameters which have to be determined.
A requirement for the remote sensing analyses in the project RAVE which have to be accomplished and combined is the definition of standardised coordinate systems (map projections). That accurate mapping necessitates a geometric transformation of the remote sensing data towards a geodetic reference system.

4. REFERENCES

EU: White Paper – European transport policy for 2010: time to decide, European Communities 2001

FGSV (2001): Handbuch für die Bemessung von Straßenverkehsanlagen HBS FGSV-Verlag Köln.

MARZ: Merkblatt für die Ausstattung von Verkehrsrechnerzentralen und Unterzentralen, Bundesanstalt für Straßenwesen 1999

TLS: Technische Lieferbedingungen für Streckenstationen, Bundesanstalt für Straßenwesen 2002

Werninghaus, Rolf: The TerraSAR-X Mission. In: 5th European Conference on Synthetic Aperture Radar, Proc EUSAR 2004, Vol. 1, VDE Verlag GmbH, Berlin and Offenbach, Germany 2004

Runge, H.; Breit, H.; Eineder, M.; Börner, E.; Ruhé, M.; Dalaff, C.; Kühne, R. D. (2003): Image is everthing - Modern high resolution sensing satellites could be about to offer a valuable insight into traffic congestion around Europe, In: Annual Review 2003, Reihe traffic technology International 2003, S. 195-197.

Kühne, R. D.; Ruhé, M. (2002): From Vision to reality, In: Traffic Technology International, Nr. Aug/Sep.

Kühne, R. D.; Dalaff, C.; Ruhé, M. (2003): Multisat-Webservice Mobile On-Demand Services for Mobility and Traffic, In: Guoqing, Z.; Oktay, B.; Menas, K.; Yang, R. [Hrsg.]: Future Intelligent Earth Observing Satellites, Hierophantes Publishing / Science, ISBN 0-9727940-0-X, S. 143-158.

Dalaff, C.; Reulke, R.; Kroen, A.; Ruhé, M.; Schischmanow, A.; Schlotzhauer, G.; Tuchscheerer, W.; Kahl, T. (2003): A Traffic Object Detection System for Road Traffic Measurement and Management, In: Institute of Information Sciences and Technology, Massey University [Hrsg.]: IVCNZ Image + Vision comPuting 03, S. 78-83, IVCNZ Image + Vision comPuting 03, November 25-27, 2003, Palmerston North, New Zealand.

Ernst, I.; Sujew, S.; Thiessenhusen, K.-U.; Hetscher, M.; Raßmann, S.; Ruhé, M. (2003): LUMOS - Airborne Traffic Monitoring System, In: IEEE 6th International Conference On Intelligent Transportation Systems, 12-15 October 2003, Shanghai, China, IEEE 6th International Conference On Intelligent Transportation Systems, 12-15 October 2003, Shanghai, China.

Kühne, R. D.; Dalaff, C.; Ruhé, M.; Rupp, T.; Froebel, L.; Janschek, K. (TU Dresden, Institute of Automation); Tschernyk, V. (TU Dresden, Institute of Automation); Behr, P. (FhG-FIRST Fraunhofer Institute for Computer Architecture and Software Technology) (2003): Mobile on-demand Services for Mobility and Traffic, In: IEEE 6th International Conference On Intelligent Transportation Systems, 12-15 October 2003, Shanghai, China, IEEE 6th International Conference On Intelligent Transportation Systems, 12-15 October 2003, Shanghai, China.