Road Traffic Incident Management and Situational Awareness

VRIJE UNIVERSITEIT

ROAD TRAFFIC INCIDENT MANAGEMENT AND SITUATIONAL AWARENESS

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan

de Vrije Universiteit Amsterdam,

op gezag van de rector magnificus

prof.dr. F.A. van der Duyn Schouten,

in het openbaar te verdedigen

ten overstaan van de promotiecommissie

van de Faculteit der Economische Wetenschappen en Bedrijfskunde

op maandag 7 oktober 2013 om 13.45 uur

in de aula van de universiteit,

De Boelelaan 1105

door

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Cover design and printed by: Tappan communication and !MPRESSED.

Keywords: Traffic incident management, net-centric information systems, situational awareness, information quality, mobile phone data.

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Abbreviations

ANWB	The Royal Dutch Automobile Association
ATSSA	American Traffic Safety Services Association
BCR	Benefit/Cost Ratio
BTS	Base Transceiver Station
BSC	Base Station Controllers
CDT	Cell Dwell Time
CEDR	Conference of European Road Directors
COP	Common Operational Picture
DDDAS	Dynamic Data Driven Application Systems
DOT	Department of Transportation
ECTP	European Construction Technology Platform
EIF	European Interoperability Framework
EPC	Electronic Product Code
ERTRAC	European Road Transport Research Advisory Council
ETSC	European Transport Safety Council
FCC	Federal Communication Commission
FCD	Floating Car Data
FEMA	Federal Emergency Management Agency
FHWA	Federal High Way Administration
GHOR	Geneeskundige Hulpverlening Organisatie in de Regio
GMES	Global Monitoring for Environment and Security Program
GPS	Global Positioning System
GRIP	Gecoördineerde Regionale Incidentbestrijdings Procedure

GSM	Global System for Mobile Communications
HCI	Human-Computer Interaction
HLR	Home Location Register
ICT	Information and Communication Technology
IDABC	Interoperable Delivery of European eGovernment Services to Public Administrations, Businesses and Citizens
IM	Incident Management
IP	Internet Protocol
ISO	International Organization for Standardisation
IMOOV	Informatie Model Openbare Orde en Veiligheid
IR	Incident Response
ISA	Interoperability Solutions for European Public Administrations
ITS	Intelligent Transport Systems
IQ	Information Quality
KIM	Kennis Instituut Mobiliteit
KLPD	Korps Landelijke Politie Diensten
LBS	Location Based Services
LCM	Landelijk Centraal Meldpunt
LPR	License Plate Recognition
MSC	Mobile Switching Centre
MTS	Mobile Traffic System
NBD	Network Based Defence
NCO	Net-Centric Operations
NCMS	National Crisis Management System (LCMS - Landelijk Crisis Management Systeem)
NCW	Network-Centric Warfare
NDW	National Road Database
NEC	Network Enabled Capabilities

NFPA National Fire Protection Association

NTIMC National Traffic Incident Management Coalition

NIMS National Incident Management System

NIS Network Information System

NPR National Private car Regulation

NTR National Truck Regulation

NUG National Unified Goals

OD Origin-Destination

OGC Open Geospatial Consortium

RSS Received Signal Strength

RTMC Regional Traffic Management Centre

RVC Regionale VerkeersCentrale

RWS RijksWaterStaat

SA Situational Awareness

SSA Shared Situational Awareness

SIMN Netherlands Incident Management Foundation (Stichting Incident Management Nederland)

SMS Short Message Service

SO System Optimum

SOA Service Oriented Architecture

STI Lorry Salvage Consultant

STIMVA Lorry Incident Management Foundation (STichting Incident Management VrachtAuto’s)

SQ System Quality

TAM Technology Acceptance Model

TERN Trans-European Road Network

TRL Transport Research Laboratory

TRAA Towing and Recovery Association of America

TRC Transport Research Committee

UML	Unified Modeling Language
UC2	Ubiquitous Command and Control
UE	User Equilibrium
UMTS	Universal Mobile Telecommunications System
US	United States
VCNL	National Traffic Management Centre (VCNL - VerkeersCentrum NederLand)
WGS	World Geodetic System
VLR	Visitor Location Register
WSDOT	Washington State Department of Transportation
WHO	World Health Organization
W3C	World Wide Web Consortium
XML	eXtenisble Mark-up Language

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Preface and acknowledgements

"Awareness - One day at a time"

"The PhD or Philosophiae Doctor is the very highest accomplishment that can be sought by students. A fully formed scholar should be capable of generating and critically evaluating new knowledge; of conserving the most important ideas and findings that are the legacy of past and current work; and of understanding how knowledge is transforming the world in which we live, and of engaging in the transformational work of communicating their knowledge responsibly to others".

Walker *et al.*, The Formation of Scholars (2008)

In the final stages of my PhD, I read this definition of what is a PhD. This definition intrigued me because it gave me a deeper awareness about the specific responsibility that comes with earning a PhD. In this description, generation, conservation, and transformation, are the key elements. This made me aware what were the main triggers when I originally started my long journey towards a PhD degree.

Generation has to do with learning, curiosity, creativity, and exploration. The will to generate new knowledge has always been a driving force during my entire life. Starting this long journey, through different phases (LTS, MTS, HTS, HEAO and University), this feeling was always a strong source of motivation. Step by step, one day at a time, I know that good things come to those who want it most, and without struggle there is no progress.

Conservation implies understanding the history and fundamental ideas of the discipline, and also understanding how the fields fits into the larger, and changing, intellectual landscape.

Transformation speaks of the importance of representing and communicating ideas effectively, which calls for diversity and a multidisciplinary approach. I always had a strong interest in gaining knowledge from different research areas, and especially in integrating concepts with different perspectives from several disciplines and transforming them into new ideas.

This awareness helped me to work through the different stages of my research process. But other forms of awareness were the main focus of this dissertation. Awareness in general, is the state or ability to perceive, to feel, or to be conscious of events, objects, or sensory patterns. Awareness is also a concept used in computer and cognitive science, and can be used to improve the situational awareness for daily traffic Incident Management. This was my main research goal.

Nevertheless, moving into the academic environment was never an easy process. Writing this dissertation and conducting the associated research forced me to push out several boundaries. This thesis concludes, alongside to my full-time job, six years of research as a PhD student at the Department of Spatial Economics at the VU University Amsterdam. My interest in Geography and Spatial and Transport Economics was triggered by my previous education and the fruitful discussions I had with Henk Scholten at the beginning of, and during, my PhD process. It was my friend and colleague Michel Grothe who inspired me to start my PhD, and introduced me to Henk to fulfill the role as my promotor. Without any doubt, it needs to be said that Henk was my great inspiration, motivator, mentor, supervisor, and gave me hope, direction, knowledge, valuable time, and the perspective to accomplish the challenging and demanding process of achieving a PhD degree. With deep respect, I am truly thankful that I had the great opportunity to cooperate with Henk during this demanding process.

Fortunally, I had the luck that Piet Rietveld agreed to be my other promoter. I appreciated the fruitful conversations and valuable advice Piet gave me, to guide me through the case studies. His enthusiasm was a driving force to help me gain the scientific skills necessary for advanced statistical analyses.

Special thanks and respect goes to Peter Nijkamp. Working with Peter demands commitment, dedication, and precision, and forces you to take the scientific research area seriously. Submitting papers with Peter is an inspiring process, and gives you skills of critical self-reflection. These valuable lessons will definitely help me during my further (scientific) life.

The support from my own organization was a challenging process through the many changes within the Rijkswaterstaat. In the early stage of my PhD, Geert van der Linden, and Raymond Feron were my copromotors. I really wish to thank them for their valuable time and their confidence. However, I was really pleased that, in the critical phase of my PhD, my colleague Maarten van der Vlist was willing to take over this role. Maarten gave me valuable insights on how to critically assess the scientifically generated knowledge for practical usability. I am also very thankful for his support that helped me to have the space to work on my PhD within the Rijkswaterstaat.

As mentioned before, I am always curious to discover new scientific areas. I would especially like to thank Jan Smits for his support, knowledge and discussions on legal and innovative issues. I know Jan as a supervisor from the Technical University Eindhoven where I finished my Master's degree. I appreciate his critical and encouraging reflections during my University years and my PhD research which shaped my attitude to the academic environment.

Sometimes you have the luck to meet inspiring people. I was privileged to work with Euro Beinat. I admire Euro for his creative, innovative, and scientific approach in several research areas. During my PhD I had the chance to work with him on several projects such as collective sensing, context-awareness, mobility, social media, and mobile phone data. This experience helped me to shape my research.

The main topic of this PhD is traffic Incident Management. At the Rijkswaterstaat I became a member of the National Incident Management platform. There I had the opportunity to work with Ben Immers, who can truly be entitled as the founding and scientific father of traffic IM in the Netherlands. Ben' work helped me to gain knowledge of this interesting research area. Also our many discussions gave me valuable lessons about the main challenges and issues in modern traffic IM.

Traffic Incident Management can to some extent been seen as a special case of Crisis Management. Since 2005, I have had the privilege to meet Sisi Zlatanova at several international conferences on Geo-Information for Disaster Management (GI4DM). My geo-information background gave us common ground to have interesting discussions about the relationship between these two research areas.

During my PhD it was always interesting to meet academics who had already finished their PhD. The critical feedback of Maria Teresa Borzacchiello, at the beginning of my PhD, helped me to develop the necessary skills to publish my first papers in academic journals. I would like to thank Maria Teresa for her enthusiasm and knowledge which guided me through this challenging process. During my case studies I had the chance to work with Emmanouil Tranos. I appreciate the valuable lessons I learned for Emmanouil on how to handle Big data with the statistical software. Even though on occasion I had some hard times, Emmanouil always was there for me when I really needed him. I really enjoyed working with you.

Sometimes you also find very smart students. I especially want to thank Maarten Kriekaert for all his time and effort during the net-centric case studies. It is fair to say I also learned a lot from Maarten during our many discussions. Besides his own two Bachelor studies, he always found the time and energy to help me when necessary.

Organizing the net-centric field exercise was a challenging task during my PhD. Without the help of many colleagues it would have been impossible. With deep respect, I truly want to thank the entire Geodan team who helped me with the net-centric case study.

In the Rijkswaterstaat, I am also a member of the Programme Office Incident Management (PPIM), and I would like to thank Rosamaria Carhuapoma, Gerrit Broekhuizen, Michel Kusters, Eeltje Hoekstra, Ernst Lettink, Florian Ockhuysen, Willem Rozendal, Jan van Hattem and Martijn Elting for their support.

As mentioned before, my journey towards the PhD degree was a long and challenging road. It would not have been possible with the help of some great people I met during my previous education. First of all, I would like to mention Ram Ramsahai from the MTS Breda. Ram showed me that it is only with hard work that you will be able to succeed. This changed my attitude and made me realize the true value of education. I will never forget your wise words which encouraged me to continue. Another person I want very much to thank is Henri Dekker from the HTS Utrecht. Henri made it possible for people who have a full-time job to have the possibility to attend this school in the evening. These were hard and demanding years and it was never easy. Henri always knows how to motivate people, and made me realize there is more in life than Geodesy.

I also wish to thank my true friend John Sewcharan. From him I learned a number of valuable life lessons which opened my eyes for many reasons. I miss our warm conversations, and they will be remembered.

I wish my parents could be there to witness the finalization of my long process towards earning a PhD degree. I am fully aware of all the sacrifices they have made. With deep respect I am truly thankful for everything you have done for me. So this one is for Theo and Joke. I am also very grateful to my sister Vivian for her constant support over the years.

Specially thanks go to my children Anouk and Sidney. I hope this PhD will motivate them to also succeed in life. I have great confidence that with hard work and their talent they can realize their dreams. They can count on my support.

Last, but certainly not least, I would like to thank Khadija Raji. She is the only one who has seen the countless nights and weekends of work that went in this dissertation. She was always very kind, patient, and supportive, and encouraged me to keep going. For sure it was not an easy time for her. I know it was sometimes hard, especially during my last year. However, she always found a way to keep us motivated. I am fully aware of this. Thanks for everything!

John, August 2013

1 Setting the Scene

1.1 Introduction

We live in a risk environment where risks are caused by modernization, and are thus an important characteristic of our modern society. Economic globalization and the inherent transport of goods and people all over the world are together the driving force behind these increasing risks and vulnerability. The world's population rose in 2011 to around 7 milliard people nowadays. More than 50 per cent of the world's population live in urban areas (United Nations, 2009). The increase in population and its density has led to an intensity of production, transportation and an associated travel behavior, with more trips and longer distances, while at the same turn heavy traffic gives rise to constrains on mobility.

The Netherlands is the only European country which is in the world's top 10 list of the most densely populated areas, with approximately 403 people / km^2. Since the early 1970s, everywhere in the developed world, steadily growing traffic volumes and traffic intensity have led to enormous congestion and mobility problems, especially during the rush hours. The goal of sustainable mobility is one of the biggest challenges in modern traffic management. As a result of the large number of road users on many road networks, congestion occurs frequently, mainly at regular bottlenecks. This leads to congestion and travel time losses, while it is also difficult for the traveller to estimate how long the journey will take. When congestion is caused by regular bottlenecks, travellers can globally assess how much time loss is due to congestion on most routes. It is however, much more difficult to estimate the travel time losses caused by irregular and unexpected situations, such as traffic incidents, adverse weather conditions, road works and events. In particular for road users, it is often difficult to predict in advance when these situations will occur and how long the associated delay will be. That is precisely why irregular situations may contribute significantly to the unreliability of travel times. This largely depends on how often irregular situations occur, and what is the impact of the situation concerned (loss of capacity and reliability of travel times). The increasing discrepancy between the trend in mobility and the increase in capacity since 1980 is striking.

Efficient road networks are increasingly seen by governments across Europe as being key to supporting and sustaining economic growth, as they enable the movement of goods and services around the country. Economic constraints are causing national road authorities to innovate as they look for cost-efficient ways to tackle congestion and develop more effective traffic Incident Management (IM) measures. In many European countries, this has led to an emphasis being placed on the better use of existing infrastructure and IM capabilities, rather than investing in more costly systems, equipment, and working methods.

Traffic incidents have a significant impact on a reliable transport system and are an increasing cause of traffic jams, congestion and lost vehicle hours. Besides having direct impacts in terms of property damage, injuries, fatalities and other road safety effects for road users in the vicinity of traffic incidents, they are also relevant for mobility. Incidents can quickly lead to congestion and associated travel delay, wasted fuel, increased pollutant emissions, and higher risks of secondary incidents.

IM is, in general, the policy that, through a set of measures, aims to reduce both the negative effects on the traffic flow conditions and the effects on safety, by shortening the period needed to clear the road after an incident has happened. IM is one of the most important instruments for the better utilization of the main infrastructure that reduces congestion or traffic jams, and may seriously reduce the number of casualties on the roads. Furthermore, there is a strong economic need to reduce the impact of these incidents.

1.1.1 Improved cooperation between the emergency services

The organizations which are responsible for traffic IM are the road authority and public emergency services (Police, Fire Brigade and the Ambulance services). The road authorities need to ensure a safe and reliable transportation system. The transportation network enables access to emergency incidents, and, increasingly, provides real-time information about roadway and traffic conditions. The Police have the legal responsibility to support public transportation with IM-related tasks in terms of road safety and, in the event of a crime, the question of guilt. The Fire Brigades primary tasks are to administer initial first aid to road victims, to remove victims from crashed cars, and to avoid or reduce the release of (dangerous) substance. The Ambulance team makes an estimate of the magnitude of the injured, determines which victims needs first aid, and handles life-threatening situations. Private IM organizations' main tasks are towing, repair, and insurance services.

Since the 1970s there has been an increasing number of registered incidents on the Dutch road network with a total of approximately 100,000 a year in 2010. They vary from the breakdown of vehicles to serious road accidents with material damage and fatal causalities. They thus account for approximately 270 incidents a day. This leads to the need to structure the IM activities in terms of organization, work processes, and cooperation. Successful traffic IM presupposes a multidisciplinary approach. Since the formal introduction of IM in the early 1990s, the importance of cooperation of different actors in the IM network has increased, and is an important constraint for the further improvement of the IM process. This cooperation is clearly defined in the IM policy rules (Dutch Ministry of Transportation and Water Management, 1999). As well as the public organizations, more actors have become involved and been institutionalized. Formal work processes are standardized and new legal measure and policy rules have been introduced. Cooperation has become a crucial factor to apply successful IM.

The main challenge in traffic IM is '*the importance of speed*' to decrease the response time of the emergency services. This relies in particular on flexible communications and information systems. In many studies, information sharing and the introduction of new technology has been identified as important constraints for the further improvement for cooperation. These create serious challenges because traditional organizations tend to mainly focus on their own tasks and information processes.

Information systems play an important role in carrying out daily IM activities. Interagency exchange of information is the key to obtaining the most rapid, efficient, and appropriate response to highway incidents from all agencies. Public safety agencies and transportation organizations often have information that is valuable to each other's operations.

For example, better incident detection and notification, road situation information, incident site status, and coordination information (US NCHRP, 2004).

1.1.2 Information and system quality

Various papers have concluded that information quality and system quality are major hurdles for efficient and effective multi-agency emergency services, and are crucial for the success of information systems (Lee *et al*., 2011). Information systems cover collecting, processing, distributing, and using data by organizational processes or people (Strong *et al.*, 1997), and the management of information is essential for the coordination of emergency response (Ryoo and Choi, 2006). The concept of '*quality*' is often defined in terms of '*fitness for use*' (Juran *et al.*, 1974), '*fitness for intended use'* (Juran and Godfry, 1999), and '*fitness for purpose*' (Harvey and Green, 1993), and must be in line with the requirements of end users (Wang and Strong, 1996). In the information systems literature, quality itself is relatively 'ill-defined' (Nelson *et al.*, 2005). The concept of quality is usually bound to the specific object such as a specific product, process, service or information system.

Information quality plays a crucial role in improving Situational Awareness (SA) for traffic IM. It can be seen as an important constraint for further improving the cooperation between emergency responders in order to apply successful traffic IM measures.

1.2 The role of Situational Awareness

The key obstacle to effective crisis response is the communication needed to access relevant data or expertise and piece together an accurate understandable picture of reality (Hale, 1997). The crucial element to obtain this '*understandable picture of reality*' for traffic IM is to improve the quality of the 'situational interface' of the Traffic Management Centre and the cooperating control centres. In the literature, this is known as the concept of '*Situational Awareness*' (SA). Endsley (1995) proposed a general definition of SA that has been found to be applicable across a wide variety of domains (Roy, 2007). She defines SA as the perception of the elements in the environment within a period of time in space, the comprehension of their meaning, and the projection of their status in the near future. Most simply, in practical terms SA generally means '*knowing what is going on around you*'. Blash *et al.* (2006) noted that there are two main communities that are looking at SA:

- The Human-Computer Interaction (HCI) community: The term SA is most commonly used in the field of HCI (see, e.g., Endsley and Garland, 2001). The concerns of this community are to design computer interfaces so that a human operator can achieve SA in a timely fashion. From this point of view, SA occurs in the mind of the operator as a mental state. This includes the visualization challenge, as mentioned by Mulgrand and Landsman (2007), and also the domain of context awareness (Dey and Abowd, 1999; Dey and Abowd 2000; Dey, 2001).
- The data fusion community: SA is also used in the data fusion community where it is more commonly referred to as "situation assessment" (e.g. Steinberg *et al.*, 1999). From a military perspective '*Data fusion*' is defined as *"the process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats as well as their significance*" (White, 1987; 1988). The process of data fusion uses overlapping information to detect, identify, and track relevant objects in a region. The term 'data fusion' is used because information originates from multiple sources. This includes the information management challenge, as mentioned by Mulgrand and Landsman (2007). Bharosa (2011) identifies this as "net-centric information orchestration". This can also be applied to develop an information system for traffic IM.

SA is a mental state, while fusion products support that state. A key enabler to meeting the demanding requirements of high-quality SA for optimal decision making is data fusion. SA is essential to reach almost any objective of traffic IM improvement which is related to information technology. The main goal is to provide a full picture of the incident, the mobility, and area consequences in (near) real time, in order to improve the situational interface for the IM actors.

1.3 New information concepts to support Situational Awareness

SA for traffic IM can be achieved by the introduction of a Common Operational Picture (COP). A COP offers an incident overview that enables effective, consistent, and timely decisions to be made. In order to maintain SA, communications and incident information must be continually updated. Having a COP during an incident helps to ensure consistency for all emergency responders engaged in an incident (Homeland, 2008). This makes it possible to have the same kind of information about the incident, including the availability and location of resources and the status of assistance requests. Establishing and maintaining context in a COP is increasingly being recognized as a fundamental requirement for information fusion (Steinberg and Rogova, 2008).

A Common Operating Picture (COP) is widely used to support SA for command and control in net-centric operations (Wark *et al.*, 2009). Architectures to support traffic IM information systems can be historically characterized as hierarchical solutions which mainly focus on the internal work processes of individual organizations. This causes many problems in terms of communication, cooperation, and information sharing between the different IM responders. In recent years there has been a growing interest in the use of 'net-centric' information concepts to improve the cooperation between different organizations which have a common goal. The basic principle of net-centric working is that the information you own, which could be useful for other organizations, you share with others based on peer-to-peer solutions.

In Harrald and Jefferson (2007), it is stated that: "*The transfer of the concepts of SA, COP and net-centric working from its safety and combat origins to the complex, heterogeneous emergency management structure will be exceedingly difficult, and that short term strategies based on the assumption that shared situational awareness will be easily achieved are doomed to failure*."

In the literature there are no studies which focus on the introduction of these concepts in traffic IM. These concepts are mainly discussed for large-scale disasters and emergency services. Traffic incidents happen on a daily basis, and the response is normally carried out by well-trained and experienced emergency personnel. This should make it relatively easier to adopt these concepts and apply them to traffic IM. It is obvious that introducing this new technology to improve SA within the IM network is a major innovation challenge for the coming years.

1.4 The use of telecom data to support Situational Awareness

Sensor concepts concern the emerging discipline of making sense of aggregated anonymous individual sensor data and digital traces, in order to understand the dynamics of an industry, city or community. This information is the basis to understand the dynamics of complex environments. An interesting source of individually-based information on the space-time position and behaviour of persons is, in principle, available from mobile (or cell) phone data derived from the GSM network. This trend is merging into a new concept of '*Collective sensing*' which is defined as "the ability to reconstruct collective human behaviour from individual anonymous digital traces which have a direct or indirect relation to a social collective phenomena". The basis of collective sensing lies in '*digital footprints'* (Girardin *et al.*, 2009). The large deployment of pervasive technologies has led to a massive increase in the volume of records of where people have been, and when they were there. The digital traces left by individual people while interacting with cyber-physical spaces are accumulating at an unprecedented breadth, depth and scale (Zhang *et al.*, 2010). These records are the digital footprint of individual mobility pattern (Liu *et al.*, 2010).

In recent years, data deriving from mobile phone records have attracted the attention of researchers in different fields as a proxy for various types of social and spatial interaction. Geographers and spatial scientists soon started to realize that the use of this new data source can provide new insights to better understand spatial structures and urban and population geography at a high spatio-temporal resolution. There is a wealth of research on the use of information technology to the support emergency services, but the literature on how to support crisis management with telecom data is sparse. Traffic IM is a much more limited domain than general emergency management: However, it can be seen as a special case of simplified emergency response. To a certain extent, the examples above can also be applied to design a traffic IM system based on telecom data.

1.5 Aims and objectives of the thesis

To carry out the IM process in an effective and efficient way, the need for spatial real-time information and supporting information systems is large. The key obstacle to effective crisis response is "*the communication needed to access relevant data or expertise and piece* *together an accurate understandable picture of reality*" (Hale, 1997). Well-established communication and information technology and clear organizational responsibilities among the emergency services are the most important issues for IM. In fact, they are a prerequisite for the effective application of IM. The 'situation' interface and the 'control' interface in a Traffic Management Centre are the two main domains where information systems play a crucial role.

Information technology is essential to improve information-sharing and decision making for emergency responders (Graves, 2004). It has already drastically reshaped the way organizations interact with each other (Lee and Whang, 2000). Interagency exchange of information is the key to obtain the most rapid, efficient, and appropriate response to highway incidents from all agencies.

The assumption is that '*net-centric working*' is a basic constraint to achieve shared SA based on a COP between the different IM organizations. An improved situational interface is created by detection, warning, and verification, all based on better information. Better information leads to a better response by the emergency services. By better responding, resources are used more effectively so that better action can take place. This leads to a better outcome, to the faster clearance of an incident site, and therefore to a reduction of traffic jams and lost vehicle-hours.

The aim of this thesis is to analyze how Situational Awareness can be improved to support daily traffic Incident Management.

This can be achieved by the introduction of new concepts in information technology and using additional data sets. The related research questions are:

1. How is traffic IM organized in terms of an actor-network approach, and what are the main policy goals (Chapter 2)?
2. How can new concepts in information technology contribute to improve the cooperation and information-sharing between emergency services (Chapter 3)?
3. What are the main problems in terms of information, communication, and coordination in traffic IM (Chapter 6)?

4. What is the effect of the development of a COP in terms of information and system quality for traffic IM (Chapter 7)?

5. In what way can telecom data improve traffic management (Chapter 4)?

6. How can telecom data be used to improve SA for traffic IM (Chapter 5)?

7. Is telecom data a useful method to detect anomalies for traffic incidents (Chapter 8)?

This thesis is organized in nine chapters, and consists of three empirical studies. Chapter 2 gives an overview of traffic IM, and describes the main challenges and obstacles to improve the cooperation between IM responders. Chapter 3 gives an extensive literature review of new information technology concepts, and how they can be applied to traffic IM. Chapter 4 analyses how the use of aggregated ammonized telecom data can be used for applications in transportation. Chapter 5 provide in more details on how this can be used to improve the SA for traffic IM. Chapter 6 provide an empirical analysis of the critical success conditions for effective IM in the Netherlands based on an Internet survey questionnaire administered to employees of the main IM stakeholders. Chapter 7 report the results of an empirical analysis of the effectiveness of net-centric information systems to improve the cooperation between public and private IM organizations in terms of information and system quality for end-users. Chapter 8 investigates how telecom data can be used as a (real-time) detection tool for different scales of incident types. In Chapter 9 we give a summary of our findings concerning how the introduction of new information concepts and additional data sets can improve the SA of emergency responders. Figure 1.1 depicts the relationship between the various chapters in this dissertation.

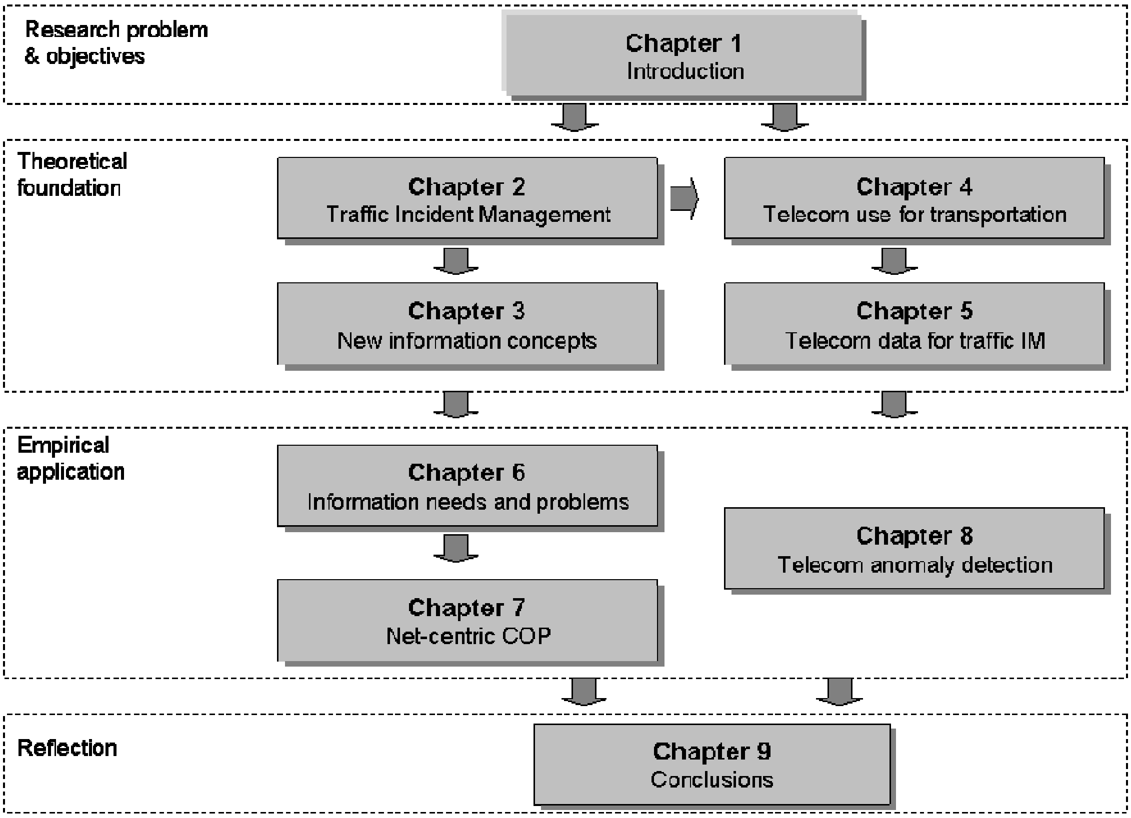

Figure 1.1: Structure of the thesis

1.6 Scope of the thesis

Effective decision making in traffic IM greatly depends upon immediate access to, and interpretation of, local information within the context of the overall environment at any particular point in time. Information, communication, and coordination are becoming increasingly important to apply traffic IM successfully, and are some of the most important measures for traffic management. Almost all information needs have a spatial (geographical) component. Traffic IM can be seen as a special simplified form of Crisis management. The architecture and standards for traffic IM need to find a delicate balance between developments in traffic management, crisis management, geo-information management and interoperability, and legal issues. There are a number of different possible path and innovative ways to improve SA. Rogers (1995) sees an innovation as '*an idea that is perceived to be new to a particular person or group of people*'. Hence, the first focus of this thesis is to analyse how the traditional way of information sharing can be improved with the introduction a 'net- centric' approach and a COP. We will look at the current data sets, methods and problems. Central to this analysis is to measure which information quality constructs will fit with the user needs to improve SA. The second focus is to analyse how aggregated ammonized telecom data can support IM and improve SA.

2 Traffic Incident Management*

2.1 Introduction

Only a few centuries ago, 20 per cent of the worlds population lived in cities. With more than half the population living in urban areas since 2007, there is a gradual transition of our society towards what has been called the 'urban century'. This transition is continuing with urbanization rates exceeding 70 per cent in various European countries (Mega, 2010). This mega-trend in population movement towards the city is the result of an exponential growth in world population and a rural-urban drift (Nijkamp and Kourtit, 2011). According to a European Commission (2010) report, the urbanization rate may have risen to about 80 per cent in the EU. The phenomenon of the 'Urban centuary' raises many research and policy concerns.

Clearly, policy makers have made many efforts in the last 20 years to design policies which promote the use of Information and Communication Technologies (ICT) in order to realize sustainable urban development. The digital revolution enabled cities and policy makers to realise the link between ICT and urban development. As a result, various forms of city concepts have been developed including such as; *wired cities* (Dutton, 1987); *technocities* (Downey and McGuigan, 1999); *creative cities* (Florida, 2005); *knowledge-based cities* (Carrillo, 2006); *real-time city* (Townsend, 2000; Calabrese *et al.*, 2011a); *WIKI cities*

* Based on: Steenbruggen, J., van der Vlist, M. and Nijkamp, P. (2013). Traffic Incident Management in a Digital Society - Challenges and obstacles in information technology use in urban Europe. *TF&SC*, (Resubmitted after revision).

(Calabrese *et al.*, 2007a; Ratti *et al.*, 2007b); *digital cities* (Komninos, 2008), *Live City* (Resch *et al.*, 2012) and one of the latest concepts is the *smart city*.

Smart cities can be defined as “territories with a high capacity for learning and innovation, which results from the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management” (Komninos, 2006). The term ‘smart city’ is often used interchangeably with *intelligent*, *wired*, or *digital* city. Hollands (2008) provides a comprehensive review on the smart city concept. The role of ICT is the main smart city subject discussed in the literature. Smart cities are mostly related with the design and applications of ICT – both as digital infrastructure and ICT usage – at the level of cities and regions (Komninos, 2002). Digital technologies have changed our ways of living and working. For example, the relationship between physical travel and telecommunications has been studied extensively in the literature as an objective to understand the direction in which the use of telecommunications influence mobility behaviour (Nobis and Lenz, 2009). Mokhtarian (2003) has identifies four possible relationships between physical travel and telecommunications: *Substitution*, c*omplementarity*, *modification,* and *neutrality*.

There is a great potential for digital technologies which should be exploited for the better management of complex urban systems. These systems are marked by connectivity and accessibility, and need to be governed from a systematic perspective in which ICT may plays an important role. An important problem in densely-populated urban agglomerations is the vulnerability caused by traffic accidents. This Chapter aims to map out critical success factors of Incident Management (IM) which is based on advanced digital technologies.

2.2 Incident Management defined

Europe has a relatively high population density, and consequently also a dense transportation network, especially in and around urban agglomerations in Western Europe. This region is one of the most urbanized areas in the world. High density networks may become vulnerable in peak hours. This prompts the question whether information technology can be instrumental in guaranteeing these networks a smooth throughflow in urban areas. Road networks are part of a country’s transport infrastructure, and are therefore subject to general transport policies. Traffic incidents have a significant impact on the normal operation of road networks. This impact has a vast effect on all road users and the surrounding community. Casualties need to be recovered quickly from the scene of an incident, and secondary incidents need to be avoided. Traffic delays due to incidents result in loss of time, disruptions to public transport schedules, financial loss to freight operators and businesses, and increased vehicle emissions due to traffic idling for extended periods of time.

An 'incident' is generally defined as "*an unforeseen (unpredictable) event that impacts on the safety and the capacity of the road network and that causes extra delay to road users*" (EasyWay, 2011). The term 'incident' is defined in the Dutch regulatory framework as "*all the events (such as accidents, dropped cargo, stranded vehicles, collisions with incidents involving hazardous materials), which affect (or may affect) the capacity of the road and hinder the smooth flow of traffic with the exception of broken down vehicles on the hard shoulder, where there is a minimal and acceptable risk regarding the traffic flow and safety of the other traffic*" (Dutch Ministry of Transportation and Water Management, 1999). Each EU Member State has its own strategy and definitions for handling traffic incidents (Dutch Ministry of Transportation and Water Management, 1999; ECMT, 2007; UK HWA, 2009; CEDR, 2011; EasyWay, 2011). Central in all these definitions are the planned and coordinated measures for safe and quick restoration to normality. IM is, in general, the policy that, through a set of measures, aims to reduce both the negative effects on the traffic flow conditions and the effects on safety, by shortening the period needed to clear the road after an incident has happened. It can also been seen as a process to detect, respond, and remove traffic incidents, and to restore traffic capacity.

The handling of an incident can be described on the basis of the activities necessary to reduce the damage caused by an incident. This serves to show where problems arise in the clearing of incidents, and is useful for determining what measures are needed (Knibbe *et al.*, 2006; Immers *et al.*, 2009). In the literature there is no general agreement on the different phases of IM (see Table 1; Özbay and Kachroo, 1999; Nam and Mannering, 2000; Corbin and Noyes, 2003; US FHWA, 2000; Dutch Ministry of Transportation and Water Management, 2005a; UK HWA, 2009). In our analysis, we use Zwaneveld *et al.*'s (2000) simplified version of IM phases, which comprises four phases: alerting; response and arrival; action; and normalization. In some examples, the detection and warning phase are combined. In the literature, sometimes the normalization and flow recovery time are also combined into one phase. The verification phase is also an important process. However, in many examples, this phase is not included. An attempt to create a shared European agreement on the process phases can be found in CEDR (2011).

Table 2.1: Differences in the definition of the traffic IM process phases

<table>
<tr><th>United States

Federal Highway Administration (2000)</th><th>Europe

CEDR (2011)</th><th>Europe

EasyWay (2011)

Deployment guide</th><th>Netherlands

Zwaneveld et al. (2000)</th><th>Netherlands

Dutch Ministry of Transportation and Water Management (2005a)</th></tr>
<tr><td>detection</td><td>discovery</td><td>discovery</td><td rowspan="2">detection</td><td rowspan="2">alerting</td></tr>
<tr><td>verification</td><td>verification</td><td>verification</td></tr>
<tr><td rowspan="2">response</td><td rowspan="2">initial response</td><td rowspan="2">initial response</td><td>warning</td><td rowspan="2">response</td></tr>
<tr><td>driving or arrival</td></tr>
<tr><td>site management</td><td>scene management</td><td>scene management</td><td>operation or action</td><td>action</td></tr>
<tr><td rowspan="3">clearance</td><td>recovery</td><td>recovery</td><td>normalization</td><td rowspan="3">normalization</td></tr>
<tr><td>restoration to normality</td><td rowspan="2">restoration to normality</td><td rowspan="2">flow recovery</td></tr>
<tr><td>normality</td></tr>
</table>

Strategies to prevent incidents are, of course, preferable to strategies designed to respond to incidents. In many cases, human or technical failure plays an important role (Wegman, 2007). The main causes of road deaths are speeding, driving under the influence of alcohol or drugs, and not using seat belts[1]. Governments need to ensure that comprehensive laws cover the main risk factors (World Health Organization, 2009a; European Transport Safety Council, 2011a).

Traffic IM can be seen as a special case of (simplified) crisis or disaster management in terms of organization and work processes. Disaster management involves a cycle which should consist of an organized effort to mitigate against, prepare for, respond to, and recover from a disaster (FEMA, 1998). Informed decisions are a prerequisite for the formulation of successful mitigation, response, preparedness, and recovery strategies. To a great extent,

[1] http://ec.europa.eu/transport/road_safety/topics/behaviour/index_en.htm

however, successful strategies depend on the availability of accurate information presented in an appropriate and timely manner (Grothe *et al.*, 2005). This is more or less in line with traffic IM. Cooperation between the emergency services, in terms of coordination, communication, and information-sharing, is becoming increasingly important in order to apply traffic IM successfully. The emergency services have traditionally been alerted and have shared information via traditional landline and mobile phone calls. Historically, each organization has developed information systems which are primarily designed as closed systems that mainly support their own specific IM tasks. Even within organizations there are still many problems in terms of system diversity, architecture, and standards used. However, organizations have begun to realize that introducing new interoperable system concepts is important for significantly improving cooperation. It is important to observe that almost all information has a spatial (geographical) component, so that geo-science tools – especially in urban areas – play a crucial role for developing innovative ICT tools for traffic IM. We now provide a concise overview of recent IM developments in the Netherlands.

2.3 IM developments in the Netherlands

The origin of traffic IM can be found in the US (Koehne *et al.*, 1991). To “keep Washington on the move”, an Incident Response (IR) programme has been initiated by the Washington State Department of Transportation (WSDOT), which started as a pilot in 1990. Washington is a state of contrasts: on the one hand, the state has vast unpopulated areas. On the other hand, it has a number of large urban areas which have major mobility problems. In the north-western part of Washington, Seattle and Tacoma form a large conurbation. Vancouver in the south-west of Washington is a part of the cross-state Portland conurbation. The Seattle-Tacoma conurbation is most comparable with the Dutch traffic situation in terms of mobility problems. This area is a vast metropolitan area that has a population of about 3.2 million. The size and population density of the Seattle-Tacoma metropolitan area are roughly comparable with that of the northern part of the main Dutch urban area, the Randstad (Lassche and Jacobs, 2009). In 1991, the Washington State Department of Transportation commissioned a study that led to the "*Framework for developing Incident Management Systems*" (US FHWA, 1991)[2].

The US definition of Traffic IM is "a planned and coordinated process to detect, respond and remove traffic incidents and restore traffic capacity as safely and quickly as possible" (US FHWA, 2000). Events like September 11 in 2001 and the widespread impacts of major weather events like Hurricane Katrina in 2005 caused the realignment and redefinition of traffic IM, and underscored its critical role in national preparedness. Transportation agencies are recognizing that traffic IM is more than just a tool for increasing mobility and reducing congestion. In 2003, the U.S. Department of Homeland Security developed the National Incident Management System (NIMS)[3] which provides a framework for incident planning and response, at all levels, regardless of cause, size, or complexity (US Department of Homeland Security, 2008). All incident responders came to understand that it is increasingly important to be aware and understand each other's role, regardless of incident size or scope. The Netherlands is the first country in Europe where a formal structure for IM was introduced in the early 1990s.

2.3.1 Regulation on mobility and safety

In the Netherlands, the Ministry of Infrastructure and Environment is responsible for public works, transport, and water management, which includes the maintenance of the primary road network of 3,249 km, ensuring that the infrastructure is safe and in a good state, and that the flow of vehicles is as smooth as possible. The Dutch national government has only limited possibilities to enforce strict rules regarding IM because of the large number of involved organizations and the many laws that (in-) directly deal with IM. Therefore, IM was built upon the existing rules and responsibilities of the parties involved. The first policy rules focused more on mobility issues. Later, the policy rules focused more on the safety of emergency workers and road users, and on specific measures for towing services. A clear list of priorities has been set in mutual agreements between the emergency services (Dutch Ministry of Transportation and Water Management, 2005a; 2007).

[2] Since then this handbook has been updated twice (US FHWA, 2000; US FHWA, 2010a), so IM has a history of over 2 decades. The US traffic IM policy are stated in the 'National Unified Goals' (NUG): (1) Responder Safety, (2) Safe and Quick Clearance, and, (3) prompt, reliable and interoperable communications which are to implemented by 18 strategies (US FHWA, 2010b).
[3] http://www.fema.gov/emergency/nims/

Regulating the traffic flow around incidents by means of regional traffic centres, and ensuring the safety of the people involved are the most important tasks of the road inspectors, which is a task for the Police in normal situations. Effective use of the road network is achieved by ensuring that the infrastructure is safe and in a good state, stimulating a smooth traffic flow and reducing traffic jams as much as possible. Rijkswaterstaat is also responsible for the speedy and safe restoration of traffic circulation[4]. IM in the Netherlands is primarily based on two basic regulations which have improved the organization of the salvage process. First, there is the national private car (NPR) regulation, whereby every private car in the Netherlands must have compulsory car insurance for primary post-accident recovery. The policy thus covers the costs (in kind) of the recovery of the vehicle at the scene of the incident, and its transfer to the first available safe location, such as a petrol-filling station or parking place. This means that, immediately after an accident, a salvage company can be called to remove the vehicle(s) from the main lane, instead of first calling the Police to investigate the situation. This saves not only time in dealing with an incident but also reduces the risk of subsequent accidents. This results in a reduction of handling time of 15 minutes (Feenstra *et al.*, 2002; Immers, 2007b). The second regulation, the National Truck Regulation (NTR), is similar to the NPR, but for trucks and lorries. The reduction in handling time is 60 to 90 minutes (Dutch Ministry of Transportation and Water Management, 1997). Many trucks in the Netherlands are not insured for primary post-accident emergency recovery. The main Dutch road authority (Rijkswaterstaat) guarantees the transport costs to a safe (working) spot[5].

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[4] Tuning and safeguarding the interests of all involved parties makes it possible to act satisfactorily on the basis of violating Article 5 which is concerned with endangering road safety. The Road Traffic Law (1994) lays down additional rules based on Article 2 of the Road Traffic Law (1881) or Wrongful act (Civil law book Article 6:162 BW and Rijksweg 12-arrest HR 19 December 1975, NJ 1976/280) against Rijkswaterstaat or infringement of title of ownership of Rijkswaterstaat as road owner. Removing damaged vehicles from incidents, stalled vehicles, and lost cargo (spilled loads) from roads is based on laws in the private domain as a result of a tort (Wrongful act) committed against the road operator. This power is described in the Policy rules for Incident Management (Dutch Ministry of Transportation and Water Management, 1999) (Staatscourant 27 April 1999, No. 89 and amendments of 5 March 2003, 15 September 2004, and 19 November 2007).

[5] For this first initial recovery, the towing company nearest to the incident location will be used. In 2008 more than 4000 truck incidents took place (of which approx. 750 were accidents), with a monthly average of more than 330. In incidents involving trucks it tends to take some time before the main lane can be cleared for other traffic, thus causing traffic congestion. A broken down vehicle which is left on the highway without any passengers can also be removed by the Road Authorities or the Police. The costs for towing are borne by the car owner. Similarly, there is a delayed and fast towing measure for trucks (Staatscourant 27 April 1999, No. 89 and amendments, 9 November 2007/ Nr. RWSCD BJV 2007/28228). *Delayed towing* is a first towing to remove the truck from the driving lane. The *fast towing* measure is a first towing where no special measures are taken to avoid the damage to the truck. These measures are taken when there is a hinderance to traffic flow and safety. The costs for these towing activities are borne by the Road Authorities (Dutch Ministry of Transportation and Water Management, 2008a). The *Initial Safety Measures for Incidents on Motorways for the emergency workers* defines how to secure an incident situation (Dutch Ministry of Transportation and Water Management, 2005b, renewed in 2011). This results in a lower probability of a secondary accident.

In practice, there are a number of relevant laws, directives, and guidelines which have a direct or indirect relationship with the daily use of operational information systems. Examples are: the descriptive location identification system; the multidisciplinary questioning protocol; and incident evaluation. (see Dutch Ministry of Transportation and Water Management, 2003a, 2003b, 2004a). The Netherlands is one of the first European countries where IM regulations were established to create a solid basis to develop a professional IM organization and different specific IM measures.

2.3.2 Balance between policy and operation

Before 1975 there were a limited number of highways, and traffic jams did not lead to major problems in terms of mobility and safety on a nationwide scale. Between 1975 and 1995 many new main roads were built, leading to a large increase in mobility, which in turn led to serious congestion problems. The issue of traffic jams caused by incidents then came high on the political agenda. Until that time, incidents were handled only by the Police (Dutch Ministry of Transportation and Water Management, 2010). In general, traffic becomes congested when the demand is greater than the supply. The ambition of the government, defined in the *Memorandum on Mobility* (Dutch Ministry of Transportation and Water Management, 2004b), is to provide reliable and smooth travel over the entire travel trip by 2020. IM is one of the main pillars of the dynamic traffic management program that is applied to the Dutch road network. In the policy framework *Better utilization of existing infrastructure* (Dutch Ministry of Transportation and Water Management, 2008a), IM is regarded as one of the structural measures for a network-wide approach. Traffic incidents can have different effects at specific locations or times in the day. Therefore, in the Netherlands, a segment approach is currently been considered (Dutch Ministry of Transportation and Water Management, 2012).

The cost-effectiveness of IM measures in terms of traffic flow, safety, and sustainability is high on the political agenda. Traffic organizations need to achieve a balance between (economic) benefits and investment in a broad range of traffic management measures. In the Netherlands, historically, there has been considerable experience with the implementation and evaluation of traffic management measures. Since the 1990s there has been a tendency to a shift from the building of new infrastructure to a better utilization of existing infrastructure. The results of this policy have become clearly visible for road users. Since 1970, this has involved the development and implementation of many traffic measures, such as traffic signalling, ramp metering, variable message signs, and specific IM measures.

Approximately 13 per cent[6] of the traffic jams on Dutch roads are the result of incidents such as crashes and vehicles shedding their loads. The majority of these traffic jams are caused by incidents with cars (Dutch Ministry of Transportation and Water Management, 2004b). All these traffic jams contribute significantly to the economic damage. A traffic jam also creates an unsafe traffic situation, and in many cases collisions occur in the tail of the jam. This entails the risk of further material damage, as well as injury. Therefore, there is sufficient reason to limit, as far as is possible, the length and duration of such traffic jams. With the introduction of various measures (organizational and technical), it is possible to shorten the total incident duration and vehicle-loss hours. Since the introduction of IM in 1994, by 2004 there has been a reduction of 25 per cent in the average time of incident-related IM actions (Grontmij, 2004). Between 2004 and 2008 the incident duration decreased by another 10 per cent. The target is that, by 2015, the 2008 process time will be reduced by another 25 per cent (Dutch Ministry of Transportation and Water Management, 2008a).

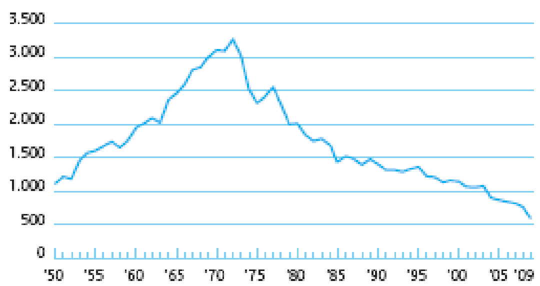

Figure 2.1a: Number of fatal casualties

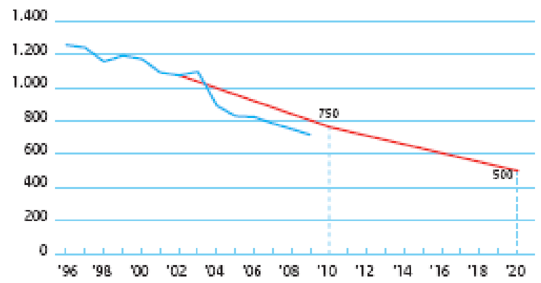

Figure 2.1b: Policy goals related to fatal casualties

Source: Dutch Ministry of Transportation and Water Management (2010).

At the beginning of the 1970s there were over 3000 fatal casualties (see Figure 2.1). By 2020 the Dutch government plans to reduce the number of fatal casualties to 500, and the number of injured to 10,600. In 2010 there were 640 fatal casualties, and approximately 17,000 injured. The goals are defined in the strategic plan *Traffic safety* (Dutch Ministry of Transportation and Water Management, 2008b) which includes an action program, which describe the specific measures.

[6] In practice this number is much higher. Delays of traffic incidents during rush hours and regular bottlenecks are mainly excluded in this percentage.

2.3.3 Type and numbers of incidents

On a yearly basis there are over 100,000 incidents (see Table 2: Leopold and Doornbos, 2009), varying from small accidents to major multi-vehicle incidents, causing casualties and damage to the road and its supporting structures. While relatively few incidents involve trucks, these incidents cause immediate, large-scale traffic jams that catch public attention.

Because there are different organizations involved in the operational handling of IM, there are some difficulties in giving exact figures on IM. The main problem is the definition of different types of incidents. For example, for the nationwide Network Information System (NIS) of the Rijkswaterstaat (the Road Authority), there are four types of incidents: breakdown of vehicles; incidents with only material damage; those involving injured persons, death, fire, and dangerous goods; and investigation of guilt or crime[7]. Another aspect is the goal of registration. The traffic control centre is responsible for registering (logging) all the incident data to support the complete IM process. These registrations are basic input for all other off-line processes such as IM-evaluation and statistical accident registration. However, the Road Inspector is the main source for all relevant data, but his primary task is to clear the incident site as soon as possible. Registration is considered a secondary, low-priority task. The involvement of towing services is financially regulated in contracts, which gives another economic drive for good registration. Also data conversions from the regional traffic centre to the national Network Information System (NIS) cause some loss of data quality. Table 2b and 2c contains the incidents registered by towing services.

[7] There are five Regional Traffic Management Centres, and each use their own registration and information systems, and also use different definitions of incident categories. Morever, not every incident (for example, a broken-down vehicle) is registered. The breakdown of vehicles on the hard shoulder, where there is a minimal and acceptable risk regarding the traffic flow and safety, is handled by the ANWB (Royal Dutch Automobile Association) without the involvement of the Road Inspector of the Rijkswaterstaat. The Police have their own classification.

Table 2.2 (a): Number of traffic incidents in the Netherlands

	Breakdown of vehicles		Only material damage		Heavy accidents (injured, trucks)		Unknown
number of incidents	61,287		12,926		1,720		24,681
percentage of total incidents	61%		13%		2%		24%
contribution to reduce incident time (1994-2008)	36% cars	22% trucks	26% cars	13% trucks	17% cars	10% trucks	-
mean contribution reduction time (1994-2008)	Approximately 30%						
contribution to reduce incident time (2004-2008)	13% cars	6% trucks	9% cars	3% trucks	5% cars	2% trucks	-
mean contribution reduction time (2004-2008)	approximately 10%						

Source: Leopold and Doornbos (2009).

Table 2.2 (b): Registered private cars

number of incidents with passenger cars	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
breakdown	1141	1912	3096	3582	4831	5893	11380	15847	22736	24558	33472
unknown	7471	5861	6098	6157	6047	6041	153	171	198	7399	123
accident	15832	18138	17661	18663	20798	20692	24366	25294	24465	20571	20160
Total	**24444**	**25911**	**26855**	**28402**	**31676**	**32626**	**35899**	**41312**	**47399**	**52528**	**53755**

Table 2.2 (c): Registered trucks

number of incidents with trucks	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
breakdown	440	639	771	948	1051	1204	1559	2057	2678	3008	3384
load	7	14	21	11	2	4		3	1		
unknown	6	5	8	38	8	16	10	4	20	12	39
accident	644	835	787	709	764	927	777	1034	1058	933	841
Total	**1097**	**1493**	**1587**	**1706**	**1825**	**2151**	**2346**	**3098**	**3757**	**3953**	**4364**

2.3.4 Economic costs and benefits of congestion

Recurring congestion occurs when normal traffic demand exceeds the physical capacity of the freeway. This congestion typically occurs due to systematic capacity shortages during high traffic volume periods (e.g. morning and afternoon peak periods), and is predictable in terms of its location, duration, time, and effect (Skabardonis *et al.*, 1997). Non-recurring congestion is the result of a short-term reduction in the capacity of a roadway (e.g. traffic incidents, work zones, special events etc). In the Netherlands, traffic accidents and delays are estimated to cost €10.4-13.6b/year of which delays alone cost €2.8-3.6b/year. Delays attributable to incidents amount to 12 per cent of this, i.e. €336-432m/year. IM is estimated to avoid €100-130M in social costs compared with an annual investment of €27m, implying a high Benefit/Cost Ratio (BCR) of between 4 and 5 (Leopold and Doornbos, 2009). The financial sacrifices of road usage in congested urban areas is indeed significant.

2.4. IM as an actor network approach

IM in the Netherlands depends on cooperation between Rijkswaterstaat (the Dutch Road Authority) and other emergency response services. Together, they have set up new guidelines and protocols in order to shorten the time which is needed to clear the road after incidents. These guidelines are discussed and established in the National IM Platform. The cooperation between different organizations is clearly defined in Article 2 of the Policy Rules (Dutch Ministry of Transportation and Water Management, 1999). This was the initial start of the IM network which can be seen as a public-private partnership. To get a full picture of this network, we first look at how IM was introduced in different stages. Then we look in more detail at the actors, their role, and the legal mandate. Finally, we focus on how IM is becoming an information network.

2.4.1 IM development stages

Between 1995 and 2010, the development of IM in the Netherlands began to take shape, and was introduced in six different stages or time frames which partially overlap (see Figure 2.2, based on Zwaneveld *et al.*, 2000).

The '*orientation*' stage started at the end of the 1980s with an orientation on international IM activities. A number of to the USA, England, and Sweden confirmed and stimulated the ideas on IM in the Netherlands (Dutch Ministry of Transportation and Water Management, 1998, 2002, 2006, 2009). McKinsey and Company (1995) investigated the causes of congestion in the Netherlands. The audit revealed that the congestion caused by incidents was a significant proportion of the total. This stage ended in 1995 with the publication of an IM manual. (Dutch Ministry of Transportation and Water Management, 1995).

The '*pilot project*' stage started in 1994 and ended in 1997. Following the Action plan for implementing the recommendations from the report *Congestion reducing road management* (McKinsey and Company, 1995), in 1996 and 1997 this resulted in the preparation of four pilot projects for national implementation. Several IM measures were tested on motorways around the cities of Utrecht, Rotterdam, and Amsterdam, which laid the basis for the national introduction of the Policy Rules for IM (Dutch Ministry of Transportation and Water Management, 1999).

The '*organization*' stage started during the previous stage, and ended in January 1997 with the foundation of the 'Project office for Incident Management'. Several emergency services are represented within this organization, e.g. the Police, Fire Brigade, transport authorities, motorway operators and insurance companies. The platform's task is to implement the national regulations and different IM measures. To this end, the platform has formulated agreements about the cooperation between the emergency services on motorways. Additional measures were prepared and initiated to accelerate the handling of the different IM phases (Dutch Ministry of Transportation and Water Management, 2005b). The '*implementation*' stage started in 1997, and consisted of the national introduction of IM measures. To limit the social damage that occurs when traffic jams form around incidents, in the late 1990s the Rijkswaterstaat signed a covenant with the Insurers' Association and the sector organizations. The Rijkswaterstaat is committed to implementing IM measures on the Dutch trunk road network. The aim of these IM measures is to ensure the safe and quick handling of incidents so that the traffic flow restrictions caused by an incident are lifted as quickly and safely as possible. It goes without saying that good victim assistance and the safety of both emergency service workers and other road users are important considerations.

The '*professionalization*' stage was created with the establishment of the IM Consultation in 2008 and the reports *Guide to professional IM* (Immers, 2007a, b) and *Smart goals for IM* (Immers and Landman, 2008). This phase is characterized by the increasingly close cooperation of partners and the sharper demarcation of responsibilities and powers.

Currently, we are in the '*integration*' phase which is characterized by increased road use, higher expectations of road users, and high ambitions in terms of traffic flows and safety. This is closely linked to financial cuts in IM services and a slow retreat of the role of the police in IM tasks that make it necessary for all parties to work together even more closely with an emphasis on better communication and information sharing.

Since the start of the professionalization and integration phases, information-sharing between the emergency services involved has become increasingly important for a quick and appropriate response. These efforts have a direct correlation with public safety and mobility. Information-sharing allows multiple agencies to identify the necessary resources and provide coordinated traffic IM. It also provides the motoring public with information upon which to base their travel choices. With the introduction of various measures (organizational and technical) it seemed to be possible to shorten the total incident duration and lost vehicle-hours. However, it is important to realize that the public and private IM actors involved have their own specific task and legal responsibility. This is an important constraint to develop new information architectures and systems to improve collaboration between different IM chain members.

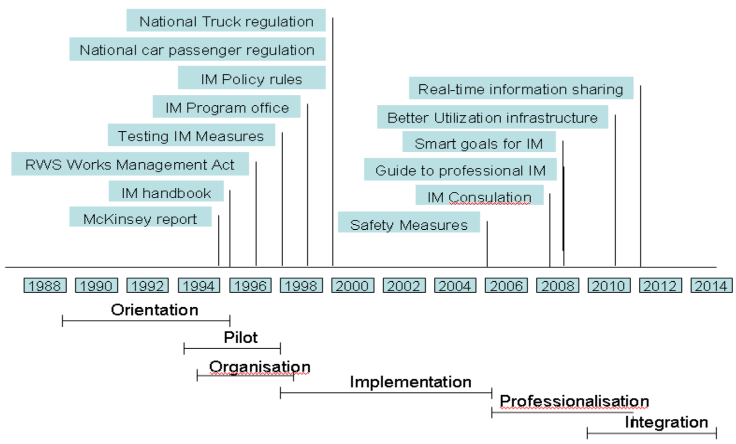

Figure 2.2: IM development stages in the Netherlands

2.4.2 Public IM actors

The public IM emergency services are the Road Authority, Police, Fire Brigade, and the Ambulance services. The Rijkswaterstaat has, in the context of the law the Rijkswaterstaatworks Management Act (1996), the public responsibility for the efficient and safe use of the main road network[8].

The Dutch Police Law (1993) makes the Police responsible for settling the incident. Most incidents on the highways are reported by the 112 emergency lines coming in to the control room of the Police. They will inform the surveillance units of the Police and, if necessary the Fire Department Control Centre, the Ambulance Dispatch Centre and the regional traffic centre. The Police coordinate the effective handling of the incident with the other emergency services. In the case of disasters, this responsibility shifts to the Fire Department and Municipality. The handling of IM by the Police is based on the Dutch Road Traffic Law (1994). Under Article 2 of the Police Law, the police have the legal responsibility to support public transportation with IM-related tasks, in terms of road safety and towing services.

The activities of the Fire Brigade are based on the Dutch Fire Brigade Law (1985) and the Dutch Municipality Law (1992). Their primary tasks are ministering first aid to road victims, removing victims from crashed (damaged) cars, and avoiding or reducing the release of toxic or dangerous substances. The Ambulance team makes an estimate of the magnitude of the injured, determines which victims need first aid, and handles life-threatening situations based on the Dutch Law on Medical Aid in Accidents and Disasters (WGHOR, 1991). In cooperation with the Fire Brigade it assists in removing victims from damaged vehicles. In 2010 the legal basis of the Police, Fire Brigade and Ambulance was replaced by the Dutch Law on Safety Regions (2010). Private actors also play an important role in the daily handling of traffic IM. Hence, information systems need to have clearly defined interfaces to share public-private information.

[8] In the Netherlands, there is one National Traffic Management Centre for the coordination of major incidents. For the daily operational tasks, there are five Regional Traffic Management Centres, from which traffic management measures can be taken for the entire road network. These centres are managed by the Rijkswaterstaat, and are in close contact with the Central Dispatch Centre of the National Police (KLPD), the control rooms of the Regional Police and other emergency services (Dutch Ministry of Transportation and Water Management, 2000). The Netherlands Traffic Centre (VCNL)'s main objective is to stimulate a safe traffic flow, and provide reliable travel information.

2.4.3 Private IM actors

Towing, repair, and insurance services are the main tasks of private IM parties. To structure these activities on a nationwide scale, different foundations have been formed. Salvage help after an incident is a private matter between the insurer and the driver of the vehicle, arranged through an insurance policy. Insurers have assigned the execution of this service to Alarm Control Centres.

The Netherlands Incident Management Foundation (SIMN) is responsible for the towing of passenger vehicles (Gross Vehicle weight of <3500 kg) on the major roads in the Netherlands. The Foundation was established to provide support to the Road Authorities for their efforts in the area of IM. In the Netherlands, passenger cars need at least liability insurance. In this liability insurance coverage, a fee is included for initial emergency towing services, after an accident, to a safe location, such as a gas station or a parking lot. Towing aid is a private matter. The insurers have assigned this task to the call centres. The Foundation ensures the involvement of individual companies. This operational role is fulfilled by exploiting what is called the National Central Hotline (LCM)[9].

The Lorry Incident Management Foundation (STIMVA) is responsible for the central coordination of the use of towing services and equipment. In practice, this is a cooperation between insurance companies, the Dutch branch organization for Transport and Logistics, their own transport organization, the Royal Dutch Transport Organization (KNV), and the Rijkswaterstaat[10].

The Lorry Salvage Consultant (STI) is a cooperation between the Dutch fire insurance companies, expertise bureaus, and cleaning reconditioning companies. All salvage message are handled directly from the Fire Department to the international Insurance Aid Service (VHD-group). The primary goal is to minimize the direct and indirect claims, by respecting the needs of the insured at the time. The VHD-group provides assistance for medical treatment

[9] The LCM acts as a central sharing point for incoming incident reports on the part of the Police and Road Authorities. Each message received by the LCM, is translated into a mission for a towing company which has a contract with the Foundation.

[10] The STIMVA provides the use of salvage companies for trucks (Gross Vehicle weight > 3500 kg). This operational role is fulfilled by exploiting what is called the Central Service Desk for Truck Accidents (CMV). Application of the usual method of disposal trucks often requires the careful use of advanced equipment, and the application of prescribed procedures for storage as safely and quickly as possible. In this way, the chance of damage to vehicles, cargo, and the roads is as small as possible. After that, the truck is towed to a safe place. This recovery process is usually time-consuming, and causes significant delays for traffic on the network. The handling costs of recovering and towing of breakdown trucks are borne by the vehicle owner, regardless of the location of the incident.

and has financial responsibility as a central organization for governments. The Royal Dutch Automobile Association (ANWB) operates emergency car-repair and towing services for broken-down vehicles.

2.4.4 The IM information chain

There are many private and public organizations involved in the daily handling of IM. These have their own tasks and legal responsibility (see Table 3). IM organizations are strongly related and need to collaborate for an effective incident response. Each organization has the same kind of problems in terms of system diversity, architecture, and standards used. Information-sharing between traffic management control centres, emergency control centres, towing services and insurance companies is becoming increasingly important. To have identical situational awareness and a common handling framework for effective IM is necessary for the further improvement of cooperation.

Table 2.3: Overview of IM organizations and their roles

Organization	Public	Private	Mobility	(Road) safety	Question of Guilt	Medical Aid	Insurance	Towing Repair
Road Authority (Rijkswaterstaat) - Regional Traffic Management Centre (RTMC) - Road Inspector	X		X	X				
Police - Police Control Centre - Police officer	X		X	X	X			
Fire Brigade - Fire Control Centre - Firemen	X			X				
Medical services (GHOR) - Ambulance Dispatch Centre - Ambulance men	X			X		X		
Dutch IM foundation (SIMN) - IM recovery Dispatch Centre (LCM)		X		X			X	X
Lorry IM Foundation (STIMVA) - IM Lorry Recovery Dispatch Centre (CMV)		X		X			X	X
Recovery (towing) Service		X		X				X
VHD group		X		X			X	
Lorry Salvage Consultant (STI)		X		X				X
ANWB		X		X				X

Timely and accurate information plays an important role in the information chain between all the IM emergency services. The increasing importance of information is clearly visible from a historical perspective, which shows how traffic IM was introduced in different stages. Inter-agency exchange of information is the key to obtaining the most rapid, efficient, and appropriate response to highway incidents from all agencies. Information systems play an important role within and between organizations. A distinction can be made between the different activities (see Table 2.4).

Table 2.4: Activities to support traffic IM within and between organizations (Based on CEDR, 2011)

<table>
<tr><th>Within an organization</th><th>Between organizations (Cooperation)</th></tr>
<tr><td>Command</td><td rowspan="2">Coordination</td></tr>
<tr><td>Control</td></tr>
<tr><td colspan="2">Communication</td></tr>
<tr><td colspan="2">Information</td></tr>
</table>

‘Command’ means the authority for an organization to direct the actions of its own resources. The CEDR (2011c) report acknowledges that local scene commanders will determine the deployment of resources to the scene of traffic incidents. ‘Control’ means the authority to direct strategic and tactical operations in order to complete an assigned function. It includes the ability to direct the activities of other agencies engaged in the completion of that function. The control of an assigned function also carries with it a responsibility for the health and safety of those involved. ‘Cooperation’ is working together to achieve a common aim. ‘Coordination’ is the harmonious integration of the resources, expertise, and activities of partner organizations, with the objective of effectively and efficiently resolving the incident. ‘Communication’ is the timely exchange of ‘information’ within and between organizations. Developments in information, communication and sensor technology can provide new concepts and possibilities. The increasing number of incidents and the related economic problems are forcing IM organizations to improve their cooperation on many levels, particularly with respect to information sharing in urban agglomerations.

2.5. European policy

2.5.1 IM regulation on mobility and safety

For a long time, the European Community was unable to implement the common transport policy provided by the Treaty of Rome (European Commission, 1957), because of the different and sometimes conflicting objectives of each Member State. This led to a mixed picture in terms of congestion problems based on the growth of transport in an enlarged European Union, with a resulting imbalance between different transport modes. The Treaty of Maastricht (European Commission, 1992) reinforced the political, institutional, and budgetary foundations for transport policy which included the concept of the TERN. In 2001 this resulted in the EU White Paper '*European transport policy for 2010: time to decide'* (European Commission, 2001), which includes 60 specific measures. In relation to traffic IM the most relevant are improving quality in the road transport sector and putting users back in the heart of transport policy by improving road safety. In 2011 this White Paper was updated as '*Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system'* (European Commission, 2011). Since 2001 much has been achieved. The safety and security of transport across all modes have increased. However, the White Paper concludes that the fragmentation of research and development efforts in Europe is most harmful for traffic safety. A specific goal is to identify the necessary innovation strategies and deploy large-scale intelligent and interoperable technologies such as the '*Intelligent Transport Systems'* (ITS) to optimize the road capacity and the use of infrastructure. Members States have a direct influence on EU legislation. For traffic IM, a number of different EU organizations have been established which deal with legal EU matters. The US (US FHWA, 2010a) identifies broadly the same communication and standard issues as in Europe. They conclude that the coordination among Federal, State and local agencies or public safety and transportation agencies typically lacked cohesion. They conclude that to cope with this challenge, public and private sectors need to cooperate.

2.5.2 EU road organizations

There is great variety in the national road administrations in Europe. Examples of organizations are the Conference of European Road Directors (CEDR), the European Construction Technology Platform (ECTP), and the European Road Transport Research Advisory Council (ERTRAC). The Transport Research Committee (TRC) is another forum for strategic coordination in Europe. These organizations have defined strategies for effective traffic management and congestion. An example is the OECD/ECMT initiative of 2007 '*Managing urban traffic congestion*' (ECMT, 2007). The main findings related to traffic IM are introducing:

- coordinated IM policies to reduce the incidence of non-recurrent congestion;
- systems for coordination and integration amongst the emergency services;
- automatic incident detection systems, and traffic surveillance by cameras.

In the US we find the same fragmentation. At the national level, there are several agencies involved in the development and research of highway IM. These agencies are the Department of Transportation (DOT), National Traffic Incident Management Coalition (NTIMC), Federal Emergency Management Agency (FEMA), American Traffic Safety Services Association (ATSSA), National Fire Protection Association (NFPA), and the Towing and Recovery Association of America (TRAA). Highway IM procedures and policies developed by these agencies focus on different aspects of IM (Illinois Center for Transportation, 2011).

Recently, the Conference of European Directors of Roads (CEDR) developed the guideline 'Best Practice in Europe' for traffic IM (CEDR, 2011). The purpose of CEDR is to facilitate cooperation on a European level by exchanging experience and information in order to make progress in the road safety and road transport sector (CEDR, 2008). The main goal of IM is to manage and resolve incidents in a safe, effective, and expeditious way, considering safety, traffic flow and control damage (CEDR, 2009). Traffic IM can be viewed as one part of an integrated service to road users, whose various parts are related to dynamic traffic management, information provision, and traffic IM. They contribute in different ways to the efficiency of the road system (CEDR, 2011). By maintaining a balance between these elements, a more efficient use of network capacity can be achieved. Effective traffic IM can reduce both safety and non-safety-related costs by: reducing response and clearance times; reducing the risk of secondary incidents; ensuring the safety of incident responders; and maximizing the use of available resources (CEDR, 2011).

Another initiative comes from EasyWay, who have created a long-term vision in their '*Strategy and Action Plan*' (EasyWay, 2010c). The policy framework, defined from the road operators' perspective, constitutes high-level guidance for the period 2010 to 2020. A special roadmap summarizes the development and implementation steps to be taken, and defines the period in which this has to be done in order to fulfill the specific goals. They identify some main issues that the countries need to address in order to create a European framework for traffic IM which includes differences in the:

- organizational structure of IM responder units;
- level of agreements between IM responder units;
- involvement of road authorities and the private sector in IM;
- service levels (e.g. in relation to time of arrival and time of recovery);
- systems for incident detection and location;
- requirements/expectations of road users when involved in or influenced by an incident.

EasyWay implements most parts of the Intelligent Transport Systems (ITS) action plan (see European Commission, 2008). A new legal framework was adopted to accelerate the deployment of these innovative transport technologies, and is an important instrument for the coordinated implementation necessary to establish interoperable and seamless ITS services (European Commission, 2010). EasyWay has defined its priority ITS services, known as the *core services*, to be implemented in the coming years. For traffic IM services the deployment guidelines *Incident Management* (EasyWay, 2010a) and *Incident warning* (EasyWay, 2010b) are relevant. Recently, these guidelines have been integrated (EasyWay, 2011).

2.5.3 Road safety

In the last ten years a big effort has been made, by the European Commission and all Member states, to reduce the impact of road transport in term of fatalities and injuries. Initiatives in technology, enforcement, education and with particular attention to vulnerable road users are the key to drastically reduce the loss of lives even further. The overall objective to halve the number of fatalities between 2001 and 2010 has not quite been reached but significant improvements have been made. In the last decade, thanks to the third Road Safety Action Plan, fatalities have decreased by 43 per cent but the total number of accidents decreased by only 24 per cent and the total number of injuries by 26 per cent.

Road safety strategies traditionally focus on reducing fatalities. Injuries, however, are overlooked, and have become a major health problem. Each year more than 1 million people worldwide die as a consequence of road accidents. Traffic injuries in the European region are a major public health issue. In 2011 around 30,500 people lost their lives on the EU road network, a figure which corresponds to a medium-sized town, while around 1.5 million were injured on the roads of the European Union, at huge economic and human cost to society[11]. Road traffic accidents should be considered not only a transport issue, but also a social and public health concern, and therefore a scientific and rigorous approach should be adopted. Reducing the number and the severity of road traffic injuries is one of the strategic objectives outlined in the '*Policy Orientation on Road Safety 2011-2020*', and a priority for EU action. The new European goal is a 'zero-vision' on road safety for 2050 (see European Commission, 2011.

The fifth ETSC (European Transport Safety Council, 2011b) report provides an overview of road safety performance in Europe. This analysis is based on the road safety performance index as an instrument to support European countries to make greater efforts to enhance road safety. By comparing Member States performance, it serves to identify and promote best practice. European roads are among the safest in the world. Sweden, the UK, Malta, and the Netherlands remain the safest EU countries for road use. In 2010 in the EU27, 62 people per million inhabitants were killed on the roads. However, the accident rates across Europe vary greatly as shown in Figure 2.3.

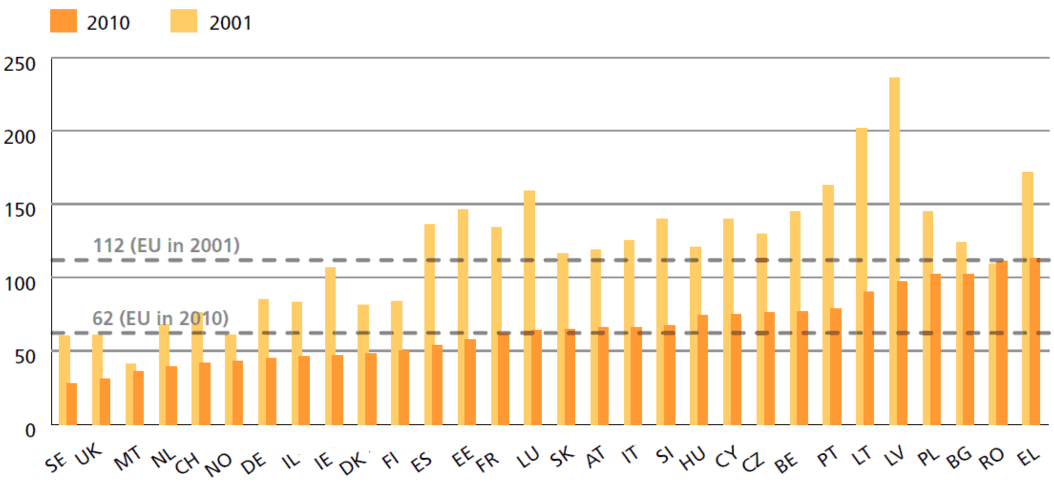

Figure 2.3: Road deaths per million inhabitants in 2010 (with road deaths per million inhabitants in 2001 for comparison)

Source: European Transport Safety Council (2011b).

[11] http://ec.europa.eu/transport/road_safety/specialist/statistics/trends/index_en.htm

2.6. EU framework for information services

2.6.1 Traffic IM

Recently, eFRAME delivered the *European ITS FRAMEWORK Architecture V4.1* (eFRAME, 2011a). Inititatives for the FRAME architecture were originally developed by the KAREN project (1998-2000), and first published in 2000. It was maintained by the FRAME-S and FRAME-NET projects (2001-2005), and since 2005 it has been supported by the FRAME forum. Since 2008 it has been extended by the eFRAME project. The main goal of the eFRAME project is to define EU user-needs and functionality as an architecture reference guide for implementing the ITS Action Plan (eFRAME, 2011b). This is defined in the *Consolidated User Needs for Cooperative Systems* (eFRAME, 2011c). It also focuses on the emergency services and traffic IM. The architecture is in line with the four interoperability levels as defined by ISA (2009). The model is based on Data Flow Diagrams. Although the Frame architecture has been available for many years, not many Member States have adopted and/or implemented it on a national scale. Furthermore, it only provides simple guidelines for technical implementation; and is just a basic need for European traffic industry.

For IM it is fundamental to create a common vocabulary to establish semantic interoperability between emergency organizations based on IDABC (see Section 2.6.3). The involved organizations use basically the same information elements, but sometimes with different syntax or meaning. Good examples are the location definition of incidents (WGS 84, specific national identification or hectometer post) and types of incident categories. Normally, the definition of a vocabulary takes a great deal of time. However, the traffic management domain already has a solid basis in the form of the DATEX2 dictionary. This provides the definition of information elements (semantic) and the exchange platform (UML and XML) which is basically the implementation of a Service Oriented Architecture (SOA).

There are also many European initiatives to use new in-car technology and cooperative systems to increase safety for road users. An example which is directly related to IM is e-Call which stands for *Pan-European in-vehicle emergency call system*. eCall is part of the *e*Safety initiative led by the European Commission (see European Commission 2001; 2003a; 2003b; 2005; 2006a; 2006b). eSafety assists in reducing the number of fatal road accidents in Europe. eCall will have an impact on (elements of) IM. Firstly, this is because it will allow existing IM procedures (as implemented on highways) to be used in incidents on secondary roads. eCall makes no distinction between the type of road. Secondly, because an eCall includes location information. This allows the response to be directed directly to the right location. The current systems of using road number, direction and roadside distance indicators still leaves room for ambiguity. The location information of an eCall will be in geographic coordinates. eCall can be enriched with information about the involved vehicle and driver. eCalls are passed on to the emergency services, giving them an early indication as to the severity of the incident and even about the vehicles involved.

2.6.2 Geo-spatial initiatives

For IM it is crucial to create a common vocabulary and to establish a semantic and technical interoperability for data sharing and exchange between the emergency organizations. The involved organizations use basically the same information elements, that sometimes with different syntax or meaning. As IM information is (geo-)spatial in nature, it is relevant to consider harmonization and interoperability efforts is this field in Europe (Masser, 2005).

The Open Geospatial Consortium, Inc (OGC) is an international industry consortium of several hundreds of companies, government agencies and universities participating in a consensus process to develop publicly available interface specifications. OpenGIS® Specifications support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT. The specifications empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications (www.opengeospatial.org). The OGC has a Risk and Crisis Working Group which liaises to ORCHESTRA to synchronise the work being done within ORCHESTRA and the OGC Technical Committee. ORCHESTRA is a project of the European Union, which designs and implements specifications for a service oriented spatial data infrastructure for improved interoperability among risk management authorities in Europe. The service oriented spatial data infrastructure will enable the handling of more effective disaster risk reduction strategies and emergency management operations. The ORCHESTRA Architecture is open and based on standards (www.eu-orchestra.org).

The general situation on spatial information in Europe is of fragmentation of datasets and sources, gaps in availability, lack of harmonization between datasets at different geographical scales and duplication of information collection. These problems make it difficult to identify, access and use data that are available. Fortunately, awareness is growing at both national and EU level about the need for quality geo-referenced information to support understanding of the complexity and interactions between human activities and environmental pressures and impacts. The INSPIRE directive proposal (2007/2/EC) is therefore timely and relevant, but also a major challenge, given the many IM stakeholder.

In 2002, the EU Commission began to the develop the Infrastructure for Spatial Information in the European Community (INSPIRE). The INSPIRE Directive entered into force on the 15 May 2007. INSPIRE is ambitious: this initiative is designed to trigger the creation of a European spatial information infrastructure that delivers to the users integrated spatial information services. These services should allow the users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an interoperable way to assist policy making across boundaries and for a variety of application areas. The application areas that should benefit from INSPIRE are environmental and spatial planning, traffic and transport, agriculture, nature development, energy resources, water management, incident and emergency management. Therefore, INSPIRE intend to improve the access to spatial information for public bodies, private organizations and companies and citizens in Europe. INSPIRE establishes a European network of data services (using the publish-find-bind concept of Service-Oriented Architectures) that is based on agreed data specifications for harmonized data. The INSPIRE Directive compels data providers (public authorities across Europe) to be compatible with the INSPIRE *Implementation rules and guidelines*.

INSPIRE offers opportunities for IM to adopt a harmonized framework for the application of the harmonized spatial data to create a Situation report (Sitrap) and a Common Operational Picture (COP) for IM. INSPIRE offers the ability to use a spatial data infrastructure to adopt the underlying data sharing platform for these new information-sharing concepts for IM. INSPIRE is complementary to related policy initiatives, such as the Commissions' proposal for a Directive on the re-use and commercial exploitation of Public Sector Information (European Commission, 2003c).

Tracking services play an important role in allocating resources for emergency services. One of the goals of the European Commission was to make available an open, global system, fully compatible with, but independent of the GPS and GLONASS global navigation systems. The Galileo program is Europe's initiative for a state-of-the-art global satellite navigation system, providing a highly accurate, guaranteed global positioning service under civilian control. The fully deployed system will consist of 30 satellites and the associated ground infrastructure. Galileo will be interoperable with GPS and GLONASS. Hence, it must be possible for Galileo receivers to also use GPS satellites. Galileo is due to be launched in 2015.

Another major geospatial European project is the Global Monitoring for Environment and Security Program (GMES), for the establishment of a European capacity for Earth Observation. Users will be provided with information through services dedicated to the systematic monitoring and forecasting of the state of the Earth's subsystems. Six thematic areas are being developed: marine, land, atmosphere, emergency, security, and climate change. A land monitoring service, a marine monitoring service, and an atmosphere monitoring service, which contribute directly to the monitoring of climate change, and to the assessment of mitigation and adaptation policies. Two additional GMES services address, respectively, emergency response (e.g. floods, fires, technological accidents, humanitarian aid) and security-related aspects (e.g. maritime surveillance, border control).

2.6.3 Interoperability

Interoperability is the ability of diverse systems and organizations to work together (inter-operate). The term is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organizational factors that impact system-to-system performance. In 2004 the European Commission decided to create an interoperability framework to support the delivery of pan-European eGovernment services for public Administrations, Businesses and Citizens (IDABC: European Commission, 2004). Interoperability, from the 'European Interoperability Framework' (EIF) perspective, is defined as "*the ability of information and communication technology systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge*". The IDABC program provides guidelines to achieve interoperability with respect to three aspects:

- technical interoperability: technical issues of linking computer systems, and the definition of open interfaces, data formats and protocols including telecommunications;

- semantic interoperability: ensuring that the precise meaning of exchanged information is understandable by any other application not initially developed for this purpose;
- organizational interoperability: modelling business processes, aligning information architectures with organizational goals, and helping business processes to cooperate.

On 31 December 2009, the new ISA (Interoperability Solutions for European Public Administrations) program replaced the activities of the 2004 IDABC program and delivered a European Interoperability Framework (EIF) draft version 2.0 (ISA, 2009). The EIF 2.0 adds a legal level and a political context to the interoperability levels, as originally defined by IDABC (European Commission, 2004). Legal interoperability focuses on an aligned legislation, so that exchanged data is accorded proper legal weight. In the political context it is necessary to make sure that cooperating partners have compatible visions, aligned priorities, and focused objectives.

The key for IM interoperable participants is thus sharing information. However, each IM actor its own jargon or technical terminology. The first step to sharing information is sharing a dictionary, a common set of definitions (semantic interoperability). After that we can look at the technology infrastructure that is needed to support what must be accomplished by any of the participants (technical interoperability). The driving force of this study of the possible and desirable is the set of tasks that will be needed to accomplish the tactical and strategic goals of the systems (organizational interoperability). Any requirement that is to be supported by the technology must be derived from these tasks. One of the conclusions from IDABC is that there is a shift from conventional closed systems to more interoperable systems based on SOA. In SOA information and business processes are provided in a generic way using open standards. The basic elements are a common vocabulary (semantic), using eXtenisble Mark-up Language (XML) and, web services over a telecommunication infrastructure (technical).

Interoperability within the geo-sector will be reached progressively as metadata, data and services compliant with the INSPIRE Implementing Rules are becoming available and will require the active involvement of all actors identified in INSPIRE, namely European Union Member States relevant Institutions and the Commission.

2.6.4 Standardization of sensors, identification and location technologies

Several organizations, such as ISO (www.iso.org), EPC global (www.epcglobal.org), w3 consortium (www.w3.org) and OpenGeospatial consortium (www.opengeospatial.org), operate with a broad mandate from industry and governments to ensure that technologies and services interoperate starting from the lowest level of the technology stack. The push for interoperability derives from business requirements and the possibility of developing added value services. On the other hand, interoperability eliminates one of the tradition strongholds of technology suppliers and the ability to lock-in customers to proprietary technologies that are expensive to replace. In spite of the drive towards interoperability the incentive to exploit possible open spaces, first mover advantages, or early monopolies, will remain and counterbalance the interoperability push. The benefits of standardization would be lost if in different parts of the globe, or in different sectors, or areas organizations would have to invest in different technologies for location and RFID.

For the implementation of a GDI it is necessary that it complies with certain standards. In the past there was a strong focus on data delivery, the last few years data discovery and delivery through internet, intranet and extranets is more common. Apart from national initiatives there are three main standardization organizations that play an important role in the 'opening up' from the geospatial community. These standardization organizations are the Open Geospatial Consortium, The ISO TC/211 and the W3C.

The working group TC/211 defines standards in the field of digital geographic information. This work aims to establish a structured set of standards for information concerning objects or phenomena that are directly or indirectly associated with a location relative to the Earth. These standards may specify, for geographic information, methods, tools and services for data management (including definition and description), acquiring, processing, analyzing, accessing, presenting and transferring such data in digital / electronic form between different users, systems and locations. The work shall link to appropriate standards for information technology and data where possible, and provide a framework for the development of sector-specific applications using geographic data (www.isotc211.org).

The World Wide Web Consortium (W3C) is an international consortium where Member organizations, a full-time staff, and the public work together to develop Web standards. W3C's mission is: To lead the World Wide Web to its full potential by developing protocols and guidelines that ensure long-term growth for the Web. W3C primarily pursues its mission through the creation of Web standards and guidelines. Since 1994, W3C has published more than ninety such standards, called W3C Recommendations. W3C also engages in education and outreach, develops software, and serves as an open forum for discussion about the Web. In order for the Web to reach its full potential, the most fundamental Web technologies must be compatible with one another and allow any hardware and software used to access the Web to work together. W3C refers to this goal as "Web interoperability." By publishing open (non-proprietary) standards for Web languages and protocols, W3C seeks to avoid market fragmentation and thus Web fragmentation (www.w3c.org).

2.6.5 Legal aspects

With the introduction of IAF 2.0 (ISA, 2009), legal aspects play an increasing role by accomplishing interoperability. Besides technological and market developments, the adoption and introduction of location technologies were influenced, for example by security and privacy issues. In terms of privacy, it is especially the tracking of people or goods transported which raises many privacy issues. As defined by Westin (1970) "Privacy is the claim of individuals, groups or institutions to determine when, how, and to what extent information about them is communicated to others, and the right to control information about oneself even after divulgating it". In this definition a person's privacy corresponds to the control of that person's information. Legislators have addressed personal information in various laws, which have implications for location and sensor services. To protect personal data from an economic perspective, extensive attention is paid in European law, in general, and more specifically for use in electronic communications. Article 7 of the Charter of Fundamental Rights of the European Union (European Commission, 2000) focuses on some general issues on the respect for private and family life: "Everyone has the right to respect for his or her private and family life, home and communications". Directive 1995/46/EC (European Commission, 1995) provides the legal framework for the protection of individuals with regard to the processing of personal data, while Directive 2002/58/EC (European Commission, 2002) addresses location privacy specifically, stating that location data can be processed only after being anonymized or after having gained the consent of the user, who should be perfectly informed of the use that will be made of his/her personal data. In a broader context, information-sharing is constrained by a number of other legal aspects. For example, Smits and de Jong (2008) identified seven legal design principles for the introduction of a Common Operational Picture (COP) for traffic IM: proportionality; explicit organizations goals; respect for fundamental human rights; interoperability; data availability; protection of personal data; and financing regulated by governments.

2.7 Discussion

At its core, IM is a vehicular traffic-support system, originally intended to clear traffic incidents as quickly as possible, but its implementation in practice has always took the functionality further, to include any activity to support the most efficient movement of traffic, regardless of the circumstances. As such, a large number of agencies and people are involved in its implementation, its uses, and its consequences. This organically grown and extended IM is a systematic, planned and coordinated effort to prevent, detect, respond to and remove any incident, or remedy any condition that hinders optimal traffic flow, spanning all agencies and other concerned organizations and individuals that have a stake in its effectiveness.

Much of what is needed is already available. Each of the communities mentioned above has been or is working on its own private optimizations, data structures, communication protocols, procedures and knowledge-base, both theoretical and practical. Each group is operating as a team, trying to optimize their own part of the world. However, the optimal position for each group separately will not automatically produce a system-wide optimal position. The reason is the synergetic behaviour of the components of such complex systems. If we are concerned only about clearing incidents but not about improving the everyday performance of the transportation network, then we are missing the larger savings (systems pay back) possible from improvements in the entire system.

The use of location methods and sharing of spatial information is currently limited. A typical location report will consist of a road number, and a direction and distance marker number, which is considered to be ambiguous. Furthermore, it reflects the current practice in which IM is limited to highways. On secondary roads, road markers may not always be present. Noting a location by (secondary) road number will only give the emergency services an indication of where the accident has taken place. Using geo-spatial information can not only speed up an event in IM but also provide a cheaper alternative to current methods.

However, before consider the service, the data sets and infrastructure have to be addressed. The current situation in IM clearly does not address new technologies or interoperability between systems. While there can be an argument about privacy issues, this is a matter for policy not technology.

The developments in the Netherlands show more or less the same fragmentation with regard to EU initiatives. Since the 1990s, ITS in the Netherlands has been based on cooperation between the government and the private sector. ITS Netherlands was founded as a public-private institution in 1996. Traffic IM is one of the main priorities in the Netherlands in terms of creating ITS tools in the several steps involved in this process, including: incident detection (e.g. with cameras and e-Call), communication between emergency services, and the provision of traffic information to the end-user. In terms of ITS standards, the Netherlands actively participates in existing global and European standardization platforms such as ETSI, CEN and ISO. An overview of the ITS-related initiatives in the Netherlands, based on Directive 2010/40/EC, can be found in the document *ITS in the Netherlands* (Connect, 2011). DATEX2, for example, is used in information-sharing in the national road database (NDW) for traffic management, but is not used to share incident information between responders. Currently, within crisis management, the safety regions are implementing the National Crisis Management System (LCMS - Landelijk Crisis Management Systeem), which is based on a net-centric approach. However, this system only supports large-scale disasters, and not daily traffic IM and does not have a direct relation with traffic management. From the geo-information sector, GEONOVEM is currently working on an information model on homeland security (IMOOV). This provides the definition of information elements (semantic) and the exchange platform (UML and XML), which is basically the implementation of a SOA. The Netherlands is the first EU country which has tried to develop a COP for IM based on a net-centric approach to improve situational awareness. This is a challenging task when there is a lack of concepts, architecture, and standards. However, this can set the scene for future developments in the EU. The following general conclusions can be drawn:

- In an urbanized Europe with a dense transportation network, the professional development of IM technology is a pre-requisite for sustainable urban and transportation strategies.

- Since the 1970s there has been an increasing number of incidents on the European roads. In the Netherlands there are approximate 270 incidents a day, which are an increasing cause of traffic jams, congestion and vehicle lost-hours;
- More public and private actors are getting involved which has led to the IM information network. Information services are seen as an important instrument to improve cooperation;
- Almost all IM related information has a spatial component to improve situational awareness;
- National governments have limited possibilities to enforce strict rules regarding IM because of the large number of involved organizations and the many laws that are (in-) directly dealing with IM. However, legal aspects and the political context have become increasingly important for accomplishing interoperability;
- In the last decade significant improvements have been made to reduce the impact of road transport in terms of fatalities and injuries. However, many efforts still have to be made to reach the new European ‘zero-vision’ goal on road safety for 2050;
- Despite efforts towards European harmonization, there is still considerable variety of IM deployment across Europe, with a lack of uniform architecture, standards, data models, and definitions, and there is no general agreement on the different process phases;
- Solutions for interoperable information systems for traffic IM need to balance between standards in traffic management, disaster management en the geo-information sector;
- A European IM interoperable framework should at least address four specific goals: cross-border management between countries; increase of support at the crisis management level; information-sharing between public and private road authorities, and the emergency services and, a uniform IM application on the TERN infrastructure;

3 A Common Operational Picture to Support Situational Awareness*

3.1 Introduction

The goal of sustainable mobility is one of the biggest challenges in modern traffic management. Sustainable mobility refers to the social and ecological objectives of transport, in particular, the minimization of environmental damage, the maximization of transport throughput, and the minimization of fatalities and injuries in the transport sector. Steadily-growing traffic volumes and traffic intensity since the early 1970s have led to enormous congestion and mobility problems, especially during the rush hours. Irregular situations like traffic incidents, adverse weather conditions, road works, and unforeseen events such as dropped cargo and stranded vehicles increase these mobility problems. There is a clear need for appropriate traffic management in case of a disruption of regular traffic.

Traffic Incident Management (IM) is "a planned and coordinated process to detect, respond and remove traffic incidents and restore traffic capacity as safely and quickly as possible" (US Federal Highway Administration, 2000). The IM concept is also gradually introduced in the EU. For instance, in the Netherlands, IM is defined as "all measures that are intended to clear the road for traffic as quickly as possible after an incident has happened, to ensure safety for emergency services and road users, and control the damage" (Dutch Ministry of Transportation and Water Management, 1999). Road networks are part of a country's transport infrastructure, and are therefore subject to general transport policies. Road traffic injuries in the European Union are a major public health issue, as they claim about 127 thousand lives per year (World Health Organization, 2004). In addition to this intolerably high

* Based on: Steenbruggen, J., Nijkamp, P., Smits, J. and Grothe, M. (2012). Traffic Incident Management, A Common Operational Picture to support Situational Awareness of Sustainable Mobility, *International Journal of Transport Economics*, No.1, pp. 131-170. March 2012.

number of lives lost, about 2.4 million people per year are injured in road traffic accidents. Over 1.2 million people die each year on the world's roads, and between 20 and 50 million suffer non-fatal injuries. Most likely, road traffic injuries will rise to become the fifth leading cause of death by 2030 (World Health Organization, 2009b). In terms of safety this puts the topic of traffic Incident Management (IM) high on the political agenda. The importance of IM, besides its direct impacts in terms of property damage, injuries and fatalities, and road safety for the road users, is also high for safe and reliable mobility. In general, traffic becomes congested when the demand is larger than supply, i.e. when there are more travelers than the road can cope with. Incidents can quickly lead to congestion and associated travel delays, wasted fuel, increased pollutant emissions, and higher risk of secondary incidents. Incident are an important cause of congestion and their contribution to the total traffic congestion cost is high.

The handling of an incident can be described on the basis of the duration of an incident. This process serves to show where problems arise in the clearing of incidents, and is useful for determining what measures are needed for coping with specific situations. The duration is defined as the period of time in which the traffic flow is disrupted due to an incident. The amount of delay and impact that results from the incident depend on the duration of the different distinct phases. In the literature, there is no general agreement on the different process phases covered by IM (Özbay and Kachroo, 1999 ; Corbin and Noyes, 2003 ; US Federal Highway Administration, 2000 ; Dutch Ministry of Transportation and Water Management, 2005a). In this thesis we will use a more detailed description which, in practice, covers all the different process phases found in the literature. The following phases (or time periods) can be identified (based in particular on Zwaneveld *et al.*, 2000) (see also Figure 3.1):

- Phase 1 : detection and verification time ; the time that elapses between the detection of the occurrence, and verification of the incident;
- Phase 2 : warning time ; the time required to alert all necessary emergency services ;
- Phase 3 : response, driving, and arrival time ; the length of time required by the emergency service alerted to reach the location of the incident ;

- Phase 4 : operation or action time ; the length of time required to move 'damaged' vehicles onto the hard shoulder. lanes are then free for normal traffic use ;
- Phase 5 : normalization time ; the time required to take the damaged vehicles from the hard shoulder to a location out of sight of road users ;
- Phase 6 : flow recovery time ; the time that elapses between the moment that the incident has been fully removed and the disappearance of the tailback.

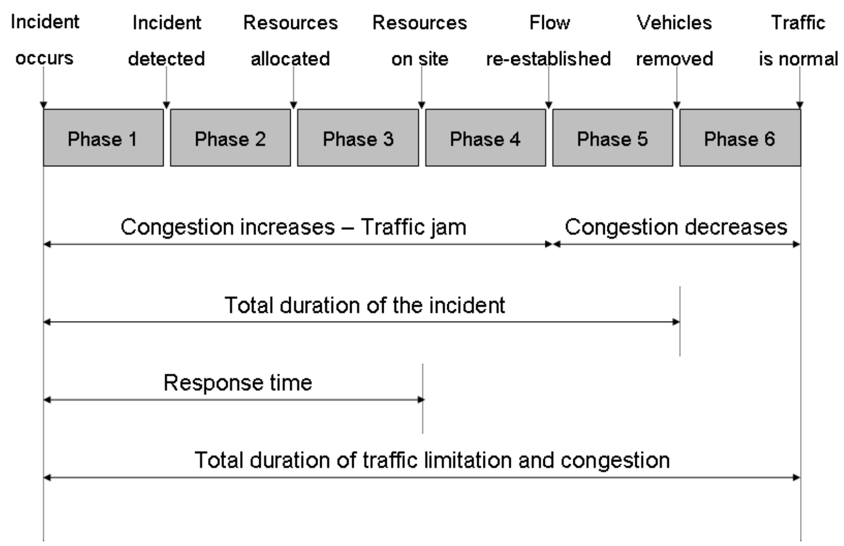

Figure 3.1: Different phases of the IM process

Source: Zwaneveld *et al*. (2000)

3.2 The importance of IM and mobility consequences

3.2.1 Providing reliable travel times to road users

As a result of the large number of road users on many road networks, congestion occurs frequently, mainly at regular bottlenecks. This leads to congestion and travel time losses, while it is also difficult for the traveller to estimate how long the journey will take. When congestion is caused by regular bottlenecks, travellers can globally assess how much time loss is due to congestion on most routes. It is much more difficult to estimate the travel time losses caused by irregular and unexpected situations such as traffic incidents, adverse weather conditions, road works and events. In particular for road users, it is often difficult to predict in advance when these situations will occur and how long the associated delay will be.

That is precisely why irregular situations may contribute significantly to the unreliability of travel times. This largely depends on how often irregular situations occur, and their relative impact (loss of capacity and reliability of travel times). Rising from 10 per cent in 1995 (McKinsey and Company, 1995), nowadays approximate 12-13 per cent (Knibbe *et al.* 2004 ; Dutch Ministry of Transportation and Water Management, 2004b ; Schrijver et al, 2006 ; KIM, 2010) of all traffic jams on Dutch roads are the result of traffic incidents. Figure 3.2 shows the division between regular and irregular congestion for the situation in the United States (US FHWA, 2004). 55 per cent of this congestion is caused by less predictable and irregular situations. In this respect there is a big difference between the Netherlands (13 per cent) and countries like the US (25 per cent), Germany (33 per cent) and France (12 per cent) (see ECMT, 2007). An important explanation of these differences is the way how these percentages are estimated.

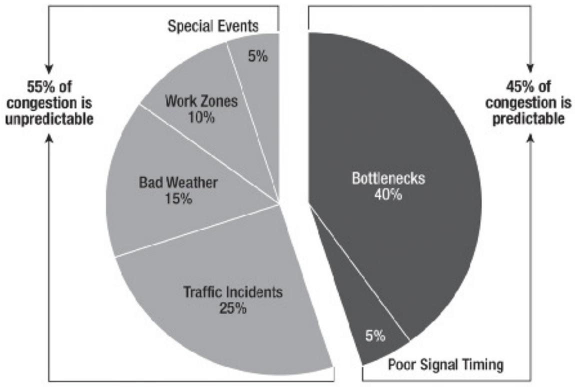

Figure 3.2: Causes off the existing congestion

Source: US FHWA (2004). Note: Data reflect national estimates

3.2.2 Increasing discrepancy between mobility and capacity

The importance of investing in the application of IM on the road network is illustrated in Figure 3.3. This figure shows both the trend in mobility in the Netherlands and the growth in the length of the highway network since 1980. The increasing discrepancy between the trend in mobility and the increase in capacity since 1980 is striking. The increasing volume of traffic jams (in terms of vehicle kilometres per kilometre traffic lane, strain on the highways network) is the consequence of this. In turn, the increasing imminence of jams means that even small discontinuities in the vehicle flow can result in a traffic jam. Moreover, the consequences of a disruption (hours lost by vehicles) have become much greater (KIM, 2010).

However, it is a challenge to find out whether through the application of IM, the negative effects of incidents can be reduced considerably (Dutch Ministry of Transportation and Water Management, 2003c).

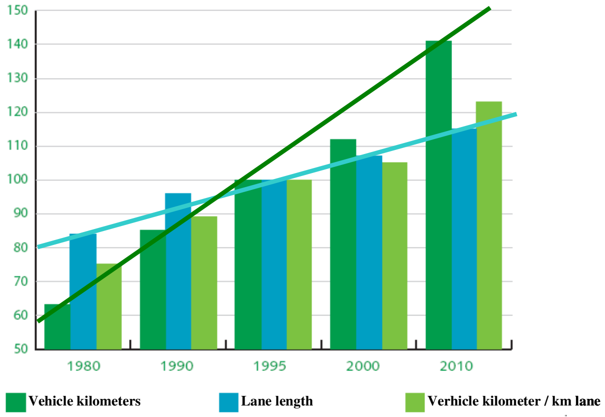

Figure 3.3: Developments in vehicle kilometres and lane length in the Netherlands (index 1995=100)

Source: Dutch Ministry of Transportation and Water Management (2003c)

Note: Green en blue lines show the discrepancy between mobility and network capacity

From 2000-2008, traffic volumes increased by an average of 2 per cent per annum. In 2009, traffic volumes fell by 1 per cent. Apparently a small increase in traffic volumes leads to a large increase in traffic congestion or, conversely, a relatively small decrease in traffic volumes leads consequently to a relatively large decrease in traffic congestion. In recent years, this relationship between traffic volumes and traffic congestion has intensified. Presumably, the reason for this is that the maximum capacity of the main motorway network is reached at increasingly more places and during an increasingly larger share of the day. The Dutch road network is heavily loaded, especially when compared to its neighbouring countries (see Table 3.1). The heavy load means that during large parts of the day little spare capacity is available. Consequently, incidents have a big impact.

Table 3.1: Comparison of traffic intensities between the Netherlands and surrounding countries

Country	Road	Day-intensity	Year
Belgium	R0 Brussel: Woluwe Zuid – Diegem	190,708	2008
	R1 Antwerpen Borgerhout – Berghem	186,480	2008

England	M25 – Western links from A1(M) to M23	213,000	**2009**
	M60 – Manchester West	186,000	**2009**
Germany	A3 AD Heumar – Nordrhein Westfalen	187,860	**2009**
	A100 Dreieck Funkturm – Kurfürstendamm	191,400	**2005**
Netherlands	A1 Muiden – Muiderslot	184,964	**2009**
	A4 Kp. Pr. Clausplein – Delft Noord	241,719	**2009**
	A4 Hoofddorp – Kp. De Hoek	208,287	**2009**
	A10 Kp. Nieuwe Meer – Amstelveen S108	202,591	**2009**
	A12 Utrecht – Nieuwegein Noord	207,021	**2009**
	A15 Kp Ridderkerk – Hendrik Ido Ambacht	239,728	**2009**
	A16 Kralingen – Pr. Alexander	205,098	**2009**
	A27 Kp. Rijnsweerd – Kp. Lunetten	190,652	**2009**
	Etc.		
	In total 15 road lanes > 180,000 vtg.		

Source: Immers (2011).

Congestion occurs when the demand (the number of vehicles that pass per unit of time) is greater than the capacity (number of vehicles per unit of time that can be carried by a road). Next to IM, also other instruments like road pricing has been seen as an important measure to deal with congestion problems (Marcucci, 2001 ; Marcucci and Danielis, 2002 ; Marcucci and Marini, 2003 ; Marcucci *et al.*, 2005). If the network is heavily loaded, more incidents occur (due to limited residual capacity for long periods of the day), which leads to more congestion and more unreliable travel times. This is a compelling argument why professional IM should be considered as an important instrument on the Dutch road network.

3.2.3 Costs of traffic jams and delays

With 30 million hours lost through traffic congestion in 1990 per annum to a level of approximately 44 million hours in 2000, it is apparent that nowadays many hours are lost due to congestion in the Netherlands. For car drivers, between 2000 and 2008 the number of delays caused by traffic jams and congestion rose by 55 per cent. In 2009, the economic crisis caused that figure to fall by 10 per cent. Time loss due to traffic jams and congestion increased by 40 per cent from 2000 to 2009 (see table 2).

Table 3.2: Time loss due to traffic congestion

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Travel time losses (2000 = 44 mln) lost vehicle hours	100	118	110	113	122	131	143	153	155	140
Traffic volume (number of kilometres	100	102	104	105	108	109	111	114	114	113
Average travel time		100	98	99	100	101	103	104	104	102
Unreliability		100	94	94	101	102	105	115	114	104

Source: KIM (2010)

The total congestion costs on the Dutch main road network for 2009 are estimated to range from €2.4 to 3.2 billion. Between 2000 and 2009, these costs increased by 50 to 60 per cent. It is striking that in 2009, for the first time since 2000, the congestion costs decreased compared to the previous year. Congestion costs in 2009 were roughly 10 per cent below those of 2008. This decline is entirely attributable to the decline in the number of lost vehicle hours. If various measures, including the construction of peak-hour and extra lanes, roadwidening works, traffic information systems and traffic IM, had not been undertaken during this period, travel time loss would have increased by 13 per cent (KIM, 2010).

3.2.4 Incident numbers and time reduction

On a yearly basis there are about 100,000 incidents on the Dutch road network (Leopold and Doornbos, 2009), varying from small accidents to major multi-vehicle incidents, causing casualties and a vast amount of damages to the road and its supporting structures. While relatively few incidents involve trucks, such incidents cause immediate, large-scale traffic jams that catch public attention. All these traffic jams contribute significantly to the economic damage that the country suffers each year. A traffic jam also creates an unsafe traffic situation, as in many cases collisions occur in the tail of the jam. This entails the risk of further material damage, as well as injury. Therefore, there is sufficient reason to limit, as far as possible, the length and duration of such traffic jams.

Different successfully applied IM measures have led to a large decrease in duration of incidents. Since the introduction of IM in 1994, the average time of incident-related IM actions was reduced by 25 per cent in 2004 (Grontmij, 2004). Between 2004 and 2008 the incident duration decreased by another 10 per cent. The ambition is that by 2015 the 2008 process time will be reduced by another 25 per cent (Dutch Ministry of Transportation and Water Management, 2008a).

3.2.5 IM Strategies and the importance of speed

There have been several studies in the Netherlands that analyse the effects of incidents and their relation to IM measures (McKinsey and Company, 1995 ; Wilmink and Immers, 1996 ; Schrijver *et al.*, 2006 ; Kouwenhoven *et al.*, 2006 ; van Reisen, 2006 ; Knoop, 2009). They all conclude that investing in IM measures is very cost-effective. IM measures may have effects in different phases of the incident-handling process. These effects can be regarded as the objectives of IM measures. IM is one of the most important instruments of traffic management in the Netherlands that reduces congestion or traffic jams, and may seriously reduce the number of casualties on the roads.

Classical IM strategies are aimed at minimizing the negative effects of nonrecurrent congestion that is due to incidents. There is a strong quadratic relationship between the duration of an incident and the response time required from the traffic management centre and the emergency services. Response time (speed of emergency aid) plays an important role as shown in Figure 3.4. The formula shows that the consequences of an incident are proportional to the square of the accident duration. This quadratic relationship illustrates the importance of IM. The value of the factor depends on the capacity and the load on the road section concerned. Thus, the number of lost vehicle-hours as the result of an incident depends on the time required to clear the road for traffic following an accident, the road capacity, and the extent to which the road capacity is filled (Immers, 2007a). The basic idea is that fast clearance of the incident scene can help to reduce the incident-related congestion. The early and reliable detection and verification of incidents together with integrated traffic management strategies are important contributions which can improve the efficiency of the incident response. There are several studies that have analysed the factors that determine the duration of the incident (Hall, 2002 ; Lee and Fazio, 2005).

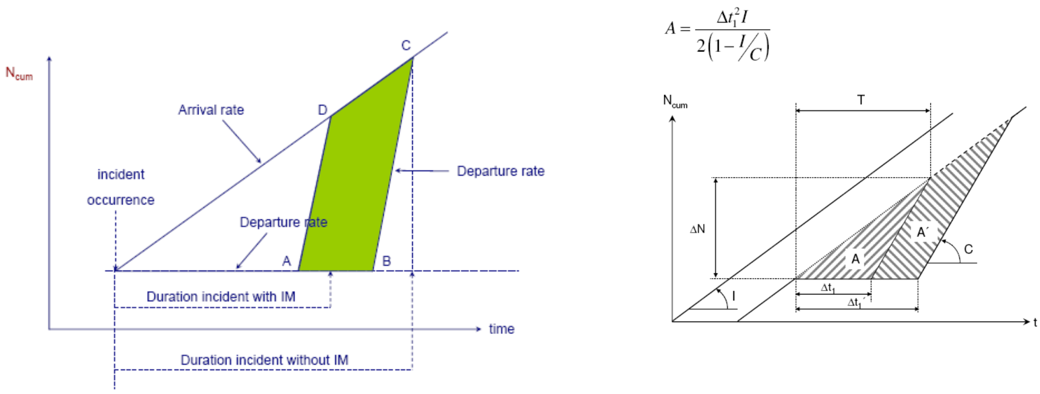

Figure 3.4: Relation between incident duration and response time

Source: Immers (2007a)

Δt = difference in time when incident occur till incident is cleared.

I = demand pattern; C = outflow of cars, which will reduce (almost) to zero during an incident.

When an incident duration is reduced from Δt to $\Delta t´$, this gives a reduction of lost vehicle hours by $A´$.

An incident means that the available capacity of a road cannot be fully used, because one or more lanes is blocked. This effect has been extensively studied. Thus, for a 3-lane road investigated, the residual capacity (the capacity of the road which is still available for traffic movement) is a function of the number of blocked (non-negotiable) lanes. Table 3 shows the remaining capacity (Dutch Ministry of Transportation and Water Management, 2012).

Table 3.3: Reduction of capacity (as a percentage of the original capacity) due to an incident

Number of blocked lanes	Hard shoulder	1 lane (of 3) blocked	2 lanes (of 3) blocked	0 (traffic jam caused by viewers)
Reduction capacity	28%	64%	82%	31%

Source: Immers *et al.* (2009).

It is evident that the loss of one or more lanes has a big influence on the available capacity. A vehicle on the hard shoulder already leads to a capacity reduction of 28 per cent (residual capacity = 72 per cent). If a lane must be closed, the remaining capacity is only 36 per cent (a reduction in capacity by 64 per cent). An accident leads in the other lane (due to the traffic jam caused by viewers) to a capacity reduction of 31 per cent on the carriageway in the opposite direction. In the United States we find similar figures based on the results of a study in Washington State (WSDOT, 2011). The figures indicate that it would be very helpful to remove the involved vehicles as rapidly as possible from the highway to the hard shoulder or, even better, to a parking lane located out of sight of the road users. In the Netherlands there are IM roads (driving time <15 min.) and IM+ roads (driving time <30 min.). Table 4 shows the level to which this criterion has been accomplished. There has been a slight decrease in the service level between 2008 and 2010.

Table 3.4: Services level emergency related driving times to incidents.

Incident time	2008	2009	2010
Between rush hours	82%	81%	79%
Outside rush hours	93%	93%	91%

Source: Dutch Ministry of Transportation and Water Management (2011)

However, to apply successful IM measures, it is relevant to know how these can improve the congested network. It is relevant to realize that traffic incidents do not have the same effects at different locations or at different times on a highway. Therefore, the highways are categorized in four new groups (see Figure 3.5). The importance of speed is strongly related to the impact that it has on congestion. Apart from that, it is also relevant if the incident occurs during the rush hours (between 06:00 – 10 :00 a.m. and 3 :00 – 7 :00 p.m.).

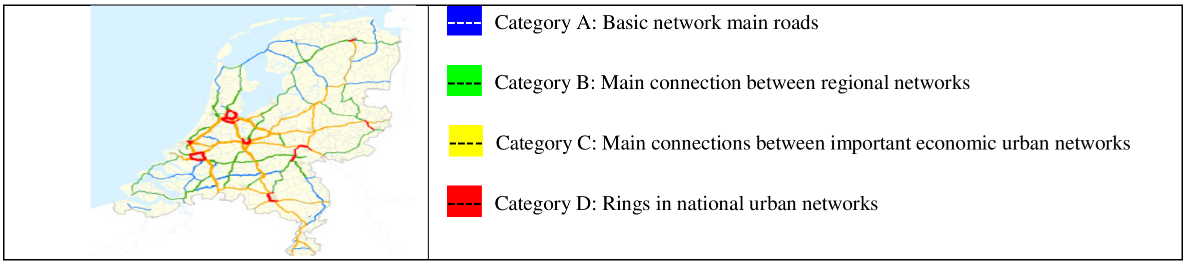

Figure 3.5: New network categorization in the Netherlands

Source: Dutch Ministry of Transportation and Water Management (2011)

3.2.6 Balancing between System Optimum (SO) and User Equilibrium (UE)

Different instruments have been proposed in the past to tackle congestion in metropolitan areas : road pricing, fuel taxation, improving public transportation, and so on. Another instrument, extensively studied in literature, is the use of advanced information systems based on ICT in transport networks (Emmerink *et al.*, 1996). An example of ICT policy is the introduction of automatic detection systems of incidents by use of cameras (Versavel, 1999). Information provision to drivers is believed to improve their knowledge of traffic situations and this may improve their decision making. This relation is shown in Figure 3.6.

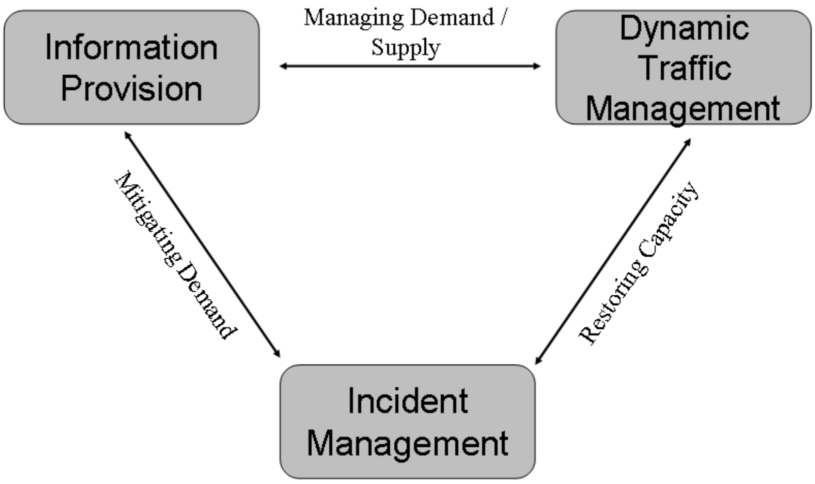

Figure 3.6. Incident Management in relationship to other traffic management services.

Source : CEDR (2011).

Unfortunately, the real-world picture is less unambiguous than such on intuitive reasoning. At an aggregated level, improved decision making by road users might imply that information will direct traffic flows to the user equilibrium. Most network optimization theories are based on two principles introduced by Wardrop (1952). The inequality between the first (user equilibrium) and second (system optium) principle on congested situations indicates that information provided to drivers does not necessarily foster the system optimum (Emmerink *et al.*, 1996). Under dynamic user equilibrium conditions, traffic is assigned such that for each origin-destination pair in the network, the individual travel costs experienced by each traveller, no matter which combination of travel route and departure time he/she chooses, are equal and minimal. The system optimal flow is determined by solving a state-dependent optimal control problem, which assigns traffic such that the total network cost is minimized (Chow, 2007).

A widely recognized restriction in Wardrop's concept is that it assumes that all users have full information on the traffic situation ; this is unlikely to happen in practice due to al kinds of stochastic incidents on congested road networks. The network characteristics can be deterministic or stochastic. Given the large variations in daily travel times on road networks, it is reasonable to assume that travel costs are stochastic (Mirchandani and Souroush, 1987).

Thus, the assumed difference in knowledge of the traveller and network characteristics may feature different possibilities of an User Equilibrium (UE) (Emmerink *et al.*, 1996). Real-time information is a natural mitigation strategy in stochastic networks and may have an advantage if it reduces uncertainty (Gardner *et al.*, 2011). Travellers generally have limited options to choose alternative routes, depending of course on the way the road network is designed.

The aim of introducing new information concepts, as described in this Chapter, is to reduce the response times of emergency services during an incident. Reducing response times are depending on the way how information systems are designed to support the cooperation between emergency agencies. Currently used methods are mainly based on telephone communication. The benefits can relatively easily be measured by using existing databases and comparing them with the response times after introducing these new concepts. However, these response times are also subject to other factors, such as road and weather conditions.

3.3 Information systems for traffic incident management

To carry out the IM process in an effective and efficient way, the need for (spatial) real-time information and supporting information systems is large. The key obstacle to effective crisis response is “the communication needed to access relevant data or expertise and piece together an accurate understandable picture of reality” (Hale, 1997). A well-established communication and information technology and clear organizational responsibilities among emergency services are the most important issues for IM. In fact, they are a prerequisite for the effective application of IM.

The ‘situation’ interface and the ‘control’ interface in a traffic management centre are the two main domains where information systems play a crucial role (see Figure 3.7). The situation interfaces of the traffic management system for monitoring consist of induction loops, cameras, and human observers. For the traffic measure support, the road authorities use variable message signs, speed limitation signs, ramp metering and peak/plus lanes, and special measures for IM. Peak/plus lanes are additional traffic lanes that can be opened to traffic if demand so requires. When closed, the lanes are for the exclusive use of the emergency services.

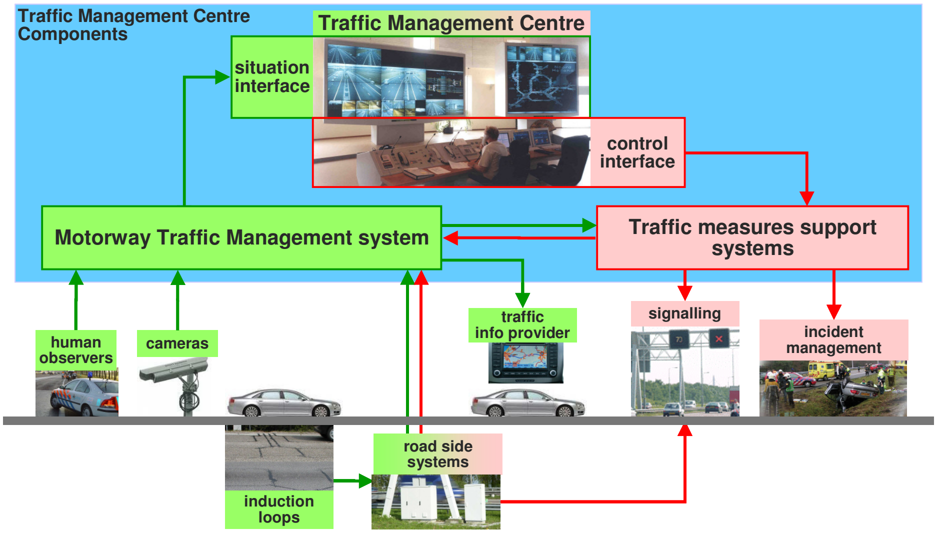

Figure 3.7: Traffic management building blocks.

In current research, there are some general principles that are at the base of successful emergency response information systems (see Turoff *et al.*, 2000). In the latter study, the authors describe 12 fundamental roles that should be supported by an emergency management system. As traffic IM can be seen as a special case of emergency response, to a certain extent these principles can also be applied to design a traffic IM system. These are clustered in Table 5, based on the situation and control interface.

Although traffic IM is a much more limited domain than general emergency management, the following design principles will also apply to this domain. First of all, in order to prevent information overload, relief workers should receive only relevant information. It is also necessary to understand what has actually happened during the incident and to be able to review this information to improve the incident response.

Because of the dynamic situation of incidents, it is important that the system can be reconfigured, for example, by changing priorities and filtering options. It should be possible to transfer roles or tasks to other persons ; it should, therefore, also be possible to check which resources are available. Since critical decisions require the best possible up-to-date information, providing this information should be facilitated by an IM information system as much as possible.

Table 3.5: Fundamental roles for an emergency management system.

Situation interface	**Control interface**
• Analyse the situation • Edit, organize, and summarise information • Report and update situation • Oversight review, consult, advise	Resources • Request resources (people and equipment) • Allocate, delay or deny resources • Maintain resources (logistics) • Acquire more or new resources • Coordinate among different resource areas Information • Alert all with a need to know Organization • Assign roles and responsibilities when needed • Set priorities and strategy (e.g. Command and Control)

Source : Turoff *et al.* (2000).

Information technology is essential to improve information-sharing and decision making for emergency responders (Graves, 2004), it has already drastically reshaped the way organizations interact with each other (Lee and Whang, 2000). Interagency exchange of information is the key to obtain the most rapid, efficient, and appropriate response to highway incidents from all agencies. Increasingly, such information must be shared across system with different organisational and jurisdictional boundaries. Public safety agencies and transportation organizations often have information that is valuable to each other's operations. Examples of these are (see US NCHRP, 2004) better:

- incident detection and notification can engage appropriate public safety resources sooner, provide more rapid medical care to save lives, minimize injury consequences, and reduce transportation infrastructure disruption;
- road situation information can speed up the delivery of emergency (and support) resources to the scene;
- incident site status and coordination information can improve the safety of emergency responders and speed up incident stabilization, investigation, and clearance.

3.4 Net-centric-enabled capabilities for IM

Architectures to support traffic IM information systems can be historically characterised as hierarchical solutions which mainly focus on internal work processes of individual organisations. This causes many problems in terms of communication, cooperation and information sharing between the different IM responders. In recent years there has been a growing interest in the use of 'net-centric' information concepts to improve the cooperation between different organisations with a common goal. In practical terms, the concept of 'net-centric' can be defined as "participating as a part of a continuously evolving, complex community of people, devices, information and services interconnected by a communications network to achieve optimal benefit of resources and better synchronization of events and their consequences". This could be very helpful to support daily traffic IM.

The concept of 'Network-Centric Warfare' (NCW) has for example appeared to be very useful in the development of new capabilities for military operations, disaster management, homeland security, and emergency management. Network-centric warfare can trace its immediate origins to 1996 when Admiral William Owens introduced the concept of a 'System of Systems' (Owens, 1996). Owens described the evolution of a system of intelligence sensors, command and control systems, and precision weapons that enabled enhanced situational awareness.

As a distinct concept however, 'network-centric warfare' was introduced publicly by the US Naval Institute (Cebrowski and Gartska, 1998). It is a new military doctrine or theory of war, now commonly called 'network-centric operations'. It seeks to translate an information advantage, enabled in part by information technology, into a competitive advantage through the robust networking of well informed geographically dispersed forces. This concept was first applied in the USA in the mid-1990s, together with the concept of 'Information Age Warfare' (see Alberts *et al.*, 2000 ; Alberts *et al.*, 2001 ; Alberts, 2002).

The concept of Information Age Warfare is based on the emergence of information technologies and the role they can play in modern warfare. Information plays an important role in military operations, and technological advances now make it possible to provide more complete, more accurate and timelier information to decision makers. Many experts believe the terms 'information- centric' or 'knowledge-centric' would capture the concepts more aptly because the objective is to find and exploit information. The network itself is only one of several enabling factors. This networking, combined with changes in technology, organization, processes and people, may allow new forms of organizational behaviour.

Traditionally, military organizations have provided information to the forces in three ways (Alberts, 2002) :

- commands (directives and guidance);
- intelligence (information about the adversary and the environment), and
- doctrine (how it is going to be done).

At the beginning of the 21st century, several other countries began to develop their own view on NCW. In the literature, different examples of definitions and concepts of Net-centric Operations can be found : Network Enabled Capabilities – NEC (UK) ; Ubiquitous Command and Control – UC2 (AUS) ; Network Based Defence – NBD (Sweden) ; and Net-Centric Operations – NCO (US and NATO).

A few years later, the term NEC was also used by other government agencies in papers on disaster management and homeland security (Boyd at al., 2005). For example, in the Netherlands, there is an initiative between the Ministry of Defence and the Ministry of the Interior, named Net-centric Experimentation, where the NEC/NCW concepts are used for disaster management and homeland security (Brooijmans *et al.*, 2008).

NEC offers decisive advantages through the timely provision and exploitation of information and intelligence to enable effective decision making and actions. NEC has three overlapping and mutually dependent dimensions : networks, information, and people. All three dimensions need continuous development to reach the full potential of NEC. At the heart of NEC is the network of networks to distribute information.

The networked information environment provides the capability to acquire, generate, distribute, manipulate, and utilize information. Information is essential for decision making. Decision makers at all levels will need to identify what information is required, and how to obtain it (UK Ministry of Defence, 2005). The real value is reflected in the NEC value chain (see Figure 3.8).

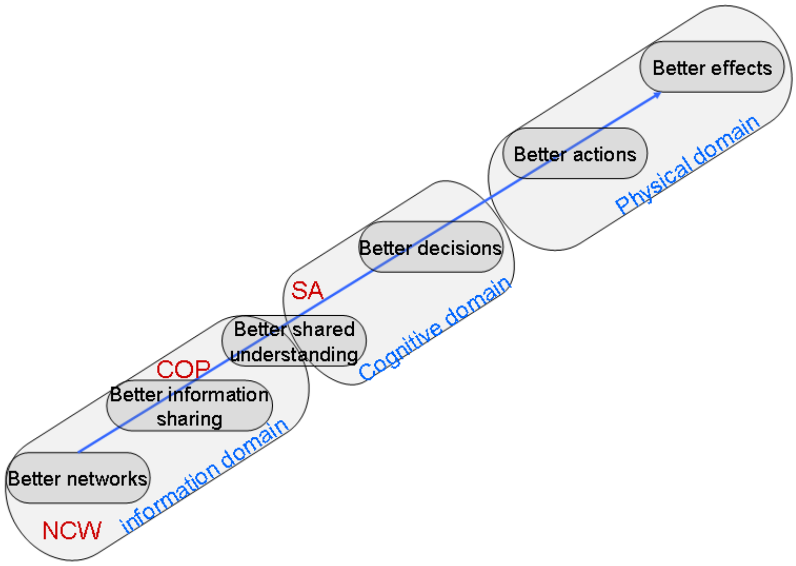

Figure 3.8: Network Enabled Capabilities (NEC) value chain

Source: UK Ministry of Defence (2005)

As traffic IM can be seen as a special case of disaster management and homeland security, the NEC concept and the value chain can also be applied to design a traffic IM system. This will be elaborated hereafter.

3.5 Common Operational Picture

A Common Operational Picture (COP) is a term widely used within the military domain to support situational awareness (SA) for Command and Control in net-centric operations (Wark *et al.*, 2009). It has been defined in many ways. Some definitions address the joint, multi-service, and interoperability aspects of the COP. The US Department of Defense (2005), for example, defines a COP in the following way : "a single identical display of relevant information shared by more than one command.

A COP facilitates collaborative planning and assists all echelons to achieve situational awareness. In practical terms, a COP for military use is defined as : "commanders need to know where all their own troops are, where their enemies are, and various other information about the battlefield (or battlespace)". This knowledge is described in terms of SA. The concepts of (shared) SA and a COP have been adopted by the military as guiding principles for combat operations (Pentagon, 2006). Other definitions address the way in which the information can be contained in a COP. A military view of this definition of a COP[12] is a "distributed data processing and exchange environment for developing a dynamic database of objects, allowing each user to filter and contribute to this database, according to the user's area of responsibility and command role."

The COP provides the integrated capability to receive, correlate, and display a common tactical picture. The concept of a COP has now also been adopted as a goal for law enforcement, emergency management, firefighters and other first responders (Harrald and Jefferson, 2007). During the last few years, there has been a significant interest from various actors in designing information systems for the use of a COP in crisis response. It is widely used to support SA for command and control in net-centric operations (Wark *et al.*, 2009). In line with different military views for emergency services, there are several approaches (for example in Homeland, 2008), which focus on information : "A COP is established and maintained by gathering, collating, synthesizing, and disseminating incident information to all appropriate parties". Focussing on cooperation and multi-services : "Achieving a COP allows on-scene and off-scene personnel to have the same information about the incident, including the availability and location of resources and the status of assistance requests." Additionally, a COP offers an incident overview that enables effective, consistent, and timely decisions to be made. In order to maintain situational awareness, communications and incident information must be updated continually. Having a COP during an incident helps to ensure consistency for all emergency management/ response personnel engaged in the incident.

FEMA (2009), for example, applies the definition of a COP with reference to a single disaster or incident which is representative of many others : "A COP offers a standard overview of an incident, thereby providing incident information that enables the Incident Commander/Unified Command and any supporting agencies and organizations to make effective, consistent, and timely decisions. Compiling data from multiple sources and disseminating the collaborative information COP ensures that all responding entities have the same understanding and awareness of incident status and information when conducting operations." This definition supports that a COP is a product of a successful SA environment.

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[12] www.dtic.mil/cjcs_directives/cdata/unlimit/3151_01.pdf

If SA is the culmination of comprehensive information sharing for the operating environment, then a COP is a compilation of that body of knowledge, captured and distributed.

As traffic IM can be seen as a special case of emergency response, a COP can also be applied to design a traffic IM system. IM involves the coordinated interactions of multiple public agencies and private-sector partners. In the literature, some reports analyze information sharing between different IM organizations. Different methods have been used to describe how organizations share information (US NCHRP, 2004). However, they are still far from sharing detailed and situational information, and do not use a COP or net-centric operations. They mainly focus on interoperability issues. In a more recent report (U.S. Department of Transportation, 2009) which also focuses on information needs, issues and barriers for information sharing between public and private IM organizations, they do not use either the concepts of a COP, shared SA, or net-centric operations.

3.6 Context in a common operational picture

To create intelligence in a COP to support traffic IM it is relevant to understand which context variables are needed. Clearly this is directly related to the end user perspective. For traffic IM these are the operators in the traffic management central and the fieldworkers. The main objective of context aware computing is to make interaction with computers easier and more supportive for human activity. This can be done in several ways, one of the most important being the filtering of the information flow from application to user to prevent the problem of information overload (Schmidt *et al.*, 1999). In other words, getting the right information or services at the right moment in the right context. Vice versa, the flow of information from user to application can automatically be enriched with relevant context information, of which time, location and identity are usually the most important context elements. The impact that the different context variables have on information systems largely depends on the specific characteristics of the process and information needs which they support.

Context is defined by van Eijk (*et al.*, 2004) (see also Dey, 2001) as “any information that can be used to characterize the environment of a person that is considered relevant to the user, the device or the service”. From a computer point of view, context is defined more concisely by Moran and Dourish (2001) as being “the physical and social situation in which computational devices are embedded”. Dey and Abowd (1999, 2000) distinguish between primary and secondary context types. Primary context types describe the situation of an entity, and are used as indices for retrieving second level types of contextual information. Küpper (2005) referred to the context ‘data’ as the ‘primary context’ (main categories : time, location, identity and activity) and the context ‘information’ as the ‘secondary context’ (categorized into personal, technical, spatial, social and physical contexts).

Both Pascoe (1998) and Schilit *et al.* (1994) have attempted to categorize the features of context-aware services using two orthogonal dimensions that describe on one axis, whether the task is to obtain information or to execute a command, and, on the other axis, whether the task is executed manually or automatically. Dey and Abowd (2000) discuss these taxonomies in detail and finally come up with a general list of three context-aware features which can also be applied to develop a context-aware services for traffic IM :

- presentation of information and services to a user (getting information);
- automatic execution of a service (executing command);
- tagging of context (by the user) to information for later retrieval (storing information).

Feng *et al.* (2009) claimed to be the first to incorporate the notion of context awareness for providing customized SA. They stated that : “Whereas Context awareness is about exploiting the context of a user and helping the user to have a more effective interaction with the system by actively changing the system’s behavior according to the user’s current context or situation, Situation awareness focuses more on the modelling of a user’s environment to help the user to be ‘aware of his current situation.” In literature there are several attempts to define a context (2006) suggest a context model based on activity theory. This context taxonomy incorporates the tradition in context-aware systems, and the general concepts found in activity theory. Other definitions have simply provided synonyms for a context, for example, by referring to context as the environment or situation. Some consider context to be the user’s environment, while others consider it to be the application’s environment. Brown (1996) defined context as “the elements of the user’s environment that the user’s computer knows about”. Franklin and Flaschbart (1998) see it as the situation of the user. Ward *et al.*,

(1997) view context as the state of the application's surroundings, while Rodden *et al.*, (1998) define it as the application's setting. Hull *et al.*, (1997) even included the entire environment by defining context as aspects of the current situation.

The variety of attempts to define a context indicate the difficulty to define context in a general yet useful way to create an intelligent COP. In spite of the lack of a consistent, unified and operationally-useful definition of context, there are certain types of information dimensions that systematically appear in the literature and applications on context-aware computing. The relevance of some variables, or groupings, changes according to the use of the services that rely on context information. What is essential is that any context-aware service within a COP provides a clear definition of the context variables that influence the service itself. This is important in order to justify the use of these variables in terms of added value or usefulness to the service, but also to identify the technical features of the service that rely on context information. In Table 3.6 we give some examples where context variables are contained in a COP and need to be shared between different IM chain members. We combine these with the different IM process phases as defined in Zwanenveld *et al.* (2000). The logging of such information is very useful for incident evaluations.

Table 3.6: Examples of context variables contained in a COP

IM Phase Context information	Phase 1 and 2 Detection, Warning (notification) and Verification	Phase 3 Response, Driving and Arrival	Phase 4 Site Management Operation (action)	Phase 5 and 6 Normalization, Flow Recovery
Location	- incident location	- location of emergency vehicles - location emergency services	- safety zone of incident location	- location of traffic jam information caused by incident
Time	- date and time incident - warning time emergency services	- prognosis driving time vehicles - prognosis total incident time - departing time to incident - arrival time by incident	- realization of safe incident location - waiting time for towing service - clearance time of towing service	- normalization time - flow recovery time
Activity	- detection of incident by road users (drivers), cameras, police, road inspector, towing services and e-call - warning other emergency services - verification information - allocate resources - incident registration	- availability and capacity emergency services (resources) - informing emergency services - driving to incident location - Incident registration	- safety of location established - stabilization of rescue operation - cleaning or recovering and clearance of road - coordination between emergency services - incident registration	- stabilization of incident situation - clearance time for peak lanes
Identity	- Incident number, type and magnitude (number involved vehicles, injuries and severity).	- identification of emergency material (vehicles) - identification of emergency workers	- aid question for traffic management measures, injured, fire, towing vehicles, road reparation - coordination of emergency - police investigation (question of guilt)	
Environmental context	- sensors which provide a direct (near) real-time status of the incident location and the environment in terms of safety and mobility consequences (video, camera, temperature sensors, photodiodes, telecom data, RF beacons, fire detection, airpolution detectors, etc.	- location of critical infrastructure - information about events	- weather conditions - historical information - information of other incidents in surrounding area - information about damaged infrastructure	- road conditions in the surrounding area (blocked roads, traffic jams)

3.7 Situational awareness

Most simply, SA has been generally defined as "knowing what is going on around you" (Adam, 1993 ; Adams *et al.*, 1995 ; Endsley and Garland, 2000). Although the term 'Situational Awareness' itself is fairly recent, the evolution and adoption of the concept has a long history as described by Harrald and Jefferson (2007). The concept of SA finds its roots in the long history of military theory (Tzu, S., 512 BC) in combination with net-centric information concepts (Alberts *et al.*, 2000 ; Alberts *et al.*, 2001 ; Alberts, 2002). Most of the related research was originally conducted in military aviation safety in the mid 1980s to design computer interfaces for human operators (Endsley 1988 ; Dominguez *et al.*, 1994 ; Endsley, 1995, Naval Aviation Schools, 2006 ; NASA, 2006). The concepts of SA and COP have been adopted by the military, as a whole, as a guiding principle to define and/or oversee combat operations.

SA has been identified as one of the primary factors in accidents attributed to human error (see Hartel *et al.*, 1991 ; Redding, 1992 ; Merket *et al.*, 1997 ; Nullmeyer *et al.*, 2005). The SA literature gives many examples of incidents, which could have been avoided if operators had recognized the situation in time. SA is especially important in work domains where the information flow can be quite high, and poor decisions may have serious consequences. It is also a field of study concerned with perception of the environment which is critical to decision makers in complex, dynamic areas such as aviation, air traffic control, power plant operations, military command and control, emergency services, and more recently in traffic IM (Steenbruggen *et al.*, 2012a). Klein (2000a) present four reasons why SA is important : 1) SA appears to be linked to performance ; 2) limitations in SA may result in errors ; 3) SA may be related to expertise ; and 4) SA is the basis for decision making. A distinction can be made between individual and shared or team SA, which will be explained in the next sections.

3.7.1 Definitions and models for individual situational awareness

Models that currently dominate the literature focus on the SA of individual operators (see Stanton *et al.*, 2001). These are individually oriented theories, including Endsley's three-level model (Endsley, 1995), Smith and Hancock's perceptual cycle model (Smith and Hancock, 1995), and Bedny and Meister's activity theory model (Bedny and Meister, 1999).

These models differ in process versus product orientation and in terms of the underlying psychological approach. For example, Endley's three-level model takes an information processing approach and is purely cognitive and does not include technological aspects.

From the individual-oriented SA theories, Endsley's information processing, based on a three-level model, is the most popular (see Salmon *et al.*, 2007). Endsley (1988) defines SA as a product comprising "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". Wickens (2008) gives an extensive review of Endsley's articles on SA theory and measurement. Endsley (2000) argues that achieving (human) SA involves combining, interpreting, storing, and retaining information. Endsley's SA model is the result of processing at three distinct levels (Endsley, 1995) :

- perception : attributes and dynamics of the elements in the environment are perceived ;
- comprehension : multiple pieces of information are integrated, and their relevance to the decision maker's goals is determined ;
- projection : future events are predicted.

Several definitions of SA have been suggested, but these generally restate the same themes (e.g. Sarter and Woods, 1991 ; Fracker, 1991 ; Dominguez *et al.*, 1994 ; Smith and Hancock, 1995 ; Adam, 1993 ; Jeannot *et al.*, 2003). Endley's theories of individual SA do not use the concepts of a 'COP' and 'network-centric operations', but are more defined as a set of goals and decision tasks for a certain job or activity of individuals within an organization. So, its context depends on what is the right information to support a SA environment. However, there is a strong relation between the quality of shared SA in terms of interaction, when the individual also works within a team to perform the required task in network-centric operations based on individual SA. As well as the different levels of SA of the environment, it is also relevant what is the SA of the team's own organization. This is also called organization awareness (see Oomes, 2004).

3.7.2 Definitions and models for shared situational awareness

A general accepted definition of shared SA is largely lacking. Endsley (1995), for example, defines ‘team SA’ as “the degree to which all of the team members develop sufficient individual SA to perform their required tasks”. However, this does not necessarily imply a sharing of SA (Salas *et al.*, 1995). According to Klein (2000b), shared SA refers to “the degree to which the team members have the same interpretation of ongoing events”. Nofi (2000) examines the definitions of ‘common operating picture’ and ‘situational awareness’, and finds through his extensive literature review that considerable ambiguity exists. SA is defined as : “The result of a dynamic process of perceiving and comprehending events in one’s environment, leading to reasonable projections as to possible ways that environment may change, and permitting predictions as to what the outcomes will be in terms of performing one’s mission. In effect, it is the development of a dynamic mental model of one’s environment.”

Nofi (2000) defines the difference between SA and shared SA : “*Shared SA implies that we all understand a given situation in the same way.*” In the multi jurisdictional or multi-agency environment, the “we” in his definition is the group of agencies and leaders that have a vested interest in understanding their shared operating environment in the same manner. From this, we can conclude that SA is maintained by the organization and shared SA is sought between organizations and others. Gross and Specht (2001) stated that “awareness information environments help to support the coordination of working groups”. Typically, they provide application-independent information to geographically dispersed members of a working group about the members at other sites: for example about their presence, availability, past and present activities. Often they consist of sensors which capture information, a server that processes the information, and indicators to present the information to the users.

Awareness information environments capture various types of information and events from the physical world and from the electronic world, and present the information to the members of working groups. As these environments can potentially have a large number of sensors that constantly capture a vast amount of information, some structuring of the information is required. Furthermore, the members of the working group need a common reference on the shared world as a basis for communication and cooperation. Context information can thus be used to structure awareness information and to provide users with this common reference (Clark and Brennan, 1991). Endsley and Jones (2001) stated that “the SA of the team as a whole depends on : (1) a high level of SA among individual team members for the aspects of the situation necessary for their job ; and (2) a high level of shared SA between team members, providing an accurate common operational picture of those aspects of the situation common to the needs of each member”.

3.8 A common operational picture for traffic IM

3.8.1 A COP within traffic IM

In Harrald and Jefferson (2007), it is stated that “The transfer of the concepts COP, SA and net-centric working from its safety and combat origins to the complex, heterogeneous emergency management structure will be exceedingly difficult, and that short term strategies based on the assumption that shared situational awareness will be easily achieved are doomed to failure.” The cooperation between the different IM actors takes place at three different levels : 1) policy, 2) management and 3) operations.

The cooperation is formalized by policy rules and contracts between the different road authorities, towing services, and insurance organizations. On an operational level, a COP can support the daily activities in terms of information-sharing between the IM field workers (e.g. road inspectors, fire brigade, medical ambulance services and police). This means that a COP provides an SA for each field worker based on their specific tasks to support IM. Harrald and Jefferson (2007) state that “Those controlling and coordinating the response and recovery will attain and maintain an accurate, shared COP and SA.” This means that for IM this task will be performed by the traffic management centres and the dispatch centres of the other emergency services (e.g. police, fire brigade, medical services and towing services).

In the literature, it is generally accepted that decision making in a Command and Control environment is composed of a number of dynamic and cyclical perceptual, procedural and cognitive activities, achieved either by humans, computer systems or both (Roy, 2007). The support of a COP for Command and Control reflects the process that delivers strategic and operational intelligence products which is generally depicted in cyclic form. ‘Intelligence’ refers to a special kind of knowledge necessary to accomplish a mission successfully (Waltz, 2003). In a military organization, Command and Control can be defined as “the exercise of authority and direction by a properly designated commanding officer over assigned and attached forces in the accomplishment of the mission”. Command and Control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. However, collaboration and information-sharing in the domain of traffic IM involves different public organizations with their own specific responsibilities. Here Command and Control plays a different role and the introduction of the military concepts needs to be carefully interpreted and applied to the specific situation.

Incident data need to be logged automatically by the field workers and the traffic management centres to obtain real-time SA at an operational level. This provides a monitoring instrument at management level. Thus, a COP also serves the management need to measure the overall IM performance in terms of response time, clearance time, the impact on traffic jams, and lost vehicle-hours. This can also provide relevant information for policy makers. Such information provides a basis for monitoring IM policy goals ; gives a instrument to justify investments in IM measures ; and offers a tool for comparing different traffic management investments in general. Finally, the introduction of a COP can also provide relevant information for road users in terms of road traffic conditions, expected travel times, and insight into the impact of an incident on the entire network.

As stated above, to introduce the concept of a COP is extremely difficult, and short term strategies are doomed to fail (Harrald and Jefferson, 2007). This means that for a successful adoption, these concepts need to be carefully introduced. A logical step is to introduce a COP in different stages. The first choice is the user perspective. It makes sense to start with those who are controlling and coordinating the response and recovery processes. They are those who will attain and maintain an accurate, shared COP and SA, as stated by Harrald and Jefferson (2007). The second choice is which IM actors will be involved. It makes sense that those who are most involved in the IM process in terms of responsibility and associated incident numbers will take the lead. For IM, these are the road authorities, the police, and the towing services. In the next stages, other IM actors can be involved. The third choice is the data which a COP contains. Table 6 defines which data are relevant in the different IM process phases, as highlighted before. One of the main problems is information overload (Endsley and Kiris, 1995). Thus it makes sense not to integrate all information as mentioned in Table 3.6 for a first introduction of a COP. The information to support IM can be clustered in different groups : 1) incident text message ; 2) geo-information and 3) sensor information (e.g. camera, detection loop, telecom data). In addition, information need to be filtered and personalized for end users. The fourth choice is the ambition level for achieving shared SA using a COP. To build up shared awareness, all teams need to share information and to share understanding of the situation (Albert *et al.*, 2002). Albert suggest a maturity model to proceed from the traditional Command and Control process to self-synchronization (see Figure 3.9) :

- Level 0 : baseline, traditional command and control ;
- Level 1 : significant amount of information sharing ;
- Level 2 : cooperation across location, function, and organization among participants ;
- Level 3 : improved level 2, by not focusing on sharing information but on what it means ;
- Level 4 : self-synchronization enabled.

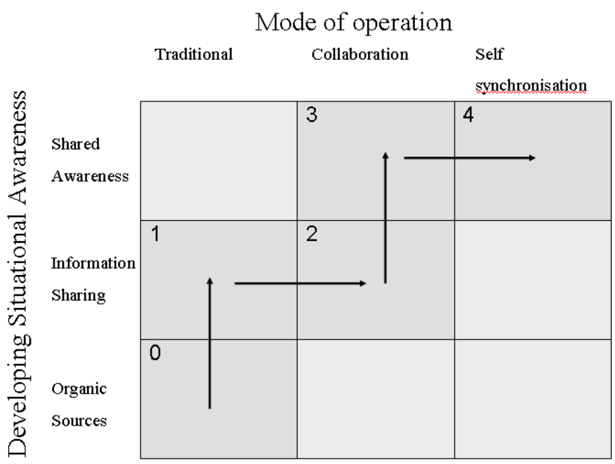


Figure 3.9: Network-Centric Maturity Model.

Source: Based on Alberts *et al.* (2002)

The current IM work processes in the Netherlands could be characterized somewhere between level 1 and 2. However, even on level 1, there are still many problems which have regularly been identified in the daily operations in terms of information sharing, communication, and coordination.

3.8.2 Measuring the value added service

Net-centric working is a basic constraint to achieve shared SA based on a COP between the different IM organizations. In Table 3.7, the components of the NEC value chain are combined with the different IM process phases as defined by Zwaneveld *et al*. (2000). The logic behind this table is as follows. An improved situational interface is created by detection, warning and verification based on better information. Better information leads to better responding of the emergency services. By improved responding, resources are used more effectively so that better action can take place. This leads to a better outcome, to a faster clearance of an incident site, and therefore to a reduction of traffic jams and lost vehicle-hours.

Table 3.7: Relation between NEC value chain and the operational IM process phases.

NEC value chain		Incident Management phase	Benefits
Better	networks	technical infrastructure	field workers and traffic management central
	Information sharing	detection, warning	improved Situation interface
	understanding	verification	based on improved Situation interface
	decisions	respond, driving and arrival	better use of resources
	actions	site management, operation, action	more effective field operations
	effects	normalization, flow recovery	reduction on traffic jams and vehicle lost hours

The term "picture" in a COP refers not so much to a graphical representation, but rather to the data used to define the operational situation. As such : "*The creation and dissemination of the COP is as much an information management challenge as it is a visualization challenge.*" (Mulgund and Landsman, 2007). To measure the value added services of SA for IM, we introduce a 3D cube (see Figure 3.10). This is based on :

- Level of SA, reformulation of Endsley's definition of SA (see Hone, 2006) ;
- SA components of IM (incident, environment and organizations) ;

- IM Process phases (see Zwaneveld *et al.*, 2000).

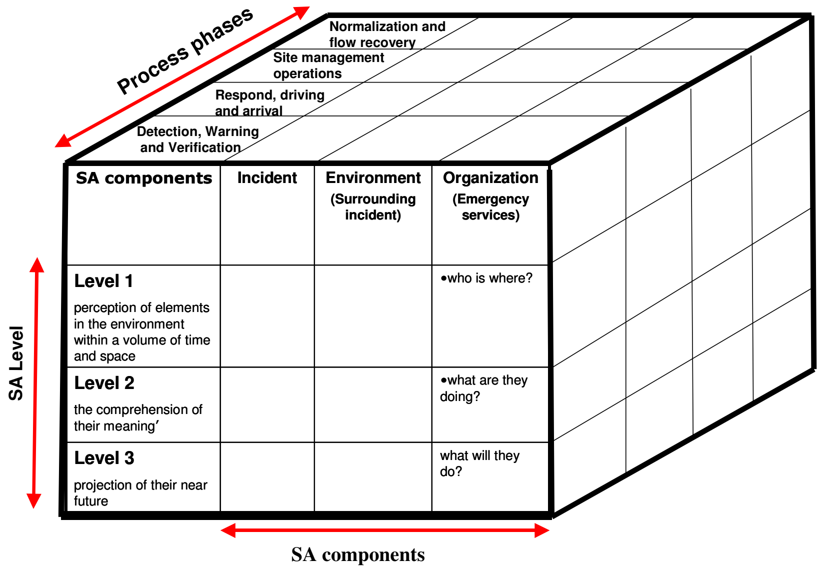


Figure 3.10: 3D cube of measuring Situational Awareness for operational traffic IM.

This 3D cube provides a basis to measure the qualitative and quantitative value added services to support SA in the daily traffic IM work process between the organisations involved. The qualitative aspects will focus on the economic effects (Koster and Rietveld, 2011) in terms of reduction of delay and lost vehicle-hours. The quantitative aspects will focus more on the quality of cooperation, system and information quality (Strong *et al.*, 1997 ; Perry *et al.* 2004 ; Singh *et al.*, 2007 ; Bharosa *et al.*, 2009) . In this context, it seems plausible to apply the so called Technology Acceptance Model (TAM) which is extensively described in literature (Davis, 1989 ; Venkatesh *et al.*, 2003 ; Wixom and Todd, 2005).

3.9 Problems of achieving a common operational picture

There are several private and public actors involved with different responsibilities and tasks to support the IM process which use their own information systems. Hale (1997) mentioned that : "*The key obstacle to effective crisis response is the communication needed to access relevant data or expertise and piece together an accurate understandable picture of reality.*" The problem with today's information systems is not their lack of information, but the difficulty to find or display the right information when it is needed. Endsley and Kiris (1995) defined this as the 'information gap'. Furthermore, a distinction can be made between having and sharing information for an effective cooperation between the different chain members. It is widely agreed that more data does not mean better information in terms of information overload.

The terms “common operating picture” and “shared situational awareness” imply that : (1) technology can provide adequate information to enable decision makers in a geographically distributed environment to act as though they were receiving and perceiving the same information ; (2) common methods are available to integrate, structure, and understand the information ; and (3) critical decision nodes share institutional, cultural, and experiential bases for imputing meaning to this knowledge. The first two steps are necessary for the common operating picture ; all three are required for shared situational awareness (Harrald and Jefferson, 2007).

In the literature, many problems have been identified in introducing these concepts. Lambert (2001, 2003) and Lambert and Scholz (2005) discuss the problems arising from the different meanings of ‘Common’ in a COP, and from the nature of information and its presentation. Mulgund and Landsman (2007) describe the different meanings of ‘picture’ in a COP. Discussions of problems with individual SA can be found in Endsley *et al*. (2003).

One tenet of the NCW is that information sharing and cooperation can enhance the quality of information and shared SA (Alberts, 2002). The value of communication networks depends upon how they are used. The primary goal is to relate effective decisions and actions to the right context. Shared SA will result by using the communication networks to disseminate a COP. To achieve a ‘shared’ SA for users in diverse roles and operating domains (*i.e.* contexts), the interpretation of a common ‘picture’ will also be influenced by their individual circumstances (Endsley, 1995). However, if we move from the more narrowly focused individual operating picture to a COP with shared SA, the problems increase (Harrald and Jefferson, 2007 ; Lambert and Scholz, 2005). Obstacles in sharing and coordinating information are discussed by Bharosa *et al*. (2010). Next to that, in an information rich environment, users can be easily overloaded (Endsley and Kiris, 1995). This must be in line with the concept of ‘*bounded rationality’* (Simon, 1972).

3.10 Retrospect and prospect

Professional IM can help to improve road safety, and to reduce traffic jams and lost vehicle hours. Road traffic casualties and injuries in the EU are a major public health issue. IM involves the coordinated interactions of multiple public agencies and private sector partners. Transportation operations and public safety operations are intertwined in many respects. Public safety providers e.g. through law enforcement, fire and rescue, and emergency medical services can ensure safe and reliable transportation operations by helping to prevent crashes and rescuing accident victims. On the other hand, the transportation network enables emergency organizations access to incidents locations, and, increasingly, provides real-time information about roadway and traffic conditions. Information systems have become increasingly important to help daily activities for supporting IM. However, information sharing between different IM organization is still in its early stages of development. Various studies have concluded that information quality and system quality are still major hurdles for efficient and effective multi-agency emergency services and are crucial for the succes of information systems (Lee *et al.*, 2011).

A Common Operational Picture (COP) to create Situational Awareness (SA) is becoming increasingly accepted as an instrument for added value by sharing information in an effective way. The introduction of these concepts is extremely difficult and short term strategies are doomed to fail. In the literature, these concepts are mainly discussed for large scale disasters and emergency services. Traffic incidents happen on a daily basis, and the response is normally carried out by trained and experienced emergency services. This should make it relatively easy to adopt these concepts and apply them to IM. Our study has shown – through a broad literature overview from different domains – that the use of a COP is a promising way for applying smart IM. Clearly, more work needs to be done to explain and empirically measure in a statistically consistent way the benefits of such systems, and to overcome the many problems and policy implications as identified in the literature. This will be part of future research. The following general conclusions can be drawn:

- IM is very relevant for mobility management and the direct impacts of traffic incidents in terms of delay, property damage, injuries and fatalities, and road safety for the road users;

- Effective IM activities rely on flexible communications and information systems;
- The concepts of COP, SA, and NCW have their roots in the military domain and may have merits if adopted in emergency and disaster management environments;
- In the literature, there is not yet an accepted model which defines the context variables used in a COP to provide SA for IM;
- There are still many challenging issues to be resolved which are mainly related to the cognitive domain;
- The successful adoption of these concepts needs to be carefully introduced in different stages.

4 Mobile Phone Data for Traffic Parameter and Urban Spatial Pattern Assessment*

4.1 Introduction

Location-based digital information — often originating from mobile phone data — has gained much popularity in recent years as a real-time operational vehicle for urban, environmental and transport management. Interesting applications are inter alia the use of private or public spaces by individuals (see, e.g. Calabrese *et al.* 2010b), the concentration of people in a city (see, e.g. Reades *et al.* 2009), the activity spaces of commuters (see Ahas *et al.* 2006), nonrecurrent mass events such as a pop-festivals (see, e.g. Reades *et al.* 2007), the entry of tourists in a certain area of attraction (see e.g., Ahas *et al.* 2007, 2008), or the estimation of spatial friendship network structures (see Eagle *et al.* 2009).

Especially in the transportation sector, the potential applications are vast, and consequently, the use of cell phone data has shown a rapid increase in urban transport applications. These data offer a rich source of information on continuous space–time geography in urban areas. They can be used for daily traffic management, but also for incident management, for instance, in case of big fatalities, terrorist attacks, or mass social events such as festivals or demonstrations. In the present Chapter we will analyse in particular the use of cell phone data for incident and traffic management in urban areas. The main question to be addressed is how to anticipate and control unexpected events in a transportation system, either on road segments or entire networks. Effective and timely control measures call for real-time detailed data on traffic movements. The possibility offered by micro-electronic devices to identify the geographic positions and flows of people opens unprecedented ways of addressing

* Based on: Steenbruggen, J., Borzacchiello, M.T., Nijkamp, P. and Scholten, H. (2011). Mobile phone data from GSM networks for traffic parameter and urban spatial pattern assessment: a review of applications and opportunities. *GeoJournal*. (4 May 2011), pp. 1-21

several policy issues such as urban security, incident control, organization of services for citizens, traffic management, risk management and so on. In particular, the opportunity to gather real-time data about location and movements by means of mobile (or cell) phone activities may have an enormous impact on traffic management, given also the interests that private telecommunication companies might have in this market. Moreover, it immediately calls for real-time applications to city management, especially concerning the optimization and the regulation of the transportation system. Intelligent Transportation Systems are based on the concept of a dynamic equilibrium between traffic demand and transportation supply. This might be achieved by means of a system able to orient its performance to the request that people have to move, in order to maximize the capacity of the system and to minimize the waste of energy and resources (Cascetta 2009). Consequently, a system able to forecast the demand and to anticipate its evolution is needed. Presently, many efforts have been made to obtain models capable of forecasting traffic demand (econometric demand forecasting models, neural and Bayesian networks, stochastic processes, etc.) and to understand the way it moves on transportation networks (traffic flow models, etc.). The problem is that all these efforts have been only marginally tested on real and complex sites, since the cost needed to gather the huge amount of data required is, in most cases, unaffordable. As an example, the US Government has recently funded the very big NGSIM project (US Department of Transportation, 2008) aimed at providing, to the world's research community, data to test and to develop all possible traffic-related models. Albeit invaluable for very specific transportation applications, these data are collected by cameras only on short stretches (few hundreds of meters) of a set of roads in North America. There are different techniques to collect traffic data: vehicles' trajectories are mostly collected by means of remote-sensing and object-tracking from video or photo cameras; positions of vehicles are obtained by applying Global Positioning System (GPS) technology, whose advantages are the high accuracy, the precise timing of the system and the high sampling frequency of the measures (Punzo *et al.* 2009), while the shortcomings are due to the fact that only a limited number of vehicles, equipped with GPS device, can be tracked. Loop detectors are the most widely used technique for traffic volume detection. The system is constituted by one or more magnetic loop detectors put in the road infrastructure, connected to a device able to pick data, located at one side of the road. To have detailed information about how loop detectors use magnetic properties to count traffic volume (counts) and traffic flows we refer to Papageorgiou (1991). In recent years, a new typology of data deriving from mobile phones, and in particular from the GSM network, has attracted the attention of researchers, due to the huge amount data that may be collected at the individual level, and to the possibility to obtain high levels of accuracy in time and space. These features make mobile phone data ideal candidates for a large range of applications, in particular in the transportation field. The history of GSM network is rather recent: in 1982, the European Commission on Postal and Telecommunication Administrations created the GSM (Groupe Spécial Mobile) to develop Second Generation Standards for digital wireless telephone technology (GSM Association 2009). In 1987 a memorandum of understanding was signed among 13 countries to develop the cellular system. The GSM (Global System for Mobile Communications) network was launched for the first time in 1991 and already in 1993 there were over a million of subscribers in 48 countries operated by 70 carriers (Emory University 2009). At present, 80% of the mobile market makes use of GSM technology in more than 212 countries, reaching over 3 billion people, (PR NewsWire 2009). Recent market surveys show that in various countries cellular phone penetration attains and, in some cases, exceeds 100% (Caceres *et al.* 2008). Since mobile phones move with people and vehicles, the big market penetration is one of the advantages of the use of mobile technology for estimating traffic related parameters, once known the location of the device. The first occasion leading to seriously consider the location potentialities of the mobile network stems from European and American regulations regarding electronic communications networks and services, according to which public telephone network operators receiving calls for the emergency calls number should make a caller’s location information available to authorities in charge of handling emergencies (European Commission 2002a). These regulations motivated telecommunication companies to investigate the network capabilities of determining the location of fixed and mobile users. Therefore, from the middle of the 1990s, several studies and projects have been carried out, and, in particular, over the past decade a number of research studies and operational tests have attempted to develop wireless location services in sectors like tourism, energy distribution, public transportation, urban planning, disaster management, traffic management, etc. Indeed, many fields nowadays require the use of location technology, and in several cases this need is inducted by the increasing speed of the technology growth. The motivation for this Chapter is the need to systematize the literature regarding the use of mobile phone data in the field of the estimation of traffic parameters. More specifically, against this background the aim of this contribution is to provide a review of past studies, projects and applications on wireless location technology, by highlighting the advantages and limitations of the process of retrieving location information and transportation parameters from cellular phones, and by trying to clarify: (a) which data types can be retrieved from the GSM network and how they are currently used; (b) whether it is possible to individuate a fill rouge among the number of studies in the field; (c) which are the main research issues connected with the use of telecom data in transportation applications.

4.2 Mobile phone data location methods

In order to understand the mechanisms allowing the derivation of the location of a mobile phone from the signals it sends to the network, it is worth clarifying how the GSM network works (www.gsmfordummies.com, accessed 29 July, 2009). It is relevant to note that in the present study novel kinds of network such as UMTS (Universal Mobile Telecommunications System) will not be considered, but they could be input for further research along the same lines.

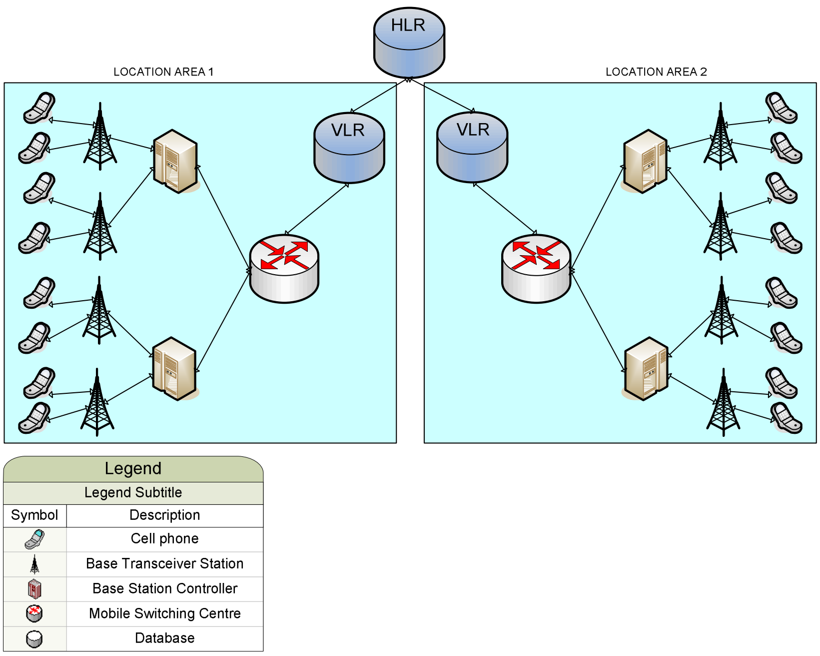


Figure 4.1: GSM network scheme

As shown in Figure 4.1, physically the Base Transceiver Station (BTS) is the Mobile Station's (the mobile phone, aka handset) access point to the network. A cell is the area covered by one BTS (not visible in the figure). The network coverage area is divided into a set of cells, named Location Areas (LAC). The BSC (Base Station Controllers) is a device that controls multiple BTSs. It handles the allocation of radio channels, frequency administration, power and signal measurements from the Mobile Station. The heart of the GSM network is the Mobile Switching Centre (MSC). It handles call routing, call setup, and basic switching functions. An MSC handles multiple BSCs and also interfaces with other MSCs and registers. Location Management from a GSM network is possible by means of a system of databases, the HLR (Home Location Register) and the VLR (Visitor Location Register). The HLR is a large database that permanently stores data about subscribers, including the current location of the mobile phones. The VLR is a database that contains a subset of the information located on the HLR. It contains similar information as the HLR, but only for subscribers currently in its Location Area. The position of a mobile phone is derived from an automatic process that maintains the network informed about the phone location, depending on the phone status.

By means of a system involving the exchange of signalling messages between the phone and the network, the so-called Location User process is able to determine the position of the cellular at the Cell-ID level. The operator knows the coordinates of each cell site and can therefore provide the approximate position of the connected mobile. To overcome this approximation, two methods are mentioned in the literature (Promnoi *et al.* 2008); (a) Received Signal Strength (RSS) methods, a technique that estimates the position of a mobile phone by matching the signal strength with the neighbouring reference points; (b) triangulation, based on the difference of the arrival instant of the signal from the same handset to a set of different receiving base stations. The mobile station measures the arrival time of signals from three or more cell sites in a network. The network measures the transmission time of these signals from the relevant cell sites. By combining these two pieces of information it is possible to estimate the position of the mobile phone.

These methods need the network to be synchronized and require additional network elements which are not strictly necessary for the GSM communication, namely the SMS (Short Message Service) or IP traffic. For this reason, cell-based location data, without any form of improvement through RSS or triangulation, are currently the most used techniques. Apart from location information, GSM network provides mobile phone activity parameters, which offer the information about the rate of use of the network. The most used activity parameters to estimate transportation parameters are handovers, cell dwell time and communication counts. A good comprehensive review is given in Caceres *et al.* (2008) and Ratti *et al.* (2006).

Handovers (also called hand-off) refer to the switching mechanism of an on-going call to a different channel or cell. It is the mechanism of managing a permanent connection when the phone moves through two cells of the network. Hereby the phone call changes from one base station to the other without quality loss. This information is stored in the above mentioned HLR and VRL network databases. Together with the Mobile Switching Centers (MSC) they provide the call routing and roaming capabilities of the GSM network.

The Cell Dwell Time (CDT) represents the duration that a cellular phone remains associated to a base station between two handovers. This parameter is used in the literature referring to each individual cell, and thanks to the comparison among multiple adjacent cells it allows estimating traffic congestion. The actual use of the network also provides useful indicators. The standard unit of measurement of telephone traffic used by most network operators is an Erlang, where one Erlang equals one person-hour of phone use. Such data is aggregated and made anonymous in terms of usage time and depends on the number of communications and their duration.

Telecom operators also measure a range of additional traffic features, for instance, for billing, network planning and network quality control. These include the number of new calls, the number of terminating calls, the average call length or the number of SMS messages. It is worth to clarify that data can be collected from the mobile phones not only when a call is made by the user, but also when the device is simply switched on. In the next section it will be explained how such cell-phone parameters have been used in the literature so far to retrieve traffic parameters.

4.3 Review of projects using mobile phone data for traffic parameters estimation

In this section a short description of the most important field test deployments and simulation studies aimed at the estimation of traffic-related parameters is provided. Details are offered in Table 1, in which the projects are listed, where possible in chronological order. Since there has been quite a number of review studies in the field, for a thorough description of the main projects and simulations studies, the interested reader is referred to Fontaine *et al.* (2007) and Caceres *et al.* (2008), which only exclude the most recent projects. Hereafter only the main features of the studies will be highlighted.

4.3.1 First attempts from the US

The first recorded big project investigating mobile phones as vehicle probes is the CAPITAL project (Cellular APplied to ITS Tracking And Location), which started in 1994 (University of Maryland Transportation Studies Center 1997). It has been the first big project using an extensive set of data from a mobile company, and obtaining position through triangulation methods promoted by the academic, the public and the private sector as well (Table 1). Unfortunately, the location accuracy of about one hundred meters was not sufficient to obtain reliable traffic information (see Table 2). Several other studies followed in North America. It is worth to mention here the US Wireless Cooperation Tests with deployments in San Francisco and Washington DC, using the RadioCamera technology (Yim and Cayford 2001; Smith *et al.* 2001), which, however, suffered from having a small sample size and from being able to track only the phones being in an on-call status. Together with CAPITAL, these early generation systems based on wireless signal analyses and triangulation had significant problems in determining true location of the cellular phone and were largely unsuccessful (Fontaine *et al.*, 2007).

4.3.2 European efforts

After the early American attempts there was a shift from wireless signaling analyses to handoff-based techniques. A first European effort to use the mobile cellular network for road traffic estimations based on handovers was initiated in Italy, in a simulation study by Bolla and Davoli (2000). Claiming to be the first attempt in this field, this study analyzes the use of location information to estimate on-line traffic conditions of important roads and highways by exploiting the presence of mobile phones on board of vehicles. The presence of a cellular terminal could be detected at the vehicle's entrance in monitored roads. This quantity was then used to estimate average vehicle density, flow and speed in every cell.

Another early European example can be found in the UK (White and Wells 2002), where the Transport Research Laboratory (TRL) developed a system to generate journey times and traffic speeds from OD matrices based on billing data from the telecom network. This study only uses a subset of all monitored phones, resulting in a very small sample size.

In more recent years, in a number of European countries (e.g. France, Belgium, Germany, Spain, Austria, Finland, Italy, UK and The Netherlands) different field tests, simulation studies and evaluations took place. Most of these projects focused on how to obtain reliable travel times and travel speeds from the telecom network. An extensive study of cellular probes has been carried out within the framework of the STRIP project (System for Traffic Information and Positioning) in Lyon, France (Ygnace 2001). This project evaluated the feasibility of 'Abis/A probing' location technology for travel time estimates. Abis/A Probing system is a network-based solution that gathers data from the cellular service providers. The system uses Abis and A interfaces, which include algorithms and databases of information to identify the location of a cellular phone. Results were compared with data from loop detectors, both on an inter-city motorway and an intra-city freeway, with major errors in the second case. A significant relationship between the number of outgoing calls and the level of incidents was found (Caceres *et al.* 2008).

Another example of travel time estimates was carried out in Finland by the FINNRA (Finnish Road Administration) in 2002 (Kummala 2002; Virtanen 2002), with the aim of estimating traffic data from mobile phone data exploiting the signalling messages exchanged between the phones and the network, eventually using License Plate Recognition (LPR) to validate the results (Caceres *et al.* 2008). There were more accurate results produced when the traffic was monitored over longer stretches of about 10 km. The data were affected by some problems such as parallel roads and pedestrians. Also the location of the base stations was not always optimal to support traffic management information systems.

4.3.3 Telecom companies projects

In 2003, the telecom carrier Vodafone, in collaboration with the Institute of Transport Research of the German Aerospace Center, used double handovers (a combination of data from two successive handovers from the same mobile phone, which is possible if the call duration is long enough) and signalling data from the network to generate information traffic flows and traffic speeds around Munich (Thiessenhusen *et al.* 2003).

LogicaCMG developed in 2004 the Mobile Traffic System (MTS) to monitor traffic speed and to provide road authorities with the possibility to manage traffic flows and traffic congestion (www.logica.com, accessed July 28, 2009). The system was tested in the province of Noord-Brabant in Netherlands and validated with field data from floating cars, number plate surveys and induction loop detectors. The British company ITIS Holding developed in 2006 a pilot project based on the 'Estimotion' technique in the province of Vlaanderen in Belgium. They monitored traffic on highways to verify traffic speed between two arterials. Also here the objective was to assess whether data collected from mobile phones (e.g., travel times) provided accurate traffic information. The validation study compared traffic data from cellular floating vehicles with other traffic sources such as single inductive loop detectors and GPS-equipped probe vehicles. The general conclusion was that the technology was fairly able to accurately detect the traffic trends over time and per road segment. The prediction was however most accurate in the case of free traffic flows rather than in congested conditions (Maerivoet and Logghe 2007).

In the TrafficOnLine project in 2006 in Germany, the already mentioned idea of double handovers was used (Birle and Wermuth 2006). In order to validate the results, double handovers, loop detectors and floating car data (FCD) from taxis equipped with GPS were compared. As a result, it was shown that mobile phones can provide a reliable detection of traffic congestion, depending on the covered area. Better results were obtained for motorways compared to urban roads. To improve the results in urban environments, information of existing buildings, which were responsible for handovers in overlapping coverage and signal strength of adjacent cells, were used. Problems were related to a small sample size, because only phones that made sufficient long calls within an entire cell were included. It was concluded that reliable data only could be generated in case a single roadway link exists into the border zone between two cells, so that it can be uniquely identified.

4.3.4 Recent projects outside Europe

Enlarging the view outside Europe, in North America a number of field studies have been carried out on the use of handovers to estimate traffic features. In 2003, Airsage deployed a monitoring system in the Hampton road region in Virginia based on cellular handoffs and transitions between sectors of cells to produce traffic speed and travel time. The University of Virginia performed the evaluation in 2005 and found significant errors. It was concluded that, as of December 2005, the Hampton Airsage system could not provide the quality of data desired by the Virginia Department of Transportation (University of Virginia Center for Transportation Studies 2006; Smith 2006).

In 2005, in collaboration between ITIS holding and Delcan Corporation, another project was initiated based on the 'Estimotion' technology in Maryland (Delcan Corporation 2009). They used handovers to detect traffic events like congestion and accidents. The data were tested during 2006 by the University of Maryland, which found that average errors were approximately 10 mph on freeways and 20 mph on arterials. The quality degraded significantly during a.m. and p.m. peak periods.

In 2007, the Minnesota Department of Transportation carried out a field test around Minneapolis in collaboration with the telecom operator Sprint PCS network (Liu *et al.* 2008). The travel times and travel speeds were compared against ground truth conditions. In 2008, around the San Francisco Bay Area, the Mobile Millenium project was started (Amin *et al.* 2008), whose aim is ''to design, test and implement a state-of-the-art system to collect traffic data from GPS-equipped mobile phones and estimate traffic conditions in real-time'' (http://traffic.berkeley.edu/theproject.html, accessed July 29, 2009). The project has organized a big field test deployment consisting in tracking the location and changes in position of informed users, carrying Nokia mobile phones equipped on purpose inside their vehicles. In exchange, participants received, free of charge, traffic information on the screen of their mobile. This project is still going on.

The study of Bar-Gera (2007) in Tel-Aviv compared the performance of the WLT data, detection loop data and floating car data to validate travel times. Intervals without congestion showed little variation of mean travel times. In 2007, in a field test in an area around Bangkok in Thailand, some researchers have developed a methodology for detection and estimation of road congestion using CDT (Pattara-Attikom and Peachavanish 2007; Pattara-Attikom *et al.* 2007). CDT from multiple adjacent cells was used to estimate traffic congestion. The sample size includes mobile terminals in active mode (on call) and idle modes (turned on). They classified measurements in three levels of traffic congestion based on duration. The results showed that the duration of CDT estimated the degree of congestion with an accuracy level between 73 and 85%. However they concluded that many issues need to be solved before actual implementation can take place.

4.3.5 Research on O-D matrix estimation

Regarding applications not concerned with travel times or travel speeds, which seem to be the main traffic parameters researchers are looking at, two recent (2007–2008) simulation projects on the OD matrix can be found in Spain (Caceres *et al.* 2007) and Korea (Sohn and Kim 2008) both focusing on a generation of traffic flows. The project in Spain concluded that turned-on phones (active and idle modes) of only one operator should be sufficient, and proposes an adjustment factor to transform phone data in vehicle data. The project in Korea used a simulated environment for validation. They found that the accuracy of the estimation was less depending on the standard deviation of probe phones changing location than other factors like market penetration and cell dimension.

4.3.6 Research on urban behaviour

The Real Time Rome project (Calabrese and Ratti 2006) is one of the first examples of urban-wide realtime monitoring system that collects and processes data provided by telecommunications network and transportation systems, in order to understand patterns of daily life in the city of Rome. They address a broad range of research directions like: how do people move through certain areas of the city during special events (gatherings), which landmarks in Rome attract most people (icons), where are the concentrations of foreigners in Rome (visitors), and is public transportation effective where people are (connectivity). In Reades *et al.* (2007) the authors analyze how cell phone data in Rome can provide a new way of looking at cities as a holistic dynamic system. This approach can provide detailed information about urban behaviour. Erlang data normalized over space and time are used to derive spatial signatures, which are specific time patterns of use of the mobile network distinctive of a certain area. They found a mix of clusters suggesting a complex set of relationships between signatures. The visualizations generated an overall structure of the city with a correspondence between the levels of telecommunication and types of human activities. Finally, in Girardin *et al.* (2008a) the use of cell phone network data and geo-referenced photos for the presence and movement of tourists with user-originated digital footprints are explored. In the following table (see Table 1) an overview of the main information such as data source, promoters, and typology of results of the mentioned field projects is given, while in Table 2 a focus on the main characteristics of major past and recent projects is offered.

Table 4.1: Summary of studies and field test deployments (in bold the review studies from which specific information has been derived)

Years	**Project title (where available)** **(Reference)**	**Promoters**	**Location**	**Data source**	**Used cell-phone parameters**	**Target Traffic estimations**	**Results**
1994-1997	**CAPITAL** *(University of Maryland Transportation Studies Center, 1997)*	Federal Highway Administration Virginia Department of Transportation Maryland State Highway Administration University of Maryland Bell Atlantic NYNEX Raytheon, Farradyne	Washington D.C, USA.	Data from Bell Atlantic NYNEX Mobile's cellular network	Position through triangulation	Traffic Speed	Only 20% of probes generated speeds 100 m position accuracy Not consistent traffic monitoring
1999 2002	*(White and Wells, 2009)*, ***(Caceres et al., 2008)***	Highway Agency UK Transport Research Laboratory BTCell net (O2)	Kent, UK	Billing data from BTCellnet	Initial and ending position of the mobile phone	OD matrix	Small sample size Phones on call Groups able to transmit their position to server
2000	*(Yim and Cayford, 2001)*,	US Wireless	San	44 h of wireless	Position of the mobile phone –	Traffic	60 meter mean location

	(Fontaine et al., 2007)	Corporation University of California-Berkeley	Francisco Oakland, USA	data from US Wireless	call duration	Speed	accuracy 60% of locations could not be matched to road No usable data generated
2000 2001	*(Smith et al., 2001),* ***(Fontaine et al., 2007)***	US Wireless Corporation Virginia Department of Transportation Maryland State Highway Administration University of Maryland University of Virginia	Washington D.C., USA	160 phone calls tracked every 2 seconds, generating 4800 data points every minute	Cellular phone position	Traffic Speed	5% of 10-min intervals had no data 6 to 8 mph mean speed estimation error Some intervals had errors > 20 mph Over 20% had significant differences from reality
2001	**STRIP** *(Ygnace, 2001), (Ygnace and Drane, 2001),* ***(Caceres et al., 2008), (University of Virginia Center for Transportation Studies, 2006)***	INRETS SERTI French Government SFR carrier (Vodafone France)	Lyon, France	Mobile phone data from SFR	Position from in-vehicle mobile phones Number of phone calls	Journey times Traffic Speed Directions of movement	Inter-city speeds overestimated by 24% to 32 % Little speed variations on inter-city motorway Strong relation between call volume and number of accidents
2002	*(Kummala, 2002), (Virtanen, 2002),* ***(Caceres et al., 2008)***	Finnish Road Administration Radiolinja	Finland	Mobile phone data from Radiolinja	Time required by each phone to cross a road section from the moment it enters the service area of a base station (cell)	Travel time Journey time	Validation with License Plate Recognition (LPR) More accurate results produced when the traffic was monitored over longer stretches around 10 km Location of the base stations not always optimal
2003	*(Thiessenhusen et al., 2003),* ***(Caceres et al., 2008)***	Institute of Transport Research of German Aerospace Center Vodafone	Munich, Germany	Mobile phone data from Vodafone	Handover	Traffic flow	Errors between 20 and 30 km/h Phone flows (calls) are closely related to vehicular flows Results based on small sample size
2004	*(Rutten et al., 2004)*	Mobile Traffic Service (MTS)	Noord-Brabant, Netherlands	MTS (Mobile Traffic Service)	Handover Location update	Traffic flows Traffic	High correlation between travel times generated by MTS and by

		LogicaCMG Vodafone		data from LogicaCMG and Vodafone		congestion	the reference systems. Errors generally low between 3-4 %, with errors of 10-20 % in journey times of 20-25 minutes. Conclusions based on limited results that are publicly available.
2003 2005	*(University of Virginia Center for Transportation Studies, 2005), (Smith, 2006),* ***(Fontaine et al., 2007)***	Federal Highway Administration Virginia Department of Transportation AirSage inc. University of Virginia	Hampton Road, Virginia	Anonymous mobile phone data from Sprint US carrier	Handovers	Travel speed Travel time	68% of speed estimated had errors > 20mph Not reliable measures Airsage claimed results caused by lack of access to full data
2005	**MIT SENSEable City Laboratory** *(Ratti et al., 2006)*	MIT A1 Mobilkom	Milan, Italy	Anonymous data from a European telecoms carrier	Erlang Network counters	Call density OD of Calls	Real-time visualization dynamics metropolitan area
2005	*(Maerivoet and Logghe, 2007)*	ITIS Holdings Proximus	Flanders Antwerp Belgium	Anonymous Cellular Floating Vehicle Data (CFVD).	Handover	Travel speed	Technology able to accurately detect the traffic trends over time and per road segment. Predictions however most accurate in the case of free traffic flow rather than congested conditions.
2005 2006	*(Bar-Gera, 2007)*	Estimotion Ltd. ITIS Inc. Ben Gurion University	Tel-Aviv Israel	Cell phone data provided from Estimotion Ltd.	Handover	Travel time	Limited data during off-peak hours WLT estimates different between floating car and loop data by 10 to 30% during congested conditions
2006	**Real-time Rome** *(Calabrese and*	SENSEable City Laboratory MIT	Rome Italy	Cell phone data provided from	Erlang	Touristic, pedestrian and vehicle	Broad range of research directions demonstrating a

	Ratti, 2006)	Telecom Italia		Telecom Italia Mobile		density Travel speed	large spectrum of useful applications
2007	*(Liu et al., 2008)*	Minnesota Department of Transportation University of Minnesota Sprint PCS	Minnesota, USA	Cell phone data from Spring PCS Mobile network	Handover	Travel times	Segments with high speeds results within 10 MPH of ground truth In segments with low to moderate speeds the results become occasionally scattered Under and over estimating travel times between AM and PM peak hours where found for some roads
2007	*(Pattara-Attikom and Peacavanish, 2007), (Pattara-Attikom et al., 2007), (Hansapalangkul et al., 2007), (Hongsakham et al., 2008)*	NECTEC NSTDA Thamasat University	Bangkok Thailand	Data from probe mobile phone in vehicles	Cell Dwell Time	Traffic Congestion	Accuracy level congestion estimates between 73 - 85 %. Sample size includes phones in active and idle modes
2008 2010	**Mobile Millennium** *(Liu et al., 2008)*	Nokia, Navteq, and UC Berkeley, California Departments of Transportation	Hayward and Fremont area, California	GPS equipped cell phones	Virtual Trip Lines, Position and speed of mobile phones	Speed and travel time	Provides real-time traffic conditions to end users Free public traffic-information system Deployment, currently testing
2007 2009	**Current City Amsterdam** *(Vaccari et al., 2009)*	Senseable Future Foundation University Salzburg Vrije Universiteit Amsterdam KPN Dutch Department of Traffic Management, Rijkswaterstaat	Amsterdam, The Netherlands	Data from Dutch KPN carrier	Network parameters	Spatial network signatures	Use of telecom network data for analysis of the spatial network activity patterns

Table 4.2: **Main field test project characteristics**

	CAPITAL	US-Wireless	STRIP	Real-Time	Mobile-Century
Promoters					
Public Agencies	X		X	X	X
Research Institutions	X	X	X	X	X
Mobile phone carrier/company	X	X	X	X	X
Location technology	Triangulation	RadioCamera	Signalling messages	Ad-hoc algorithm based on ToA, TA, CDT, TDoA	GPS
Location accuracy	107 m ***(Fontaine et al., 2007)***	60 m ***(Yim and Cayford, 2001)***	100-150 m ***(Caceres et al., 2008)***	Not available	Same as GPS, 10 m ***(Spinak et al., 2009)***
Useful traffic info	No	No	No	No	Yes
Use of new technology	No	RadioCamera	Abis/A probing	Yes	No
Validation	No	Loop detectors	Loop detectors	No	Loop detectors

4.4 Illustrative application for Amsterdam

In 2007 the Current City consortium (SENSEable City Laboratory MIT; Salzburg University), in cooperation with the Dutch Ministry of Transportation, has realized a test system in Amsterdam (The Netherlands) for the extraction of mobile phone data and for the analysis of the spatial network activity patterns. This project is strongly connected to the earlier projects Mobile Landscapes in Graz (Ratti *et al.* 2007a) and Real-time Rome (Calabrese and Ratti 2006). Later on, this will be explained in more detail, as it is the project from which the authors will start their further research. The project does not focus directly on traffic patterns, but explores space–time relationships of telecom data and assesses its suitability to derive census proxies and dynamic patterns of the urban area, which in turn can be utilized to derive mobility indicators, showing the possibility of extracting near real-time data from cell phone use and to reconstruct the spatial–temporal patterns of the telecom network usage (www.currentcity.org, accessed July 29, 2009).

The main objective of this project is to address the problem of Incident Management (IM). The Dutch ministry of Transport, Public Works and Water Management is responsible for maintaining over 3,200 km of main roads, ensuring that the infrastructure is safe and in a good state, and that the flow of vehicles is as smooth as possible. Approximately 12% of the traffic jams on Dutch roads are the result of incidents such as crashes and vehicles shedding their loads (Ministry of Transportation and Water Management 2008). On a yearly basis there are about 100.000 incidents (Leopold and Doornbos, 2009), varying from small accidents to major multi-vehicle incidents causing casualties and vast damages to the road and its supporting structures. Incident Management (IM) refers to the entirety of measures that are intended to clear the road for traffic as quickly as possible after an incident has happened and to ensure safety for emergency services and road users (Ministry of Transportation and Water Management Netherlands 1999).

Several measures are currently considered to improve IM practices, under the guidance of the so-called ‘‘smart objectives’’ for the application of IM measures to the Dutch road network. Situation awareness for IM is the ability to understand the status and consequences of an incident in support of decision making. Situation awareness is essential to reach almost any other objective of IM improvement. The main purpose of this project is to provide a full picture of the mobility consequences and area consequences of an incident in near real time to create situation awareness for IM actors. Situation awareness has multiple facets. The project focuses on situation awareness for: (1) mobility and how it is affected by an incident, (2) the area surrounding the incident and (3) the site accessibility. The lack of a real-time assessment of the mobility consequences of an incident as well as of its consequences on the surrounding area hampers the decision making ability to respond to an incident and to manage its consequences. The project intends to exploits anonymous data from mobile telecom operators to create a real-time situation awareness of incident consequences, specifically:

- To detect how far the consequences of an incident reverberate on the road network and on the other mobility modes ;
- To anticipate on which other roads or transportation modes there will be congestion caused by an incident ;

- To assess the accessibility to the incident site ;
- To measure the risks for surrounding areas in case of incidents involving e.g. chemical releases.

More in detail, the project uses anonymised data of the KPN Mobile network. The data, represented by Erlang measurements and SMS counts, are used by the carrier to manage network quality. In the study area over 1,200 cells were identified, grouped in 8 LACs. It involves the city of Amsterdam and its surroundings, for an area of about 1,000 km2.

The first research goal in this project was how telecom data can be utilized for understanding presence and mobility in regular situations and during events where entire regulated flows of people are disrupted by an incident or an exceptional occasion like a football match, a music concert, a large celebration, serious traffic jams or a demonstration. This outcome could then be used to understand how a city or a mobility system can be measured, simulated and actuated to improve the quality of services provided to inhabitants (Vaccari *et al.* 2009). A first step to these goals is to create so-called normality maps (weekday–weekend and day–night patterns) over a longer period of time to be able to automatically detect anomalies.

The data have firstly been processed to generate different visualizations of the urban dynamics of Amsterdam. The primary features of the data are the weekday–weekend and the day–night pattern which affect all data. The weekday–weekend pattern is more or less pronounced depending on the area itself and appears to follow a rather predictable activity pattern within a certain range of variations. These patterns are in part the result of presence of people in a certain area and of people's mobility, but also of callers' behaviour, ranging from the obvious lower network traffic during the night to subtler behavioural caller changes that depend on the callers' context.

Figure 4.2 shows the effect of events on the network traffic. Around Queen's day (30 April), a major city gathering, the network activity peaks in certain areas such as the Rembrandtplein (the blue line), where street parties and celebrations take place, while it subsides in areas such as the World Trade Center (WTC, the red line) which shows typical weekend behaviors.

Figure 4.2: Day-night pattern and weekend pattern for the traffic at WTC and Rembrandtplein

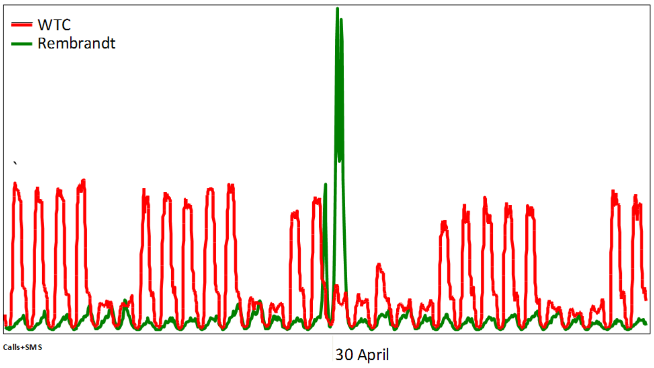
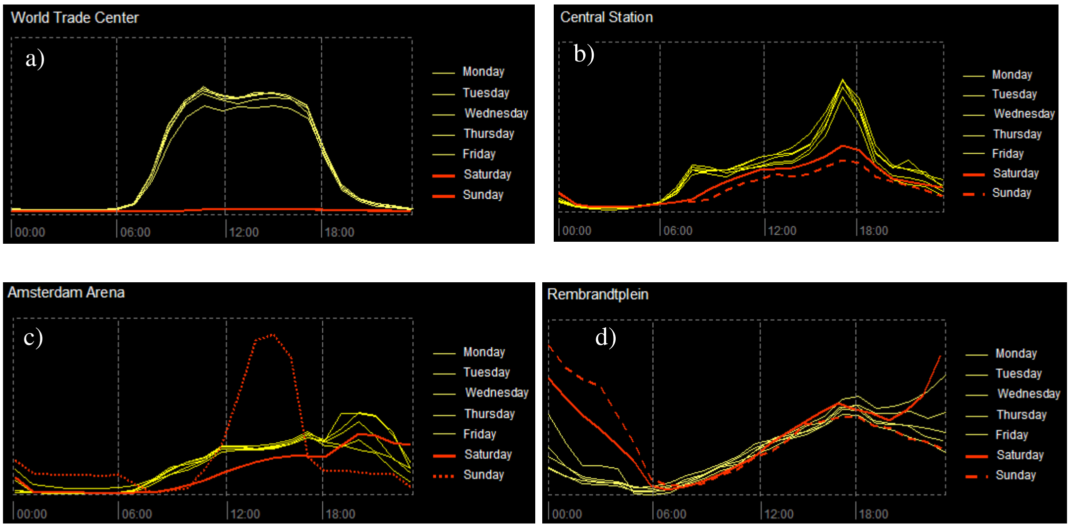


Figure 4.3: Call intensity in different Amsterdam city areas



Note: a) Business district, World Trade Center; b) Transport hub, Central Station; c) Football stadium, Arena; d) Entertainment nightlife, Rembrandt square. Source (http://www.currentcity.org/)

A more detailed data analysis in the project Current City has been carried out for a selected number of areas that are characterized by different land-use patterns and known differences in terms of how people use the area. The definition of the areas was based on the indications of the best serving coverage map overlapped to land use. The weekly patterns can be seen from the graph in Figure 4.3. The diagram shows for each day the average traffic (Erlang) over a period of 5 months (1 January – 30 May 2008). The data are normalized on the averages for comparison. Most areas, with the exception of Rembrandtplein and Arena, show a week-weekend pattern. Rembrandtplein does not respect the same pattern, and has a stable-increasing traffic during the weekends. The Arena, the area around the Ajax stadium, has a peak of activity on Sundays during soccer games.

The project Current City has presented the use of telecom data for the analysis of spatial network activity patterns based on a 1-h interval. Next steps in the project are a reduction to a 15 min time interval, a more detailed analysis of data validation and an improvement of visualizations. At the same time, some applications for crowd management, evacuation support for disaster management, incident management based on network activity patterns and traffic management for the inner city of Amsterdam where there are no detection loops will be developed.

4.5 Main research issues

4.5.1 Lessons

Road traffic analysis and prediction are two of the most attractive areas of use for mobile network data. Steady growing traffic volumes have led to enormous congestion and mobility problems, especially during the rush hours, both in urban areas and the highway networks.

While traditional measuring methods, such as road loop detectors, camera detection or floating probe vehicles, are effective and precise, there are practical and financial limitations to their use. Detection loops installed under the road pavement are regularly installed on highways but their application in urban environments appears as unfeasible given the number of roads that need to be monitored and the complexity of installation. Similar concerns can be raised for detection cameras, which are a feasible option for a limited number of measurement points. There is, however, an increasing need for less expensive monitoring systems and effective and reliable information systems.

It is not surprising therefore, that there is a growing interest in data derived from cellular networks to support the traffic parameters estimation without requiring expensive and complex installations of ad-hoc measurement systems. Looking at the results of the previous section, the first evidence that can be pointed out is that all projects so far are independently carried out, lacking any kind of cohesion among each other. Most studies are from telecommunications or electronics researchers, not from transportation researchers, and sometimes there are ambiguities in the definition of the traffic parameters to be obtained. More or less each of them proposes a different method to obtain a traffic parameter, given a mobile phone parameter. This means that the fil rouge mentioned in the introduction unfortunately has not been individuated.

However, all authors of the main reviews and applications in the field agree in considering that the following main issues affect any kind of study that would imply the estimation of traffic parameters from mobile phone data: issues regarding sample size and reliability, privacy, the role of private companies, and the role of transportation agencies (Caceres *et al.* 2008; Rose 2006). Usually these aspects are considered separately in the literature, but actually they are strictly tied one with another.

4.5.2 Sample size, reliability and accurancy

The possibility to exploit huge amounts of data from each person who carries a mobile phone in his/her pocket seems to solve the problem of small sample sizes, or at least it appears that having a sufficient sample size has a very competitive cost effect compared to expensive loop detectors field tests or camera surveys. However, it is not unusual that having lots of data could result in an indiscriminate use of them, regardless of their quality or of their peculiar meaning. According to the reviewed literature, there are different aspects to be clarified in order to identify the factors on which the right sample size depends, and they all relate to the moment of the data collection, or at least, to the modality of obtaining this data. First of all, the survey method or technology may influence the composition of the sample, which may be constituted by on-call phones only or by idle phones as well. Of course, having one or the other case drastically changes the size of the sample. The use of a sample of only on-call mobiles would guarantee higher accuracy, due to the stronger signal that the network receives from an active phone.

The survey area also has an impact on the sample size: if the data is collected on a motorway stretch, it is more likely that all the mobile phones surveyed are those inside the vehicle, which is not true for surveys carried out on streets in densely urbanized areas. Reliability of the sample is also related with the possibility to exclude from the survey the mobile phones carried by people that are not inside the vehicles, but simply walking, or travelling by bike, or by public transport, or inside a building.

Another issue that affects sample size and its reliability regards the difference between data coming from the real GSM network, without informing the subscribers using their ordinary mobile phones (e.g., data used in RealTime Project by MIT), or data coming from ad-hoc surveys, in which mobile users are informed and perfectly aware that they are being observed and agree in being tracked (e.g., the Mobile Century Project). In the first case, data are collected at a GSM network level, and therefore they cover big portions of the transportation network as well. However, data should be anonymised, and hence it is not possible to have any kind of control on them: this is the reason why so far this kind of data have been used only to obtain information about the behavior of aggregated groups of people and to study urban density and activity patterns, not to retrieve detailed traffic information. In the second case, the sample may be more reliable and useful to obtain traffic information, but of course it is smaller.

Finally, it is also possible that the cell phone in a car is used by a passenger. The presence of two, three passengers, each of them making a call with their own mobile, leads to uncertainty of counting the same car several times as the number of mobile phones that are inside it. As can be seen in Table 2, the accuracy issue, related to the precision with which the location information and traffic parameters are provided, is not at all negligible. In the first place, accuracy is affected by the methodology used for the collection; of course, the coupling of mobile positioning systems and GPS methods would improve very much the accuracy of the location information; such is the case of the Mobile Millennium project, which benefits from the precision of GPS systems, which may, however, not always be used for cost reasons. Therefore, it is important to create a balance between the accuracy needed for the application concerned and the costs to be afforded in order to achieve that level of precision. It is worth noting that, depending on the application carried out, each project and study, that involve the collection of data, cannot avoid to mention and justify the level of accuracy reached, as instead is the case in several projects. Clarifications are undoubtedly needed about the techniques to use in order to post-process the acquired raw data and isolate only the usable ones.

4.5.3 Legal issues

Besides technological and market developments, the adoption of wireless location technologies is influenced by security and privacy issues. In terms of privacy it is especially the tracking of people or goods transported which raises many privacy issues (Beinat *et al.* 2008). The use of mobile phone data from GSM network involves the cooperation of the carrier that provides them. This falls within the legal framework governed by regulations to protect the privacy of phone subscribers (Caceres *et al.* 2008). As defined by (Westin 1970) ‘‘Privacy is the claim of individuals, groups or institutions to determine when, how, and to what extent information about them is communicated to others, and the right to control information about oneself even after divulgating it’’. In this definition a person’s privacy corresponds to the control of that person’s information. This issue has been widely discussed in the literature, and it is one of the main problems that could hinder the opportunity to fully exploit the potential of WLT.

Legislators have addressed personal information in various laws, which have implications to location and sensor services. To protect personal data from an economic perspective, extensive attention is paid in the European law, in general and more specifically for use in electronic communications. Article 7 of the Charter of Fundamental Rights of the European Union (2000/C364/01) focuses on some general issues on the respect for private and family life: ‘Everyone has the right to respect for his or her private and family life, home and communications.’ Directive 95/46/EC provides the legal framework for the protection of individuals with regard to the processing of personal data (European Commission 1995), while Directive 2002/58/EC addresses location privacy specifically, stating that location data can be processed only after being anonymised or after having gained the consent of the user, why should be perfectly informed of the use that will be made of their personal data (European Commission 2002b). A way to solve this problem could be for telecom carriers to adopt an ‘opt in’ policy, for which users have to explicitly agree if their mobile phone may serve as a probe or must be excluded from the monitoring. The perception of users is that mobile phone data are extremely related to their private life, and a diffuse mistrust is spread among users who of course would avoid giving the permission to handle such private data (Ahas *et al.* 2008), thus not allowing mobile carriers to release detailed data.

For all these reasons, coming both from common sense and from legal acts, the phone location data should be received and handled in an aggregate and anonymous manner in accordance with current regulation like any other kind of information taken from the cellular network. In this way the use off cell phone data does not break the law on private data protection, as anonymous data does not associate information with specific users. Technological workaround to use anyway mobile phone data from individual users are still in an experimental stage (see e.g. Herrera *et al.* 2010), but this is an issue still under research.

4.5.4 The role of private mobile companies

In order to exploit the advantages with respect to traditional survey methods, Wireless Location Technology has to be carried out in agreement with private mobile carriers, so as not to have to organize ad hoc surveys with a limited number of informed users, but using all the universe of subscribers. In this case, another question arises. How many mobile carriers are active in an area? Most of the projects found in the literature, which could make use of this kind of data, have agreements with only one mobile carrier. What about the rest of the population, which makes use of different mobile companies for their communications? This issue is mostly taken into account only with ‘‘coefficients’’ that consider the market penetration of that particular mobile company. Therefore, sample size depends also on the willingness of the mobile carriers to make such data available.

Another aspect to be discussed is that most of the research carried out in this field is, indeed, a confidential matter of private companies, or restricted by agreements and patents. Maybe in the future, it will be possible to make use of this information, and new horizons will open for researchers, such as it happened when the military ‘‘Selective Availability’’ of GPS signal was ended by US in 2000, and a big amount of highly-accurate and reliable location data became available to civil institutions.

4.5.5 The role of transportation agencies

Governments and public authorities play an important role in stimulating both the development and implementation of wireless location technology to support traffic management, or to support their demand. There are a number of issues that need to be addressed like regulation on privacy, road safety, data ownership, performance requirements, interoperability, market structure and general economic services. In Fontaine *et al.* (2007) it is argued that transportation agencies have historically not defined suitable performance requirements for wireless location systems. Many deployments have lacked a well developed independent evaluation that quantitatively assessed the system performance. As a result, most projects were developed as a 'technology push' rather than technology which support the demand side. The symbiosis of business needs and IT capabilities creates the potential for a surveillance infrastructure, namely dataveillance. ''Dataveillance is the systematic use of personal data systems in the investigation or monitoring of the actions or communications of one or more persons'' (Clarke 1988). Dataveillance is a key concern in the adoption of location and sensor services where the government acts as the data collection hub. While regulations already provide a strict framework that, on paper, provides a high level of protection for individuals, this does not eliminate the concern that data collected for a legitimate traffic management use may eventually find other applications, either in the future or under different public order and safety circumstances.

On the other hand, transport agencies need to balance between a broad range of issues for creating the good conditions to stimulate the market to develop a new technology. These include the individuation of suitable performance requirements for wireless location systems so that validation studies can base their efforts on these target values. For transport agencies it is useful to collaborate in the early stage of promising research and development projects to understand the possibilities and limitation of the technology.

4.6 Conclusions

In this Chapter a broad overview of the present state of the art of the research in the field of the use of data from GSM networks for the estimation of traffic parameters has been provided. Although not going into the analytical details of how data are extracted from the cellular network, and how traffic parameters are estimated from cell-phone parameters, an articulated discussion of the main issues involved in this field of research has been given, raising many research questions, partly derived from the literature, but not yet or only marginally addressed, and partly coming from personal considerations by the authors. Since the GSM network was commercially launched in 1991, there have been indeed many studies and field tests carried out during the last 15 years with the original start of the CAPITAL project in 1994. The literature can be subdivided into two types of references: individual research groups that have prepared ad-hoc surveys for testing their own data processing and estimations, and big projects with the use of extensive datasets of cell phone data ad-hoc surveyed or coming from agreements with telecom operators. The following general conclusions can be drawn:

- Travel speed and travel time are the most studied estimation issues for traffic management purposes by using mobile phone data;
- Projects are often initiated by technology providers, telecom operators and transport agencies.
- Validation studies are mostly carried out by research institutions;
- The adoption of GSM data is still limited and it is a field still largely dominated by research and development. Technology is promising but not yet developed to the degree necessary for large scale utilization;
- Most of the studies focus on stretches of roads, or loops, and not on a road network level;
- Recent studies show more promising results; however transportation agencies have historically not defined suitable performance requirements for wireless location systems, which may cause ambiguities in validation studies to draw clear conclusions;
- Active systems, like GPS-equipped phones used in the Mobile Millenium project, where thousands of users agree to place these phones in their vehicles in order to transmit positioning data and receive free live traffic information, look very promising;
- Extraction of telecom network data for the analysis of the spatial network activity patterns used in the projects Real-time Rome and Current City Amsterdam opens new possibilities in using such aggregated data for traffic management.

Data from cellular phones undoubtedly open new and important developments in transportation engineering but this requires a careful analysis. Hence, there are a number of steps needed to achieve a significant confidence in the use that can be made of these data. First of all, indeed, data should be validated. For traffic management related activities, this validation can be made by comparing data obtained from cell phones with data collected with other “on-site” systems like for example video cameras or navigation systems. Obviously this should be done in different road conditions (freeways, arterials, urban roads) in order to understand the possible range of applicability. Another way to validate data collected could be to compare the estimated density of people with census data during periods with a higher probability to have people at home (for example, the early evening or the Sunday afternoon, depending on the social context). This Chapter is the first step of a study whose aim is to further investigate data deriving from the project Current City Amsterdam; the next phases of the research will include the development of a validation methodology of this data using loop detector data as ground truth, and the study of new applications in the field of traffic management. Especially for contingency management (e.g. traffic accidents, network disturbances caused by terror attacks or nature catastrophes) the use of cellular phone data may be of strategic importance in the future.

5 Mobile Phone Data to Support Traffic Incident Management*

5.1 Introduction

Traffic incident management is a complex undertaking. Incident Management (IM) is conceived of as the entirety of measures that are intended to clear the road for traffic as quickly as possible after an incident has happened, ensure safety for emergency services and road users, and control the damage (Dutch Ministry of Transportation and Water Management, 1999; US Federal Highway Administration, 2000; EasyWay, 2011). In practice IM is a set of measures that aims to minimise the negative effects on security, safety and traffic flow conditions, by reducing the clearance time following an incident. Clearly, road networks are part of a country's transport infrastructure and are therefore subject to general transport security and safety policies and measures.

Since the early 1970s, everywhere in the developed world, steadily growing traffic volumes and traffic intensity have led to enormous congestion and mobility problems, especially during the rush hours. Traffic jams can be structural (recurrent) or incidental (non-recurrent). 'Structural' (recurrent) means that they regularly recur on the same roads at the same times, because the traffic demand is greater than the available road capacity. 'Incidental' (non-recurrent) traffic jams are the result of accidents, road works and major events (Marchesini and Weijermars, 2010). These can be predictable events as in the case of road works, planned events such as sport matches or festivals, or unpredictable events like accidents, extreme weather conditions and terrorist attacks which have a direct impact on the road infrastructure in terms of capacity. When the incidents are unintentional, then we deal

* Based on: Steenbruggen, J., Borzacchiello, M. T., Nijkamp, P. and Scholten, H. (2012). Data from telecommunication networks for Incident Management: An exploratory review on transport safety and security. *Transport Policy* 2012, doi:10.1016/j.tranpol.2012.08.006.

with safety issues, whereas security issues arise when the incidents are caused on purpose for harmful reasons.

Road traffic injuries in the European region are a major public health issue, and are responsible for about 31 thousand lives per year[13]. Over 1.2 million people die each year on the world's roads, and between 20 and 50 million people suffer from non-fatal injuries. The WHO predicts that road traffic injuries will rise to become the fifth leading cause of death by 2030 (World Health Organization, 2009b). Therefore, the topic of traffic IM is one of the key concerns in transportation policy. Safety has always been a policy issue. Legislation imposing speed limits, mandating seat belts, and other measures have sought to make travel safer. These continue to proliferate. However, it is the area of security that the most recent set of policy initiatives have been drawn. For example, screening of people and freight or data security has become a major concern since 9/11.

Besides the direct impacts in terms of property damage, injuries, fatalities and other road security and safety effects for road users nearby traffic incidents, they are also relevant for mobility (Knibbe *et al.* 2006, 2007). Incidents can quickly lead to congestion and associated travel delay, wasted fuel, increased pollutant emissions and higher risks of secondary incidents. They are an important cause of congestion and increase the total cost of traffic congestion.

IM calls for real-time use of accessible traffic information. There are nowadays many sources of traffic information, but in this study we will pay attention in particular to the potential to derived traffic information from telecommunication networks, in particular the ones concerning mobile (cellular) phones. The aim of this Chapter is, therefore, to review the use of electronic data - especially GSM data - to improve the situational interface in order to aid incident response managers in a complex decision-making process. Situation awareness, intended as "*knowing what is going on around you*", is essential to reach almost any other objective of IM improvement. This is part of a wider study, whose aim is to provide a full picture of the mobility consequences and area consequences of an incident in near real time so as to improve situational awareness for IM actors or managers.

[13] http://ec.europa.eu/transport/road_safety/specialist/statistics/trends/index_en.htm

It is worth noting that there is some division within the literature concerning the definitions of ‘accident’ and ‘incident’. A ’road traffic accident’ can be defined as ‘the product of an unwelcome interaction between two or more moving objects, or a fixed and moving object’ (Whitelegg, 1987). An ’incident’ is defined as any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand. Such events include traffic crashes, disabled vehicles, spilled cargo, highway maintenance and reconstruction projects, and special non-emergency events (e.g. football games, concerts, or any other event that significantly affects roadway operations) (US Federal Highway Administration, 2000).

5.2 Electronic footprints

We will introduce the IM policy issues of the present Chapter with a general discussion of electronic data. In recent years, we have seen a rapid acceptance and use of individually-based space-time data in the transportation sector. In particular, the use of electronic data for traffic management, logistic operations, and IM is remarkable.

Spatio-temporal tracking and tracing data are not only useful for general traffic management purposes, but also for IM (e.g. non-recurrent traffic jams as a result of an accident). IM is one of the main ingredients of a dynamic traffic management system that aims to provide efficient, smooth, secure, safe, reliable and sustainable transportation flows. To this end, a traffic management centre uses normally various information sources, such as induction loops, cameras, and other monitors (including human observers). The traffic centre in charge of controlling traffic flows may use VMS (Variable Message Signs), speed limitation signs, ramp metering, rerouting, and other measures for effective incident management. Traffic management aims to offer a wide range of prevention and abatement measures in order to minimize the costs of traffic incidents by optimizing detection time, warning time for emergency services, travel and operation time for emergency vehicles, normalization and flow recovery time. Clearly, reliable data have to be used to organize all support measures effectively in case of incidents. In this context, geo-science technology may play an essential role. In addition to the use of GPS data, the awareness is growing that GSM technology may be another source of rich space-time information on individuals or objects (see also Hale, 1997; Papageorgiou, 1991; Punzo *et al.*, 2009; Turoff *et al.*, 2004).

The use of wireless location and cell phone data appears to offer a broad range of new opportunities to create sophisticated and less expensive applications for traffic management. There are indeed many advantages compared with other technologies, but there are still some important issues that need to be resolved: in particular, factors that influence accuracy, reliability, security, privacy and data quality, as well as techniques used for validation (Steenbruggen *et al.*, 2011). Another important issue is the effective use of electronic data. This concerns the performance requirements of transportation agencies, privacy issues, road security and safety implications of mobile phone use, data ownership, business models and public-private partnerships to deploy, test, improve and implement new technologies. Understanding the accuracy, reliability and timeliness of the required data is necessary for any data collection system to create value-added services (Richardson *et al.*, 1995; Hearn, 1995; Paterson *et al.*, 1999). These quality indicators are directly related to the usefulness of the information derived and also depend on the way technologies are deployed. There are differences in data quality requirements associated with different end-uses of data (Caceres *et al.*, 2008). Data may well be collected in real time, but the timeliness with which those data are made available may place limitations on potential applications. For example, accuracy and timeliness are very relevant to determine whether the data support real-time information systems, such as incident detection, or near real-time applications to provide travel time information to road users (Rose, 2006).

The acceptance of electronic data for traffic and incident management is rapidly increasing, although many applications are still at an experimental stage. The majority of field tests have attempted to monitor freeways in urban areas. Such sites were often selected, since there is a clear need to monitor traffic in congested urban areas, and they have a dense network of point detectors that can be used to calibrate and validate the performance of wireless location-technology monitoring systems. In addition, they tend to have more robust cell coverage, a higher traffic volume, simpler path estimations, and higher frequencies of handovers (Fontaine and Smith, 2007). Relatively few applications have attempted to monitor arterial roadways; they face additional complexity, such as more path possibilities, correct filtering devices in vehicles, and so forth.

Cellular phone carriers have the ability to collect and store aggregated location data on hundreds of millions of subscribers. This means that the size of cell phone samples is very high. However, obtaining a sufficient sample size of probe phones is important for reliable estimations of traffic data and for calibrating models based on aggregated measures. Rose (2006), for example, argues that probe fleet size has a direct implication for the sample size available. Different studies show that a probe fleet size between 3000 to 5000 vehicles could provide reasonable travel times in denser areas (Boyce *et al.*, 1991; Longfoot, 1991; Srinivasan and Jovanis, 1996). Of course, reliable real-time spatial information data are essential for the precise geographical positioning of people and objects. This will be considered in the perspective of space-time geography in the next section.

5.3 Space-time geography and digital data

Since the 1970s there has been a large number of statistical models applied to the understanding of road accidents. However, these models have had a tendency to neglect the spatial patterns of road accidents (Anderson, 2006). Historically, it has been argued by Whitelegg (1987) that geographers have not paid enough attention to the geography of road traffic incidents. For many years, it was considered by police, local authorities and road engineers, that road engineering, road layout, and vehicle manufacturing faults were the main causes for road incidents. However, it has become evident through increasing police awareness and related research that road incidents need to be seen in a broader geographical perspective (both spatial and temporal).

Whitelegg (1987), in his paper 'The Geography of Road Accidents', seeks to understand road traffic incidents with reference to the scale of analysis and the importance of focusing on the neighbourhood and community scale for an answer to the reduction of incidents (see below). Whitelegg then outlines the strong links between road traffic incident analysis and other geographical dimensions such as population density distribution and spatial design of neighbourhoods. There is a need for detailed quantitative analysis of individual mobility.

The history of quantitative data analysis in transport geography now already spans several decades. In the 1980s, the need for a more appropriate behavioural underpinning of spatial interaction models led to the emergence and popularity of discrete utility (or choice) models, in particular multinomial logit and probit models, later on followed by conjoint analysis modelling. Such individually-based models were proven to be consistent with aggregate-oriented spatial interaction models, and were widely accepted in the transport research community. They also turned out to be eminently suitable for actor-based policy simulation experiments, for instance, in the context of micro-simulation models and agent-based models.

All such models were widely used for prediction purposes, evaluation experiments and policy analyses in the planning and transportation science field: for example, to trace the system-wide effects of road pricing on the behaviour of car drivers. With the advent and introduction of ICT (Information and Communication Technology), the computing capacity in quantitative research showed a dramatic increase, so that spatial dynamics could also be captured in a statistically more satisfactory way. In recent years, complexity theory has made a remarkable contribution to a better understanding of the sensitivity of spatial systems evolution to endogenous non-linear space-time behaviour. Space-time dynamics (e.g. in the cellular automata domain) became an important ingredient of advanced transportation research and spatial analysis, and prompted a new departure, viz. the use of data mining methods for large data sets. The current use of computational neural networks and genetic algorithms demonstrates convincingly the great potential of more sophisticated data collection techniques. The real essence of space, as highlighted in Tobler's (1970) law *("all things in space are related to each other, but nearby things are more related than distant things")*, was taken up in a new strand of the literature addressing spatial - and spatio-temporal - autocorrelation, either as testing devices or as design mechanisms for spatial (dynamic) models (see also Tobler, 2004). Cellular automata, spatial filtering techniques, and self-organized mapping procedures ('Kohonen maps') for spatial interaction analysis were a logical follow-up and complement to the above-mentioned trends (see, e.g., Codd, 1968; Couclelis, 1997; Kohonen, 2000; Kulkarni *et al.* 2002; Patuelli *et al.*, 2010; Arribas *et al.*, 2010).

In recent years, we have witnessed the increasing popularity of Location-Based Services (LBS) and data using various kinds of electronic identification systems, so that at an individual level (a traveller, a container, a truck, or a taxi) the geographical position of a unit can be traced with great precision. Many applications are available both for purchase and for free to cell phone and other wireless device users. For example, Japanese parents are using location-based tracking devices to monitor the spatial movement of their children. This new approach will certainly generate many new applications in space-time geography.

An interesting source of individually-based information on the space-time position and behaviour of persons is in principle available from mobile (or cell) phone data derived from the GSM network. The penetration rate of mobile phones is rapidly reaching a saturation point in most OECD[14] countries, so that a system-wide coverage does in principle exist, almost in continuous space-time format. Such data - as very accurate representations of the individual space-time location - are in principle available from telephone operators. If such data - in anonymous form - could be made available to the research community, an unprecedented source of information on the space-time geography of individuals could be used in applied research (for an overview, see Steenbruggen *et al.*, 2011).

It is noteworthy that this idea of a continuous space-time map at an individual scale was already put forward by the late Swedish geographer Torsten Hägerstrand in 1967. He introduced the ‘space-time cylinder’ and its related time-space model to provide a description of both individual space-time patterns and the resulting spatial interactions, if many individuals were ‘en route’ at the same time and place, a situation caused by the universal limited supply of daily time resources. His work was regarded as a new perspective in social-behavioural geography, as it highlighted so clearly the essence of interaction and congestion phenomena in space (see Pred, 1977). Three constraints appear to act on the daily mobility pattern of individuals, viz. capability constraints, coupling constraints, and authority constraints. He also laid the foundation for activity-based transport geography, but, unfortunately, lack of data and the technology available to implement this framework often precluded a full operational application of his path-breaking ideas. Now with the potential availability of large-scale continuous space-time information databases on the spatial movements of individuals, a really interesting novel approach might be developed, which could have great implications for spatial modelling. Two such approaches can be found in the literature. The first incorporates elements of cognition by considering individuals’ preferences via the theory of affordances proposed by Gibson (1979). Cognitive constraints, e.g. choice

[14] Organisation for Economic Cooperation and Development

behaviour, were not given explicit attention in the original time-geography framework. These constraints can help personalize LBS, providing the possibility to collect more detailed information about the choices individuals make. The second approach adjusts the space-time prism concept to support interactions and activities between physical and virtual spaces (Yu and Shaw, 2008). This approach would help to model and understand how, in the age of mobile computing where a variety of activities and services can be carried out on the go, individuals are allocating their space and time resources. This will be further highlighted in the next section.

5.4 Location-based services and context awareness

Location is historically recognized as a strategic asset of cellular network providers (Teckinay, 1998). One of the most powerful ways to personalize mobile services is based on location. The use of this information enables users to experience value-added services and the cellular network provider to offer differentiation and incremental profitability by increasing its subscriber base (Drane *et al.*, 1998). The concept of LBS has become increasingly important to create intelligent information services in a broad range of domains. LBS are information and entertainment services, accessible with mobile devices through the mobile network, and which utilize the ability to make use of the geographical position of the mobile device. For example, in 1991, the European Union established 112 as the universal emergency number for all its member states (European Commission, 1999). E-112 is a location-enhanced version of 112, introduced in 2003 by the E-112 Directive (European Commission, 2003d). The telecommunication operator transmits the location information to the emergency centre. The public telephone network operators receiving calls for the emergency should make the caller's location information available to the authorities in charge of handling emergencies (European Commission, 2002a). The E-122 Directive requires mobile phone networks to provide emergency services with whatever information they have about the location from where a mobile call was made. This directive is based on the US Federal Communications Commission's (FCC) Enhanced 911 ruling in 2001. The E-112 was the driving force to invest in location-based technology (Yuan and Zhang, 2003; Kumar, 2004).

Location is the most important element to create context-aware services. Definitions of context-aware computing date back to the 1990s, the period in which Olivetti developed several context-aware applications based on what are called ‘active badges’ (Want and Hopper, 1992). Context plays a central role in human behaviour and activity, and in the way we use technology. However, it has historically been ignored in computer science (see Broens, 2004). Computers were designed as far as possible to be black boxes to enhance their abstracting power, overcome complexity, and safeguard their reliability. An important reason why context awareness of computer devices has never been a major issue is that most interaction between computer and humans has, for a long time, taken place in office-like situations with immobile desktop computers.

In the last 15 years, however, we have also witnessed a clear trend towards embedding computers in a variety of devices. Computers are becoming smaller, lighter, cheaper and at the same time more powerful. We can find microprocessors in a wide range of devices, from mobile phones, smartphones, handheld computers or cameras to electronic postcards, toys for children or home appliances. A standard car has dozens of microprocessors, while the premium car can have more than a hundred. We can also see embedded computing beyond the personal devices. Motion sensors, electronic tags or surveillance videocameras are all examples of equipment supporting collaborative work among people. The embedded computers, being part of our everyday, physical world, bring new requirements for Human-Computer Interaction (HCI). Research on this matter has been framed using names such as ‘*ubiquitous computing*’ (Weiser, 1991; 1996), ‘*pervasive computing*’ (Ark and Selker, 1999), ‘*embodied interaction*’ (Dourish, 2001a, 2001b), ‘*tangible interfaces*’ (Ishii and Ullmer, 1997), and others. These research directions may contribute on slightly different topics, but they all address HCI beyond the traditional desktop environment, where computing is embedded in the fabric of the world around us.

The idea behind ubiquitous computing is that it provides people all kind of support and automatic services, anytime, anywhere, based on their personal needs and preferences and on their current context. It includes concepts of context-aware computing and all kinds of possible sensors to detect the relevant aspects of the user-environment. Striving for a definition, Lyytinen and Yoo (2002) describe mobile and pervasive computing as conceptually different. While mobile computing is about “*increasing our capability to physically move computing services with us*”, pervasive computing is focused on the integration aspects. It is described as computers having the *"capability to obtain information from the environment in which it is embedded and utilize it to dynamically build models of computing"*. Ubiquitous computing is, according to Lyytinen and Yoo, the domain where mobile and pervasive computing meet. It means that "*any computing device, while moving with us, can build incrementally dynamic models of its various environments and configure its services accordingly*". From a systems point of view, ubiquitous computing implies interconnected, communicating networks of numerous, casually accessible, often invisible or very tiny computing devices, either mobile or embedded in almost any type of object imaginable, including cars, tools, appliances, clothing and various consumer goods. A field with an extensive literature related to ubiquitous computing and context-aware computing is that of ambient intelligence (see, for instance, Weber *et al.*, 2005). Ambient intelligence is seen as the convergence of several computing areas including ubiquitous or pervasive computing, context awareness, and intelligent systems research.

Obviously, one of the great challenges within ubiquitous computing research is to understand the relation between computing and the context in which it is embedded. What is the HCI impact of continuously changing social, spatial, temporal, or technical settings? An even greater research challenge (see Abowd and Mynatt, 2000) is to explore how computation can be made *sensitive* to the setting, and thus provide appropriate, tailored services to the user. The theme is recognized as context-aware applications.

		Place: Independent	Place: Dependent
Time	Independent	**1. Anytime, anywhere**: Tasks that can be done independent of time and place. They can be done anytime, anywhere.	**2. Anytime, particular place**: Tasks that need to be done within on a particular place but can be done whenever.
Time	Dependent	**3. Particular time, any place**: Tasks that can be done independent of place but at a certain time or in a certain order.	**4. Particular time, particular place**: Tasks that must be done on a particular place and on a particular time.

Figure 5.1: Categorization of tasks along place and time (Source: Wiberg and Ljungberg, 2001)

Context awareness and ubiquitous computing go hand in hand with the new paradigm of *'access anytime, anywhere*'. They entail a new research question on the merits of the activities carried out: Does the type of context influence the type of tasks? And, vice versa, do different tasks require different contexts? On this issue, Wiberg and Ljungberg (2001) propose the matrix shown in Figure 5.1, to categorize work tasks in terms of their geographical and temporal components. This matrix is based on the assumption that many tasks require a specific place and time to be done, so it decouples the concept of ubiquitous computing from the paradigm of '*access anytime, anywhere*'. In addition, it justifies the need to shed new light on which tasks are more or less place- and time-dependent. Vice versa, different locations and times may also determine the relevance of tasks, as well as the needs of those who carried them out. Time and place, in other words, are here considered as essential elements in classifying computing types, and form the basis of four main context classifications.

5.5 Collective sensing and security

Homeland security, transportation operations and public safety operations are intertwined in many respects. Homeland security and public safety providers (by law enforcement), fire and rescue services, and emergency medical services ensure safe and reliable transportation operations by helping to prevent crashes and rescuing crash victims. Conversely, the transportation network enables access to emergency incidents and, increasingly, provides real-time information about roadway and traffic conditions. Social media sources like Twitter, Facebook, Panoramio, Flickr and Foursquare creates new channels to collect, generate, share, circulate, and exploit information, as well as generating a different type of information (personal comments and insights).

These sensor concepts concern the emerging discipline of making sense of aggregated anonymous individual sensor data and traces to understand the dynamics of an industry, city or community. This trend is becoming so clear that the terms location services and sensor-based networks are merging into a new concept of 'Collective sensing'. This concerns the use of information activity to "detect" in real time the static and dynamic patterns of space utilization of a certain area, city, region or even and entire country. This information is the basis to understand the dynamics of a complex environment on the basis of real-time information, and to use it for operational decision making (e.g. emergency services), strategic decision making or consumer services. We define 'Collective sensing' as "the ability to reconstruct collective human behavior from individual anonymous digital traces which have a direct or indirect relation to a social collective phenomena". The sense of collective sensing lies in concepts such as 'digital footprints' (Girardin *et al.*, 2008a), 'digital signatures'

(Calabrese *et al.*, 2010b) and 'spatio-temporal signature' (Girardin *et al.*, 2008b). The large deployment of pervasive technologies has led to a massive increase in the volume of records of where people have been and when they were there. The digital traces left by individual people while interacting with cyber-physical spaces which are accumulating at an unprecedented breadth, depth and scale (Zhang *et al.*, 2010). These records are the digital footprint of individual mobility pattern (Liu *et al.*, 2009). An equivalent term used in literature is 'Digital Sociology' (see http://www.danah.org/researchBibs/sns.php, Last accessed September 19, 2010).

The key obstacle to effective emergency response is the communication that is needed to access relevant data or expertise and piece together an accurate understandable picture of reality (Hale, 1997). Next to social media sources, also data from mobile phone networks can provide new ways of using information for homeland security, transportation and public safety operations.

However, the adoption of wireless location technologies is influenced by security and privacy issues. Legislators have addressed personal information in various laws, which have implications to location and sensor services. For example Directive 95/46/EC provides the legal framework for the protection of individuals with regard to the processing of personal data (European Commission, 1995), while Directive 2002/58/EC addresses location privacy specifically, stating that location data can be processed only after being anonymised or after having gained the consent of the user, why should be perfectly informed of the use that will be made of their personal data (European Commission, 2002b).

In recent years data deriving from mobile phone networks have attracted the attention of researchers, in particular in the emergency field in order to improve the situational interface. Examples are:

- Agent-Based Modelling simulations to provide emergency responders with timely information on the status of a city or region, as well as the capability to detect, follow and possibly predict crisis events (WIPER project) (Schoenharl *et al.*, 2006a; Schoenharl *et al.*, 2006b; Madey *et al.*, 2006; Madey *et al.*, 2007; Pawling *et al.*, 2008b);

- A simulation system that models the evacuation base on autonomous intelligent agents which are used to represent various types of actors and study the effect of different disaster scenarios and types of agent behaviour (Filippoupolitis *et al.*, 2008);
- A visualization interface for emergency responders for detection, warning, response, and mitigation based on cell phone data (CAVIAR project) (Vaidyanathan *et al.*, 2008a,b; Vaidyanathan, 2010a,b; Vaidyanathan and Johnson, 2011);
- Telecom sensors used in the case of emergency evacuations (Inoue *et al.*, 2008)
- Issue and distribution of early warnings using cell-broadcasting on GSM phones to citizens (Wood, 2005; Pries *et al.*, 2006; Sillem and Niersma, 2006);
- Integrated mobile information and communication system for emergency response operations (MIKoBOS project) (Meissner *et al.*, 2006).

Traffic IM is a much more limited domain than general emergency management; however, it can be seen as a special case of emergency response. To a certain extent, the examples above can also be applied to study a traffic IM system based on data from mobile phone networks. This will be the subject of the next section.

5.6 Incident management and safety/security issues

Avoiding incidents is an even more important issue than developing strategies and technology for efficient incident response. The emergence of an incident is determined by a combination of causes. In many cases, human or technical failure plays an important role, e.g. driver distraction, alcohol abuse or motor breakdown (Wegman, 2007). However, these factors are more likely to cause an incident, if external conditions complicate the driver task, e.g. critical traffic, road or weather conditions. Therefore, preventing incident occurrence is possible for at least a fraction of all incidents for which critical traffic or weather conditions are dominant causes. Hence, strategies to prevent incidents are of course preferable, in terms of safety and mobility, to strategies designed to respond to incidents which have actually already happened.

Victims of the primary incident, emergency workers, road users (upstream of the incident and on the other side of the road), and people living near the freeway around the incident are the most important risk groups who are exposed to additional risks when an incident occurs (Knibbe *et al.*, 2006). By the term 'risk' we mean the risk of being in a secondary incident. Incidents have a direct effect on the safety of a number of the aforementioned risk groups. These risk groups are used to determine the 'group-specific' effect and the overall effect of an incident on safety, as well as the impact of IM measures on safety. The victims of the primary incident and the emergency workers usually remain in the middle of the road during incidents, which increases the probability of a secondary crash. Road users on both sides of the road often have to deal with congestion around incidents (Knibbe and Wismans, 2007). The difference in speed, at the interface between the tail of the traffic jam and uncongested traffic, is a factor for the probability of a secondary incident (Aarts, 2004).

Looking closely at Europe, there are many European initiatives to use new in-car technology, security and cooperative systems to increase safety for road users. However, for a long time, the European Union was unable, to implement the common transport policy provided by the Treaty of Rome (EEC, 1957), due to the different and sometimes conflicting objectives of each Member State. This led to a mixed performance in terms of congestion problems based on a growth of transport in an enlarged European Union with the effect of imbalance between different transport modes. The Treaty of Maastricht (EU 92/C/191/01) reinforced the political, institutional and budgetary foundations for transport policy which included the concept of the Trans-European Road Network (TERN). This resulted in 2001 into the EU white paper "*European transport policy for 2010: time to decide*" (Directive 2001/370/EC) which includes 60 specific measures. Related to traffic IM the most relevant are improving quality and security in the road transport sector and putting back users at the heart of transport policy by improving road safety. In 2011 this white paper has been updated "*Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*" (Directive 2011/144/EC). Since 2001 a lot has been achieved. The safety and security of transport across all modes have increased. Security can be seen as the set of actions through which safety is ensured, in particular against intentional threats. It encompasses all measures, actions or systems aiming at preventing intentional threats from compromising safety.

The new European goal is a 'zero-vision' on road safety, which means no casualties, including harmonize and deploy road safety technology and develop a comprehensive strategy of action on road injuries and emergency services. Another important goal on land transport security is to establish a permanent expert group with a special focus on urban security issues.

The white paper concludes that the fragmentation of research and development efforts in Europe is most harmful. A specific goal is to identify the necessary innovation strategies and deploy large scale intelligent and interoperable technologies as the "*Intelligent Transport Systems*" (ITS) to optimize the road capacity and the use of infrastructure. EasyWay implements most part of the Intelligent Transport Systems (ITS) action plan (see Directive 2008/886/EU). A new legal framework was adopted to accelerate the deployment of these innovative transport technologies and is an important instrument for the coordinated implementation to establish interoperable and seamless ITS services (Directive 2010/40/EU). EasyWay has defined its priority ITS services, so called "*core services*", to be implemented in the coming years (EasyWay, 2010c; EasyWay, 2011). The ITS Action Plan (European Commission, 2010) especially focuses on safety and security:

1. Promotion of in-vehicle safety systems
2. Introduction of Europe-wide eCall
3. Regulatory framework on safe human-machine interfaces including nomadic devices
4. Best-practice guidelines: impact of ITS on vulnerable road users
5. Best-practice guidelines: secure parking places for trucks (ITS support)

A good example, which is directly related to the IM situation interface is the project '*e-Call'*, which stands for 'Pan-European in-vehicle emergency call system'. e-Call gives the precise coordinates of an accident's location to the emergency services, which are responsible for the follow-up assistance. eCall is part of the *e*Safety[15] initiative led by the European Commission (see Directives 2001/370/EC; 2003/311/EC; 2003/542/EC; 2005/431/EC; 2006/59/EC; 2006/723/EC).

[15] http://www.esafetysupport.org/en/welcome.htm

According to an analysis conducted by the European Commission supported by the wider European project E-MERGE, eCall is supposed to achieve a reduction in accident detection time of about 50 per cent in rural areas and up to 40 per cent in urban areas. As a consequence, the time period between the occurrence of an accident and its clearance is reduced. eCall also aims to decrease congestion by 15 per cent, which will lead to a reduction in fuel consumption and thus less harm to the environment.

Recently, on 31 December 2009, the new ISA (Interoperability Solutions for European Public Administrations) program replaced the activities of the 2004 IDABC program and delivered an European Interoperability Framework (EIF) draft version 2.0 (ISA, 2009). The EIF 2.0 add a legal level and a political context to the interoperability levels as originally defined by IDABC (Directive 2004/387/EC). Legal interoperability focus on an aligned legislation so that exchanged data is accorded proper legal weight in terms of security and privacy issues. The political context make sure that cooperating partners have compatible visions, aligned priorities, and focused objectives.

5.7 Review of telecommunication research direction for IM

Incident prevention, as mentioned before, includes all necessary activities to avoid traffic incidents to occur. Collective sensing technology can support the security and safety issues of different traffic IM phases. Examples of collective sensing information are the use of social media, camera technology and telecom data. In terms of security, these technologies contribute the most in the prevention, detection and verification phases. The concept of collective sensing can be integrated in the concepts of net-centric working, Common Operational Picture and shared Situational Awareness as described in Steenbruggen *et al.* (2012b).

The Dutch project ‘Secure Lane’ is a nice example of the use of camera technology (CRIMINEE!, 2011). This concept is based on a net-centric approach to support safety chain based on intelligent camera and detection technology. This security concept was developed as a public-private partnership for services areas on motorways, truck stops and industrial areas. Main goal of these services are object security, maintain public order and safety, and law enforcement. In the pilot phase these cameras are located on different location on three main highways in the Netherlands (direction Venlo - Rotterdam A16, A58 and A67). The number plate of every vehicle is registered and compared with a black list. Next to that, also the car movements and aberrant behaviour are monitored based on combining information of different cameras. This camera security concept supports information sharing between public and private partners and improves safety by proactive security measures. In case there is a security alert, the central police is directly informed and camera data is shared for immediate action.

Another interesting area is the use of mobile phone data. Mobile telecommunication networks are complex distributed systems producing huge amounts of data continuously. The data are collected to form databases and used for network monitoring and management tools. These data include, for example, performance measurements from the radio interface and log data from application servers. A daily data set from an operational GSM network may consist of several gigabytes of data.

A major issue for emergency response managers is the problem of '*information overload*'. Studies have shown a correlation between abundant available data and bad decision making in crisis situations (Smart and Vertinsky, 1977). Good emergency response systems provide access to the large amount of available data, in such a way that the emergency response manager can use the data effectively to reach good decisions (Belardo *et al.*, 1984; Jennex, 2007). Situational awareness, which is mandatory for the successful monitoring and decision-making in many scenarios, is one of the founding characteristics of intelligent software agents. An '*agent*' can be defined as "*a computer system that is capable of flexible autonomous action in dynamic, unpredictable, typically multi-agent domains*" (Luck *et al.*, 2005).

A characterizing feature of agents is situational awareness: the agent receives sensory input from its environment and it can perform actions which change it in some way (Kowalski and Sadri, 1999). When combined with reactivity, situational awareness may lead to the early detection of anomalies and to the formulation of a suitable plan for solving them. In Florez-Larrahondo (2006), the integration of intelligent anomaly agents and traditional monitoring security systems for high-performance distributed systems is discussed.

In the present section, we will explore some theoretical concepts and tools from the literature and similar projects (e.g. Real-time Rome, WIPER, CAVIAR) to examine if telecommunication data could be a useful source to improve the security and safety of the IM process. We will focus on three different research directions, which are strongly related to improve situational awareness, proposing some research questions that could help shaping future strategies.

5.7.1 Security and safety for surrounding areas

Real-time forecasting models for the prediction of potential risks in the case of major incidents with dangerous goods for emergency services, road users, and people living near the freeway are currently not available. A forecast of the combination of incident hotspots and the real-time presence of people based on normality maps (spread over day - night, week - weekend pattern) could give useful insights on which areas are affected by the highest potential risks, and which people could be potentially affected. Near real-time counts of people represent the number of people in a certain area at a certain time. The areas can be an entire urban agglomeration, a specified zone, or an arbitrarily defined grid element.

Traffic incidents may also cause broader spatial externalities. Present societies are vulnerable to natural, industrial and man made disasters, as well as to daily traffic accidents. Major incidents (e.g. with a dangerous substance involved) on the freeway have a direct effect on the safety of the people passing close to the incident location. Currently used risk maps[16] give a static overview of the potential risks for specific areas. There is a strong need for information systems to ensure security of the surrounding areas.

Responding to incidents that involve chemical or hazardous goods requires a high level of preparedness and a precise knowledge of how many people could be exposed in the incident area (see for example, Figure 5.2). Current risk maps give a static picture of the risks, based on information from the census or other regular surveys. However, emergency operations need more than this. The current number of people affected, rather than the expected number of people affected, dictates the extent, the size, and the organization of the rescue operations. Also tracking and tracing systems could support the transport of hazardous goods.

[16] http://www.risicokaart.nl/

The following interesting research questions can therefore be raised:

- How many people are are affected by an incident and its (which can be defined by a circle with radius x) at a certain time (i.e. day – night, week – weekend, at a certain time)?
- How many lives could be saved by a more effective directed intervention?
- How could this affect the organization of the emergency and of the support infrastructures such as hospitals?
- Which telecom data give the best estimates of the presence of people?
- What will be the best location area to define ground truth for calculating the presence of people (i.e. street level, telecom cell id…)?
- Which known census data can be used for calibration to derive the presence of people?

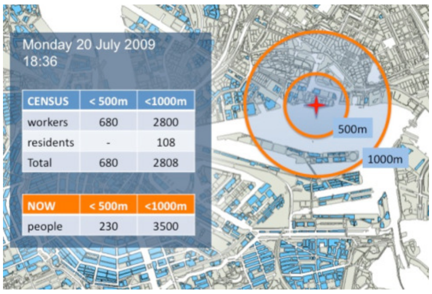


Figure 5.2: Estimated number of people are at the (incident) site

(Source: Currentcity.org, 2010)

The research questions outlined above appear very simple, but underline an extremely complex modelling exercise. The scope of this exercise is to formulate which data can be realistically derived from GSM networks, which cellular network data can be used at what spatial resolution; and which level of confidence may be taken into account. Calibration is the process of creating and validating models to derive useful data from the telecom network input.

At a very high level, this can be described as the process of modelling and fitting estimates of the desired output variables based on: (1) a certain number of real-time inputs (the telecom data stream); (2) static and dynamic spatial data (land use, road network); (3) telecom users data (caller profile, average SMS per day, etc.); and (4) ground truth (e.g. counts of people or cars).

5.7.2 Incident detection

Real-time monitoring for homeland security and IM are increasingly seen as crucial instruments to ensure a secure transportation network. There is a strong relationship between the duration of an incident and the response time required from the traffic management centre and the emergency services. Early and reliable detection and verification of incidents together with integrated traffic management strategies are important contributions which can improve the efficiency of the incident response. Currently there are several ways to detect an incident: road users involved who call the emergency number; alerts from human observers from emergency organizations such as police, road-inspectors and employers from towing services. Technical detection is also possible by (automatic) camera detection and induction loops, or by means of new ways of detection, such as the above-mentioned European e-call project. Quick incident detection is crucial for mobility consequences in terms of reducing traffic jams and vehicle lost hours.

An interesting challenge is to analyse whether telecom data could be useful for incident detection. Changes or anomalies in (the use of) the telecom network could be potential indicators. Models of anomaly detection were first used for the development of intrusion detection systems in a telecom network. Detecting anomalous behaviour is also one of the main tasks in telecom network operation (Kumpulainen and Hätönen, 2008).

Anomalies may result from faults, misbehaviour or unauthorized intrusion. It is essential to detect such situations as soon as possible, for security reasons. In the existing literature, there is still no consensus on the terminology, when it comes to the classification of various types of intrusion and anomaly detection systems. Debar *et al.* (1999a) have provided one of the most cited intrusion detection taxonomies to date. Revised versions of this classification and categories can be found in Debar *et al.* (1999b); Debar *et al.* (2000); Axelsson (2000); Arvidson and Carlbark (2003), Burbeck (2006).

There are two complementary trends in intrusion detection: (1) the search for evidence of attack, based on knowledge accumulated from known attacks; and (2) the search for deviations from a model of unusual behaviour**,** based on observations of a system during a known normal state. The first trend is often referred to as '*misuse detection*' (Jagannathan *et al.* 1993, Kumar and Spafford, 1994) or '*detection by appearance*' (Spirakis *et al.*, 1994). The second trend is referred to as '*anomaly detection*' (Jagannathan *et al.*, 1993) or '*detection by behaviour*' (Spirakis *et al.*, 1994)

The problem of anomaly detection in data networks has been extensively studied. Anomaly detection consists of identifying patterns that deviate from the normal traffic behaviour, so it is closely related to traffic modelling of data in the mobile network. The anomaly detection literature treats the detection of different kinds of anomalous behaviours: network failures (Hood and Ji, 1997; Katzela and Schwarz, 1995; Ward *et al.*, 1998), flash crowd events (Jung *et al.*, 2002; Xie *et al.*, 2008) and network attacks (Cheng *et al.*, 2002; Zou *et al.*, 2005; Wang *et al.*, 2002; Lakhina *et al.*, 2005; Tartakovsky *et al.*, 2006).

There is abundant literature on the anomaly detection problem, which describes a variety of approaches, including statistical, neural network, and machine learning methods. In statistical-based techniques, the network traffic activity is captured and a profile representing its stochastic behaviour is created. This profile is based on metrics such as the traffic rate, the number of packets for each protocol, the rate of connections, the number of different Internet Protocol (IP) addresses, etc. Two data sets of network traffic are analyzed during an anomaly detection process: one corresponds to the currently observed profile over time, and the other is for the previously statistical profile. As the network events occur, the current profile is determined, and an anomaly score is estimated by comparison of the two types of behaviour. The score normally indicates the degree of irregularity for a specific event, such that the intrusion detection system will flag the occurrence of an anomaly when the score exceeds a certain threshold.

The main challenge in developing anomaly-detection algorithms, in the field of IM, is to compare it with the 'ground truth' about the real traffic conditions. The idea is that abrupt changes in some network signalling events might be the symptom of a road anomaly (accident/ congestion), for example: (a) a drop in the handover rate; (b) an abrupt change in the Location Register update; (c) an increase in the number of calls/SMS; and (d) drastic change in the number of road users. Handovers (also called hand-off) refer to the switching mechanism of an on-going call to a different channel or cell. It is the mechanism of managing a permanent connection when the phone moves through two cells of the network. Hereby, the phone call changes from one base station to the other without quality loss. This information is stored in the Home Location Register and Visit Register Location network databases. The most basic indicator of anomalous behaviour in a cell phone network is an increase or a decrease in cell phone call activity within a given geographical area. This type of anomaly can be detected by monitoring a time series consisting of the number of calls made in disjoint time intervals of a fixed size, e.g. the number of calls made every 15 minutes.

A nice example of the use of statistical techniques with telecom data can be found in the project Real-time Rome where spatial signatures based on K-means clustering technique are analysed (see Reades *et al.*, 2007). These spatial signatures can be the basic approach for anomaly detection. Clustering allows the use of the local thresholds, taking the local variance of the data into account. There are several ways to use clustering for anomaly detecting (Tan *et al.*, 2005). In a basic clustered distance-based method, the data are clustered and the distances to the nearest cluster centroids are calculated for each data sample. Samples that are very far away from the centroids are considered anomalies. The threshold can be, for example, the 95 per cent percentile of the distances, thus assuming that 5 per cent of the data are anomalous.

Clustering is an appealing non-parametric method because it allows various classes of '*normal*' and '*abnormal*' behaviour to be captured. This may be quite useful since, in addition to detecting anomalies caused by events that have never been seen before, knowing the various types of '*abnormality*' would allow us to identify interesting events that have already been seen. The goal of clustering is to group similar data items together. There are three major types of clustering algorithms: partitional, hierarchical, and incremental (Jain *et al.*, 1999). A few methods have been developed for clustering data streams (Guha *et al.*, 2003; Aggarwal *et al.*, 2003). Stream clustering algorithms are similar to incremental algorithms. Hybrid clustering combines two clustering algorithms (Cheu *et al.*, 2004; Chipman and Tibshiran, 2006; Surdeanu *et al.*, 2005). Partitional and hierarchical clustering algorithms may also incrementally incorporate new data into the cluster model (Jain *et al.*, 1999).

An example of anomaly detection for streaming data to detect crisis events can be found in the project WIPER (see Schoenharl *et al.*, 2006a; Schoenharl *et al.*, 2006b; Madey *et al.*, 2006; Madey *et al.*, 2007). The techniques they analysed for detecting anomalous patterns of spatial activity are a hybrid clustering algorithm that combines k-means clustering and statistical process control (Pawling *et al.*, 2006) and the Markov-modulated Poisson Processes (Yan *et al.*, 2007).

The Markov-modulated Poisson process, which uses a Poisson process in conjunction with a hidden Markov model to identify anomalies in the data, is described by Ihler *et al.* (2006, 2007). A Poisson process models the number of random events that occur during a sequence of time intervals, and can be used to model the baseline behaviour of such a time series.

An important issue is the timeline in which the telecommunication network provides data. Interesting research questions concern what type of incidents can be detected by a telecommunication anomaly based on different time samples. Next, it is also interesting to see how other types of anomalies (e.g. big events) can be filtered out to be sure we are dealing with traffic incident anomaly detection. It is also relevant to see which anomaly detection method and which GSM telecom data is most suitable for incident detection.

5.7.3 Prediction of flows and site accessibility of emergency services

Prediction of flows and site accessibility of emergency services are crucial for fast security of the incident location and the surrounding environment. Traditionally, these data is derived from expensive detection loop data. Most of the time these technology is mainly installed in the more dense areas. Telecom data is an interesting technology which have some advantage over detection loop data. An important issue is of course avoiding false alarms.

Traffic counts measure the number of vehicles that travel past a certain point on the roadway (Caceres *et al.*, 2007). Traffic volume (flow) is the number of vehicles that pass through a point or section of a lane or roadway during a specific time period (Thiesenhusen *et al.*, 2003; Caceres *et al.*, 2008). Traffic congestion originates from the existence of some event that causes change in typical average speed values and travel times associated with a section. (Ygnance *et al.*, 2001). Traffic density is closely related to congestion. It is defined as the number of vehicles occupying a given length of a lane or roadway at a certain instant. It is expressed as '*vehicles per kilometre*'. This is a key parameter to measure the quality of service on a road section (Ratti *et al.*, 2006; Hansapalangkul *et al.*, 2007; Pattara-Atikom *et al.*, 2007).

Origin-Destination (OD) matrices are used to quantify and synthesize mobility associated with persons or goods. They provide information about the number of trips performed between the origin and a destination area during a given period of time. These matrices can be produced with different levels of aggregation, depending on the level of detail desired or type of information required. By combining data on the cells and location areas in which a mobile phone has been registered, it is possible to construct journeys from which OD data may be inferred (Caceres *et al.*, 2007; White and Wells, 2002; Sohn and Kim, 2008). Two recent simulation projects on the OD matrix focusing on the generation of traffic flows can be found in Spain (Caceres *et al.*, 2007) and Korea (Sohn and Kim, 2008). The project in Spain concluded that turned-on phones (active and idle modes) of only one operator should be sufficient, and proposes an adjustment factor to transform phone data into vehicle data. The project in Korea used a simulated environment for validation. They found that the accuracy of the estimation was less dependent on the standard deviation of probe phones changing location than on other factors such as market penetration and cell dimension.

5.8 The Amsterdam telecom casestudy

In this section, we briefly describe the first results of our project 'Current City Amsterdam' studying a real-time telecommunication system in the city of Amsterdam, to support homeland security, traffic safety and IM. On a yearly basis in the Netherlands there are about 100,000 incidents (Leopold and Doornbos, 2009), varying from small accidents to major multi-vehicle incidents causing casualties and vast damage to the road and its supporting structures. According to information available in the Netherlands, approximately 30 to 44 million hours were lost in 1990 due to traffic congestion. Translated into monetary costs, this is equivalent to a loss of €700 million (Dutch Ministry of Transportation and Water Management, 2007a,b). After the introduction of IM policy in the country, in 1999 the average time of incident handling was reduced by 25 per cent (Grontmij, 2004, Leopold and Doornbos, 2009). Between 1985 and 2004, approximately 10 to 13 per cent of all traffic jams on Dutch roads were the result of incidents such as crashes and vehicles shedding their loads (McKinsey and Company, 1995; Knibbe *et al.* 2004; TNO, 2006). In 2008 incidents accounted for 21 per cent of lost vehicle hours (Dutch Ministry of Transportation and Water Management, 2008a), so they are among the most important causes of the presence of traffic jams. The ambition is that by 2015 the 2008 process time will be reduced by another 25 per cent (Dutch Ministry of Transportation and Water Management, 2012).

5.8.1 introduction

This Current City Amsterdam project took place between 2008 and 2011. The Current City consortium (SENSEable City Laboratory MIT; Salzburg University), in cooperation with the Dutch Ministry of Transportation and the Vrije University Amsterdam, has introduced a test system in Amsterdam (the Netherlands) for the extraction of mobile phone data and for the analysis of the spatial network activity patterns.

Since 2005 the MIT's SENSEable City Lab and related partners paid special attention of the use of GSM data around different cities in order to gain insight into complex and rapidly changing spatial urban dynamics phenomena. Examples are Milan (Ratti *et al.*, 2005; Pulselli *et al.*, 2006), Graz (Ratti *et al.*, 2007a), Rome (Reades *et al.,* 2007; Reades *et al.*, 2009, Calabrese and Ratti, 2006; Calabrese *et al.*, 2011a), Newyork (Ratti *et al.*, 2008), Amsterdam (Steenbruggen *et al.*, 2011), Bangkok (Soto and Frıas-Martınez, 2009), Hongkong (Liu *et al.*, 2009) and Massachusetts (Martino *et al.*, 2010). They also analyzed different regions in Belgium (Lambiotte *et al.*, 2008; Blondel *et al.*, 2008; Krings *et al.*, 2009; Blondel *et al.*, 2010; Expert *et al.*, 2011) and even entire countries like Great Britain (Ratti *et al.*, 2010). An early attempt to construct a dynamic map of Amsterdam is '*The Amsterdam Real-Time Project*' (Polak, 2002), and is based solely on the movement of a selected number of people carrying GPS receivers and being tracked in real time.

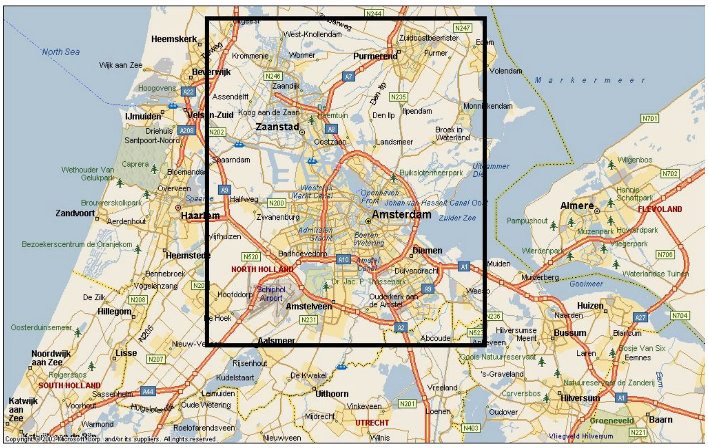


Figure 5.3: Overview of Amsterdam test area

More in detail, the Current City Amsterdam project uses anonymized data of the KPN mobile network. In the study area over 1200 cells were identified, grouped in 8 LACs. It involves the city of Amsterdam and its surroundings, covering an area of about 1000 km^2 (see Figure 5.3). Data included, for each sector are new calls, SMS, handovers, Erlang and (a standard unit of measurement of traffic volumes, equivalent to 60 minutes of voice) and number of location updates.

The project does not focus directly on traffic patterns, but explores space-time relationships of mobile phone data and assesses their suitability to derive census proxies and dynamic patterns of the urban area, which in turn can be utilized to derive mobility indicators, showing the possibility of extracting near real-time data from cell phone use, and to reconstruct the spatial-temporal patterns of the telecom network usage.

The GSM cellular network is built from radio cells based on two best serving cell maps generated by antennas with two different frequencies overlaid at each other, namely 900 MHz and 1800 MHz. In order to obtain the real mobile phone use-pattern of a certain place in the city, the two Best Serving Area maps have been integrated. The telecommunication operator applies special scripts to extract the necessary data for the project. All received data is cell-based with a duration interval of one hour. The raw data contains aggregated information from one hour in a certain cell. Each cell contains a large number of grids. The spreading of cell traffic to grids is not simply a division but takes into account that land-use changes the spread: spreading thus depends on the land use type that is present in a certain cell.

The design and operation of our prototype application is shown schematically in Figure 5.4. The system has three main components: 1) Data sources, storage streaming telecom data and pre-processing; 2) Data management, modelling and support system; and 3) Web-based applications for users.

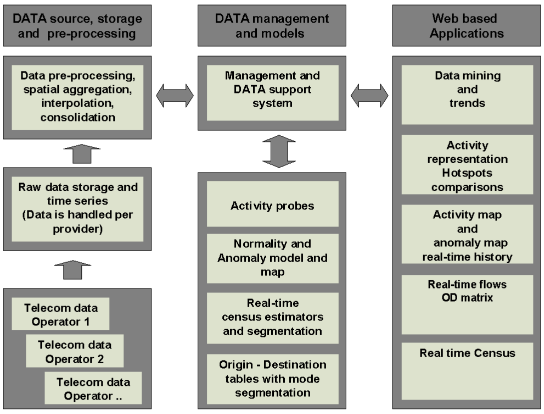


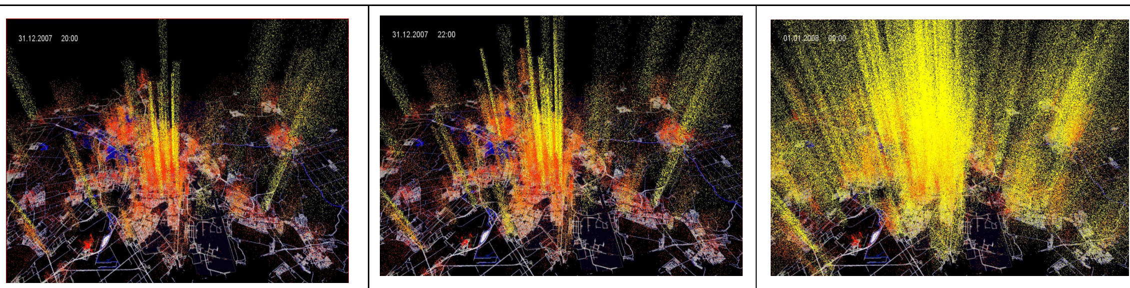
Figure 5.4: Overview of telecom system architecture

The Current City[17] approach is closely related to the concept of Dynamic Data Driven Application Systems (DDDAS)[18]. It entails the ability to dynamically incorporate additional data into an ongoing application, and creates a rich set of new challenges for applications, algorithms, systems, software, and measurement methods. A nice example of the use of the DDDAS concept similar to Current City is WIPER (Madey *et al.*, 2007). The concept is characterized by '*Dynamic Data*', the first two Ds in DDDAS. In the Current City system the dynamic data is cell phone activity. Another nice example of the DDDAS concept is 'Firegrid'[19]. This is an initiative to create a next generation real-time emergency response system using GRID technology. Challenges are sensing, modelling, forecasting, feedback and response.

5.8.2 Normality maps for anomally detection

The first research goal of the Current City Amsterdam project was how telecom data can be utilized for understanding presence and mobility in regular situations and during events where entire regulated flows of people are disrupted by an incident or an exceptional occasion such as a football match, a music concert, a large celebration, serious traffic jams or a demonstration. Figure 5.5 shows the increase of SMS activity during New Year's Eve on December 31, 2008. Each dot on the map represents one sent SMS which captures an increase in human activity during New Year's Eve.

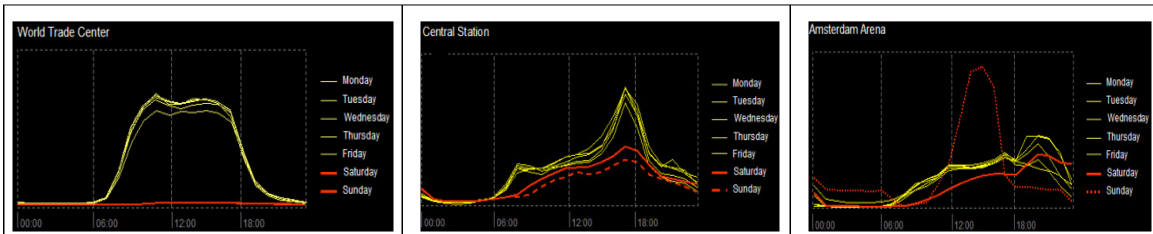
[17] www.currentcity.org.
[18] http://www.dddas.org/
[19] http://www.firegrid.org/



5a: 31-12-2008. 20:00 hour	5b: 31-12-2008. 22:00 hour	5c: 31-12-2008. 24:00 hour

Figure 5.5: Number of SMS sent during New Year's Eve (Source: http://www.currentcity.org/)

A more detailed data analysis has been carried out for a selected number of areas that are characterized by different land-use patterns and intensity differences in terms of how people use the area. The definition of the areas was based on the indications of the best serving coverage map overlaid on land use. The daily patterns in terms of normality maps over all weekdays can be seen from the graph in Figure 5.6, which helps us to understand the spatio-temporal variability of the mobile phone data. The diagram shows for each day the average traffic (Erlang) over a period of five months (1 January - 30 May 2008). The high spatio-temporal resolution of the mobile phone data will enable us to extract conclusions at a very fine-grained scale. The data are normalized on the averages for purposes of comparison (Steenbruggen *et al.*, 2011).



6a: World Trade Centre	6b: Central Station	6c: Football stadium, Arena

Figure 5.6: Call intensity (measured in Erlang during a 24-hour period) in different Amsterdam city areas: a) Business district, World Trade Centre; b) Transport hub, Central Station; c) Football stadium, Arena (Source: http://www.currentcity.org/)

5.8.3. Anomaly detection for traffic IM

A next step in our analysis is anomaly detection for traffic incidents. In order to find out how the telecom network responds to the unusual situation of the road traffic incident, we analyzed several cases, located at highways in different parts of the Amsterdam ring roads. All the incident information and characteristics were obtained from the database of the Dutch traffic management central of Rijkswaterstaat. Four different counters are used for the IM project. Three of them measure aggregated human activity in the network: number of received calls (Terminating Calls –TC), number of executed calls (Originating calls – OC), number of text messages, both sent and received (SMS) and the fourth counter is called Index of Human Activities (IHA) and it is the sum of these counters. In total there are 295 telecom cells intersecting with the motor traffic roads. For each cell we created normally maps spread over 24 hours a day and 7 days a week.

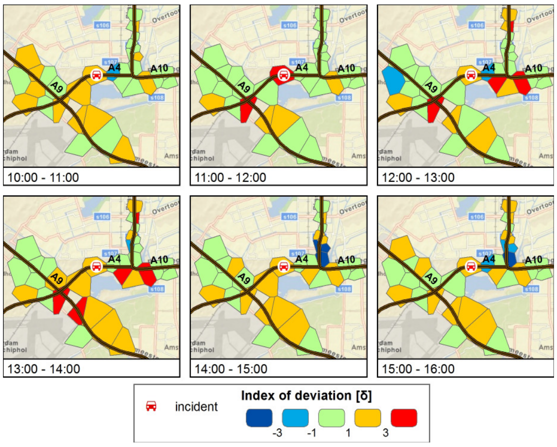


Figure 5.7. Index of deviation of the Index of Human Activities before, during and after an incident.

Figure 5.7 contains a geographical representation of an example of an incident which took place on the 10th of June 2010 between 11:48 and 13:37 on the A4 at km 1.9. As clearly visible in the plots, anomalies where detected in the telecom cell where the incident took place and at intersection points after the incident occurred. Some first general conclusions can be drawn on the selected incidents:

- In most of the cases the telecommunication data allowed for the reconstruction of the traffic scenario during and after the incident, in terms of where and when the event repercussions could be visible.
- the Index of Deviation seems to be a good indicator of the abnormal situation on the highways even if computed for highly aggregated data., however it shows incidents as well as abnormal traffic jams prior to the incident;

- Even from small incident around a half hour some repercussions in the telecom data can be captured, however data sets with better time resolution, e.g. <10 minutes, would be crucial;
- If an incident happened a few minutes before the end of the telecom data interval, data sets with better time resolution, e.g. <10 minutes, would be crucial;
- Speed limitations on the speed plots agree with the anomalies visible by the use of telecom data and where visible for all analyzed incidents.

5.9 Conclusion and further directions

In this Chapter, we have given an overview of the possibilities opened up by the use of location based services, in particular of GSM data, within the domain of transport safety and security. In the following a SWOT analysis is provided, summarizing the results obtained from the bibliographic review and the case studies shown in the previous sections.

Table 5.1: SWOT Analysis of the GSM Technology applied to transport safety and security

	Strengths • (near) real-time information; • full coverage of entire region or country; • very large and rich database (big data); • relatively low costs compared to exiting technologies such as camera's and detection loop data.	**Weaknesses** • current timeline intervals (e.g. 15 min. - 1 hour); • geographical cell structure, dens areas have smaller cell coverage the rural areas; • complex modelling for data validation.
	Opportunities • compatible with existing collective sensor data such as camera's, detection loop data, and navigation systems; • promising technology in many sectors such as urban geography, urban dynamics, human mobility, travel behaviour, social networks, commuters and tourist, crisis management and traffic management.	**Threats** • availability due contracts with telecom operators (no open data such as social media); • privacy issues and data protection.

Indeed, while possessing plenty of the opportunities, the usage of telecom data for IM has also limitations. First of all, the data scale and spatial aggregation is very unlikely to correspond with the road network. In case of big cells, it is always difficult to identify which portion of activity comes from the people located exactly on the highway and which is produced by the surrounding areas. This leads to complex modelling and difficulties in data validation.

Another issue is linked to small cells, where information loss can be the problem. If travellers are registered to the telecommunication network with cells located close to but not intersecting roads, then there is the risk of missing the relationship between incident and telecom traffic. These problems are a direct result of the architecture of the telecom network, and are generally operator-independent in that they affect all operators. This could be reduced in various ways. One option is to disclose the mobility characteristic of single users to detect sequential cell registrations and thus provide a far better distinction between stationary users and travelers. This approach would require data availability at the level of the single user, which is currently not the case with the telecommunication operator. However, once obtained such data, the solution is definitely worth exploring. Another option is to have access not only to aggregated cell data but also to radio characteristics of the communication (e.g. signal strength). This would for instance allow the distribution of users in a cell based on distance from the antenna and thus populate the maps in a way that is much closer to the ground truth.

Another limitation for the incident analysis is time granularity. It is most problematic in case of small events, when the traffic repercussions did not last too long. Of course, this difficulty could be solved by obtaining telecommunication data with better time resolution e.g. < 5 minutes, which should also be the aim for the future research on IM. Nevertheless, any chosen period would always represent a limitation, to be addressed during data interpretation.

The last constraint of the telecommunication data concerns its content. For the IM we have four different counters available, but including some others could also bring interesting information. As for other needs of IM, the one which is possibly addressable in future is the assessment of people/vehicles presence on a defined highway section, or in the risk area surrounding the incident. Although converting telecommunication activity into a certain number of persons relying only on the mobile phone data is very challenging, additional data could possibly make the task feasible, specifically samples of individual traces on the network, that can be used as calibration mechanism for less precise data. Addressing the computation of flows should be also possible, but only on the condition of using more sophisticated data available on the single user instead of cell level.

The statistical methods used for our analyses are rather straightforward. The next step is to use more sophisticated statistics such as linear regressions and panel analyses to explore in more detail the time-space relation between telecommunication data and traffic incidents.

As regards opportunities and strengths of the technology, electronic data may be instrumental in building up an efficient and effective IM information system, in particular using Location Based Services (LBS) data. A particularly interesting case of LBS data is offered by GPS and GSM data. The use of GSM data from cellular networks is very recent and has great potential. It provides near real-time information, almost a full coverage of entire region or country; the availability of a very large and rich database, coupled with relatively low costs compared to exiting technologies. Moreover, the technology is compatible with existing collective sensor data such as cameras and loop detectors' data; and represents a promising technology in many sectors such as urban geography, urban dynamics, human mobility, travel behaviour, social networks, commuters and tourist, crisis management and traffic management.

Smart management of incidents in traffic systems has become a major challenge to road traffic operators and incident managers. In the case of distributions of traffic flows, it is necessary to assess direct on-site and wider spatial consequences, in order to mitigate the road traffic externalities and restore a smooth traffic flow. To that end, a broad information base - including access to the site and the risks for surrounding areas - is needed. This Chapter has demonstrated – through a broad overview and several examples from first pilot studies – that GSM data embody a great opportunity for smart IM. Clearly, more work needs to be done to explain the benefits of such systems, but the first test cases appear to be highly promising.

The following general conclusions can be drawn:

- the topic of traffic IM is one of the key concerns in transportation security and safety policy regarding the number of road traffic casualties per year and the impact on mobility;
- the use of telecom data has a great potential to provide new types of information services to create an accurate understandable picture of reality to improve situational awareness for the daily IM work processes;

- there are limited examples in the literature where telecom data are analysed for IM and most projects focus on general traffic and emergency management;
- timeliness seems to be an important issue for incident detection, and thus further research is needed to see if the use of telecom data can improve existing methods (e.g. cameras, detection loops, e-call, e-112, and human observers);
- normality maps based on telecom data in combination with land use is a promising approach to improve incident detection and calculate the presence of people;
- the use of telecom data for incident detection is strongly related to the magnitude of an incident or an event;
- telecom data could provide a real-time overview of the current number of people who are affected in case of incidents with dangerous goods; Clearly, more research is required in terms of modelling and validation with ground truth;
- telecom data could be a useful source for the prediction of flows and site accessibility of emergency services; more research is needed in terms of statistical analysis and integration of different data sources such as loop detection data.

6 Identification of Problems and Needs in Information Sharing

6.1 Identification of the problems in the IM operations

To identify the main problems in information, communication and coordination between IM organizations, we take a three-level approach. First, we use the evaluation reports of the IM programme office, which organize monthly regional sessions with the involved IM organizations. We use only those results which particularly focus on problems related to information. Based on these insights, we set up a half-day regional shadow session with all the relevant IM actors. The main goal of this exercise was to gain knowledge of to what extent these problems occur in the daily handling of traffic incidents. Finally, we use an Internet questionnaire administered to the relevant stakeholders to get a good overview of the main issues in the Netherlands.

6.1.1 Results of the regional evaluation sessions

The current identified information, communication and coordination problems for traffic IM are summarized in Appendix 2. These were collected in 2012 during ten regional evaluation sessions with the Rijkswaterstaat (RWS) (Road Inspector, Road Traffic Coordinator, Traffic Officer of Duty), and personnel from the Police, Fire Brigade and Ambulance service. Together with an evaluation team, they replayed past incidents step by step. Each incident was evaluated in great detail, and then recommendations for improvement were categorized. For the purposes of this study, we used only those results which specifically focus on problems related to information.

The problems are clustered in six categories of problems with the incident; the surrounding environment; organization information; coordination; technology; and registration. To verify to what extent the identified problems, from these ten evaluation sessions, occur in the daily IM operations, we set up a half-day regional shadow session with all the relevant IM actors.

6.1.2 Results of shadowing session of the traffic IM operations

On 14 May 2012, we set up a shadowing session in an operational IM environment to verify the scale on which the problems identified on basis of the the regional evaluation sessions occur. To get a realistic picture, the shadowing session was held simultaneously by different IM organizations.

The following organizations participated: three RWS Regional Traffic Management Centres (Geldrop, Utrecht en Rhoon); the National Traffic Management Centre (RWS VCNL); the Safety Region Brabant Zuid-Oost (Police, Fire Brigade and Ambulance service); and the national central hotline for towing services (LCM). The LCM acts as a central sharing point for incoming incident reports on the part of the Police and the Road Authorities. Each message received by the LCM is translated into a mission for a towing company which has a contract with the IM Foundation. It is important to note that the results of the shadowing session for the LCM were identical for each incident type. They act as a call centre and there is no active communication with the towing service in the field. Problems which occur with the incident notification are directly handled by the towing companies and there is no direct feedback during the IM process. This feedback takes place in a later stage after the incident scene is cleared. Also false incident notifications are shared in a later stage, purely for administrative reasons. Most of the time, the towing companies in the field have a direct communication with the RWS Regional Traffic Management Centre (RWS RTMC). Therefore, the shadow results of the LCM are not further reported.

The shadowing took place in from 6:00 hr. to 12:00 hr. The participants (traffic road managers and the centralists) were observed by a shadowing technique which is a useful method for observing participant behaviour (McDaniel and Gates, 1998). The shadowing of all participants was done by a group of colleagues from the RWS who had been instructed to use a predefined form. This form was based on a list of the main problems which had been identified in the previously described regional evaluation session. The form was structured in different categories of problems with the incident; surrounding environment; organization information; incident detection, notification; communication; incident handling; and the involved IM organization per incident category.

To structure the results, we made a distinction between the different types of traffic incident: object on the highway; broken-down vehicles; accidents with only material damage; accidents with injuries or casualties; and special incidents (e.g. those involving dangerous goods, fire, driver unwell, animal on the road). It is important to note, that there is no uniform incident classification between the emergency organizations. However, in practice, this rarely leads to major problems. Nevertheless, this makes it difficult to establish the yearly incident evaluations, and almost impossible to compare the IM performance between IM organizations. For the purpose of our study, we will use the IM classification of RWS.

The main findings can be summarized as follows. Problems with incident information focus on: location, type of the incident, number of vehicles, number of casualties, and the involvement of dangerous goods. At the RWS Regional Traffic Management Centres, there were in total 33 incident notifications. For the two incident types, object on the highway and broken-down vehicles there are almost no problems. For the more complex incidents, the most problems occur. The main problems are the accuracy of the incident location and the number of involved vehicles and persons. The percentage of wrong communicated information was: 46 per cent for incidents with only material damage; 37 per cent for incidents with injuries and 18 per cent for special incidents. There were, in total five false incident notifications and on eight occasions the notification contained the wrong type of incident. For the RWS National Traffic management Centre (RWS VCNL), there were hardly any problems. Incidents are in general handled by the RWS Regional Traffic Management Centre. There were also no false incident notifications. For the Safety Region, it was a relatively very calm morning. There were only four incident notifications. Even thought there were only a few incidents, there still were some problems. The main issue was that the incident type and the related information changed during the incident handling. The underlying complexity is that the Safety Regions do not have access to the camera images of the highways. Therefore, they mainly depend on information from the RWS Regional Traffic Management Centre and their own fieldworkers.

Problems with information about the surrounding environment focus on diverse aspects of the handling of an incident, such as the status of the road conditions, traffic flows, roadworks, weather conditions, potential risks posed by dangerous goods, and special events such as pop concerts and large sports events. In the RWS Regional Traffic Management Centre, they normally have a good overview of the environment. Most of the time, the appropriate safety and traffic management measures are applied. The incident types ‘object on the highway’ and ‘incident with only material damage’ had no problems. In the more complex incidents there were some issues associated with applying the correct traffic management measures. This was mainly caused by incorrect information about the incident location or the type of incident. For example, with one incident it took 6 minutes before this information was communicated correctly. In this specific example there were no cameras available to verify the received information. In such circumstances, the RWS Regional Traffic Management Centre depends heavily on information from the fieldworkers. Other issues concerned notifications of animals on the road or a ‘ghost rider’. It took a relatively long time before they concluded it was a false incident notification. For the RWS National Traffic Management Centre (RWS VCNL), there are hardly any problems. All incident notifications came directly from the RWS Regional Traffic Management Centre. The measures were directly coordinated within the RWS. It is important to note that RWS National Traffic Management Centre does not have direct contact with the fieldworkers. This coordination lies completely with the RWS Regional Traffic Management Centre. Due the limited number of incidents handled by the Safety Region, there were hardly any problems. In most cases, the Safety region has no active role in closing roads. The main issue for environmental information is that the Safety Region has no access to camera images. Therefore, it is important that there is good communication between the RWS Regional Traffic Management Centres and the Safety Regions. However, it is important to note that the contacts and the quality of cooperation varies between the RWS and the Safety Regions. This is mainly caused by agreements with the regional partners.

Problems with organization information and the coordination of activities focus on the allocation of resources and the communication between the emergency organizations. The RWS Regional Traffic Management Centre had the greatest problems with this information category. This is mainly because they are the largest operational IM organization. This is also directly linked to the type of incidents. Not every incident category calls for the same degree of cooperation (see Appendix 3).

In the case of a broken-down vehicle, there is only contact with the RWS Regional Traffic Management Centre, the Road Inspector, the towing service, and the ANWB. For the more complex incidents there is also a strong involvement of the Safety Regions and RWS National Traffic Management Centre (RWS VCNL). For the allocation of resources, there is hardly any communication between organizations. There is also no information available at what time the different emergency services arrive at the scene of the incident. This problem is also caused because not all highways are equipped with cameras. In seven cases, this was the direct reason why information could not be verified. We can therefore conclude, that the cooperation between organizations can be still improved.

The communication between organizations causes the main problems. This is mainly because shared information is not complete or is shared too late. Sometimes they do not communicate at all. It is important here to note that there are great regional differences. The RWS National Traffic Management Centre has hardly any problems. This is mainly owing to their specific role in the IM process. Their main partner is the Regional Traffic Management Centre. This means that they do not have a overview of activities of other organizations. The Safety Region had few problems during the observations. It is obvious that they do not have a good overview of the activities of other organizations and neither do they know at what time fieldworkers arrive at the incident location. Also there is hardly any feedback of the activities from other organizations. Most of the time, this information is shared with their own fieldworkers at the incident location.

Incident detection can be done with the help of different sources of information. The main sources for the incident detection are the national emergency phone number (E112), the Road Inspector, the RWS Duty Officer, the fieldworkers of the Police, the ANWB, the towing services, and the RWS Regional Traffic Management Centre (based on camera images). In the near future, e-call is expected to be the main source of incident notification.

Based on our analyses and observation, we can conclude that the main issues identified in monthly evaluation sessions have been confirmed in our shadowing exercise. There are still some major improvements possible in the daily information, communication and coordination activities of the IM process. The most important problems are associated with the information of the incident. Issues concerning environmental information are mainly related to the more serious incidents. This category becomes an issue if an incident escalates to a higher GRIP level.

Furthermore, the status information and activities of other organization are, in general, not shared between emergency organizations. In summery, this shadowing exercise confirms the known problems, although the observation period was limited to one morning of observation. To confirm our observation on a national level, we used an Internet questionnaire administered to the relevant stakeholders. This will be discussed in the next section.

6.2 Internet questionnaire[20]

Traffic IM is apparently a sine qua non for the smooth operation of infrastructure in urban areas. It is a complex undertaking that needs to be reviewed regularly, with the aim to identify critical success conditions for effective traffic IM. In our analyses of the current status of traffic IM deployment, we used an Internet questionnaire administered to the relevant stakeholders (see Table 6.1).

The respondents to this questionnaire are the RWS (RTMC and VCNL), the Safety regions (Police, Fire Brigade and Ambulance), the towing services (LCM and CMV), and the Royal Dutch Automobile Association (ANWB).

The main goals of this research are: to get a clear and critical overview of the main information, communication, and coordination issues; to gain knowledge of the main information needs of each IM organization; and to see what is the information dependency from an actor-network approach.

[20] Based on: Steenbruggen, J., van der Vlist, M. and Nijkamp, P. (2012). Traffic Incident Management in a Digital Society - An actor-network approach in information technology use in urban Europe. TF&SC, Special issue Upgrading the city via technology, forthcoming.

Table 6.1: Overview of the participants of the internet questionnaire

		Frequency	Percentage	Valid percentage
Valid	Police	74	25.7	31.4
	Fire Brigade	41	14.2	17.4
	Ambulance (GHOR)	34	11.8	14.4
	ANWB	4	1.4	1.7
	RWS RTMC	52	18.1	22.0
	RWS VCNL	9	3.1	3.8
	Towing (LCM)	11	3.8	4.7
	Towing (CMV)	11	3.8	4.7
	Total	**236**	**81.9**	**100.0**
Missing	System	52	18.1	
Total		**288**	**100.0**	

Note: GHOR = Geneeskundige Hulpverleningsorganisatie in de Regio; RTMC = Regional Traffic Management Centre;VCNL = VerkeersCentrum NederLand; LCM = Landelijk Centraal Meldpunt; CMV = Centraal Meldpunt Vrachtauto's

Figures 6.1 and 6.2 give an overview of the mean age of the respondents. The mean age is 43 and is spread equally over the different IM organizations.

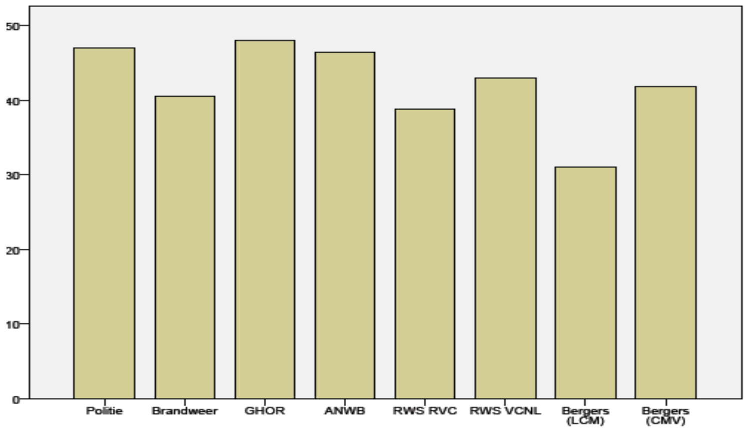


Figure 6.1: Mean age of the different IM organizations (N=236)

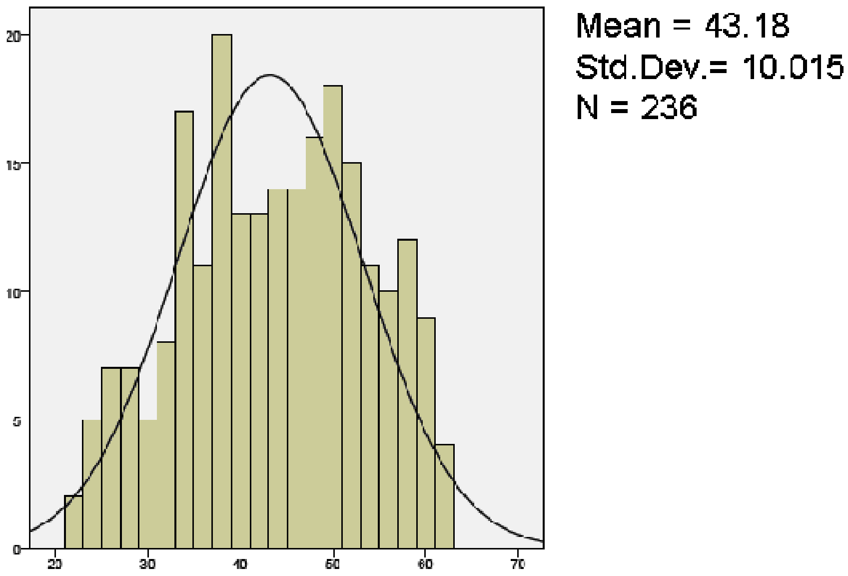


Figure 6.2: Spread of age over the different IM organizations (N=236)

Figures 6.3 and 6.4 show the education level of the participants. The largest group has an MBO level of education. A relatively small percentage has an HBO level of education. The Ambulance service (GHOR) and the ANWB have relatively the highest education level. The other organizations are more or less comparable.

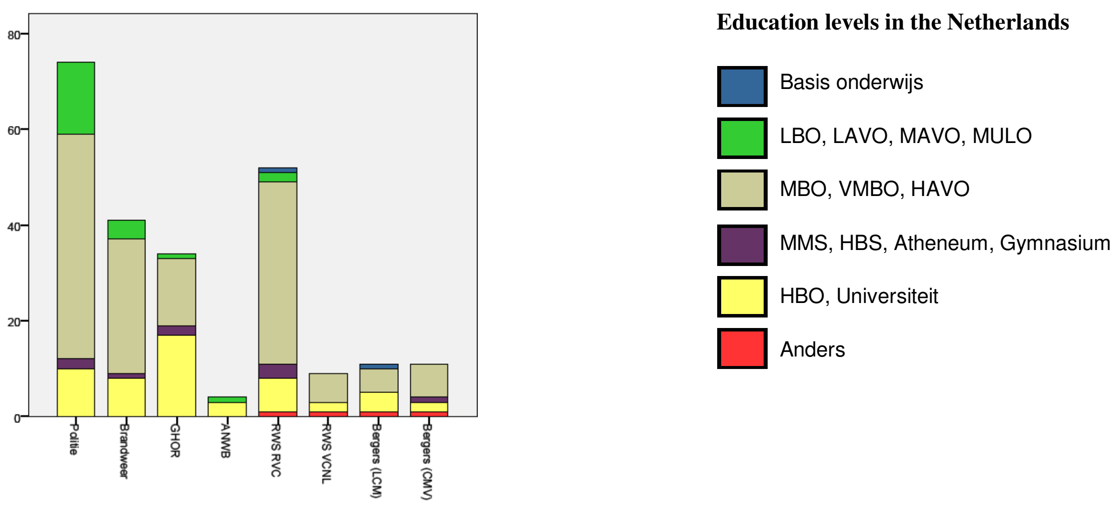


Figure 6.3: Spread of education level per organization (N=236)

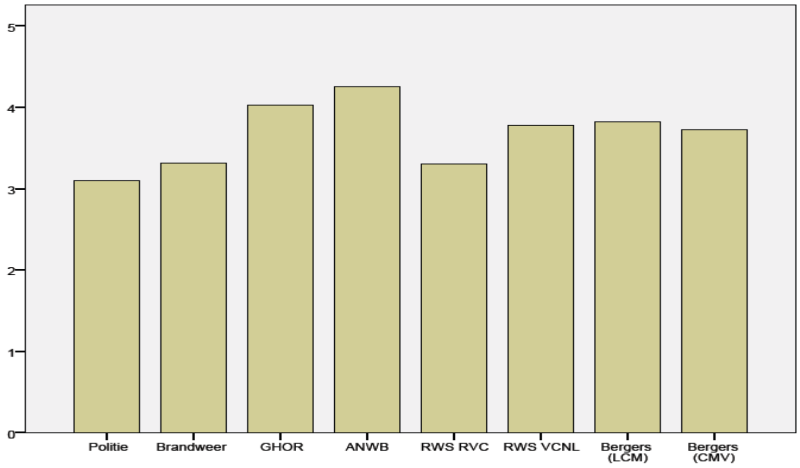


Figure 6.4: Spread of mean education level per organization (N=236)

Figures 6.5 and 6.6 provide an overview of the number of years experience that participants have had in their current IM function. The spread of work experience is the most significant in the Police and the Fire Brigade. The CMV has relatively many personnel who had just started in their current function. Within the Regional Traffic Management Centre (RWS RTMC), the largest group of personnel has between 1 and 10 years experience. Within RWS VCNL this lies between 1 and 20 years. The mean value of working experience for all organizations lies between 5 and 20 years. We can conclude, therefore, that the IM work field can be characterized as being very stable and has well-trained and experienced personnel.

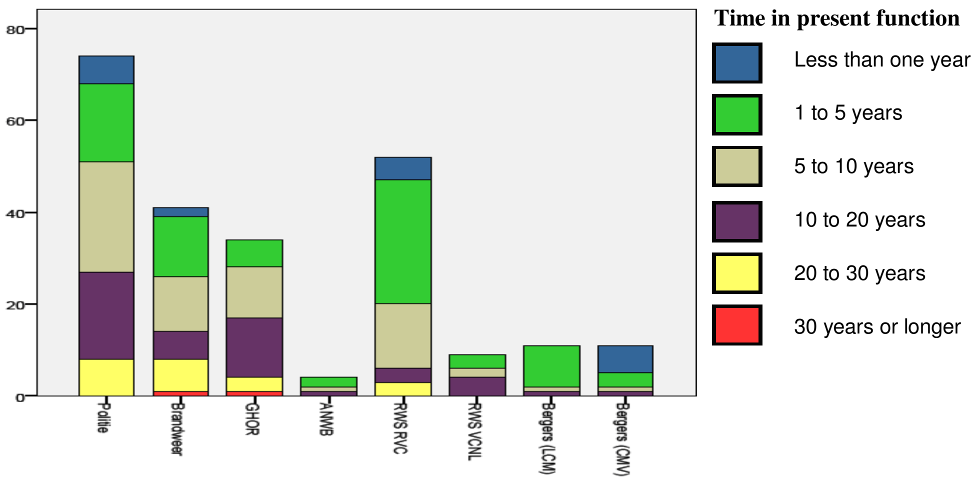


Figure 6.5: Years of experience in the current function (N=236)

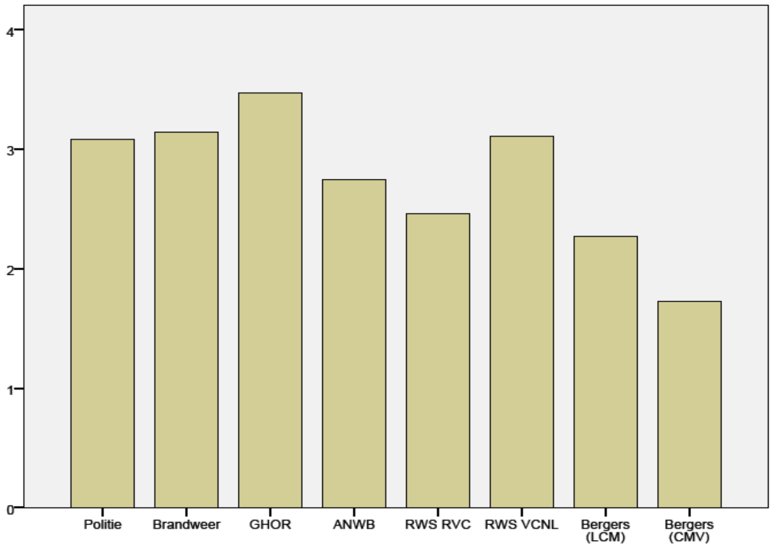


Figure 6.6: Mean years of experience (N=236)

Figures 6.7 and 6.8 indicate which level of experience IM personnel have in terms of the crisis management GRIP levels. The ANWB and the towing organizations (LCM and CMV) have hardly any experience with crisis management. As expected, the most experience can be found within the Safety Regions (Police, Fire Brigade and GHOR) and the National Traffic Management Centre (VCNL) of the Rijkswaterstaat.

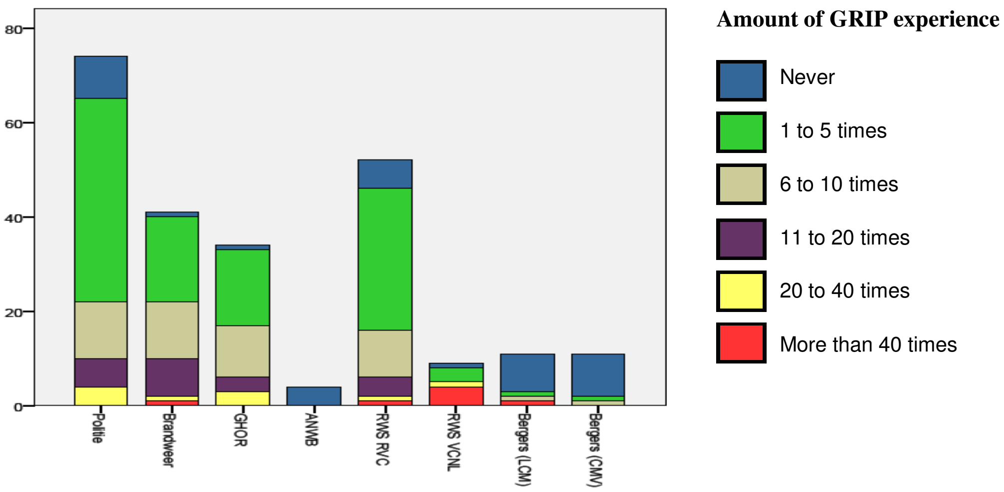


Figure 6.7: GRIP experience per organization (N=236)

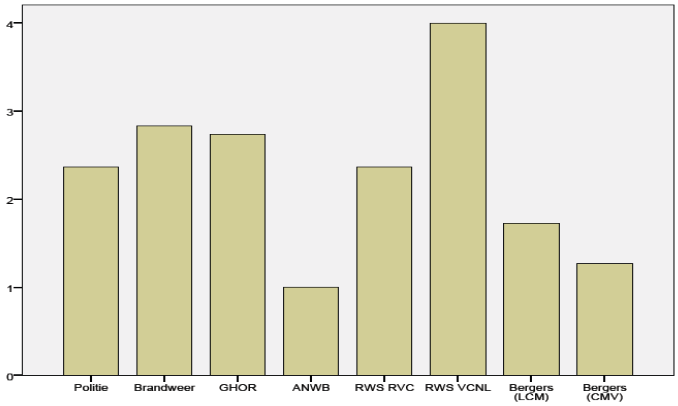


Figure 6.8: Mean GRIP experience per organization (N=236)

6.3 Information, communication, and coordination problems

Figure 6.9 describes the main information problems which occur during the incident notification process. Problems are, in general, issues which delay or confuse the effective handling of an incident. We distinguished nine different categories.

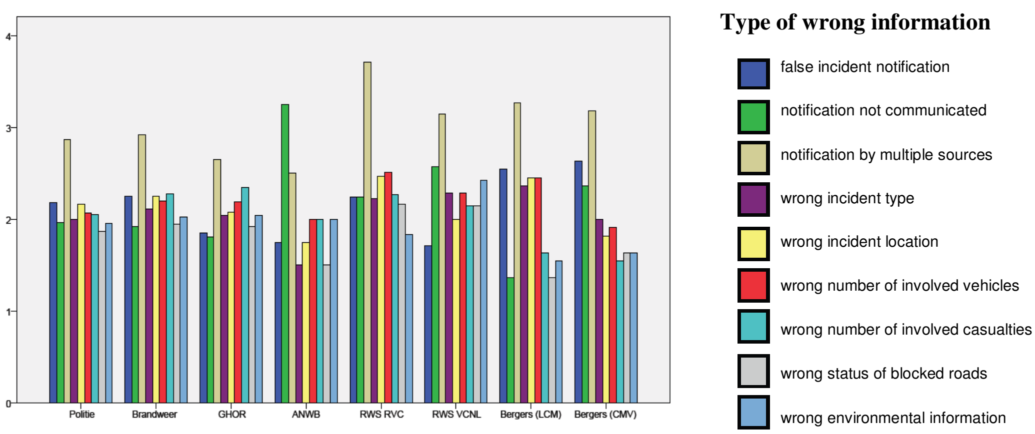


Figure 6.9: Incident information notification issues (N= 205)

Note: 1 = never; 2 = sometimes; 3 = regularly; 4 = often; 5 = very often (Likert scale 1-5).

Note 2: Politie = Police; Brandweer = Fire Brigade; GHOR = Ambulance services; ANWB = The Royal Dutch Automobile Association; RWS RVC = Rijkswaterstaat Regional Traffic Management Centre; RWS VCNL = Rijkswaterstaat National Traffic Management Centre; Bergers LCM = Towing Central Service Desk for Car Accidents; Bergers CMV = Towing Central Service Desk for Truck Accidents.

The Safety Regions (Police, Fire Brigade, and Ambulance) give approximately the same picture. The Ambulance service has most problems with respect to receiving the wrong number of involved casualties. The main problems for the Police and the Fire Brigade are false incident notifications. The towing services' main problems are also false incident notifications, and the LCM regularly faces being given the wrong number of involved vehicles. The ANWB is sometimes not informed about an incident. The Regional Traffic Management Centre (RWS RTMC) main issues concern, being directed to the wrong incident location, and being given the wrong number of involved vehicles.

There is a strong (quadratic) relationship between the duration of an incident and the handling time required from the Traffic Management Centre and the emergency services (Immers, 2007a). The early and reliable detection and verification of incidents, together with integrated traffic management strategies, are important contributions which can improve the efficiency of the incident response. Figure 6.10 indicates in which phase IM organizations have the most information problems. Here, it is clearly visible that the most problems occur in the first phases of the incident. In addition, the coordination of IM measures also plays an important role in effective IM handling. Figure 6.11 shows that organizations do not have a good overview of the activities of the other organizations. It is clear that these two aspects (information problems and coordination) need some improvements in the cooperation between the emergency services.

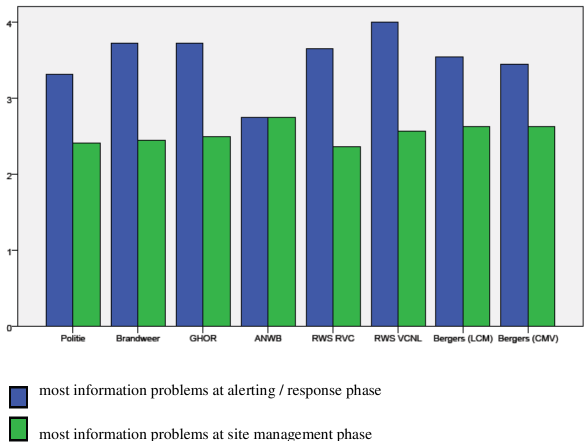


Figure 6.10: information problems per phase (N=205)

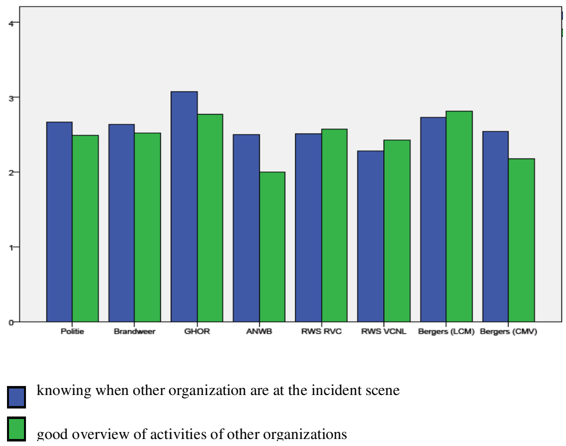


Figure 6.11: Coordination problems (N=205)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

6.4 Telephone communication

This section describes the main problems with telephone communication (fixed lines, mobile phones and C2000) during the daily handling of traffic incidents. A distinction is made between two types of question. First, we look at current problems of telephone communication. Second, we ask involved organizations whether only telephone communication is sufficient for effective IM handling. Current problems focus on: technical problems, miscommunication, the tendency for callers to make their own interpretation; and the time-consuming nature of this method of communication. The other questions focus on whether only telephone communication is sufficient for effective IM handling, and supports cooperation between different IM organizations.

Figure 6.11 gives an overview of how IM organizations score their current problems. A high score means fewer problems. There are some significant differences. In general there are some problems with telephone communication. It is clearly visible that the organizations found that telephone communication alone is insufficient for the daily handling of IM, and does not support cooperation between IM organizations. There is clearly a need for other communication tools.

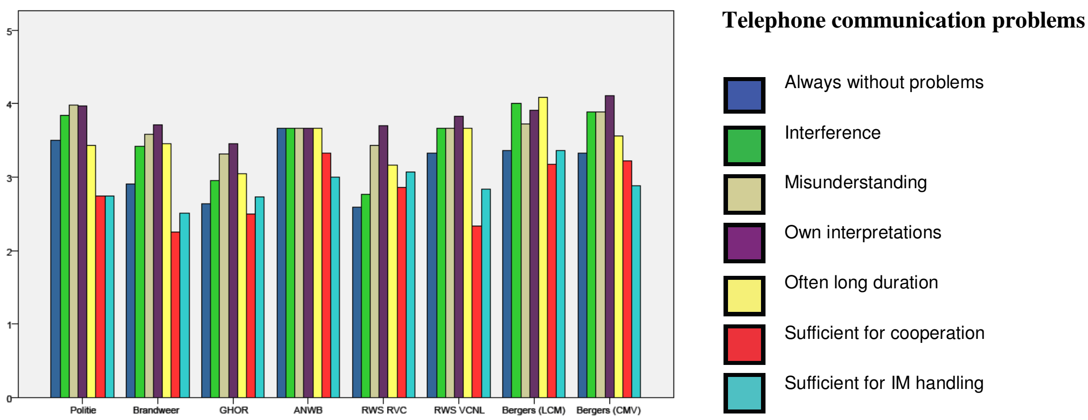


Figure 6.11: Problems with telephone communication per organization (N= 184)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

Figure 6.12 gives an overview of the mean values. The scores lie between the 3 and 4. The main issues are miscommunication and own interpretation. The scores which indicate that telephone communication alone is sufficient to support IM and that it supports effective cooperation lie between 2 and 3. We can conclude, therefore that there is a strong need for additional information systems.

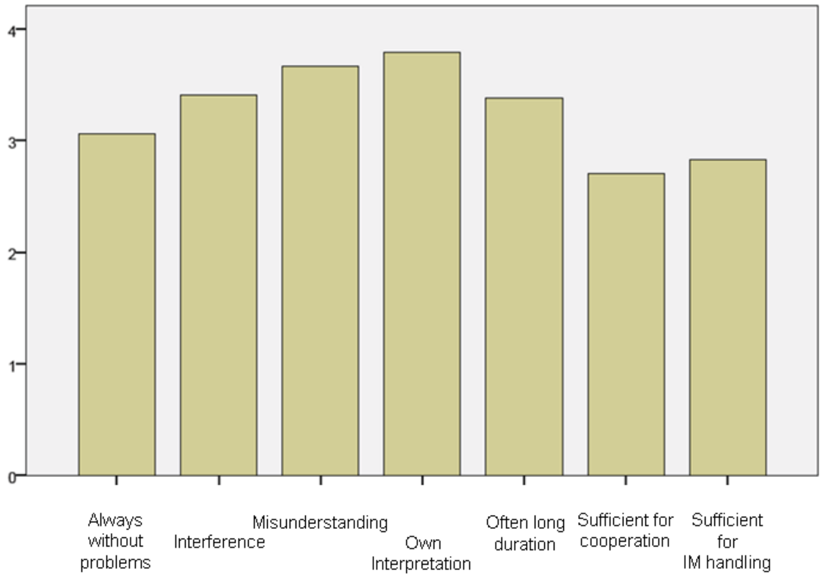


Figure 6.12: Mean values of telephone communication problems (N= 184)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

6.5 Information needs

This part of the questionnaire was designed to see what specific information is necessary to support a traffic IM information system. We made a distinction between three categories: incident; surrounding environment; and organization information. Figure 6.13 gives an overview per organization, and the three main categories of specific information are discussed below.

Incident information

In the guideline, *First Safety Measures for incidents on the highways*, there is a clear list of priorities for handling traffic incidents. These are: the safety of the emergency workers; primary aid for the victims; smooth traffic flow; and the control of infrastructure. In order of importance, safety has a higher priority and then comes smooth traffic flow. It is, however, surprising to see that the safety and the status of potential victims scores lower than the other information categories. The Ambulance (GHOR) score is clearly higher than that of the other organizations. Location information has the highest score. And cargo information and dangerous goods have also a high priority, with the exception of the LCM. Nearly all the items score between 4 and 5. This indicates that information about the incident has a high priority.

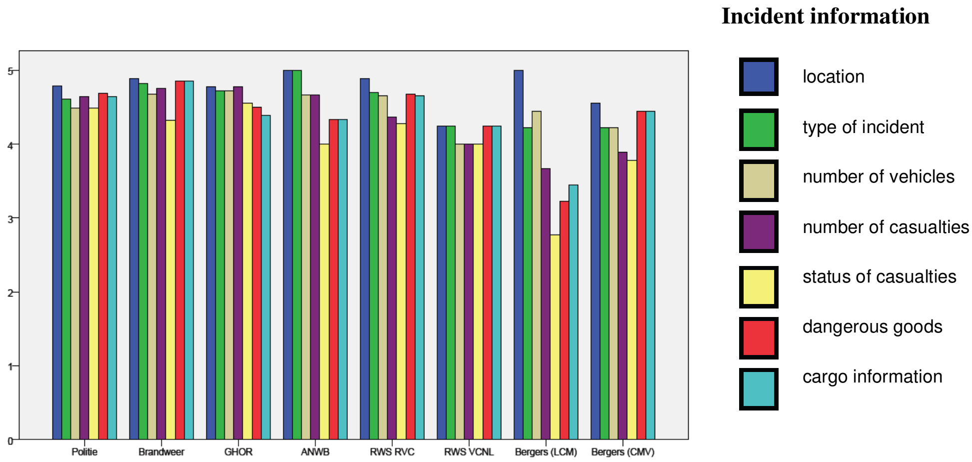


Figure 6.13: Information requirements on the incident (N= 165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

Environmental information

The need for environmental information is divided into nine categories (Figure 6.14). Here, there is clearly more variety in the scores. Information about blocked lanes is scored high by the RWS RTMC and RWS VCNL. The status of blocked roads and the best driving route to the incident scene scored high for all organizations. The Ambulance services (GHOR) and LCM are less interested in environmental damage. This group is considered as important but scores significantly lower than information about the incident.

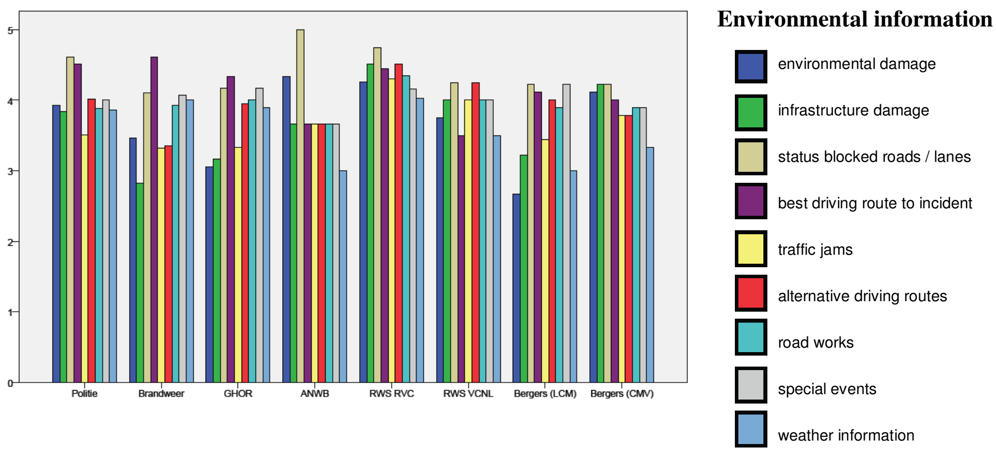


Figure 6.14: Information needs on the environment (N= 165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree(Likert scale 1-5).

Organization information

It is remarkable that organizational information needs scores approximately equally for all organizations, with exception of the LCM (Figure 6.15). The need for organization information is at approximately the same level as environmental information. Within the Safety Regions (Police, Fire Brigade and Ambulance), the functionality to view the status and location of fieldworkers of other organizations already exists. But, for the RWS, ANWB, LCM and CMV, this functionality does not yet exist. If it were available, this would clearly improve the cooperation between emergency organizations.

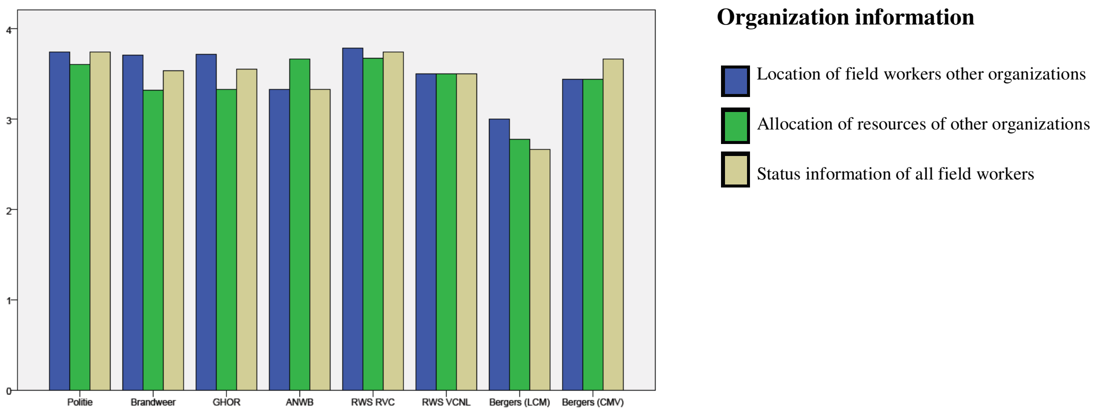


Figure 6.15: Information needs of the IM organizations (N= 165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

6.6 information needs and system functionality

In the current IM domain, most information is shared by telephone communication. In this section, we analyze which functionality organizations would like to have to handle incidents and to improve the cooperation between emergency organizations. Here, there is a distinction between additional information sources and system functionality. Information sources are: text messages, camera images, multi-media, social media and mobile/porto phone. System functionality includes the ability to: automatically push incident notifications; share messages at once with all organizations; filter that can be used to personalize information; notify information changes, and identify the reliability of information. The results are presented in Figure 6.16.

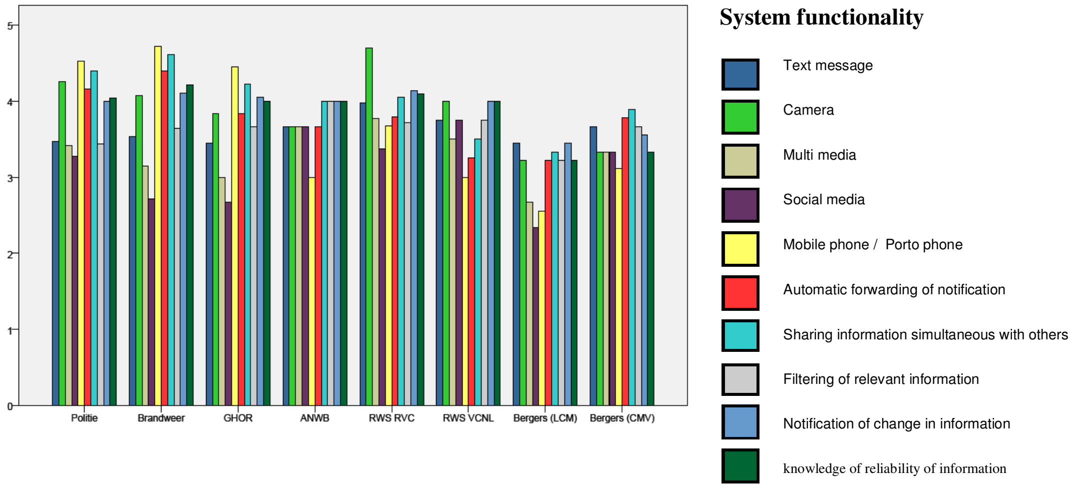


Figure 6.16: Desired system functionality per organization (N=165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

Camera images are identified as important for all IM organizations. Text messages score a little lower. A picture says more than words. For the safety regions mobile phone and porto phone communication are identified as very valuable. This is less important for the other organizations. The Safety Regions score Social Media a little lower then other organizations. For the ANWB and the Regional Traffic Management Centres, this is more important. The ability to automatically push incident information, share messages at once with all organizations, and notify information changes score high for all organizations. A filter that can personalize information scores a little lower.

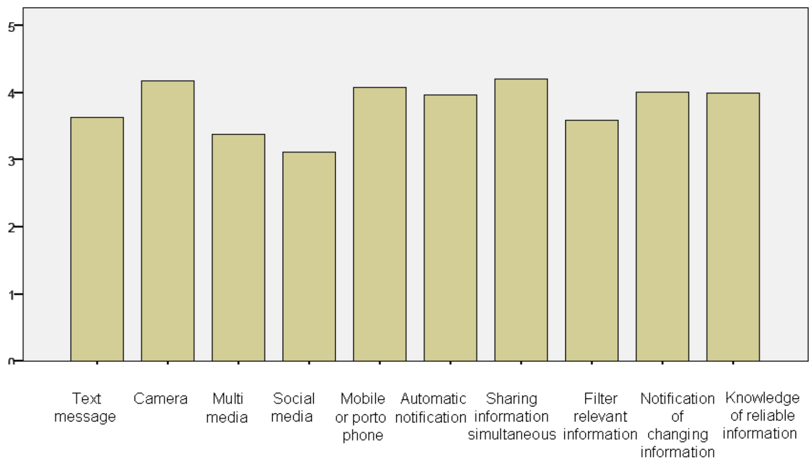


Figure 6.17: Mean scores of desired functionality (N=165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

In general, the scores are between 3 and 4 (see Figure 6.17). We can thus conclude that most of this functionality is relevant for all IM organizations. In the current situation, this functionality is available only on a limited scale within the Safety Regions (Police, Fire Brigade and Ambulance (GHOR)).

6.7 Information quality

This section focuses on the information quality as perceived by the participants of currently used information systems to support traffic IM (see Figure 6.18). There is not a great variation between the scores. In particular, completeness of information is scored low by the Regional Traffic Management Centre, the Fire Brigade, the GHOR, the LCM and the CMV. In general, the score lies between 3 and 4. This means that organizations indicate that some significant improvements can still be made in information quality.

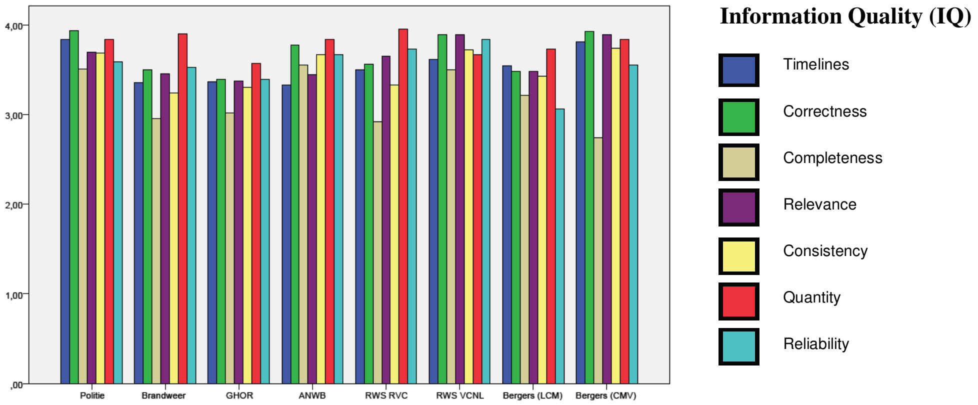


Figure 6.18: Current information quality per organization (N=165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

In Figure 6.19 the mean value of the IQ scores are shown. Completeness, consistency, and reliability of information score a little lower than the other IQ items.

Figure 6.19: Mean value of information quality (N=165)

6.8 System quality

This section focuses on the system quality as perceived by the participants of currently used information systems to support traffic IM (see Figure 6.20). By 'information systems', we mean all systems that are currently used to support the daily IM handling. Having between 4 and 5, the ANWB score is significantly higher the other IM organizations. The Safety Regions score approximately the same (between 3 and 4). The Rijkswaterstaat has the lowest score. The towing organization LCM scores a little higher than CMV. In Figure 6.21 the mean value of the SQ scores are given. The values lie around 3. Here we can conclude that major improvements are possible.

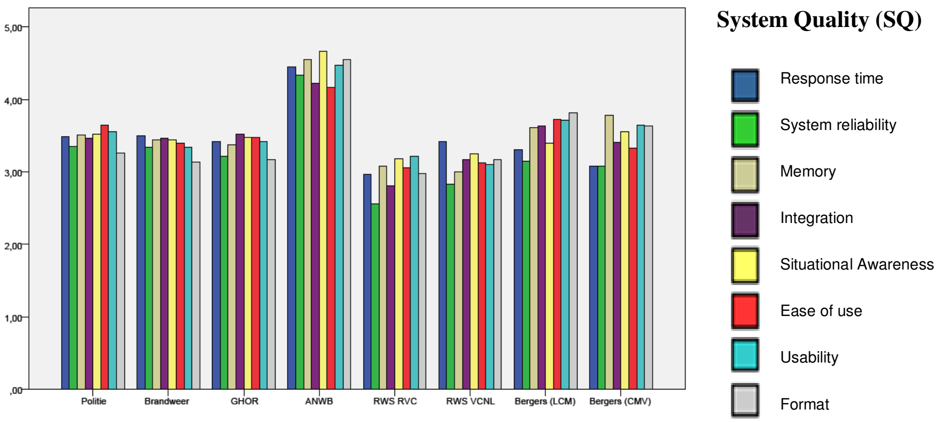


Figure 6.20: Current system quality per organization (N=165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

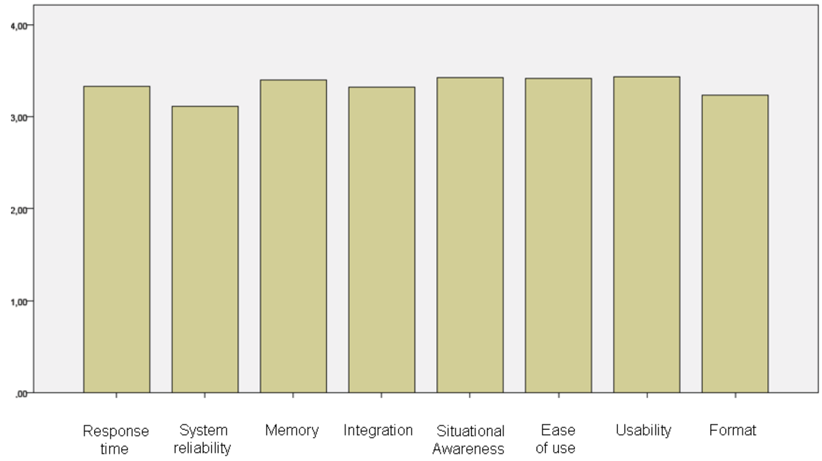


Figure 6.21: Mean value for system quality (N=165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

Figure 6.22 indicates how organizations currently perceive how information systems support traffic IM. It is clearly visible that the current systems better support their own activities than cooperation between different IM organizations.

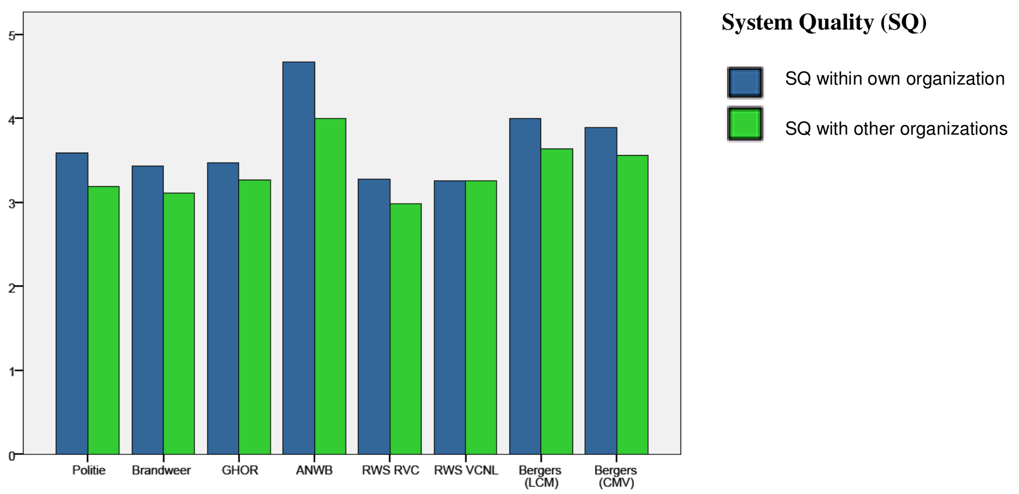


Figure 6.22: Mean perceived value for how information systems support IM (N=165)

Note: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree (Likert scale 1-5).

6.9 Information dependence

Understanding operational dependency and the information requirements of participating IM organizations can have a catalytic impact on interagency information-sharing

(Ren *et al.*, 2008), and motivate more responders to share their information actively with other agencies. The collaboration between emergency organizations is clearly described in Article 2 of the Policy Rules (Dutch Ministry of Transportation and Water Management, 1999). This was originally the start of the IM actor network of different public and private organizations on the national and the regional level (see Sections 2.3 and 2.4). In these policy rules there is some general agreement on how to cooperate for effective IM handling. This includes specific measurements on communication, cooperation, organization, and responsibilities. This is necessary because each organization has its specific role and legal responsibility.

The work of Bharosa *et al.* (2010) provides an overview of factors which influence information-sharing and coordination on three levels: community, agency, and individual. Dependencies proved to be an appropriate starting point for the study of coordination (Gonzales, 2008). In practice, coordination is about resolving or managing dependencies between activities. This can be traced back to the organizational design theories of different scholars (e.g. Marchand and Simon, 1958; Galbraith, 1974; Mintzberg, 1979; Malone and Crowston, 1994). This view is also generally associated with notions of problem-solving, goal-seeking, and decision making by rationally bounded agents. Most multi-agent dependence can be reduced to information dependency (Fan *et al.*, 2005). During a crisis or emergency, many of the logistical problems are not caused by lack of resources, but by the failure to coordinate their distribution (Malone and Crowston, 1994). This challenge of coordinating resource distribution and activities becomes harder if we take into account that the network of response agencies changes as the phases of emergency response evolve (Chan *et al.*, 2004). This difficulty is just an example of the complexity of coordinating a emergency response effort.

Table 6.2: Information dependence on other organizations (N=162)

	RWS	Police	Fire Brigade	Ambulance	ANWB	Towing
RWS RTMC	4.26	4.21	4.00	3.77	3.60	3.81
RWS VCNL	4.50	3.75	3.00	2.75	3.00	3.75
Police	3.71	3.94	3.45	3.49	2.76	2.71
Fire Brigade	3.71	4.07	4.11	4.11	2.32	2.18
Ambulance	2.94	4.06	3.89	4.00	2.56	1.89
ANWB	4.33	3.33	3.00	3.00	4.33	3.33
Towing LCM	4.27	4.00	1.82	1.82	3.55	3.64
Towing CMV	4.00	3.78	2.67	2.67	2.78	3.89
Total (Weighted)	**3.85**	**4.02**	**3.58**	**3.54**	**2.97**	**2.98**

Note1: in the first column only the Regional Traffic Management Centre is included.

Note2: In the last column the mean value of the towing (LCM and CMV) is shown.

To understand the network operation, it is thus important to understand the inter-organizational strength in terms of information dependence. Table 6.2 indicates how each organization scores its information dependence on other organizations: in other words, how dependent organizations are on information from other organizations in order to be able to effectively handle an incident. From this table it is clear that the various organizations are most dependent on the RWS and the Police. In second place, we find the Fire Brigade and the Ambulance service and then the towing and repair services. We did not distinguish between different types of incidents. In addition, we can see that the CMV (trucks) is more dependent on the Fire Brigade and the Ambulance service than the LCM is, while the LCM has a stronger relationship with the ANWB than the CMV does. The Fire Brigade and the Ambulance service results indicate that they are less dependent on the towing services.

We can compare the results from Table 6.2 with those of Table 6.3 to see how organizations score each other. This is interesting because it reflects the interdependence of the organizations. This shows the strength of the individual relationship in terms of information dependence. The cells shaded in green indicate, for each of the organizations in Column 1, what are the organizations on which they most depend. The main IM organizations for the Regional Traffic Management Centre (RWS RTMC) are the Police, the Fire Brigade and the Ambulance service. The towing and repair services score a little lower. The National Traffic Management Centre (RWS VCNL) sees the Police as its most important player.

Table 6.3: Cross-information dependence (N=162)

	RWS	Police	Fire Brigade	Ambulance	ANWB	Towing
RWS RTMC	-	1.13	1.08	1.28	0.83	0.92
RWS VCNL	-	1.01	0.81	0.94	0.69	0.94
Police	0.88	-	0.85	0.86	0.83	0.69
Fire Brigade	0.93	1.18	-	1.06	0.77	1.00
Ambulance	0.78	1.16	0.95	-	0.85	0.87
ANWB	1.20	1.21	1.29	1.17	-	1.00
Towing LCM (cars)	1.12	1.48	0.83	0.96	1.07	-
Towing CMV (trucks)	1.05	1.39	1.22	1.41	0.83	-

Note 1: In the first column only the Regional Traffic Management Centre is included.

Note 2: In the last column the mean value of the towing services (LCM and CMV) is shown.

The Police are seen as the strongest information organization. This can be explained historically, because originally they also had the responsibility for traffic management. In recent years, this role has slowly been handed over to the RWS. The Fire Brigade is strongly related to the Police and the Ambulance services. The Police are the most important player for the Ambulance service. The ANWB sees all players as important. The LCM's main players are the RWS, the Police and the ANWB. The CMV has a strong relationship with the RWS, the Police, the Fire Brigade and the Ambulance services. This provides good guidance for developing new information systems to support traffic IM.

Table 6.4 shows how the actors' own information is relevant for other IM organizations. The RWS, the Police and the ANWB all indicate that they believe that they are a strong information provider for other organizations. This is in line with Table 6.2, with the exception of the ANWB.

Table 6.4: Own information that is valuable for other organizations – weighted values (N=162)

	RWS	Police	Fire Brigade	Ambulance	ANWB	Towing	Total
RWS RTMC	4.33	4.21	4.14	4.05	3.58	4.30	**4.10**
RWS VCNL	4.50	3.25	3.00	2.75	4.25	2.50	**3.38**
Police	4.22	4.20	4.04	4.00	3.20	4.00	**3.94**
Fire Brigade	3.57	4.00	4.04	4.04	2.68	3.00	**3.56**
Ambulance	2.94	3.89	3.83	3.89	2.44	2.17	**3.19**
ANWB	4.67	4.00	4.00	4.00	4.67	4.00	**4.22**
Towing LCM (cars)	3.45	3.00	2.36	2.36	2.82	4.36	**3.06**
Towing CMV (trucks)	3.67	3.56	2.78	2.78	2.89	4.22	**3.32**

Note1: in the first column only the Regional Traffic Management Centre is included.

Note2: In the last column the mean value of the towing (LCM and CMV) is shown.

Table 6.5 provides an overview of the cross-information dependency from Tables 6.2 and 6.4. This more or less confirms the findings from Table 6.3. Now in Table 6.5, The Police and the RWS are seen as the strongest information organizations, but not the ANWB. The cells shaded green indicate which organizations in the first column consider themselves to be the strongest providers of information with respect of each organizations in the first Tables 6.2 and 6.4.

Table 6.5: Cross information dependence (N=162)

	RWS	Police	Fire Brigade	Ambulance	ANWB	Towing
RWS RTMC	0.98	1.00	0.97	0.93	1.01	0.89
RWS VCNL	1.00	1.15	1.00	1.00	0.71	1.50
Police	0.88	0.94	0.85	0.87	0.86	0.68
Fire Brigade	1.04	1.02	1.02	1.02	0.87	0.73
Ambulance	1.00	1.04	1.02	1.03	1.05	0.87
ANWB	0.93	0.83	0.75	0.75	0.93	0.83
Towing LCM (cars)	1.24	1.33	0.77	0.77	1.26	0.83
Towing CMV (trucks)	1.09	1.06	0.96	0.96	0.96	0.92

Note1: in the first column only the Regional Traffic Management Centre is included.

Note2: In the last column the mean value of the towing (LCM and CMV) is shown.

6.10 Adoption rate of net-centric information systems

Net-centric information systems are relatively new to the traffic IM domain. Implementing these systems is a complex undertaking, and can be considered as a major innovation in the daily IM operations. In this section we highlight the main factors that can influence the rate of adoption. According to Everett Rogers (1995), there are five qualities that determine between 49 and 87 per cent of the variation in the adoption of new products or services (Table 6.6).

Table 6.6: Definition of adoption factors (adopted from Rogers, 1995)

Factors	**Definition**
Relative Advantage	How improved an innovation is over the previous generation.
Compatibility	The degree to which an innovation is perceived as being consistent with the values, past experiences, and needs of potential adopters.
Complexity or Simplicity	If the innovation is perceived as complicated or difficult to use, an individual is unlikely to adopt it.
Triability	How easy it is to experiment with an innovation. If a user is able to test an innovation, the individual will be more likely to adopt it.
Visibility	The extent to which an innovation is visible to others. An innovation that is more visible will drive communication among the individual’s peers and personal networks and will in turn create more positive or negative reactions.

First we analyse whether the respondents are familiar with net-centric information systems. We will then look more into the adoption factors as identified by Roger (1995).

6.10.1 Familiar with net-centric systems

This subsection concerns how well known, to the respondents, is the concept of net-centric information systems. This gives an average score of 2.92 (N=164). This means that less than the half of the respondents have knowledge about this concept. There is a significant difference in knowledge between the organizations (see Figure 6.23). The Safety Regions and the ANWB score much higher than the other organizations. Within the Rijkswaterstaat, there is relative little knowledge. This is a clear indicator that introducing this concept needs to be carefully managed, especially because the Regional Traffic Management Centre is the key IM player.

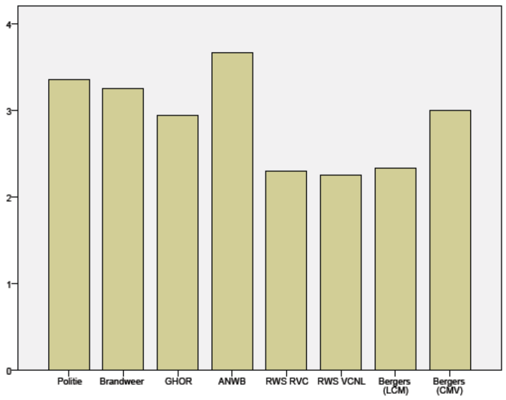


Figure 6.23: Familiar with net-centric systems (N=162)

6.10.2 Complexity

This is the degree to which an innovation is perceived as difficult to understand and to use. New ideas that are simpler to understand are adopted more rapidly than innovations that require the adopter to develop new skills and understandings. The scores lies approximate around 3 (see Figure 6.24). There is no significant difference in the perceived complexity between organizations. The ANWB score slightly higher than the rest of the organizations. This also confirms that the introduction of net-centric systems needs to be carefully managed.

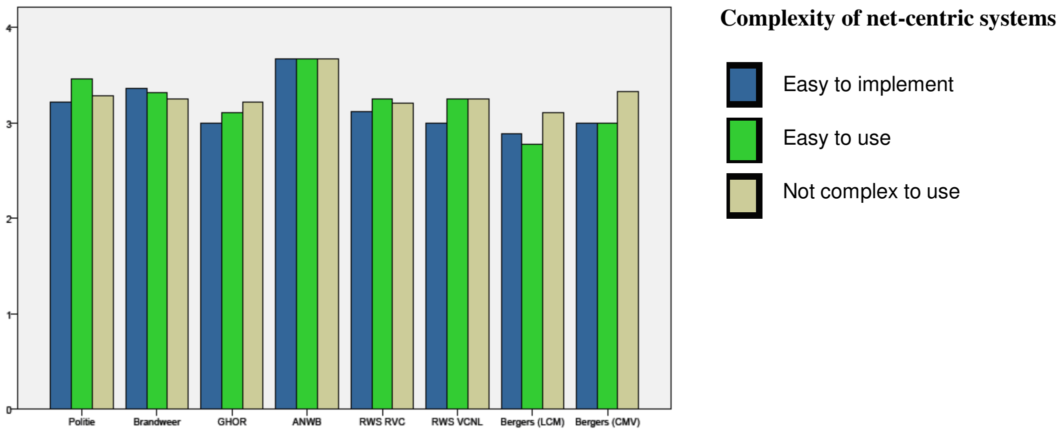


Figure 6.24: Perceived complexity of net-centric systems (N=162)

6.10.3 Relative advantage

This is the degree to which an innovation is perceived, by a particular group of users, as better than the idea it supersedes, and is measured in terms that matter to those users, like economic advantage, social prestige, convenience, or satisfaction. The greater the perceived relative advantage of an innovation, the more rapid its rate of adoption is likely to be.

It is interesting to see that net-centric systems are actually not well known, but there is a relatively strong perceived usefulness of such systems (see Figure 6.25). The average values lie between 3 and 4. This is a clear indicator that net-centric systems have the potential to be adopted within the IM domain.

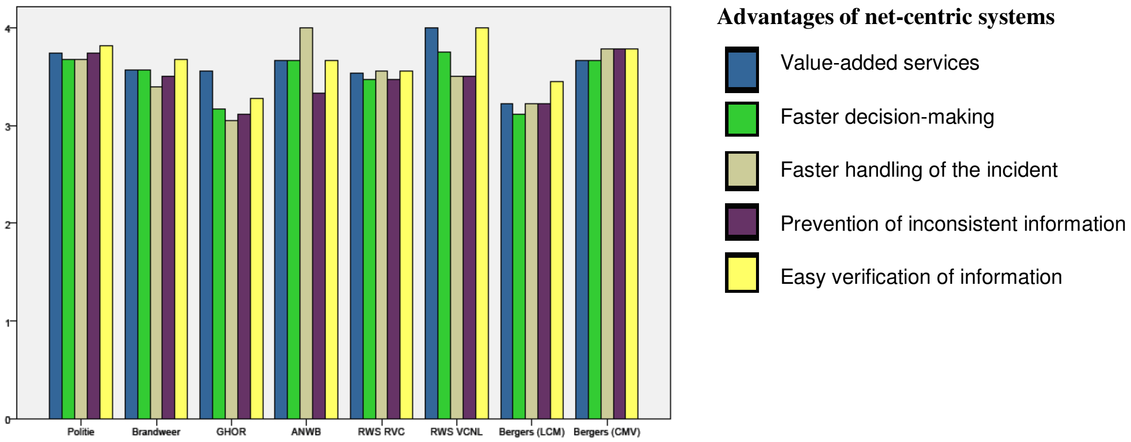


Figure 6.25: Relative advantage of net-centric systems (N=162)

Another question focuses on where IM organizations see the potential benefits. As is evident in Figure 6.26, all organizations clearly indicated that net-centric systems have a strong value for all incident types, with the exception of the towing organization LCM. Also this is a strong indicator that net-centric systems actually have their roots in the military domain, the respondents indicate that these systems also support incidents and not merely the more complex disaster management events.

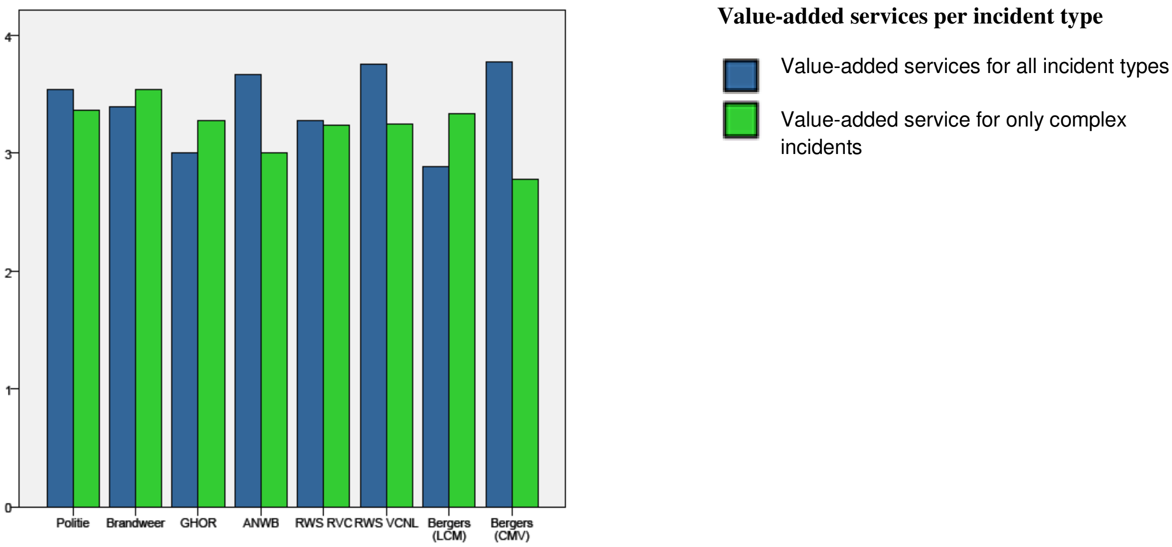


Figure 6.26: Value added services between different types of incidents (N=162)

6.10.4 Compatibility

This is the degree to which an innovation is perceived as being consistent with the values, past experiences, and needs of potential adopters. An idea that is incompatible with their values, norms or practices will not be adopted as rapidly as an innovation that is compatible. As is clearly visible in Figure 7.27, all organizations see net-centric systems as being more or less compatible with their existing IM systems. The scores lie slightly between 3 and 4. This is also a strong indicator that net-centric systems fit well within the IM operations, and are a logical next step in a new generation of IT solutions.

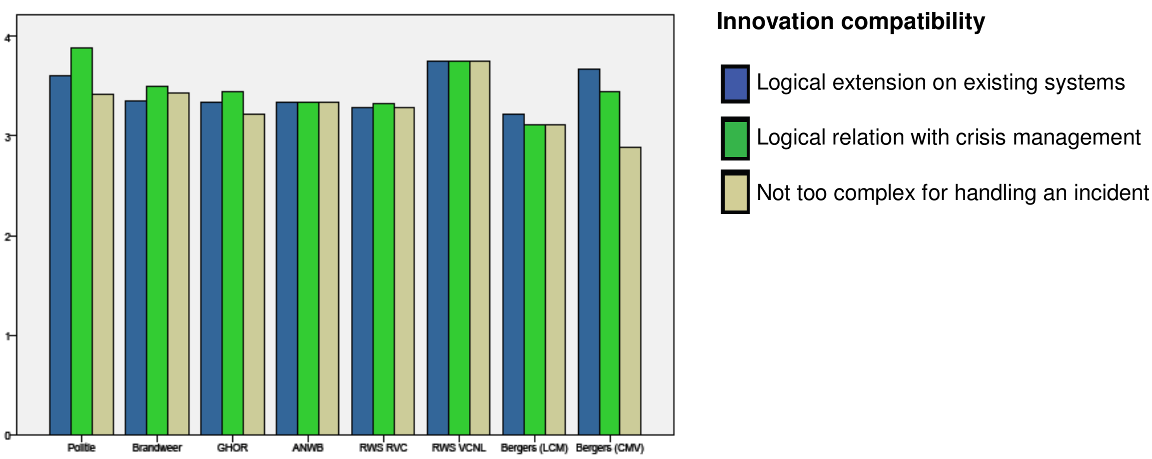


Figure 6.27: Compatibility of innovation with existing values, past experiences, and adopter needs (N=162)

6.10.5 Visibility

The easier it is for individuals to see the results of an innovation, the more likely they are to adopt it. Visible results lower uncertainty and also stimulate peer discussion of a new idea, as the friends and neighbours of an adopter often request information about it. Visibility is a strong indicator in the discussion on and the acceptation of, new technology. The results are slightly below 3. This means that there needs to be some special attention to this indicator.

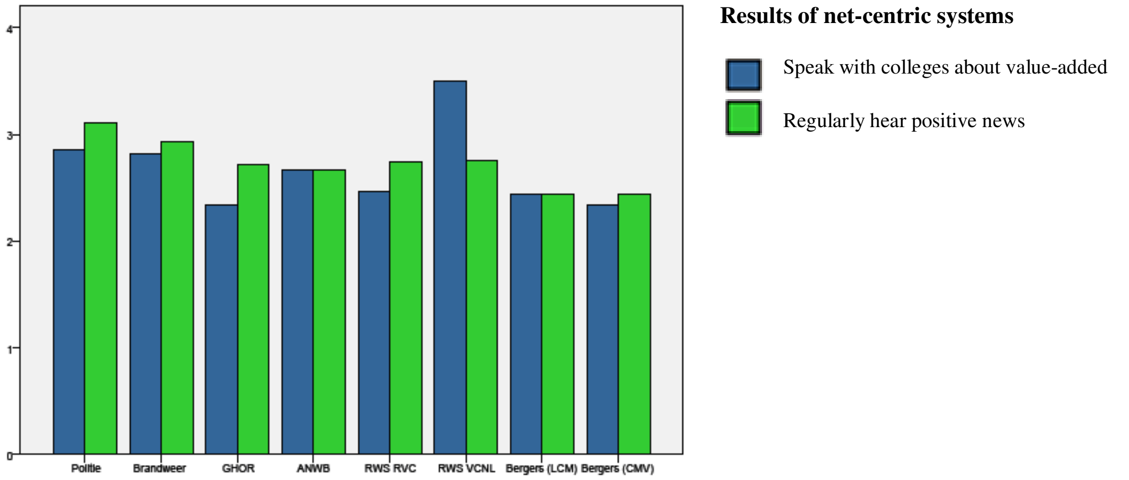


Figure 6.28: Visible results of net-centric systems (N=162)

6.10.6 Triability

This is the degree to which it is positive to experiment with an innovation on a limited basis. An innovation that is triable, represents less uncertainty to the individual who is considering it.

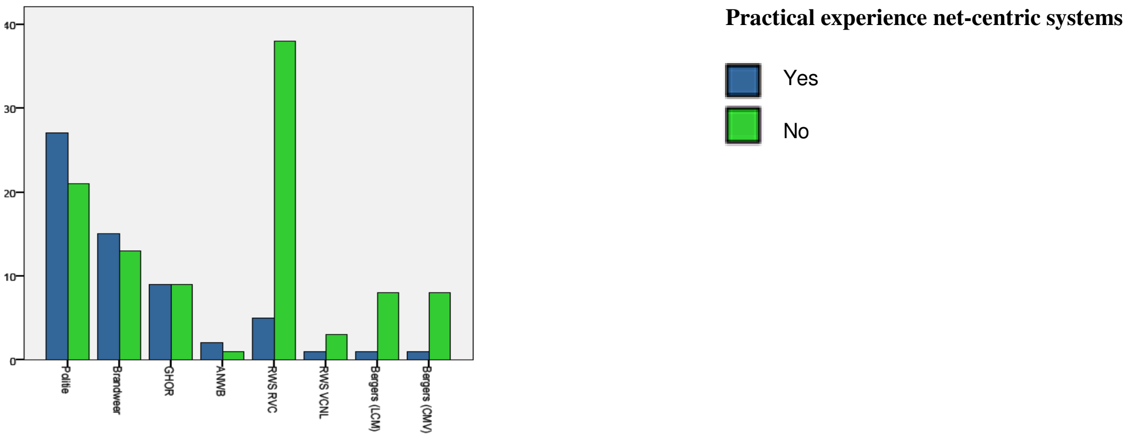


Figure 6.29: Practical experience with net-centric systems (N=162)

If an idea can be tested in a controlled environment, there is a higher chance that the innovation will be accepted more quicker. It is therefore crucial to give potential end users the chance to experiment with net-centric systems. The next three questions highlight what is the attitude to net-centric systems. The first question asked whether the participants had practical experience with these systems. 101 of the 162 participants had never worked with these systems (see Figure 6.29).

The second question focuses on the attitude of the participants to see whether they consider that a collaborative training exercise would help to improve the information sharing between different IM organizations. 145 of the 162 participants think that cooperative training would help to improve the quality of information sharing (see Figure 6.30). This is a strong indicator that organizing training sessions on a regular basis is very relevant to adopting net-centric systems.

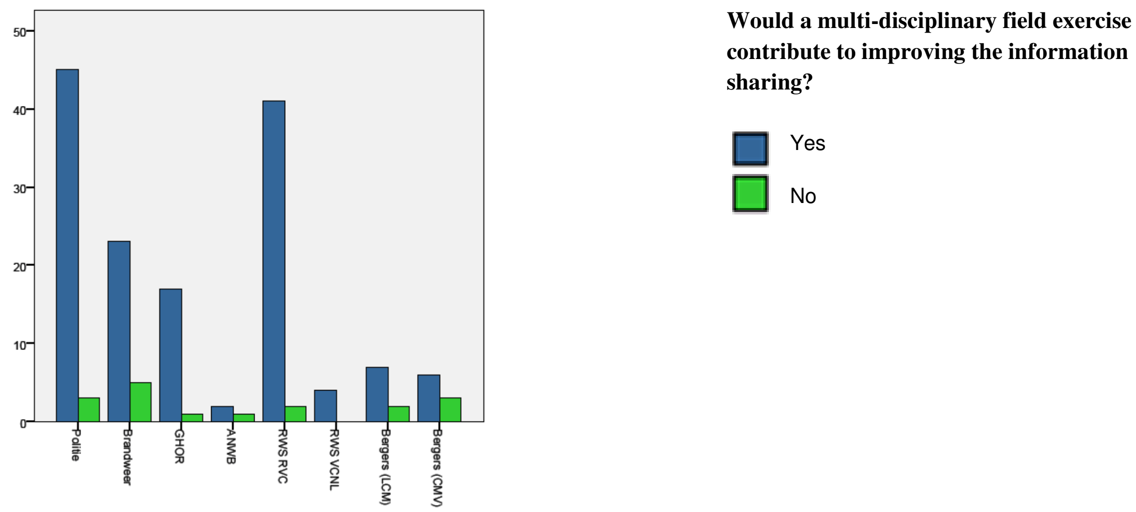


Figure 6.30: Attitude to training with all IM organizations (N=162)

The third question asks about the willingness to participate in a field exercise to experience the value-added services of net-centric systems. 141 of the 162 participants were willing to participate in such training (see Figure 6.31). Here we can conclude that the respondents are in favour of improving the daily handling of traffic incidents. This means that in the Netherlands there is clearly a positive attitude to improving IM, in particular with regard to information sharing, between the emergency services.

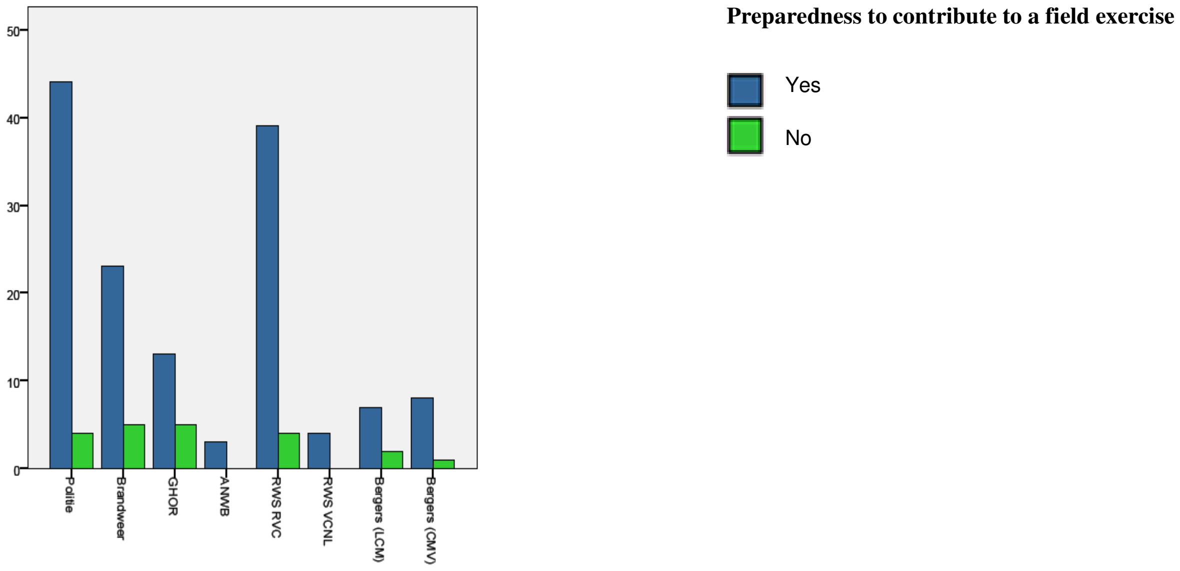


Figure 6.31: Willingness to participate in a net-centric field exercise (N=162)

6.11 Discussion

In this chapter, we used an Internet questionnaire, administered to the relevant stakeholders, to analyse the current status of traffic IM deployment in the Netherlands. The results provide some new insights and also confirm some previous assumptions. The most relevant topics are:

- the main information, communication, and coordination issues;
- knowledge about information quality and system quality;
- knowledge of the main information needs and system functionality of each IM organization;
- the information dependency arising from an actor-network approach;
- specific factors that influence the willingness to adopt new information concepts.

In general, we can state that, in the Netherlands, the application of IM is supported by highly professional public and private organizations. In the operation or action phase (scene management), the cooperation between IM organizations is very effective. However, the results of the questionnaire confirm that there still a lot to gain from improving the information provision necessary to support the IM process. Particular at the beginning of the IM process (detection, verification and allocation of necessary resources), there are still many information, communication, and coordination problems.

Besides that, there is a clear view on how emergency operators and traffic managers judge their current systems in terms of information quality and system quality. Telephone communication is an important instrument for communication and coordination, but additional information systems are necessary for the effective handling of a traffic incident. The questionnaire also provides a clear view of how each respondent scored the desired information needs and required system functionality to support the daily handling of traffic IM. It is important to observe that the outcomes differ per organization.

Finally, we can conclude that the willingness-to-adopt the concept of new net-centric information systems among IM organizations is very high. All organizations underline the value-added service of such a concept. There are clearly some introduction aspects which need special attention. A nice example is the information dependence between IM organizations. All organizations play an important role in the cooperation of the IM network. However, some organizations such as the Police and the Traffic Management Centres of the Rijkswaterstaat are the dominant players in terms of information provision. This is an important constraint for the introduction of net-centric systems.

Another important issue is practical experience and knowledge of net-centric systems. The Safety Regions (Police, Fire Brigade and Ambulance service) clearly have more knowledge and experience than the other organizations (the Rijkswaterstaat and the towing and repair services). Special attention needs to be paid to these issues.

The relatively high rate of participation in the Internet questionnaire confirmed that traffic IM is identified as an important topic. Information, communication, and coordination are important constraints to improve the daily handling of traffic IM in terms of road safety and mobility issues. The large number of new insights and amount of knowledge gained by this questionnaire is thus a good starting point for the introduction of a new information concept, such as net-centric system which can be used to create a Common Operational Picture (COP) to improve Situational Awareness (SA).

7 Effectiveness of Net-centric Support Tools for Traffic IM*

7.1. Introduction

The early and reliable detection and verification of incidents, together with integrated traffic management strategies, are important contributions to improve the efficiency of the incident response. In the Netherlands, several studies have analysed the relationship between Incident Management (IM) measures and the consequences of incidents (McKinsey and Company, 1995; Wilmink and Immers, 1996; Schrijver *et al.*, 2006; Kouwenhoven *et al.*, 2006; van Reisen, 2006; Knoop, 2009). IM emerges as one of the most important instruments of traffic management in the Netherlands, as it serves to mitigate and reduce incident effects, congestion and traffic jams, and eventually it may considerably contribute to reducing the number of casualties on the roads. All studies conclude that investing in IM measures is a very cost-effective strategy in road traffic management.

IM measures affect multiple phases of the incident-handling process. Classical IM strategies are aimed at minimizing the negative effects of congestion caused by an incident. Because of the quadratic relationship between the duration of an incident and the negative consequences of an incident, response time (speed of emergency aid) plays an important role in determining the overall incident effects. For instance, the number of lost vehicle-hours as the result of an incident depends on the time required to clear the road for traffic following an accident, the road capacity, and the extent to which the road capacity is filled (Immers, 2007a). The basic idea is that fast clearance of the incident scene can help to reduce the

* Based on: Steenbruggen, J., Kriekaert, M., Scholten, H., Rietveld, P. and Vlist, M. van der (2012). Effectiveness of Netcentric Support Tools for Traffic Incident Management - Results of a field experiment, in: Zlatanova, S., Peters, R., Dilo, A. and Scholten, H. (ed.) Intelligent Systems for Crisis Management, Geo-information for Disaster Management (GI4DM) 2012, pp. 217-250. Springer Heidelberg. ISBN 1863-2246

incident-related congestion. Improving Situational Awareness (SA) for emergency services is crucial for the quick clearance of the incident scene. Klein (2000a) presents four reasons why SA is important: a) SA appears to be linked to performance; b) limitations in SA may results in errors; c) SA may be related to expertise; and d) SA is the basis for decision making.

Breton and Rousseau (2003) state that SA measurement can be seen as a process where three questions need to be answered: 1) Why measure SA?; 2) What type of SA is measured?; and 3) How can it be measured? In the literature there are many definitions of SA. However, various papers address the difficulty in the development of SA measurement techniques (Gilson *et al.*, 1997; Endsley and Garland, 2000). Stanton *et al.* (2005) identified over 30 different approaches to measure SA. Salmon *et al.* (2006) categorize these into different types of SA measure. Models for SA that currently dominate the literature (see Stanton *et al.*, 2001) are individually oriented theories, including Endsley's three-level model (Endsley, 1995); the perceptual cycle model (Smith and Hancock, 1995) and the activity theory model (Bedny and Meister, 1999). Of the individual-oriented SA theories, Endsley's information processing based three-level model is the most popular (Endsley, 1995). Its counterpart measurement approach, the Situation Awareness Global Assessment Technique (SAGAT: Endsley, 1995) is the most commonly used procedure for measuring SA, despite questions regarding its validity as an SA measure (Salmon *et al*., 2006). However in the literature there is no general model that can be applied to traffic IM.

To measure SA it is crucial to include the concept of 'quality of information systems'. The term 'information systems' covers collecting, processing, distributing, and using data by organizational processes or people (Strong *et al.* 1997). The concept of 'quality' is often defined in terms of '*fitness for use'* (Juran *et al.*, 1974), '*fitness for intended use'* (Juran and Godfry, 1999) or '*fitness for purpose*' which has been a widely-used approach by quality agencies that is usually based on the ability of an institution to fulfil its mission (Harvey and Green, 1993). In the information systems literature, quality itself is relatively "ill-defined" (Nelson *et al.*, 2005). The concept of quality is usually bound to the specific object, such as a specific product, process, service, or information system. Different authors identify information and system quality as the key factor for information system success (Shannon and Weaver, 1949; Mason, 1978; DeLone and McLean, 1992). However, various authors have concluded that information quality and system quality are the major hurdles for efficient and effective multi-agency emergency services, and are crucial for information systems' success (Lee *et al.*, 2011). Information Quality (IQ) and System Quality (SQ) form an important requisite to achieve SA. There is a wealth of literature on information system success in profit-oriented business-environments research regarding information quality dimensions. However, the literature on the public sector emergency services and traffic IM regarding information-sharing across different agencies and the quality of information-sharing is scarce, and empirical support is almost non-existent. Our research will address the following questions:

- Which constructs are relevant to measure information quality and system quality for traffic IM (literature review)?
- How was the new information system appreciated by end-users in terms of IQ and SQ?
- Is there a difference in terms of communication and coordination between the two groups?
- How has SA improved the performance of the decision-making process (outcomes)?
- What are the main issues using net-centric systems as experienced by end-users?
- What are the effects of scenario complexity on the benefits of net-centric systems?

7.2 Assessing the effectiveness of net-centric information systems

7.2.1 Situation awareness

Endsley (1988) defines SA as a product comprising "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". A Common Operational Picture (COP) is the basis to create SA for the emergency services to support traffic IM. A COP is established and maintained by gathering, collating, synthesizing, and disseminating incident information to all appropriate parties (Homeland security, 2008). Achieving a COP allows on-scene and off-scene personnel to have the same information about the incident, including the availability and location of resources and the status of assistance requests. This can be achieved by the introduction of net-centric information systems which provide the capability to acquire, generate, distribute, manipulate, and utilize information. The relationship between these new information concepts for traffic IM is extensively described by Steenbruggen *et al.* (2012b).

SA consists of the terms ‘Situation’ and ‘Awareness’ which are both relevant in terms of measuring the value-added services to improve existing information systems. ‘Awareness’ systems can be broadly defined as those systems that help people (emergency workers) to construct and maintain awareness of each others’ identity, location, activities (tasks), context or status (Markopoulos *et al.*, 2009). A general definition of ‘Situation’ can be found, for example, in Pew (2000) who defines it as the surrounding environment (spatial awareness), mission goals, system availability, and physical human resources, and each ‘crew member’ must know the current activity of other crew members. Wickens (2002), for example, defines SA components as geographical awareness, system awareness, and task awareness. There are some common elements in these definitions such as organization, system- and environment-related variables. However, in the literature there is no general model that can be applied to traffic IM. Therefore, we use three elements of information which define ‘Situation’ in order to support traffic IM awareness: incident information; information specifically related to the environment of the incident; and information about the emergency organizations involved in dealing with the incident.

Hone *et al.* (2006) has stated, that although Endsley’s definition (1988) of SA is very good, it has some major problems. The definition cannot be operationalized. The three levels are treated as sequential and are often called perception, comprehension, and prediction. In the real world, *perceptual inputs* are both sequential and parallel. *Comprehension* starts with the first perceptual input. *Prediction* can start before *comprehension* is completed. So, Level 1 and Level 2 cannot be separated, and it may be hard to distinguish Level 3. Hone *et al.* (2006) reformulates Endsley’s definition of SA: 1). ‘a person’s perception of elements in the environment within a volume of time and space’ to ‘Who is where’?; 2). ‘the comprehension of their meaning’ to ‘What are they doing’? and; 3) ‘the projection of their near future’ to ‘What will they do’? Hone *et al.* (2006) made a good step for SA to be operationalized. However, he only talks about people (organizations), but for traffic IM there are also other elements that are relevant. In Table 1 we give an overview of some examples of traffic IM information components and what to measure at the different levels of SA.

Table 7.1: Measuring levels for SA and traffic IM information components

SA components	Incident	Environment (surrounding of the incident)	Organization (emergency services)
Level 1 Perception of elements in the environment within a volume of time and space (Who or what is where?)	• What is the incident location? • What type of incident? • What is the nature of the incident?	• Where is the congestion located? • Where are the traffic jams? • Where are the road users?	• Which emergency organizations are involved? • Where are the managers / emergency services?
Level 2 The comprehension of their meaning (What are they doing? What does it mean?)	• What causes the incident? • What is the number of injuries? • Is there release of dangerous goods?	• What causes the congestion: incident, events, weather? • What is the site accessibility for emergency services? • How many people are in the area?	• How should we respond? • Which traffic management strategies do I have at my disposal?
Level 3 The projection of their near future (What will they do? Which impact it will have?)	• When will the road be cleaned?	• How far will the consequences of an incident reverberate on the road network? • What risks are there for the surrounding area (e.g. chemical releases?	• What will they do (activity)? • At what time will they be (t)here?

Note: Adapted from Endsley (1995) and Hone *et al.* (2006)

7.2.2 Information quality

The management of information is essential for the coordination of emergency response (Ryoo and Choi, 2006). Information (or data) quality (IQ) can be seen as an important requisite for improving cooperation between IM emergency responders. IQ must be in line with the requirements of end-users (Wang and Strong, 1996). IQ is difficult to observe, capture or measure (Singh *et al.*, 2007) and can be considered a confusing concept (Evans and Lindsay, 2005). In the literature, a great deal of attention has been paid to the attributes of IQ. This refers to attributes that are important for end-users and IQ has multiple dimensions by which we can measure it (Miller, 1996). Data quality is established during three procedures within the information manufacturing cycle, which evolves through a sequence of stages: data collection, organization, presentation, and application (Strong *et al.*, 1997). Many studies have confirmed that IQ is a multidimensional concept (Ballou and Pazer, 1985; Wand and Wang, 1996; Wang and Strong, 1996; Huang *et al.*, 1999). Several researchers have identified different dimensions of IQ. However, until now, a uniform list of the IQ attributes (constructs) does not exist. For example, Strong *et al.* (1997) group the IQ dimensions into four categories. These categories capture different dimensions with a similar degree of information quality. The categories are: intrinsic; accessibility; contextual; and representation. These categories are widely acceptable in the literature (Li *et al.*, 2003) and form the only framework that has been involved and refined over the years, and proposes empirically tested items for IQ measurements (Lee *et al.*, 2002). However, in the literature many papers have their own classification. We analysed 15 papers from the literature to see which IQ dimensions are most used. We made a distinction between generic information-quality dimensions (Miller, 1996; Wang and Strong, 1996; Strong *et al.*, 1997; Lee *et al.*, 2002; Delone and McLean, 2003; Eppler, 2003; Wixom and Todd, 2005; Parker *et al.*, 2006) and specific applied IQ dimensions for emergency services (Perry *et al.*, 2004; Singh *et al.*, 2007; Bharosa *et al.*, 2009 and Bharosa, 2011). We looked at which dimensions, within the five identified IQ groups, are most relevant for emergency services (Table 2).

Table 7.2: Most relevant information quality dimensions identified in the literature

IQ groups	Information quality constructs
Intrinsic	Accuracy, Objectivity, Believability, Reputation
Accessibility	Accessibility, Security
Contextual	Relevancy, Value added, Timeliness, Completeness, Quantity (information overload)
Representation	Interpretability, Concise, Consistency, Comprehensive
Others	Correctness, Currency, Precision, Format, Availability, Reliability (validation), Personalization

Intrinsic data quality indicates that information has quality in its own right that is inherent to the data, and which consists of context-independent dimensions. *Accessibility of data quality* focuses on the role of information systems that store, process, and deliver data to the end-user, and, in particular it refers to the ease with which available information can be accessed and/or is easily and quickly retrievable (extracted) from the system and very relevant for the emergency services. Relatively few researchers have paid attention to conceptual definitions (Knight and Burn, 2005). The definition of *accessibility* is framework-dependent. Some frameworks do not even consider it as a dimension of IQ (ECIS, 2009). In some papers, *security* is also seen as an important dimension (Singh *et al.*, 2009). In ECIS (2009) the increasing importance and relationship between *accessibility* and *security* is analysed in detail. Emergency services are information-intensive processes (de Bruin, 2006) and their effectiveness is largely dependent on the availability of the necessary information (Davenport and Prusak, 1998). There is also an ongoing debate about the relation of *accessibility* to IQ and System Quality (SQ). Some see *accessibility* more as a system quality dimension. *Contextual data quality* highlights that data quality must be considered within the context of the task concerned. The three most used contextual quality dimensions for emergency services are *timeliness* (Quarantelli, 1997, Dawes *et al.*, 2004; Christopher and Robert, 2006; Horan and Schooley, 2007; van der Walle and Turoff, 2007; Singh *et al.*, 2009); *relevancy* (Singh *et al.*, 2009); and *completeness* (Samarajiva, 2005; Townsend *et al.*, 2006). One of the main problems is information overload (Endsley and Kiris, 1995). Simply put, information overload is the notion of receiving too much information. It is widely agreed that more data does not mean better information. In an information-rich environment, users can be easily overloaded (Endsley and Kiris, 1995). This must be in line with the concept of '*bounded rationality*' (Simon, 1972). Therefore, *quantity* is also identified as an important construct. Eppler and Mengis (2003) provide a framework for information overload. *Representational data quality* looks at aspects related to the *format* of the information and its meaning. It concerns whether the information is presented in an easily interpretable, understandable, concise, and consistent way. The most used representational quality dimensions for emergency services is *consistency* (Strong *et al.*, 1997, Perry *et al.*, 2004; Singh *et al.*, 2007). For example, if several organizations identify an inconsistency in a different incident location, this delays decision making (Fisher and Kingma, 2001). Inconsistent information from multiple sources sometimes points to different answers. It is difficult to determine which information is correct, and which is false. Besides the four categories of Strong *et al.* (1997), there are also other IQ dimensions that are relevant for the emergency services. *Correctness* is mentioned as relevant in several studies and has a strong relation with the contextual data quality *completeness*. *Validation of data* is also mentioned as an important dimension (O'Leary, 2004; Singh *et al.*, 2007) which is strongly related to *correctness* and *reliability*. Reliable information is needs to be correct and is based on data that you can trust on (Wang and Strong, 1996). Two relatively new dimensions are *personalization* and *context awareness*, which both have strong relations with the contextual data quality dimension *quantity*. *Personalization* is related to context-aware computing whose primary goal is to make interaction with computers easier and more supportive for human activity. This can be done in several ways, one of the most important being the filtering of the information flow from application to user to avoid receiving irrelevant information and thus preventing the problem of information overload (Schmidt *et al.*, 1999). In other words, it is crucial to the right information at the right moment in the right context. Table 3 contains an overview of the IQ constructs we used for our field exercise.

Table 7.3: Overview of the selected information quality dimensions

Construct	Definitions (adapted from Perry et al. 2004)
Timeliness (currency)	The extent to which the currency of information is suitable to its use Applicable and helpful for the task at hand (Singh *et al.*, 2009)
Correctness	The extent to which information is consistent with ground truth
Completeness	The extent to which information relevant to ground truth is collected
Relevance	The proportion of information collected that is related to the task concerned
Consistency	The extent to which information is in agreement with related or prior information
Quantity (overload)	Information overload occurs when the information-processing requirements (information needed to complete a task) exceed the information-processing capacity (the quantity of information one can integrate into the decision-making process) (Eppler and Mengis, 2003)
Reliability (verification)	The extent to which information is correct and that one can trust it (Wang and Strong, 1996)

7.2.3 System quality

Although the study of System Quality (SQ) has a long history (for an extensive historical overview, see Delone and McLean, 1992, 2003), it has received less attention than information quality in literature (Bharosa *et al.*, 2009, Lee *et al.*, 2011). SQ is a concept used to measure and evaluate the multiple dimensions of the information processing system itself (Delone and McLean, 1992). SQ is related more to the characteristics of the information-processing system, and closely related to service quality and ease of use than to its resulting product. However, they are not the same. *Ease of use* can be seen as a consequence of SQ. *Ease of use* is more an overall indicator of perceived user satisfaction. *Usability* is how the system supports the primary tasks of the end-user. IQ constructs are more related to the output of an information system. SQ reflects the information-processing system required to produce that output (Nelson *et al.*, 2005). *Accessibility* and *system reliability* are seen more as system-related SQ dimensions. They represent defined properties that are largely independent of usage. *Accessibility* has been suggested as an important dimension in emergency response (Quarantelli, 1997; Dawes *et al.*, 2004; Comfort and Kapucu, 2006; Christopher and Robert, 2006; Horan and Schooley, 2007). It defines the role of information systems, that store, process, and deliver data to the end-user, and, in particular, it refers to the ease with which information (data) is available, can be accessed and or easily and quickly retrievable. *System reliability* is the technical availability of the system. *Response time*, *integration*, *memory*, *format* and *Situational Awareness* (SA) are more task related SQ dimensions. In the literature, *format* has also been identified as an IQ construct (Lee *et al.*, 2002; Wixom and Todd, 2005; Singh *et al.*, 2007). It can be defined as the meaning of the information, and concerns whether the information is presented in an easily interpretable, understandable, concise, and consistent way. Most of the time this is presented in a predefined format. Therefore we include this construct in SQ. Table 4 contains an overview of which SQ constructs are the most important to support a net-centric traffic IM system for our field exercise.

Table 7.4: Overview of selected system quality constructs

Construct	Definitions	Category
Accessibility	The degree to which a system and the systems related information it contains can be accessed with relatively low effort (Nelson *et al.*, 2005)	System-related
System reliability	The degree to which a system is dependable (e.g. technically available) over time (Nelson *et al.*, 2005)	
System response time	The degree to which a system offers quick (or timely) responses to requests for information or actions (Nelson *et al.*, 2005)	
Integration	The degree to which a system facilitates the combination of information from various sources to support business decisions (Nelson *et al.*, 2005)	Task-related
Memory	The degree to which the information (flow) and, tacit and explicit knowledge can be stored and organized in the system for reuse	
Format	The degree to which information is presented in an easily interpretable,	

	understandable, concise, and consistent way	
Situational awareness	The degree to which the system supports knowing what is going on around you (Adam, 1993; Adams *et al.*, 1995; Endsley and Garland, 2000).	
Ease of use	Satisfaction with user-interface (Nelson *et al.*, 2005)	Perceived operational satisfaction
Usability	'*fitness for use'* (Juran *et al.*, 1974) or '*fitness for purpose*', which is based on the ability of an institution to fulfil its mission (Harvey and Green, 1993)	

7.2.4 Impact on the decision process

Hone *et al.* (2006) stated that in the real world the perceptual inputs for cognitive processes for SA are both sequential and parallel. This means that the level and quality of SA need to be combined with the time duration of the incident. The duration is defined as the period of time in which traffic flow is disrupted due to an incident. The amount of delay and the number of impacts that result from the incident depend on the duration of the different distinct phases. The following phases (or time periods) can be identified (based on Zwaneveld *et al.*, 2000): detection, verification and warning time; response, driving, and arrival time; site management operation or action time; and normalisation and flow-recovery time.

The 3D model in Figure 7.1 is the basis to create a COP to support personalized SA related to the different user perspectives of the emergency services involved. The term "picture" in a COP refers not so much to a graphical representation, but rather to the data used to define the operational situation. As such, "*the creation and dissemination of the COP is as much an information management challenge as it is a visualization challenge*" (Mulgund and Landsman, 2007). Both aspects are relevant to support SA. This means that, for each IM phase, information needs to be available and shared in the right place and time, and presented in a way that a task-technology fit is accomplished for different end-users so information overload is avoided (Endsley and Kiris, 1995). A way to achieve this goal is net-centric working (see Steenbruggen *et al.*, 2012b).

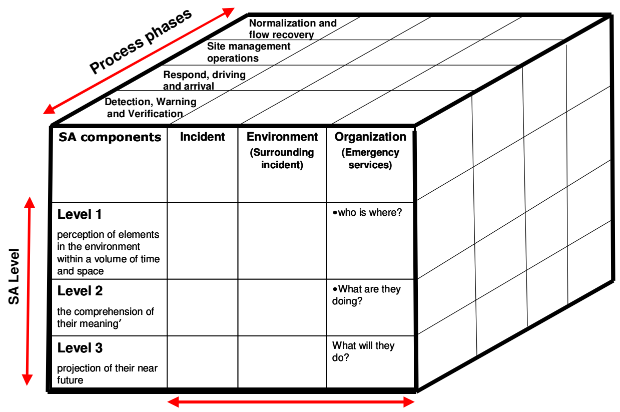


Figure 7.1: 3D model for measuring Situational Awareness for traffic IM

7.3 Design of the experiment

7.3.1 Supporting traffic IM in the Netherlands

Incident Management (IM) is, in general, the policy that, through a set of measures, aims to reduce both the negative effects on the traffic flow conditions and the effects on safety, by shortening the period needed to clear the road after an accident has happened. It can also be seen as a process to detect, respond, and clean-up traffic incidents, and to restore traffic capacity. There are many private and public organizations involved in the daily handling of IM. The public IM emergency services are the Road Authority, Police, Fire Brigade, and the Ambulance services. In the Netherlands, the Rijkswaterstaat has, in the context of the law called Rijkswaterstaatworks Management Act (1996), the public responsibility for an efficient and safe use of the main road network. Towing, repair, and insurance services are the main tasks of private IM parties. Together, the different parties have set up new guidelines and protocols in order to shorten the time that is needed to clear the road after incidents.

Timely and accurate information plays an important role in the information chain between IM emergency services. Inter-agency exchange of information is the key to obtaining the most rapid, efficient, and appropriate response to highway incidents from all agencies. Information systems play an important role within and between organizations. Current IM practices still have many issues which have regularly been identified in the daily operations in terms of information-sharing, communication, and coordination.

IM organizations are strongly related and need to collaborate for an effective incident response. Each organization has the same kind of problems in terms of system diversity, architecture, and standards used. Information-sharing between traffic management control centres, emergency control centres, towing services and insurance companies is becoming increasingly important. Achieving identical SA and a common handling framework for effective IM is necessary for further improvement of cooperation.

7.3.2 Hypotheses to be tested

Four hypotheses are tested to evaluate the effectiveness of the net-centric information systems:

1. Net-centric systems improve the appreciation of IQ and SQ by end users.
2. SA improves the performance in the decision making process of the emergency organizations.
3. Net-centric systems improve the communication and coordination of the emergency organizations.
4. Scenario complexity affects the design principles of net-centric systems.

7.3.3 Set-up of the experiment

In the field exercise we introduce new information concepts such as net-centric working, and a COP to improve information and system quality. This is the basis for an improved SA, which leads to better decisions, better actions, and thus better effects. To test these concepts we set up a field exercise. On 25 May 2012, a national IM test took place in the city of Eindhoven (the Netherlands). Five incident scenarios were simulated to measure the value added by a net-centric system. Participants were randomly assigned to one of two groups. The test group used the net-centric systems while the control group used traditional tools. The net-centric system provided the possibility to exchange pictures of the incident (see Figure 7.2a), to see where other parties were, and send text-messages to all parties at once. The control group used a system that had similar capabilities as their daily practice systems and communicated via telephone. The communication between the different actors was recorded by a group of students, based on shadowing. Computer loggings of the communication that took place in the system were also recorded. Questionnaires were handed out to all actors participating on the tests. At the end of each scenario, respondents filled out a questionnaire on IQ. After all scenarios were considered, questions on SQ were answered.

Figure 7.2a: Centralist in action

Figure 7.2b: Fieldworkers on the scene

7.3.4 Participants

The demographics of the participants in the field exercise are shown in Table 7.5, which shows: number of participants, average age, gender, condition, organization, work experience, GRIP (2006) experience and education. Due the limited number of participants in the field experiment, these attributes are not used for statistics but simply for information.

Table 7.5: Demographics of participants field exercise

Participants	16
Average age	44.1
Gender	**n**
Male	14
Female	2
Condition	**n**
Test group	9
Control group	7
Organization	**n**
Regional Traffic Management Centre	2
Road district Rijkswaterstaat	4
Emergency room ANWB	3

Experience	**n**
0 - 1 year	0
1 - 5 years	4
5 - 10 years	5
10 - 20 years	5
20 - 30 years	1
More than 30 years	1
Experience Grip 2 incidents or higher	**n**
0 times	8
1 - 5 times	7
More then 5 times	0

Towing services	3
Towing emergency room CMV (trucks)	3
Towing emergency room LCM (cars)	1

Education	**n**
Lager onderwijs	1
LBO, LAVO, MAVO, MULO	1
MBO, VMBO, HAVO	9
MMS, HBS, VWO	0
HBO, Universiteit	5

7.3.5 Net-centric software tool

The introduction of new data sets and information concepts can be helpful in solving the identified problems and in reducing the time interval between the detection of the incident and the re-establishment of traffic flows in a significant way. This is particularly the case when information systems are linked to the information needs of actors involved in the IM process. The report '*Successful Response Starts with a Map*' (National Research Council, 2007) concludes, on the basis of various workshops and interviews, that during major disasters in the United States, there was a lack of correct information. The report indicates that the information needed for disaster response consists primarily of specific location information. This information is also referred to as 'spatial information'. The report also recommends that preparations for future disasters must always be based on this spatial information. Attention to the spatial information also remained limited in the Netherlands until recently, but people are becoming increasingly aware that the spatial component is crucial, not only for the realization of the information but also for communication of the information (Neuvel *et al.*, 2011). An example of a technical specification of an early attempt to develop a system to improve information sharing and SA can be found in Vink (2009).

Scholten *et al.* (2009) drew up a conceptual diagram on how to work with this spatial information, which was based on four frameworks that are integrated using technology, and which can realise the information in question. Firstly, there is the *Organisational framework*, in which the boundary conditions are established, such as standards, legal conditions, security, etc. The *Data framework* contains a collection of all the necessary basic data, both static and dynamic. The *Analytical framework* describes the way in which the processes that play a role in a disaster can be analysed and modelled. The most important models pertain to floods, forest fires, evacuations and the spread of hazardous materials. Finally, there is the

Visualization and Communication framework, in which descriptions are given of how the spatial information is displayed and communicated, using maps, images and audio as well as texts.

The technology (GIS) enables the frameworks to be integrated and information systems to be built. These systems also have various forms, such as the part for the crisis control centre (single or multiple), the part for the drivers of the vehicles, the part for the mobile crisis control centre, and the part for the mobile users in the field. Communication between these users is crucial and must take place seamlessly. Each of them has the same common picture, and supplements this picture with specific information from the appropriate field of knowledge. This means that the information is not shared in a hierarchical manner, in which a central point of information usually does the sharing (Client-Server Model). Instead, each organization involved is both a source and a recipient. This model is referred to as 'peer-to-peer technology'. The technical details for such a peer-to-peer model for disaster response is provided in Scholten *et al.* (2008). This form of communication improves the speed of information exchange, and makes the network more robust. Further detailing of such a net-centric approach to provide spatial information for disaster response has the following functionalities:

- Information comes from various sources and various areas of knowledge, and also goes back to them;
- Information exchange takes place between the experts, without the intervention of the management hierarchy;
- The information is Geo-information, because the location aspect (location awareness) is essential;
- Ultimately, decision making takes place within the management hierarchy;
- Decision making requires complex information, sitreps (situation reports) and sitplots (situation plots).

It is assumed that better and faster sharing of information in this network will result in a better deployment, resulting in increased efficiency during disaster response. The bases for this are: correct information: the right people: the right place and the right time. The starting points for the Traffic IM System (TIMS) are as follows:

- The TIMS must be seen as a basis facility which can be expanded if necessary to include additional facilities, functionalities, data, and participants;
- The TIMS consists of a Geographical Information System, a Text System, a Logging System, a voice system, and a Security System. All these components are integrated;
- The participating actors are connected to the TIMS, which gives them access to all the information that is being shared; and
- The TIMS supports the disaster-response decision making, in terms of both operations and policy.

The functionalities of the TIMS include a text application for writing and sending messages and instructions to participants. Symbols are used to check whether the messages on the user's tab have been read and acted on. The functionalities of TIMS also include a Geographical Information system (GIS) for sharing, combining, analysing, and visualizing data and information. The GIS makes it possible to clarify the current and future disaster situation in a single map image. The question we are asking ourselves is an obvious one. Will the use of such a TIMS system also result in an improved IM response?

The support system used for sharing textual information was developed in MS-Groove and is known as 'sitekst' (situation text). The system works with tabs and each participating organization has its own tab. The tabs are primarily intended to indicate the information position of the various departments; other actors can view the tabs. All messages sent and received are automatically placed and stored on the tab. This also makes each tab a logbook of the information exchange. The user-functionalities for sharing spatial information in TIMS were designed on the basis of a location-driven approach, so that, with the help of the sitplot application, it is possible to gain insight into where the incident is, what the context of the environment of the incident is, and which measures have been taken. Various analyses can also be carried out on the basis of the available data.

All the functionalities are targeted at achieving a complete, current and common picture of the situation as quickly as possible, and anticipating future developments on site. This common situation picture, with the sitplot (situation plot) as information product, is built up by all the plotters in the various emergency centres. The common situation picture is visible on each individual PC on which the sitplot application is running. The plotters in the various organizations can build up their situation picture separately. Active users are shown on the user-interface by means of different colours. If a user has added data to a sitplot, or amended data in a sitplot, a notification message is generated. By clicking on a user, the map layers of the user are added to the list of map layers.

7.3.6 Scenario descriptions

To create realistic use cases that reflect the daily IM work activities, the scenarios were built upon several IM reports, which describe in detail the IM process phases and the role of the different emergency organizations (Dutch Ministry of Transportation and Water Management, 2005a) and contain input from well-trained emergency workers. By the design of the scenarios, we include different operational user-perspectives (e.g. centralist, road inspectors, road users), as well as the specific goals of strategic management operations and policy makers. In the field exercise five different simulated IM scenarios were played out in near time. They varied in complexity from the breakdown of vehicles and small collisions (GRIP1) up to complex incidents with dangerous goods, serious impact on the environment, multiple involvement of cars and trucks, severe casualties, and complex traffic management measures (GRIP 3), which involve complex organization and coordination measures from multiple emergency organizations.

Each scenario is based on logs of real incidents and covers all existing work processes such as applying safety measures, avoiding congestion, traffic management for closing and redirecting traffic flows, towing activities, cleaning roads, and repairing the damage of infrastructural works. The test group and the control group played the scenarios simultaneously. The situation in the ‘field’ was simulated by a maquette. Table 6 provides a brief description of the five scenarios including the specific aim of each one.

Table 7.6: Scenario descriptions

Scenario 1a, Truck next to highway (GRIP-0) *Thursday 15.30 on the A67 42.1 km*	
	This is an incident without victims, only material damage and the congestion builds up. There is a truck stranded next to the highway. The incident is reported to the police by passing road users mobile calls to the emergency number (E112). The incident notifications differ in accuracy. The 112 emergency room sent the notification to the allocated emergency centre (Police, Fire Brigade GHOR). They sent a Police car. In the net-centric environment the regional traffic centre is able to view this notification. The focus of this scenario is a confusion of the exact incident location that was caused on purpose by the researchers. The first emergency vehicle heading for the incident notices this mistake. In normal situations, the other involved actors would not receive this information, but hopefully now they will, and this confusion will not cause delay for the other involved actors.
Goal of scenario: *This scenario is based on the fact that the emergency centre (Police, Fire Brigade GHOR) sometimes does not know the exact location of the incident. They do not have access to camera images from the traffic management centre. Therefore, they do not have a good overview of the incident scene. This causes different problems, such as sending emergency cars to the wrong location and not having detailed information about which measures need to be taken. Therefore, they sometimes allocate inappropriate resources to the incident scene. If they have access to real-time cameras they have better situational awareness of the incident.*	

Scenario 1b, Broken-down car (GRIP-0) *Tuesday 8.00 on A2 ring road Eindhoven busy but no traffic jams.*	
	There is a broken-down vehicle on the ring road of Eindhoven. The driver of the vehicle contacts the ANWB. The ANWB dispatch centre immediately sends a service car to help the driver.
Goal of scenario: *The importance of this scenario is a detection of the incident with wrong location information. The first emergency service arrives at the wrong location. In normal situations other emergency services will also drive to the wrong location. Net-centric information-sharing assumes that this wrong information is detected more quickly. Other emergency centres will communicate this information directly to their own field-workers. This will avoid a waste of valuable process time in the handling of the incident.*	

Scenario 2, Truck loaded with iron scrap and several victims (GRIP-1) *A2 Right, 171.1 km*	
	This scenario is a GRIP 1 scenario. Several victims are involved. A truck driver loses control, slips through the crash barrier and hits a pillar supporting a flyover on the right side of the road. The truck is loaded with iron scrap. The driver and his companion are severely injured and the Fire Department needs to cut them loose from the cabin. The cargo is scattered over the road. The pillar supporting the flyover is severely damaged. A large traffic jam starts to build up behind the incident.
Goal of scenario: *This is a large incident with severe traffic problems and congestion. The incident escalates on a national scale with the involvement of all emergency organizations. The aim of this scenario is to show that, with quick information sharing between all emergency services, the incident can be cleared more rapidly. To complicate the scenario, there is a secondary incident in the tail of the traffic jam. Therefore, the resources of the emergency services need to be managed over the different incidents. There are several casualties, there more vehicles involved, and the road is blocked due to lost cargo of the truck.*	

Scenario 3, Truck loaded with iron scrap and several victims (GRIP-2/3) *A2 Right, km. 171,1*	
	A truck catches fire. The driver panics and makes an emergency stop, causing the truck to slip and eventually stop horizontally across the road, blocking all the traffic. Driving behind the slipping truck, there is another truck loaded with meat, which is also forced to brake hard. In doing so, it also slips on the tarmac and loses some of the cargo. Behind the two slipping trucks enormous damage and congestion builds up in which several trucks and private cars are involved. Because of the many (emergency) resources involved in this incident, the route to the incident gets blocked. An alternative route is needed to reduce traffic jams.
Goal of scenario: *This scenario is created to demonstrate that an early shared common operational picture (COP) between the emergency services involved can improve the decision-making process so that the necessary actions can be taken more quickly. Because of*	

the great chaos on and around the incident scene, many emergency services struggle to get a good overview of the impact of the incident. There are many issues such as applying appropriate traffic and safety measures. Apart from that, it is also very difficult for the emergency services to arrive at the incident location owing to blocked roads and traffic jams.

Scenario 4, Hazardous cargo and fire, fatal casualties (GRIP-3) *A2 East 159,3*	
	A collision between a truck (transporting a tank containing isobutene) and a car. The truck has tipped over and the car has caught fire. A second car gets involved in this fire, followed by two more cars. The fire causes black smoke that can be seen from a great distance. Many people call in to report the incident. The truck was transporting hazardous cargo (isobutane), and hit the casing of the electrical infrastructure, while the traffic management systems in the immediate area break down. As soon as the Fire Department arrives, they confirm that this incident concerns the transport of isobutene, which is highly flammable and explosive (risk of explosion from heating of the tank containing liquid gas). The situation is scaled up to GRIP 3 and everyone is evacuated within a radius of 500 metres. The driver of the truck and the drivers of the two cars that caught fire did not survive the accident.
Goal of scenario: *This is a full scenario with all emergency services and the safety region. This scenario shows that sharing information on the environment of the incident scene helps the traffic management centre to better coordinate the incident, and helps to apply effective traffic management measures.*	

7.3.7 The experiment

This study is based on realistic traffic IM scenarios that cover a wide range of different types of incidents in terms of vehicles involved, casualties and complexity. The field exercise was set up with two group of participants: a test group that used the specially developed net-centric systems and a control group that used traditional systems (Figure 7.3). Both groups were able to use telephone communication. Each group consisted of emergency centralists and emergency fieldworkers. The actual incident scene was simulated by a maquette (see Figure 7.2b). For each group the scenarios were facilitated by an exercise staff (experiment organization). They initiated text messages to create the starting point for each played scenario. After each scenario a central evaluation of the participant experience was carried out. These discussions were input for the exercise staff to improve the next scenario.

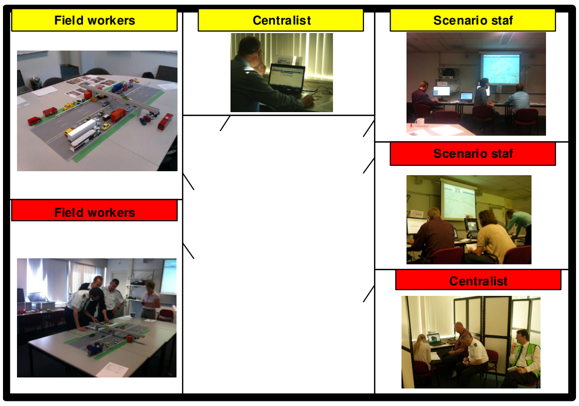


Figure 7.3: Arrangements of participants

We used different research methods to be able to analyse the results (see Figure 7.4). Data on individual perceptions regarding the tools were acquired from the participants' responses by questionnaires. After each scenario, both groups had to fill in a questionnaire on IQ. After all scenarios were considered, both groups filled in a questionnaire on SQ. All the scenarios were 'shadowed' by students. Shadowing is a useful method for observing participant behaviour (McDaniel and Gates, 1998). The shadowing of all participants was done by a group of students who had been instructed to use a predefined form. All text messages with the net-centric system were logged.

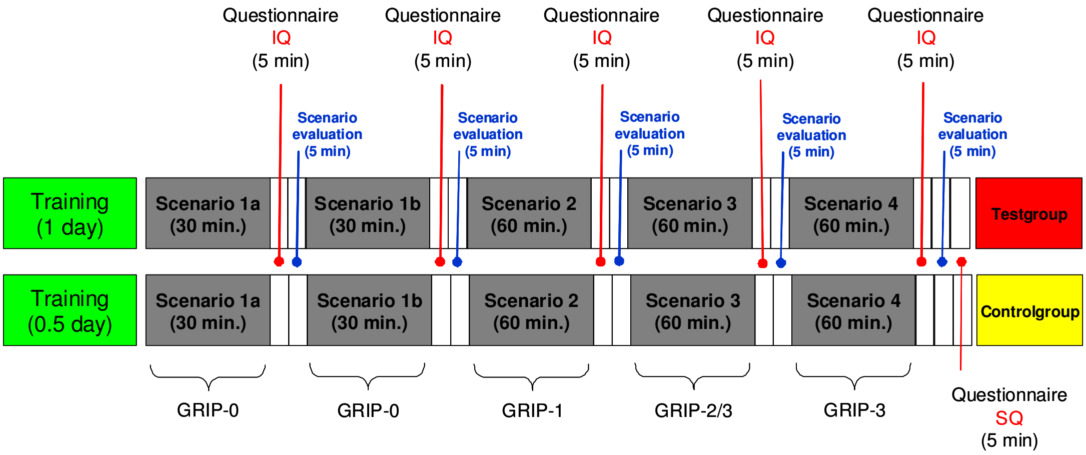


Figure 7.4: Timelines representing the experiment protocol

7.3.8 Limitations

Even though this net-centric field exercise is based on realistic scenarios, the present empirical approach has some limitations. We chose to play the scenarios with well-trained emergency workers. An important consequence of this decision is that we needed to ask operational organizations to provide us with the necessary resources; these organizations had to plan these activities in a busy operational environment. This proved to be extremely difficult. Furthermore, we worked with a test group and a control group. That meant we had to double the necessary capacity. Given these constraints, the field test was limited to 16 observations This relatively small sample size might have influenced the precision of the results. A larger sample size would also have provided results with more statistical significance. A larger sample size proved to be impossible to realize due to limitations of time and the emergency workers' availability.

We used real stakeholders who are all well-trained and skilled emergency workers. However, they had different backgrounds. Their work experience varied between 1 and roughly 30 years. The participants also had different educational backgrounds and did not have hands-on experience with net-centric information systems. To overcome this limitation, we provided all participants with one full day of training to acquire some background knowledge on the information concepts, and to train them in use of the system. Next to that, the participants for the test group and control group were randomly chosen. To avoid the control group being influenced, only the test group was trained in the net-centric system. This excludes the effect of background knowledge and experience.

Another limitation is that not all organizations were involved. The Police, Fire Brigade and GHOR did not participate as the centralist; they only had a role as field-workers with the maquette. The research staff simulated the role of the centralist. Loggings were predefined as input for the other emergency services.

7.4 Results of the experiment

7.4.1 IQ and SQ questionnaires

The *first* hypothesis was: "Net-centric information systems improve the appreciation of IQ and SQ for traffic IM". Testing this hypothesis involved comparing the perceived IQ and SQ of each scenario between the test group and the control group. To measure IQ we use seven constructs. To validate each construct we asked two or three questions after each scenario. The most common measure of reliability of scores for a sample is the coefficient of internal consistency, or Cronbach's alpha (Cronbach, 1951). A Cronbach's alpha of 0.70 or higher is generally considered as an acceptable value of internal consistency.

Scenarios 1a and 1b were used as cases on GRIP level 1. These are relatively small incidents with vehicles. Following evaluation discussions after these scenarios, it was obvious that participants needed some hands-on experience to get used to working with the new systems. In the first scenario (1a) the control group scored higher on the constructs *correctness*, *consistency*, and *verification*. For example, in normal situations the traffic management centre uses cameras next to the highway for verification. Now they had to learn to use text messages to verify shared information. This caused some difficulties. In the next scenario (1b), the test group scored better on all constructs with the exception of *consistency*.

Scenario 2 was the first complex scenario. This scenario is characterized by many phone calls and sharing text messages in the net-centric system. As well as that, there were multiple incidents to complicate the decision-making process in the scenario. This causes many problems in communication between the emergency service and the coordination of activities. The control group scored better on all constructs with exception of *timelines* and *verification*. In the t-test, timelines scored significantly better then the test group. This is in line with the loggings of the shadow observations. The incident notification information and the arrival of the emergency services to the incident scene was significantly faster in the test group with exception of the Fire Brigade and the Ambulance services. They arrived 3 minutes later. Only with the environmental information, such as traffic management measures, the control group performed better. The main issue in the test group was information *overload*.

In Scenario 3 there was clearly a learning effect from the second scenario. The test group scored better on all constructs with the exception of *overload* and *verification*. Overload was still the main issue. They had difficulties in using the predefined tools to filter relevant information. This also made it hard to verify shared information. However, the test group performed significantly faster then the control group. In Scenario 4, it was clearly visible that the test group were starting to have hands-on experience using the net-centric system. They scored better on all constructs, with the exception of *relevance*. This is mainly because the filters for personalization of information system were still too complicated to use.

The outcomes of perceptions on information quality IQ in the various scenarios are presented in Tables 7 to 11. We find that the internal consistency of the various items to measure IQ dimensions is, on average, satisfactory (Cronbach's alpha is larger than 0.7 in a clear majority of the cases). With the exception of Scenario 2, the test group reports higher information quality dimensions than the control group. However, given the small number of participants, the differences are in most cases not significant. *Timeliness* is the dimension with the best score in the comparison between test group and control group.

Table 7.7: IQ results for scenario 1a

Scale*	Items	Average Test group N= 8	Average Control group N=6	Indication Reliability (Cronb. α)*	Test value	*p*
Timeliness1a	3	3.9	3.4	0.84	1.57	0.173
Correctness1a	3	3.4	3.6	0.71	-0.55	0.594
Completeness1a	3	3.3	3.2	0.88	0.26	0.798
Relevance1a	2	3.8	3.4	0.75	1.12	0.286
Consistency1a	3	3.4	3.6	0.76	-0.45	0.569
Overload1a	3	3.2	3.2	0.34	0.13	0.900
Verification1a	3	3.2	3.6	0.61	-1.05	0.316
Total 1a	20	3.4	3.4		0.06	0.950

Table 7.8: IQ results for scenario 1b

Scale*	Items	Average Test group N = 8	Average Control group N = 4	Indication Reliability (Cronb. α)*	Test value	*p*
Timeliness1b	3	3.0	2.8	0.52	0.47	0.651
Correctness1b	2	2.8	2.4	0.75	0.85	0.418
Completeness1b	3	2.7	2.3	0.81	0.97	0.356
Relevance1b	3	3.5	3.1	0.79	1.02	0.333
Consistency1b	2	2.5	2.8	0.74	-0.45	0.663
Overload1b	3	3.4	3.3	0.23	0.29	0.775
Verification1b	2	3.5	3.0	0.73	0.82	0.433
Total 1b	18	3.1	2.8		1.46	0.176

Table 7.9: IQ results for scenario 2

Scale*	Items	Average Test group N = 9	Average Control group N= 7	Indication Reliability (Cronb. α)*	Test value	*p*
Timeliness2	3	3.4	2.9	0.43	2.12 sign.	0.053
Correctness2	2	3.4	3.5	0.74	-0.41	0.686
Completeness2	3	2.1	2.8	0.81	-1.78 sign.	0.096
Relevance2	2	3.1	3.4	0.77	-0.77	0.454
Consistency2	3	3.5	3.7	0.65	-0.55	0.592
Overload2	3	3.3	3.4	0.54	-0.34	0.738
Verification2	3	3.5	3.2	0.58	0.80	0.438
Total2	19	3.2	3.2		-0.32	0.751

Table 7.10: IQ results for scenario 3

Scale*	Items	Average Test group N = 7	Average Control group N = 6	Indication Reliability (Cronb. α)*	Test value	*p*
Timeliness3	3	3.6	2.9	0.82	1.73	0.113
Correctness3	3	3.3	2.9	0.92	0.83	0.426
Completeness3	2	3.0	2.9	0.78	0.40	0.701
Relevance3	3	3.5	3.2	0.16	1.02	0.328
Consistency3	3	3.3	3.2	0.93	0.14	0.888
Overload3	2	3.3	3.4	0.86	0.10	0.923
Verification3	2	3.1	3.6	0.87	-1.05	0.361
Total3	18	3.3	3.1		0.77	0.463

Table 7.11: IQ results for scenario 4

Scale*	Items	Average Test group N= 6	Average Control group N= 4	Indication Reliability (Cronb. α)*	Test value	*p*
Timeliness4	3	3.9	3.3	0.85	1.45	0.185
Correctness4	3	3.8	3.6	0.87	0.52	0.618
Completeness4	3	3.7	3.3	0.54	1.15	0.284
Relevance4	2	3.4	4.3	0.83	-1.57	0.156
Consistency4	3	3.9	3.6	0.83	0.77	0.461
Overload4	3	3.5	3.3	0.65	0.39	0.706
Verification4	3	3.4	3.3	0.71	0.22	0.834
Total	20	3.9	3.7		0.72	0.490

Note: Green shading indicates that the test group performed better

To measure SQ we used nine constructs. To validate each construct we asked two or three questions at the end of all scenarios. *Accessibility* was the only system-related construct that scored significantly higher in the test group. *Response time* and *system reliability* scored higher in the control group. This is mainly because we used an Internet version of the net-centric application. The system had some trouble in the performance. This is a technical issue which can be easily solved. For the task-related SQ constructs the test group scored significantly higher on *integration*, *memory,* and *SA*. Only the construct *format* scored significantly lower. This is strongly related to IQ constructs *overload* and *verification*. *Personalization* seemed to be a key issue in an information-rich environment. For perceived operational satisfaction we measured two constructs. The test group found the system complicated to use. The SQ construct *ease of use* scored significantly lower in the test group. However, a learning effect was visible. The test group started to perform relatively better after each scenario. *Usability* was scored significantly better in the test group. Here, we can conclude that the test group recognized the value-added service of a net-centric system, but that they still perceived it as complex to use.

An important other issue is that, although the fieldworkers in the test group had access to the net-centric system, and had 1 day training before the field exercise, they did not use the systems. They only used the phone with their own centralist. This situation is similar with the daily IM handling. We may conclude that there clearly need to be more done, to integrate such systems in their work processes. This confirms that net-centric systems for traffic IM need to be introduced in different stages, as described by Steenbruggen *et al.* (2012b). The introduction of these concepts are extremely difficult, and short-term strategies are doomed to fail (Harrald and Jefferson, 2007). This means that, for a successful adoption, these concepts need to be carefully introduced. A logical choice is the user-perspective. It makes sense to start with those persons who are controlling and coordinating the response and recovery processes. They are those who will attain and maintain an accurate, shared COP and SA, as stated by Harrald and Jefferson (2007). For traffic IM, this means the traffic management centre and the centralist of the emergency rooms.

Table 7.12: SQ results for all scenarios

Scale	Items	Average Test group N = 7	Average Control group N = 4	Indication of Reliability (Cronb. α)*	Test value	*p*
System related						
Accessibility	2	3.5	2.3	0.88	4.03	0.003 **
Reliability	3	2.4	2.9	0.70	-1.17	0.274
Response time	2	2.5	3.2	0.76	-1.19	0.266
Task related						
Integration	5	3.5	2.6	0.82	3.71	0.005**
Memory	2	3.1	2.1	0.62	3.83	0.004**
Format	3	2.0	2.6	0.58	-2.35	0.044*
Sit. awareness	3	3.4	2.2	0.80	5.64	0.000**
Perceived operational satisfaction						
Ease of use	3	2.5	3.4	0.84	-2.25	0.052*
Usability	3	3.3	2.5	0,83	2.53	0.032*
TotalSQ	27	2.9	2.7			

* significant at a level of 0.05.
** significant at a level of 0.01.

System quality assessments are reported in Table 12. The Cronbach alpha results show that the internal consistency of the items is reasonable to good. The differences in the assessments of the test group and the control group is rather large and significant in most cases. According to five of the SQ dimensions, net-centric working has clear advantages above current routines: accessibility, integration, memory, situational awareness, and usability. For two dimensions disadvantages are reported: format and ease of use.

7.4.2 Shadowing and system logs

The main findings of each individual scenario based on the detailed observations recorded by the 'shadowing' evaluation process and the logs created by the participants are summarized in Table 13. Each participant was shadowed by an individual observer. This information was used to reconstruct a detailed overall process description. The table is divided into three main groups: incident notification; surrounding environment consequences of the incident; and organization and coordination activities of the emergency services involved.

Table 13: Data on group performance were collected from observer notes (Shadowing) and system log.

	Scenario 1a		Scenario 1b		Scenario 2		Scenario 3		Scenario 4	
	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group
Incident notification information										
First incident notification	0	0	0	1	0, (2e 34)	0, (2e 36)	0	0	0	5
Incident location known	1	3	5	9	2	4	0 (12)	0 (9)	2	11
Type of incident known	1	3	0	1	2	4	23	32	7	11
Number of vehicles known	1	4	0	1	2	4	23	32	6	24
Number of victims known	1	3			7	12	31	31	24	-
Involvement of dangerous goods known	6 (14)	9 (-)			3	12	12	45	7	12

	Scenario 1a		Scenario 1b		Scenario 2		Scenario 3		Scenario 4	
	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group
Environmental information										
Environmental consequence	12	6	14	-	8	7	Changed	Changed	8	11
Safety measures applied (500 m.)	8	Not relevant							18 (25)	11 (14)
First decision lanes closed	12	7			8	8	5	8	8	9
Decision to close underlying network									18	14
Decision to close entire road					15 unnecessary	9	16	25	14	14
Decision alternative routes					15 unnecessary	8	4	20	25	34

	Scenario 1a		Scenario 1b		Scenario 2		Scenario 3		Scenario 4	
	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group	Test group	Contr. group
Organisation and coordination information										
Road Inspector at the incident location	11	6	11	-	8	10	7	11	12	12
RWS Officer of Duty at the incident location	16	10			11	14	16	16	12	18
Police at the incident location	15	6			6	17	8	11	6	12
Fire brigade at the incident location	14	18 unnecessary			12	9	8	11	6	11
Ambulance at the incident location					12	9	No ambulance	18 order	12	12
Towing car at the incident location			8	-	37 2e incident	29 unnecessary	10	27 2e 28	26	30
Towing truck at the incident location	14 (2e 21)	24 (2e 26)			20	28	33	46	-	-
ANWB at the incident location			8 (15)	10 wrong loc.						
Trauma helicopter					29 ordered	17 ordered	28 ordered 41	No helicopter		
Demand additional transport					42	47				
Demand environmental expert	9	23								
Demand for STI expert					14	10				
First COPI meeting					No COPI	21	34 Motorkap	38 COPI	14	22
COPI escalating GRIP 1					22	33	21 GRIP 1	23 GRIP2		
COPI escalating GRIP 2/3							28 GRIP 2		17	22
COPI conclude safety guaranteed									19	28
COPI conclude no treat for explosion									34	31
ROT operational									25	27
Cause known no camera images available									2	4
Camera images helicopter available									15	-
Insufficient water for fire brigade									7	25
Rest time incident	0	9	16	16	20	17	-	-	22	34

Note: Green = faster results for the test group; Yellow = equal results for both groups ; Red = faster results for the control group ; Orange = different interpretation scenario; Grey = not relevant.

7.4.3 Scenario evaluation

In this section we describe the main findings concerning the differences between the test group and the control group for each scenario.

Scenario 1a (GRIP 0)

The activities of the two groups had some significant differences. In general, the incident notification was available a few minutes earlier in the test group. The test group recognized that there was the possibility of an incident involving dangerous goods and decided to keep a safe distance of 500 metres till the Fire Brigade confirmed that the cargo of the truck was safe. The Fire Brigade arrived after 15 minutes and verified that there was no direct danger. In the control group, after 10 minutes it was established that there were no dangerous goods involved. The source of this information remained unclear. However, at that moment there was already a Fire Brigade heading towards the incident. The Road Inspector reports this to the Traffic Management Centre. However, after 18 minutes the Fire Brigade of the control group arrived unnecessarily at the incident scene, the Fire Brigade was not needed. In a shared information environment this would have been known by the central emergency room (Police, Fire Brigade and Ambulance services. In the test group, all organizations take measures and decisions based on shared information. They follow the procedure for trucks with dangerous goods. The different log and shadow information confirms this picture. However, in the control group the information on dangerous goods was shared by one on one communication. This led to confusion, the wrong conclusion, and unnecessary measures and activities. In the test group after 9 minutes with the net-centric system, the CMV towing services asked for a environmental expert because the truck might have dangerous goods. In the control group after 23 minutes, CMV towing service made the same request. The test group had access to more information and so makes this request 13 minutes earlier. In the test group, the towing service arrived at the incident 10 minutes earlier than the control group. The request for a second towing vehicle was 5 minutes earlier in the test group.

Scenario 1b (GRIP 0)

This is a simple scenario about a broken-down vehicle. Initially, the wrong location of the incident scene was communicated between the driver and the ANWB dispatch centre. The Traffic Management Centre saw a traffic jam on the other side of the road and contacted the ANWB, the LCM towing services, and the Road Inspector. There were no cameras available, but on the basis of the detection loop data and the traffic management information system, they conclude that the location of the incident happened on the other side of the road. The correct location of the incident was detected 4 minutes earlier by the test group. However, because of technical problems with the system this scenario had to be stopped half way.

Scenario 2 (GRIP 1)

The detection and driving phase was almost identical between the two groups in the first couple of minutes of the incident. The information about involved victims was available 5 minutes earlier in the test group. The CMV towing service reported the presence of possible dangerous goods after 3 minutes. This stayed unclear for a long time in the test group. After 12 minutes there was an indication about dangerous goods, but, during the process, there was no more communication about this subject. All emergency services arrived earlier at the incident scene with the exception of the Fire Brigade and Ambulance services, but they arrived only a few minutes later. The test group escalated to GRIP1 12 minutes later. During the handling process there was a second traffic incident which causes much confusion. The towing service for the second incident is informed after 14 minutes, but with the wrong location information. After 27 minutes the test group is informed about the second incident, this time with the correct location. 10 minutes later, the towing service of the test group arrived at the incident. The towing service of the control group was unable to find the incident, and returned with a false incident notification. After 13 minutes, the safety screen was placed at the incident location. In the control group, the safety screen was moved to the second incident. They confused information about the first incident with the second incident. Decisions on guided transport after the second incident were 5 minutes earlier in the test group. After 52 minutes, the test group implemented measures on alternative driving routes. The control group implemented no traffic management measures.

The main issue in the test group was information overload. This was the first complex scenario. They had many difficulties in using the system. They used the telephone to verify text messages in the net-centric system. Moreover, the text messages were too long and contained much specific terminology that was only known by the specialists of some of the organizations. This also caused much confusion in communication. After the evaluation, the participants of this scenario improved the text messages for the next scenarios. This was the main lesson learned from this scenario. Furthermore, both groups had major difficulties handling more incidents in the same scenario. However, with regard to the overall results of the decisions and outcomes, the test group performed slightly better.

Scenario 3 (GRIP 2/3):

There were some major differences in how the both groups handled the incident. In the test group all organizations were informed about the best driving route (since regular routes were blocked), in the control group this was only communicated after 21 minutes. In the control group there was hardly any communication about a truck fire and the status of the fire. Within the test group there is frequent communication about this subject. In the control group the severity of the fire was never communicated. This information was requested several times by the truck-towing organization (CMV). The escalation to GRIP2 was 3 minutes earlier in the test group. The fire was under control 11 minutes earlier in the test group. Because the roads were blocked, the test group requested a trauma helicopter after 28 minutes, which arrived at the incident scene after 13 minutes. The control group requested an ambulance after 18 minutes. However, they were not aware of the difficulty of arriving at the incident scene. In the test group, a picture of the incident situation was shared. This helps the emergency services to get a good overview of the incident. For example, there is detailed information available about lost cargo on the road. This was never shared within the control group. Clearly, the test group learned from the previous scenario. There was less telephonic communication, and text message were more compact, and only contained the relevant information. Also, pictures were shared to communicate about the impact of the incident.

Scenario 4 (GRIP 3):

This is a full scenario where all emergency services and the safety region were involved. The benefits of a net-centric system are clearly visible in this scenario. Also the experience of previous scenarios helped the test group to improve their performances. The incident detection information was available a couple of minutes earlier in the test group. In particular, information about the number of involved victims and dangerous goods caused some trouble. In addition, the exact incident location was known 5 minutes earlier in the test group. Besides that, the control group assumed that the incident was on the wrong side of the highway.

Communicative information about the impact of the incident on the environment also had some difficulties. The test group had a quicker overview, but, the 500 metre radius safety measures were applied more rapidly in the control group. They also arrived 4 minutes earlier to close the underlying road network. The emergency service in the test group arrived at the same time or some minutes quicker at the scene of the incident. In almost all cases, the coordination activities of the emergency services were better in the test group. The first COPI meeting was 8 minutes earlier. They then detected, for example, 18 minutes earlier that there was not enough water at the incident scene for the Fire Brigade. They also confirmed 9 minutes earlier that the incident scene was safe. The overall conclusion about this scenario is that the test group performed significantly better on almost all aspects.

7.5 Discussions

Applying net-centric information concepts is a promising solution for improving cooperation between the private and the public emergency services. They may provide useful tools in the daily handling of traffic IM. The main goal is to improve SA which contributes to faster and effective collaborative decision making. However, the research which assesses the effectiveness of these decision support tools is still ongoing. To date, there are no concrete guidelines and design principles in the literature on net-centric systems for traffic IM. Net-centric information systems have their roots in the military domain. In recent studies these concepts have also been applied in disaster management. Traffic IM can be seen as a special form of disaster management. However, the literature in public sector emergency services and traffic IM regarding information-sharing across different agencies and the quality of information-sharing is scarce, and empirical support is almost nonexistent. This study takes a step forward by evaluating the effectiveness of net-centric systems between two groups of participants. This evaluation is based on a framework that includes tests of the usefulness of the tools, information quality, and system quality. In drawing conclusions, this section discusses the results on the basis of three aspects: first, a comparison of the communication and coordination of emergency organizations in the test group and the control group; second, a value of SA in the performance of the decision-making process; and, third, how scenario complexity can affect the design principles of net-centric systems.

7.5.1 Communication, coordination, and the decision making process

The *second* hypothesis was: “SA improves the performance in the decision-making process of the emergency organizations”. Testing this hypothesis involved comparing the observed outcomes (by shadowing the participants) of each scenario in the test group and the control group. To validate this hypothesis, we focus on the speed of completeness of incident notification information, and how fast the emergency services arrive at the incident location. Table 7.14 provides an overview of the sum of minutes gained in the test group. Only the Ambulance services was 3 minutes later at the incident location in Scenario 3. In Scenario 4 the test group used a trauma helicopter. In Scenario 5 the ambulance arrived at the same time. We can conclude that the net-centric group in general performed better in the scenarios. See Appendix 1 for a practical example of the relation between the incident duration and vehicle lost hours.

Table 7.14: Sum of minutes gained in the test group in information-sharing and coordination for all scenarios

Incident notification information	Coordination and performance
First notification : 7 min. Location : 17 min. Type : 16 min. Vehicles : 33 min. Victims : 7 min. Dangerous goods : 49 min.	WIS: 1 min. OvD: 3 min. Police: 11 min. Fire Brigade: 9 min. Ambulance: -3 min Towing cars 13 min. Towing trucks: 41 min. ANWB: 2 min.

Note 1: Not all information categories are relevant in each scenario.
Note 2: Not all emergency services played a role in each scenario.
Note 3: Each emergency organization is in terms of time depending on the critical path of cooperation.

The *third* hypothesis was: Net-centric systems improve the communication and coordination of the emergency organizations. The current identified problems for communication and coordination for traffic IM are summarized in Table 7.15. These were collected during ten regional evaluation meetings with the Rijkswaterstaat (Road Inspector, Road Traffic Coordinator, Traffic Officer of duty), and personnel from the Police, Fire Brigade and Ambulance service. Together with an evaluation team, they replayed past incidents step by step. Each incident was evaluated in great detail, and then recommendations for improvement were clustered. For the purposes of this study, those categories which focus specifically on improvements for information, communication, and coordination are used.

Table 7.15: Current identified problems for communication and coordination for traffic IM

	Accuracy	Availability	Completeness	Consistency	Correctness	Format	Personalisation	Relevancy	Reliability	Timeliness
Communication and coordination issues										
E112 informs different centrers, which starts separate uncoordinated processes				■						
Police sometimes have no capacity after been informed by TMC										■
Communication about opening closed or blocked lanes (Police – TMC)		■								
No (time) information available when emergency services arrive at incident		■								
Knowing status and real-time location of emergency services		■								
Resource information not always available for towing services for RWS			■							
Relatively many unnecessary towing trips (false incident notification)									■	
Different centralists do not communicate with each other										

Central Police communicate with regional police by E112 control room										■
Sometimes Fire Brigade is informed too late										■
Information about incident is sometimes communicated too late to RWS										■
Information given to the TMC is sometimes wrong, incomplete, and unclear	■		■		■					
Incident detection via (0900-8844) is not always known by TMC		■								
No uniform incident definition and registration				■						
Sometimes no registration, RIS needs to explain situation multiple times to TMC		■								
Same incident registered independently by all involved organizations				■						
Communicate only relevant information to emergency services						■	■			
Communication between TMC and RIS not optimal due capacity problems										■
Information between TMC and RIS sometimes incorrect and own interpretation	■							■		
Information notification provided by the Police is often very brief			■			■	■			
More and better information-sharing during driving phase										■
Communication only by phones causes misinterpretation					■	■			■	
Mobile phones sometimes fail owing to system problems (coverage/capacity/accu)		■								■
Webcam /video images could provide useful information for all actors		■	■							
Sometimes the first safety measure are not appropriately applied										
Direct involvement of TMC helps to ensure safety incident location										■

Source: Ministry of Water Management and Transportation (2012).

In the first two scenarios there were hardly any complex communication and coordination issues identified. The main difficulties related to the identification of environmental consequences, such as those associated with traffic management measures. Here the control group performed slightly better in some aspects. In the more complex scenarios hands-on experience helped the test group to perform better. In the more complex scenarios there was a strong need for sharing information. As observed in the first scenarios, the participants still used mainly telephone communication. Especially in scenario 2, they had great difficulties combining the many text messages with telephone communication. This made coordination activities complicated. However, in the last two scenarios, the participants were starting to have experience with writing compact messages. We also observed that the frequency of telephone communication decreased and participants were starting to rely more on the net-centric system. For Scenarios 3 and 4, it is clearly visible in Table 7.13 that the test group performed significantly better. We can conclude, therefore that the net-centric system clearly improved the communication and coordination activities of the test group.

7.5.2 Design principles of net-centric systems

The *fourth* hypothesis was: "Scenario complexity affects the design principles of net-centric systems". The main goal of net-centric working is to improve SA by a Common Operational Picture (COP). The criteria used to design information systems which fits the needs and benefits of end-users are more than just a question of technology. Systems must be designed that ensure the information needs of the centralist and provide tools that support cognitive and psychological capabilities, especially in an information-rich and dynamic environment. Several factors influence the accuracy and completeness of SA. Humans are limited by working memory and attention. New information from multiple sources must be integrated with other knowledge. How people direct their attention in acquiring new information has a fundamental impact on which elements are incorporate in their SA. Jones and Endsley (1996) found that the most frequent error (35 per cent of all SA errors) was that all information was present but was not noted by the operator. The limits of working memory also cause constraints on SA (Endsley, 1988). Net-centric tools must be designed to support working memory and attention. This is closely related to information overload. Most of the detected problems in our field exercise to measure IQ in the more simple GRIP0 scenarios, were related to *consistency* of information. This means that only a small amount of information was shared. However, the working memory of the participants could handle the information flow, and they could easily judge the (in)consistency of the data. Telephone communication still plays an important role here. In the more complex Scenarios (2, 3 and 4) the participants had most problems with *relevance*, *overload* and *verification* of information. This is directly related to system quality constructs. Participants in the test group were pleased that the system supports the *accessibility* and *integration* of many data. They also scored higher in the task-related construct *memory*. However, the construct *format* was clearly not used and designed to avoid information overload, help their work memory, and support their attention. This is partly due the participants having little or no experience with net-centric systems. However, we did observe a learning effect during the scenarios. Clearly, more complex incidents need to have appropriate formats which are specially designed for different types of minor incidents (GRIP0) and the more seriouse GRIP incidents (GRIP 1-4). Supporting long-term memory can be achieved by creating memory functionality for later data retrieval. Formats need to be more personalized to the specific goals and tasks of each organization and the different roles within the organizations. Related to format, the nature of the information and its presentation also cause problems for end-users. Creating SA is more than just simply reading ‘dots’ on maps (Lambert and Scholz, 2005). It is about understanding the significance of such information in a operational context and decision making process. The traditional COP does not support these aspects of SA, but leaves this cognitive load for the user to cope with it (Wark and Lambert, 2007; Wark *et al,*, 2009). A more effective approach to shared SA for net-centric systems is to be able to push and pull the story behind the data, and not just the underlying data (Lambert, 2001, 2003). These are the main reasons why the system is perceived as complex. The IQ construct *times lines* and SQ constructs *situational awareness,* and *usability* scored higher in the test group. This means that a net-centric system is perceived as *useful,* but clearly there is a need to improve some technical system functionality to support IQ for daily use.

8 Traffic Incidents and Mobile Phone Intensity

8.1 Introduction

Along with the growing ubiquity of mobile technologies, the extensive data logs produced in the course of their use, have helped researchers to create and define new methods of observing, recording, and analyzing environments and their human dynamics (O'Neill *et al.*, 2006). In effect, these personal devices create a vast, geographically-aware sensor web that accumulates tracks to reveal both individual and social behaviour in unprecedented detail (Goodchild, 2007). Steenbruggen *et al.* (2012c) have identified this phenomenon as *collective sensing*, or, in other words, the reconstruction of "collective human behaviour from individual anonymous digital traces". These traces left by individual people are accumulating at an unprecedented scale (Zhang *et al.*, 2010). Barabási (2009, p. 26) stated that we are at the threshold of understanding complexity based on the availability of large data sets (Big Data). We can increasingly monitor what is going on.

In this Chapter, we explore the relationship, derived from various Big data sets, between motorway car intensity, traffic incidents, weather data and mobile phone use. We link the time-space pattern of meteorological measurements with that of mobile phone use and traffic data in the Amsterdam city region. Taking the spatial context into account, we model the frequency-domain statistics of telecom activity and how they relate to traffic incidents.

This Chapter does not focus directly on motorway traffic patterns, but explores the space-time relationships of mobile phone data and assesses their suitability to derive census proxies and dynamic patterns of the greater Amsterdam. The results have the potential to be utilized to derive mobility indicators, showing the possibility of extracting near real-time data from cell phone use, and to reconstruct the spatio-temporal patterns of telecom network use.

Urban dynamics can be monitored and assessed by a variety of proven geospatial technologies such as: GPS receivers (Polak, 2002); remote sensing technology (Herold *et al.*, 2003; Blaschke *et al.*, 2011); in-situ sensor networks (Akyildiz *et al.* 2002; Hart and Martinez, 2006; Resch *et al.*, 2010b; Sagl *et al.*, 2011); and new data sources, such as social media data (Rattenbury *et al.*, 2007; Girardin *et al.*, 2008a,b; Girardin *et al.*, 2009, Crandall *et al.*, 2009; Hayes and Stephenson, 2011, Frias-Martinez *et al.*, 2012), and data derived from the mobile telephone network.

Both the nature of Big Data derived from various sources (e.g the mobile phone network) and the related ability to disclose patterns from the wealth of information that people or machines (sensors) generate continuously provide new sources of spatial data which offer the potential to significantly improve the analysis, understanding, representation, and modelling of urban dynamics. This also presents some challenges in terms of complexity and the handling of data sets, whose size is beyond the ability of typical database software tools to capture, store, manage, and analyse these data, especially in real-time. There is no unique and universally accepted definition of Big Data, although it is common to refer to it as "*datasets whose size is beyond the ability of typical database software tools to capture, store, manage, and analyze*" (e.g. Weiss and Indurkhya, 1998; Laney, 2001). Big data is an opportunity and a challenge. While it is clear that many data management tools are inadequate to handle heterogeneous, real-time massive data quantities, there are clear opportunities to gain insight into new and emerging types of data, to make organizations more agile, and to answer questions that, in the past, were too difficult to tackle. Big Data is characterized by an exponential growth of data production, and is largely the result of the increased digitalization of our lives and workplaces.

The digital revolution enabled cities and policy makers to realize the link between ICT and urban development. As a result, various forms of city concepts have been developed including: *wired cities* (Dutton, 1987); *technocities* (Downey and McGuigan, 1999), *creative cities* (Florida, 2005); *knowledge-based cities* (Carrillo, 2006); *real-time city* (Townsend, 2000; Calabrese *et al.*, 2011a); *WIKI cities* (Calabrese *et al.*, 2007a; Ratti *et al.*, 2007b), *digital* *cities* (Komninos, 2008); *Live City* (Resch *et al.*, 2012); and one of the latest concepts is the *smart or intelligent city*. Since 2005, a number of case studies of several cities can be found as a means to gain a deeper understanding of complex and rapidly changing spatial urban phenomena. Mobile phone data is a potential data source which can make cities smarter in terms of monitoring transportation dynamics.

Scientific studies show that user-generated traffic in wireless communication networks can serve as a proxy for spatio-temporal patterns of human behavior. This user-generated traffic in wireless communication networks enable us to analyse spatio-temporal patterns of human activities (Onnela *et al.*, 2007; González *et al.*, 2008; Candia *et al.*, 2008). Human dynamics, in terms of activity patterns to capture the regular daily activity of both individuals (Brockmann *et al.*, 2006; Mateos, 2006; Shoval, 2007; Onnela *et al.*, 2007; González *et al.*, 2008; Candia *et al.*, 2008; Lazer *et al.*, 2009; Shaw and Yu, 2009; Phithakkitnukoon *et al.*, 2010; Song *et al.*, 2010a) and communities (Candia *et al.*, 2008, Sevtsuk and Ratti, 2010), have been evaluated to disclose patterns that can assist urban planning and transportation analysis, and that can support new effective traffic management measures. Several scientific studies have linked such patterns to other data in order to explore, for example: the structure of social networks (Onnela *et al.*, 2007; Calabrese *et al.*, 2010a); the physical environment (Calabrese *et al.*, 2010b); or city dynamics (Ratti *et al.*, 2006; Calabrese *et al.*, 2007a; 2011). Mobile phone data also can be used to support traffic IM (Steenbruggen *et al.*, 2012c).

Traffic incidents may also be sensitive to different weather conditions. Within the environmental monitoring domain, the amount and the availability of digital information, based on near real-time sensor measurements, have been rapidly increasing over the last few years (e.g. see Akyildiz *et al.*, 2002; Hart and Martinez, 2006). Such sensor nodes include highly mobile and intelligent sensor pods (Resch *et al.*, 2010a), as well as fixed sensor stations (Alesheikh *et al.*, 2005). Given the increasing accuracy of meteorological forecasting, understanding the relationship between weather patterns and traffic incidents can potentially provide valuable insights into understanding mobility and traffic accidents (Sabir, 2011).

The main research question of this Chapter is to examine if we can use mobile phone data to detect motorway traffic incidents (dotted line in Figure 8.1). The underlying goal is to explain which factors contribute to the mobile phone use (straight lines in Figure 8.1). In that

Figure, the relationships between the different variables used in our research are visualized. Mobile phone activity in area *i* and time *t*, is basically generated by users who are related to the spatial GSM zones of the mobile phone network.

More specifically, the communication volume of the mobile phone use depends on the specific land use (e.g. business areas, shopping centres) and other non-traffic-related features, such as weather conditions. As we selected those telecom zones which strongly overlap the motorway infrastructure, we assume that motorway traffic intensity and traffic incidents have a strong influence on mobile phone usage. However, we will also control for non-traffic-related features. In our model, the occurrence of a traffic incident is related to motorway car traffic, and is also influenced by particular weather conditions. The definition of the different variables used in our model are described in more detail in the next section.

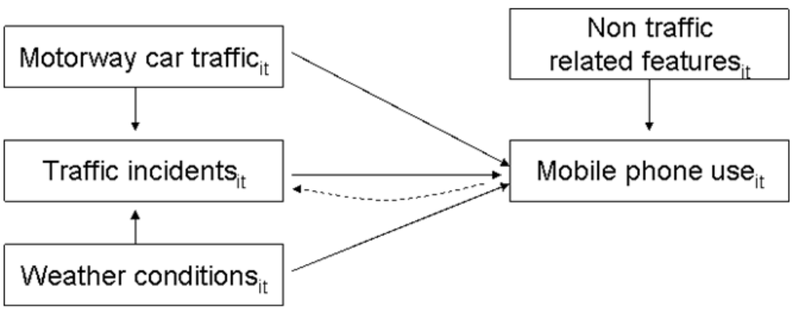


Figure 8.1: Graphical representation of our research model

The study area involves the city of Amsterdam and its surroundings, covering an area of about 1000 km^2 (see Figure 8.2).

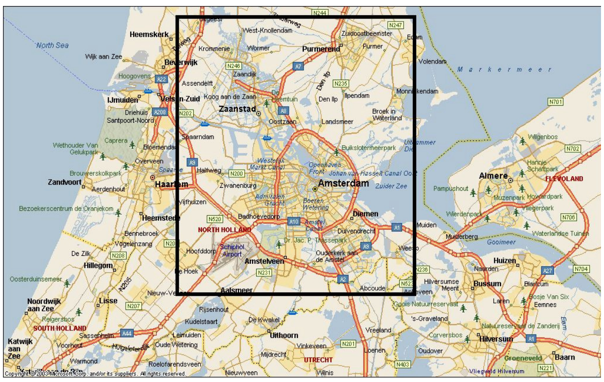


Figure 8.2: Overview the Amsterdam test area

Note: Due to the non-canonical boundaries of the sectors, the network coverage of the study area does not exactly correspond to the above box.

8.2 Data sets used

In the Amsterdam case study we used four different types of data sets for our research: motorway traffic car data; traffic incident data; mobile phone data; and meteorological sensor data. These data sets are described below in more detail.

8.2.1 Traffic incident data

We used six different types of incident categories: object on the highway; accident with injuries; driver is unwell; broken down vehicle; accident with only material damage; and accident with fire. Table 8.1 describes the number and relative share of the incident types.

Table 8.1: Descriptive statistics of hourly traffic incidents of all selected cell-id's in greater Amsterdam during the observation period 2010

Incident type	Description	Number	% Share	Avarage # incidents per hour per cell	Mean incident duration
1	Object on the highway	261	0.110	.00033	16 min.
2	Accident with injuries	59	0.025	.0000746	71 min.
3	Driver is unwell	32	0.013	.0000405	24 min.
4	Broken-down vehicle	1204	0.505	.0015224	29 min.
5	Only material damage	809	0.340	.0010229	42 min.
6	Fire	17	0.007	.0000215	57 min.
	Total	**2382**	**100%**	.0030119	

Note: Based on 790.865 hourly observation of 109 cell-id's.

The hourly variation is characterized by some significant temporal signatures. Figure 8.3 gives an overview of the hourly, daily, and monthly distribution of the incidents. During the rush hours there are significantly more incidents, with the highest peak in the evening (Figure 8.3a). During the working days there are substantially more incidents than during the weekend (Figure 8.3b). Figure 3c gives an overview of the monthly variation. It is important to note, that in our dataset, we are missing data from 9 Jan.-25 Jan. and 21 Nov.-31 Dec 2010.

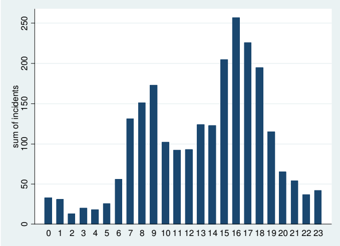
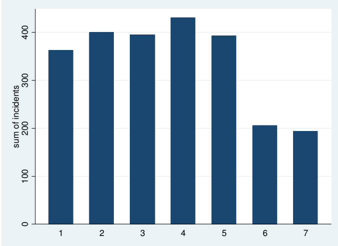
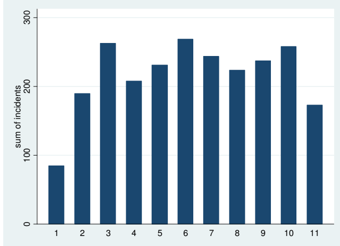
		

Fig. 8.3a: Variation of hourly traffic incidents	**Fig 8.3b: Variation of daily traffic incidents over a week**	**Fig. 8.3c: Variation of monthly traffic incidents**

Figure 8.3: Temporal spreading of traffic incidents.

Traffic incidents may be sensitive to the different types of infrastructure in the places where they occur. We made a distinction between three categories: 1 = intersection point of highways; 2 = highway with exit and entry point; 3 = straight highway. From Figure 8.4, we can conclude that most motorway traffic incidents take place in categories 1 and 2.

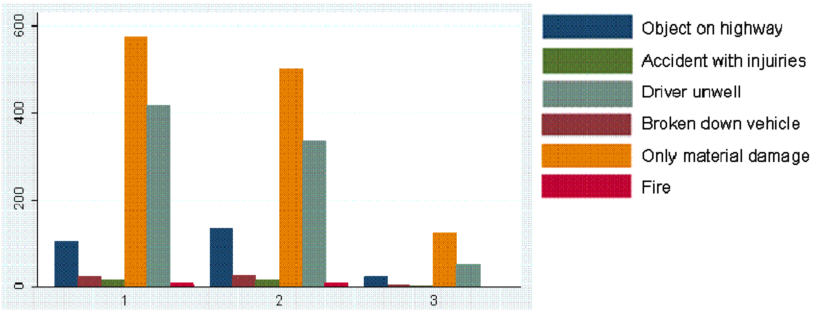


Figure 8.4: Number of incidents on different types of infrastructure

Note 1: See Table 8.1 for explanation types of incidents.

Note 2: The Figures 1, 2, 3 denote infrastructure categories.

It is important to realize that the six types of traffic incidents have a different impact on the smooth traffic flows. An important aspect is the time duration to handle an incident. Figure 8.5 gives an overview of the average time taken to handle the different types of incidents.

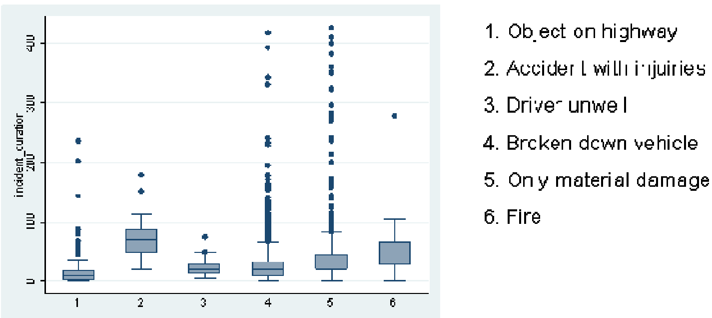


Figure 8.5: Average time duration to handle the different types of traffic incidents (in minutes).

8.2.2 Motorway car-traffic data

Parts of the Dutch road network, especially in dense urban areas, are equipped with a comprehensive monitoring system based on detection loops with a distribution of between 300 and 500 metres apart. This system allows for the collection, processing, and transmission of dynamic and static traffic data. It contains accurate information about different data types such as traffic intensity, average speeds, traffic flows, and traffic jam lengths. For the purpose of our case study, we used traffic intensity, which is the total number of vehicles which pass per hour on a specific road segment. The accuracy of these measurements lies between 95 and 98 per cent. The data were extracted from the 'MTR+' detection loop application provided by the Dutch Ministry of Infrastructure and Environment.

8.2.3 Mobile phone data

The mobile telecom data we utilize for this Chapter was supplied by a major Dutch telecom operator, and provides aggregated information about mobile phone use at the level of the GSM cells for the period 2007-2010. The project uses anonymized data of the mobile network. The raw data contains aggregated information with a temporal dimension of a 1-hour time interval in a certain cell. In the study area, over 1200 cells were identified. The telecommunication operator applied special scripts to extract the necessary data for the project. For the purpose of this case study, we select data from 1 January 2010 (h.00.00) through to 20 November 2010 (h.07.00). See also Figure 8.3.

The GSM cellular network is built on the basis of radio cells. They define the spatial dimensions of the two best serving cell maps generated by antennas with two different frequencies overlaid on each other: namely, 900 MHz coverage (the basic network with full area coverage) and 1800 MHz (capacity network only in densely populated areas). The size of a wireless cell can vary widely, and depends on many factors, such as land use and urban density. In order to obtain the real mobile phone use-pattern of a certain place in the city, the two *best serving area maps* have been integrated.

In the literature, there are a number of different geographical approaches which can be used to handle the raw mobile phone network traffic data, e.g. *voronoi* diagrams (González *et al.*, 2008; Kuusik *et al.*, 2008; Song *et al.*, 2010b; Traag *et al.*, 2011), and rasterization (Calabrese *et al.*, 2007a; Reades *et al.*, 2009; Girardin *et al.*, 2009). We chose the original best serving cell maps, because they represent a more realistic representation of the ground truth of the relationship between the original aggregated mobile phone use and the geographical area specified by the telecom operator. We merged the 1800 frequencies cells (of the capacity network) with the 900 frequencies cells (of the basic coverage network), without considering variation in land use.

The user-generated traffic in such large-scale sensor networks reflects the spatio-temporal behavioural patterns of their users. Moreover, depending on a provider's market share and mobile penetration rate, these patterns reflect to some degree the dynamics of the larger population. The anonymized and aggregated volumes of mobile traffic data include indicators for population presence (*Erlang, new calls, total call lengths, SMS*) and an indicator for movements (*handover*). The variable *total call length* is highly correlated with *Erlang*. The different telecom variables we used in our analyses are defined in Table 8.2.

Table 8.2: Description of the telecom counts used

Type of Indicator	Variable	Description
Population presence	Erlang	A standard unit of measurement of traffic volumes, equivalent to 60 minutes of voice
	New calls	The total number of new speech calls initiated in the current cell
	Total call length	The sum of all call lengths
	SMS	The total number of sent SMS
Population movement	Handover	The sum of incoming and outgoing handovers

Note: The telecom data used in our case study represents a market share higher than 45 per cent.

In order to derive spatio-temporal information from the high volume of raw mobile network traffic data, a semi-automated (geo-)processing workflow was developed. We select only those cells that have a direct relationship (overlap) with the highway infrastructure: in total 790,865 hourly measurements were selected, corresponding to 322 days and 7 hours, for each of the 109 telecom cells belonging to the area chosen for the investigation.

To make sure that the selected cell-id's represent the mobile phone usage on the highways, we selected only those cells with a certain percentage of area coverage which intersect with the highways. An important characteristic of the telecom network is that one unique GSM zone can consist of multiple geographical polygons. Owing to radio coverage, this can range from 1 to more than 100 polygons per cell-id. In dense urban areas, the number of polygons is much smaller than in rural areas. In our case study area of greater Amsterdam (the area within the black rectangle in Figure 8.6), the range of polygons from one unique cell varies from 1 to 6. For our analysis, we selected only those cells, where the sums of area coverage (m^2) of the polygons intersected with the highway, which are related to one cell-id, are larger than 70 per cent of the sum of all polygons belonging to the same cell-id. Based on these criteria, we selected 109 from the original 122 cells.

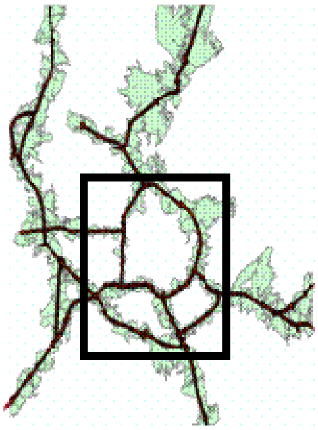


Figure 8.6: Selected cells covering the highways of Amsterdam and its surroundings

Note: The greater Amsterdam area contains 295 cell-id's; the case study area has 122 cells; 109 cells have an area coverage of > 70%.

Telecom zones are generally characterized by different land-use patterns and intensity differences in terms of how people use the area. Each type of land use has its own specific spatial signature (see Steenbruggen *et al.*, 2011). The spread of daily mobile phone patterns, over all weekdays from cell-id's which are related to highways, can be seen in Figure 8.7. This helps us to understand the spatio-temporal variability of the mobile phone data for the road infrastructure. The diagram shows the average mobile phone intensity per hour for different indicators.

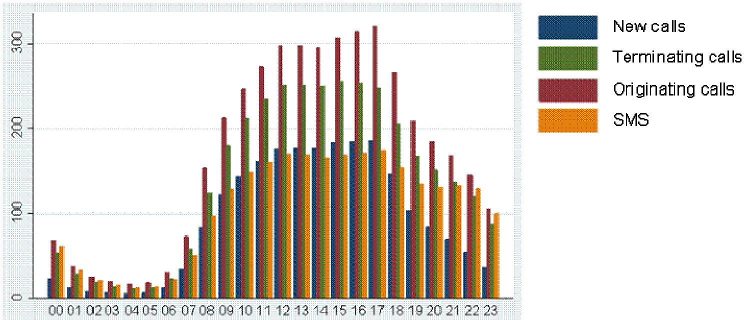


Figure 8.7: Spatial distribution of cell-id's covering the highways (the heartbeat of the road infrastructure)

Note 1: Terminating calls is the number of calls attempt to a cell-id (Mobile Terminated Calls – MTC)

Note 2: Originating calls is number of calls attempt from a cell-id (Mobile Originating Calls – MOC)

8.2.4 In-situ meteorological sensor data

There is a vast literature on the role of different weather variables in road traffic accidents. For an extensive historical literature review on weather information and road safety, see, for example, Andrey *et al.* (2001a,b, 2003) and SWOV (2009). This literature can be classified in several ways: for instance, by statistical methodology, level of aggregation, time period, geographical location, and explanatory variables; and on the basis of the type of weather measurements (e.g. hourly, daily, or monthly), etc.

In the literature, many researchers find that the total number of road accidents increases with different types of weather conditions. An important issue about measurements of weather conditions is the *number of weather factors*. Some studies focus on just one weather factor, while other studies focus on more than one. *Precipitation* is the most significant and most studied weather factor, followed by *snow, temperature, fog, wind*, etc. Examples of these studies are: *precipitation* (Satterthwaite 1976; Brodsky and Hakkert 1988; Andrey and Yagar 1993; Edwards 1996; Andrey *et al.* 2003; Keay and Simmonds 2006; Bijleveld and Churchill 2009); *snow* (Edwards, 1996; Nofal and Saeed, 1997; Brijs *et al.*, 2008); a combination of *snow* and *ice* (Kallberg, 1996); *temperature* (Stern and Zehavi, 1990; Wyon *et al*. 1996; Nofal and Saeed; 1997); and strong *wind* (Baker and Reynolds, 1992; Young and Liesman, 2007).

The *Meteorological* data used for this case study was obtained from the Royal Netherlands Meteorological Institute, KNMI (www.knmi.nl). All measurements are hourly averages, and are measured by accurately calibrated weather stations used for regional weather forecasting by the regional environmental agency (Amsterdam Schiphol Airport). We consider three meteorological variables:

- T: Temperature in units of 0.1^{o} C;
- R: Rainfall (0=no occurrence, 1=occurred during the time of observation);
- S: Snow (0=no occurrence, 1=occurred during the time of observation);

8.3. Empirical application

We adopt a three-level approach. In the first step, mobile phone usage will be regressed against motorway car traffic for those zones where data is available. Here we examine the impacts of motorway car traffic intensity and traffic incidents on mobile phone use, while controlling for different space-time variables and weather conditions. In the second step, we analyze whether an increase in motorway traffic flows is responsible for the probability of different types of incidents. In the third and last step, different types of mobile phone variables and weather variables will be used as predictors of traffic incidents, along with other control variables. The main objective of the latter modelling elements is to test the *usability* of data derived from mobile phone operators and weather data in order to calculate the marginal effects of the probability of a traffic incident.

8.3.1 Mobile phone intensity, motorway traffic, and traffic incidents

In this section we estimate the impact of motorway traffic on mobile phone use, given the temporal and spatial dimension and resolution of the data from the mobile phone operator. In order to perform this analysis, different mobile phone activity (erlang, new calls, sms and handovers) are used here as the dependent variables. The main goal of this exercise is to see which mobile phone variable is significantly related to motorway traffic derived from the detection loop database. The first analysis is limited to 7 cells for which loop data (number of cars per hour) are available.

The basic version of this model is:

$$ln(mob_{it}) = b_1 ln(car_{it}) + b_2 incident_{it} + b_3 H_t + B_1 X_i + B_2 T_t + B_3 W_t + b_4 ln(car_{it}) * H_t + B_5 X_i * H_t + B_6 T_t * H_t + B_7 W_t * H_t + \alpha_0 + \varepsilon_{it} \quad (1)$$

According to this general model (model 1), mobile phone activity (*mob_{it}*) in cell *i* and time *t* is affected by: a coefficient b_1 of motorway car traffic (car_{it}) in cell *i* and at time *t;* a coefficient b_2 of motorway incidents (*$incident_{it}$*) in cell *i* and on time *t*; a coefficient b_3 of hours of the day (H_t); a vector B_1 of fixed effects of GSM zones (X_i); a vector B_2 of weekday indicators (T_t); and a vector B_3 of various weather conditions (W_t). To incorporate into the model the time variability of our observations, in order to better understand how mobile phone use changes over time, hourly interaction terms (H_t) are introduced, for cars, cell-id's, days of the week, and weather conditions. Because the variables mob_{it} *and* car_{it} are not normally-distributed, we transform them to natural logarithms.

The results are presented in Table 8.3.

Table 8.3: OLS regression of different mobile phone variables for 7 cell-id's, using data on motorway traffic

VARIABLES	(1) ln(erlang)	(2) ln(new_calls)	(3) ln(sms)	(4) ln(handovers)
ln(cars)	0.914	1.137	1.061	1.340
	(5.306)***	(6.248)***	(5.754)***	(11.27)***
incident	0.124	0.117	0.120	0.0548
	(2.282)**	(2.027)**	(2.053)**	(1.455)
temperature	-0.000919	-0.00149	-0.000742	-0.00121
	(-4.050)***	(-6.224)***	(-3.053)***	(-7.716)***
rain	0.0189	-0.0193	0.0259	0.00801
	(0.472)	(-0.455)	(0.603)	(0.289)
snow	-0.0535	0.0134	0.0539	0.00373
	(-0.450)	(0.107)	(0.424)	(0.0455)
Hour dummies (23)		Included		
Weekday dummies (4)		Included		
Zone dummies (6)		Included		
Hourly interaction terms		Included		
Constant	-6.321	-4.923	-4.643	-5.204
	(-4.199)***	(-3.098)***	(-2.881)***	(-5.010)***
Observations	40,609	40,609	40,609	40,609
R-squared	0.918	0.877	0.846	0.953

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Note: Effects based on reference: 12:00 hr.
Note: Hourly interaction terms (H*cars_ln; H*cell-id's; H*weekdays; H*temperature; H*rain; H*snow).

The most important finding is that mobile phone use, measured in erlang and new calls, is positive and significantly related to motorway car traffic and traffic incidents. For example, an increase in car traffic of 1 per cent leads to an increase in new calls of 1.14 per cent. Similarly, an incident leads to an increase in new calls of 11.7 per cent. An interesting observation is that an incident has a lower impact on handovers (5.5 per cent) than on the other mobile phone uses, which is a signal that an incident makes traffic slower.

In order to test whether these results still hold when data on car intensity (car_{it}) is disregarded, we redefine the model. Model 2 is the same as Model 1, but now without car intensity for the same 7 cells. In the second step we compare the results for the 7 cells with those for the 109 cells. Recall that we have only car traffic measurements for 7 out of the 109 cells.

$$ln(mob_{it}) = b_1 incident_{it} + b_2 H_t + B_1 X_i + B_2 T_t + B_3 W_t + B_4 X_i * H_t + B_5 T_t * H_t + B_6 W_t * H_t + \alpha_0 + \varepsilon_{it} \quad (2)$$

Recall that, because the variable mob_{it} is not normally-distributed, we transform it to a natural logarithm. The results are presented in Tables 8.4 and 8.5.

Table 8.4: OLS regression of different mobile phone variables for 7 cell-id's, without using data on car traffic

VARIABLES	(1) ln(erlang)	(2) ln(new_calls)	(3) ln(sms)	(4) ln(handovers)
incident	0.120	0.109	0.115	0.0357
	(2.172)**	(1.886)*	(1.964)**	(0.916)
temperature	-0.000953	-0.00153	-0.000781	-0.00126
	(-4.129)***	(-6.347)***	(-3.198)***	(-7.742)***
rain	0.00439	-0.0374	0.00899	-0.0133
	(0.108)	(-0.877)	(0.209)	(-0.465)
snow	-0.115	-0.0634	-0.0178	-0.0869
	(-0.959)	(-0.504)	(-0.140)	(-1.026)
Hour dummies (23)		Included		
Weekday dummies (4)		Included		
Zone dummies (6)		Included		
Interaction terms		Included		
Constant	1.658	4.999	4.622	6.496
	(25.47)***	(73.34)***	(67.08)***	(141.7)***
Observations	40,609	40,609	40,609	40,609
R-squared	0.915	0.875	0.844	0.949

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Note: Effects based on reference: 12:00 hr.
Note: Hourly interaction terms (H*cell-id's; H*weekdays; H*temperature; H*rain; H*snow).

Table 8.5: OLS regression of different mobile phone variables for all 109 cells without using car data

VARIABLES	(1) ln(erlang)	(2) ln(new_calls)	(3) ln(sms)	(4) ln(handovers)
incident	0.116	0.0988	0.0673	0.0518
	(7.941)***	(7.050)***	(4.798)***	(4.623)***
temperature	-0.000357	-0.000429	-4.26e-05	-0.000504
	(-6.197)***	(-7.740)***	(-0.768)	(-11.36)***
rain	0.0174	0.00332	0.0218	0.0163
	(1.772)*	(0.351)	(2.304)**	(2.155)**
snow	0.00432	0.00327	0.0223	-0.0129
	(0.135)	(0.106)	(0.724)	(-0.527)
Hour dummies (23)		Included		
Weekday dummies (6)		Included		
Zone dummies (108)		Included		
Interaction terms		Included		
Constant	0.408	0.867	0.600	4.837
	(9.600)***	(21.18)***	(14.64)***	(147.7)***
Observations	790,865	790,865	790,865	790,865
R-squared	0.874	0.858	0.859	0.910

t-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Note: Effects based on reference: 12:00 hr.
Note: Hourly interaction terms (H*cell-id's; H*weekdays; H*temperature; H*rain; H*snow).

The impact of traffic incidents is still significant for both data sets (Table 8.4 and Table 8.5) and stable across the different specifications. This analysis confirms that mobile phone activity in the selected cells intersecting with the highway are affected by motorway traffic. The estimated effects of traffic incidents still have approximately the same values both with and without using the car flow data, as the hourly dummies in the second case capture the temporal variation of car traffic. Thus, the incident elasticity of about 0.04 to 0.12 (from Table 8.4) is not just a reflection of exposure. Only the weather variable temperature is negative and significant. In order to move a step forward, the next section examines the factors affecting the occurrence of traffic incidents on the highway.

8.3.2 Probit analysis on traffic incidents

In order to test whether the volume of car-traffic intensity increases the probability of a traffic incident, we follow the same logic as in the previous section. We also include mobile phone use as an explanatory variable, not because it would cause incidents, but since it may be itself affected by the incidents, and hence might serve as a proxy for traffic incidents. Thus, the main goal of this exercise is to evaluate whether mobile phone data can be used as a proxy for traffic incidents. Equation (3) presents the new model of the 7 selected cells with motorway traffic. Because the different mobile phone variables (mob_{it}) are highly correlated, we use only *erlangs* in this model. $\text{Incident}_{\text{it}}$ are the hourly motorway accidents in cell *i* and at time *t*. Mobile phone activity is presented by the natural logarithm of erlangs (mob_{it}) in cell *i* and at time *t; car_{it}* represents the natural logarithm of motorway traffic (car counts) in cell *i* and at time *t*; X_i is a vector of the fixed effects of cell-id's; T_t is a vector of time variant variables (days of the week); H_t is a vector of hours of the day; and W_t is a vector of parameters for different weather conditions.

The basic version of this model is:

$$Pr(incident_{it} = 1|x_{it}) = \mathrm{F}[b_1 ln(car_{it}) + b_2 ln(mob_{it}) + b_3 H_t + B_1 X_i + B_2 T_t + B_3 H_t + B_4 W_t + \alpha_0], \qquad (3)$$

where the link function F follows from the specification of the probit model.

The results are presented in Table 8.6, Column (1). To control for hourly effects on car traffic intensity, we do the same modelling including interaction terms for traffic car flows (car_{it}) and erlang (mob_{it}) (see Table 8.6, Column (2)).

To see if this model yields meaningful results when we exclude the car traffic intensity, we use equation 3, without (Table 8.6, Columns (3) and (5)), and with hourly interaction effects (Table 8.6, Columns (4) and (6)). The results of the 7 and 109 cells are compared.

Table 8.6: Probit analysis of the probability of an incident for the 7 and the 109 selected cells

VARIABLES	(1) 7-cells incident	(2) 7-cells incident	(3) 7-cells incident	(4) 7-cells incident	(5) 109-cells incident	(6) 109-cells incident
ln(cars)	-0.626	-0.439				
	(-3.292)***	(-1.359)				
ln(erlang)	0.133	0.176	0.138	0.123	0.146	0.138
	(2.101)**	(2.511)**	(2.136)**	(1.335)	(12.29)***	(3.182)***
temperature	0.000417	0.000404	0.000459	0.000577	0.000317	0.000338
	(0.873)	(0.830)	(0.950)	(1.173)	(2.826)***	(2.997)***
rain	0.0120	0.0115	0.0159	0.0164	0.0435	0.0422
	(0.155)	(0.147)	(0.206)	(0.210)	(2.461)**	(2.384)**
snow	0.261	0.271	0.413	0.414	-0.0558	-0.0599
	(1.402)	(1.423)	(2.373)**	(2.339)**	(-0.922)	(-0.985)
Constant	1.589	-0.250	-3.870	-4.335	-2.730	-2.678
	(0.942)	(-0.0839)	(-11.52)***	(-6.665)	(-35.49)***	(-27.83)**
Hourly dummies (23)	Included	Included	Included	Included	Included	Included
Weekday dummies (4/6)	Included	Included	Included	Included	Included	Included
Zone dummies (6/108)	Included	Included	Included	Included	Included	Included
Interaction terms	No	Yes	No	Yes	No	Yes
Observations	38,921	38,921	38,921	38,921	790,865	790,865

z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
Note: Effects based on reference: 12:00 hr., Hourly interaction terms H*ln(cars) and H*ln(erlang).
Note: See results of the same model for the marginal effects in the Appendix (A4).

The most important finding is that the coefficients for mobile phone use, in terms of erlangs, are positive and significant in all the tested models. When excluding car traffic (car_{it}), as defined in equation 3, the spatial dummy variables (X_i) of cell-id's seemed to pick up this mobile phone use.

One would expect that there is a positive relationship between the number of cars and the number of traffic incidents. The results from Table 8.6 show, when using hourly interaction terms for car flows, there is a negative but not significant relationship between the number of cars and the probability of a traffic incident. This relationship between car traffic and incidents apparently varies strongly from hour to hour. This is indeed suggested by Figure 8.8a.

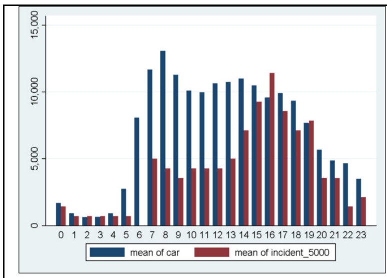


Figure 8.8a: Distribution of the hourly car traffic and sum of traffic incidents (7 selected cells)

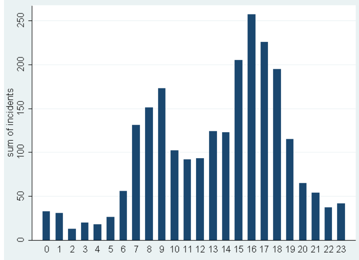


Figure 8.8b: Distribution of the hourly sum of the traffic incidents (109 selected cells)

The morning rush hours (between 6:00 hr. and 10:00 hr.) show more motorway traffic than the evening rush hour (between 16hr.-20hr.). There are clearly more incidents during the evening rush hours, with less cars, than in the morning rush hours with more cars on the road. Although this analysis contains only 7 cells, the spatial signature of hourly distribution of traffic incidents shows approximately the same pattern for all the 109 cells (see Figure 8.8b).

8.3.3 Marginal effects

In this section we go one step further to analyse for all 109 cells the more specific role of mobile phones and different weather conditions on the probability of different types of traffic incident. Therefore, we derive marginal effects (ME) from the probit models estimated in the previous section. It is important to note that these ME coefficients are not exactly the same as the output generated by OLS regressions. In the OLS regressions above the marginal effect can be directly obtained form the estimated coefficients. Since probit models are inherently non-linear, the marginal effects depend on the level of the independent variable, and also on the levels of other independent variables.

We will use the same model as Model 3, with an extension to include different mobile phone variables. The estimation details can be found in Appendix (A4). Here, we confine ourselves to a presentation of the estimates by means of the marginal effects based on the mean value of all independent variables for Model 3.

$$Pr(incident_{it} = 1 | x_{it}) = \mathrm{F}[b_1 mob_{it} + B_1 X_i + B_2 T_t + B_3 H_t + B_4 W_t + \alpha_0]. \qquad (4)$$

The results are presented in Appendix (A5) (they correspond with column (5) in Table 8.6). To control for hourly effects for telecom variables, we introduce hourly interaction terms

$$Pr(incident_{it} = 1 | x_{it}) = \mathrm{F}[b_1 mob_{it} + b_2 mob_{it} * H_t + B_1 X_i + B_2 T_t + B_3 W_t + \alpha_0]. \qquad (5)$$

The results are presented in Table 8.7 (they correspond with column (6) in Table 8.6).

Table 8.7: Marginal effects for all 109 cells with different mobile phone variables and hourly interaction terms for mob_{it}

VARIABLES	(1) incident	(2) incident	(3) incident	(4) incident
ln(erlang)	0.000582			
	(3.182)***			
ln(new_calls)		0.000269		
		(1.906)*		
ln(sms)			0.000344	
			(2.607)***	
ln(handovers)				0.000331
				(1.702)*
temperature	1.42e-06	1.18e-06	9.79e-07	1.35e-06
	(2.997)***	(2.482)**	(2.054)**	(2.771)***
rain	0.000185	0.000198	0.000191	0.000201
	(2.384)**	(2.541)**	(2.441)**	(2.522)**
snow	-0.000231	-0.000234	-0.000217	-0.000189
	(-0.985)	(-0.994)	(-0.913)	(-0.775)
Hourly dummies (23)		Included		
Weekday dummies (6)		Included		
Cell dummies (108)		Included		
Observations	790,865	790,865	790,865	790,865

z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Note: Effects based on reference: 12:00 hr.

The main findings of this model can be summarized as follows. Even after controlling for hourly effects, coefficients for erlang, new calls, and sms are still positive and significant for traffic incidents. It should to be noted that erlang and call length are highly correlated. That is why we exclude the variable call length from our modelling. The marginal effects can be interpreted as follows. A 1 per cent increase in new calls, increases the probability of an incident in one specific cell by 0.000269 *(0.01) = $2.69*10^{-6}$. This is equal to $2.69*10^{-4}$ per cent. This is clearly a very low figure, but note that the average probability of an incident is 0.00301 (see Table 8.1). So the relative increase in the probability of an incident related to a 1 per cent increase in new calls is about 0.089 per cent. Similarly, a 0.1° C. increase in temperature, increases the probability by $1.42*10^{-6}$, which is indeed a very small effect.

The last modelling step looks in more detail at the different types of incidents, as described earlier in Section 8.2.1.

$$Pr(incident\_type_{it} = 1|x_{it}) = F[b_1 mob_{it} + B_1 X_i + B_2 T_t + B_3 H_t + B_4 W_t + \alpha_0]. \quad (6)$$

The results are presented in Appendix (A6).

To control for hourly effects for telecom variables, we introduce hourly interaction terms for mob_{it}.

$$Pr(incident\_type_{it} = 1|x_{it}) = F[b_1 mob_{it} + b_2 mob_{it} * H_t + B_1 X_i + B_2 T_t + B_3 H_t + B_4 W_t + \alpha_0] \quad (7)$$

The results are presented in Table 8.8.

Table 8.8: Marginal effects for the 109 cells with interaction terms for mob_{it}.

VARIABLES	(1) Object on the highway	(2) Accident with injuries	(3) Driver unwell	(4) Broken down vehicle	(5) Only material damage	(6) Fire
ln(erlang)	-2.15e-05	2.42e-05	3.42e-06	0.000233	0.000390	-1.41e-06
	(-0.263)	(0.239)	(0.350)	(1.885)*	(3.101)***	(-0.0381)
t	1.99e-07	1.99e-07	4.76e-08	1.28e-06	-3.22e-07	9.39e-08
	(0.880)	(1.244)	(1.783)*	(3.859)***	(-1.046)	(1.253)
r	-3.47e-05	-1.36e-05	-9.02e-06	-2.26e-05	0.000294	-9.61e-06
	(-0.930)	(-0.538)	(-1.989)**	(-0.421)	(5.663)***	(-0.828)
s	-0.000177	-4.30e-06		5.36e-05	-0.000127	
	(-1.560)	(-0.0533)		(0.302)	(-0.906)	
Hourly dummies (23)			Included			
Weekday dummies (6)			Included			
Zone dummies (108)			Included			
Observations	579,431	213,278	139,232	739,833	717,952	49,137

z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Note: Effects based on reference: 12:00 hr.

The categories accidents with injuries, driver being unwell, broken-down vehicles and incidents with only material damage are all positive and significant as shown in Table A6 (Appendix). After using hourly interaction terms for erlang, only incidents with material damage are significant (see Table 8.8). The marginal effects can be interpreted as follows. A 1 per cent increase in erlang, increases the probability of an incident with only material damage in one specific cell by 0.000233 *(0.01)= $2.33*10^{-6}$. This is equal to $2.33*10^{-4}$ per cent. We find rather higher effects for broken down vehicles than for the other types of incident.

There are a number of reasons which might explain this outcome. The A10 Amsterdam ring road has the characteristic that the number of cars during the day is close to its maximum capacity. For safety reasons, before 2011, the Traffic Management Centre completely closed 1 driving lane so it could be used for emergency aid. This directly caused traffic jams, even just for broken-down vehicles compared with other types of accidents. Since 2011 (so after our study period), because of major congestion problems, this policy has been changed. Furthermore, our database only has 59 incidents with injuries. Only a part (approximately 40 per cent) of these incidents took place during rush hours (see Figure 8.9).

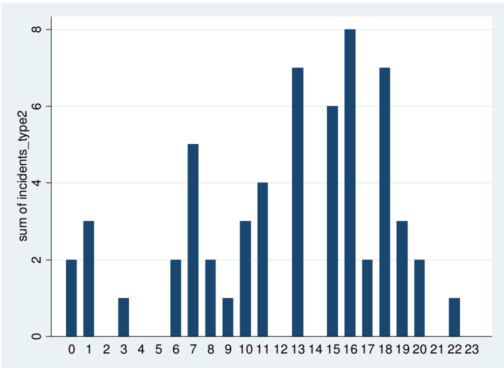


Figure 8.9: Distribution of traffic incident with injuries

Another interesting finding is that temperature is only positive and significant for broken down vehicles. One would expect that low temperatures would also be significant. The plausible explanation is that, in cold weather conditions, people are likely to have more problems with their batteries. This kind of problems occurs when drivers start their cars from their homes. Cars will need to be repaired before they can enter the highway.

Rain is only positive and significant for material damage (collisions between cars). This means that wet weather conditions significantly influence the safety on the roads. They affect incidents with only material damage but not accidents with injuries. The explanation is that drivers reduce speed (see Sabir, 2011) so that serious accidents are less probable, but still the probability of less serious accidents does increase when it rains.

8.4 Summary and conclusions

This chapter has investigated the effects of hourly variations in mobile phone intensity on the number of traffic incidents on the highways of greater Amsterdam. The use of mobile phone data to support daily traffic management, and, in particular traffic IM, is thought to be a promising research direction. The most important finding is that mobile phone use, measured in erlang and new calls, depends in a positive and significant way on motorway car traffic and traffic incidents. This analysis confirms that mobile phone activity in the selected cells are affected by motorway car traffic. The estimated effects of traffic incidents still have approximately the same values both with and without using the car flow data. The high resolution of the mobile phone data enables us to extract vital information at a very fine-grained scale. Note that, unfortunately, our telecom database has a time interval of 1 hour which clearly limits the potential use of the data. Nevertheless, the results suggest that this approach may be a useful starting point for the development of an early warning system to detect motorway traffic incidents. It should be noted that it must be seen as an additional information tool to be used concurrently with existing information and monitoring systems. In a broader perspective, it could also be used as an input for more sophisticated tools for larger disasters and crisis management.

The marginal effects of the probability of an incident are very low. This is mainly because the average overall probability of an incident in a telecom cell is 0.00301 per hour and our study area is based on the telecom zones.

A main limitation of our study is that the 1-hour time interval is too long. A reduction to 5 or 10 minutes would enable us to provide information which answers the required timelines of the end-users in the Traffic Management Centres. In addition, a more sophisticated data sample of the mobile telecom network could also further improve our findings. This consists of anonymized Origin-Destination (OD) matrices of mobile phone records of individual subscribers, so more advanced analysis could be applied.

Moreover, the data quality of the mobile telecom network also deserves further attention. A telecom network consists of a complicated structure from where to extract information. A valuable exercise is to compare the different approaches which currently dominate the literature, such as *rasterisation, veronoi* diagrams, and *spatial signatures*.

Another interesting theme would be to apply concepts such as ‘Dynamic Data Driven Application Systems’ (DDDAS), to handle real-time data flows from the telecom network, and the development of a simulation system for evacuation and the effect of different emergency scenarios and types of agent behaviour.

Finally, the process of data fusion, which combines information originating from multiple sources, could be further explored. Overlapping information, such as detection loop data, estimation of traffic flow, weather conditions, and social media data, could be used to detect, identify, and track relevant objects in a region to support situational awareness for traffic IM.

9 Summary, Conclusions, Discussion and Recommendations

9.1 Summary

The large number of road users on the dense Dutch transportation networks leads to major traffic jams, mainly at regular bottlenecks, on a daily basis. This usually causes congestion, associated travel delay, wasted fuel, increased pollutant emissions, and lost vehicle hours. And, last but not least, incidents with property damage, injuries, fatalities and other road safety effects for road users in the vicinity of traffic incidents are also part of the daily mobility issues. Each year there are over 100,000 incidents, which account for approximately 270 incidents per day. Approximately 13 per cent of the traffic jams on the Dutch roads are the result of incidents such as crashes and vehicles shedding their loads. Incident Management (IM) is one of the most important measures in modern traffic management, and the handling of these traffic incidents was object of my research. Information systems are increasingly being seen as an important tool to reduce these mobility-related problems.

The central question in this thesis can be summarized as follows: Can Situational Awareness (SA) improve the daily handling of traffic Incident Management (IM)? The current literature about SA focuses on different aspects, such as new human-centred design, data management, information concepts, data sets, and information needs for developing improved information systems to support sustainable mobility, especially in dense urban environments like the Netherlands. The main problems identified in the current IM handling focus on information, communication, and coordination issues between the emergency organizations. So the main objective of this thesis was to quantify the role of SA, based on new information concepts (net-centric working and a Common Operational Picture), in order to improve the daily handling of traffic IM, and to provide recommendations for developing new information systems to support traffic IM. In Figure 9.1 we define how the information concepts used are related to each other. Communication processes can be divided in three related domains: information, cognition and physical. The *information domain* is related to the relevant IM data. The *cognitive domain* focuses on human mental processes. The *physical domain* contains activities in the real world. In the information domain we distinguish between the net-centric system (NCW) which enables a COP to be created. In the cognitive domain, improved decisions are based on a better understanding (awareness) of the situation (SA). In the physical domain this leads to better outcomes.

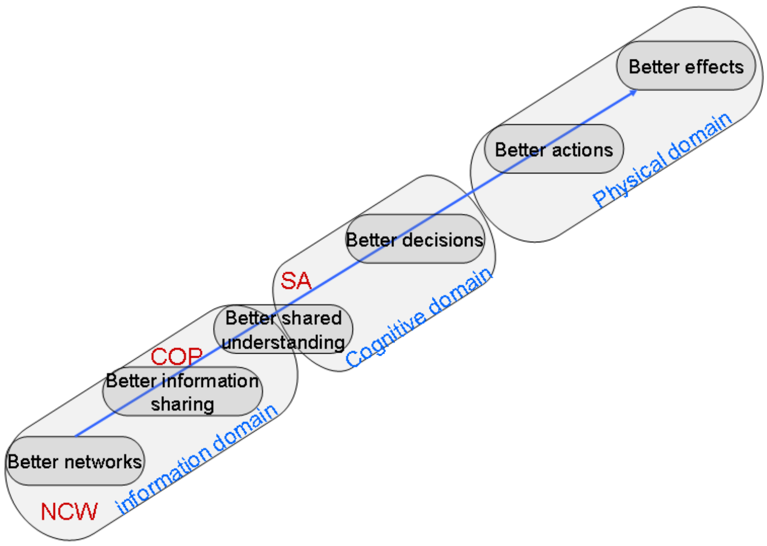


Figure: 9.1: Relationship between information concepts

Information (or data) quality (IQ) and System quality (SQ) can both be seen as important requisites in the information domain for improving cooperation between IM emergency responders, and are crucial to establish a COP which is in line with the information needs of end-users. My findings are that having a COP leads to: a better understanding of the incident situation; better cooperation between IM actors; and the improvement of the decision-making process. My research confirms that this has a positive impact on the overall IM performance in terms of response time, clearance time, the impact on traffic jams, and lost vehicle-hours. The underlying performance indicator is thus the speed of the emergency aid.

The scientific contribution of this thesis builds on existing theories and methodologies. Network-centric warfare can trace its immediate origins in the work of different authors (e.g. Owens, 1996; Cebrowski and Gartska, 1998), and was first applied in the USA (Alberts *et al.*, 2000 ; Alberts *et al.*, 2001 ; Alberts, 2002), and later adopted in disaster management and homeland security (Boyd *et al.*, 2005; UK Ministry of Defence, 2005). A COP is a term widely used within the military domain to support SA for Command and Control in net-centric operations (US Department of Defense, 2005; Wark *et al.*, 2009). The concept of a COP has now also been adopted as a goal for law enforcement, emergency management, firefighters, and other first responders (Harrald and Jefferson, 2007; Homeland, 2008; FEMA, 2009). Although the term 'Situational Awareness' itself is fairly recent, the evolution and adoption of the concept has a long history, as described by Harrald and Jefferson (2007). Most of the related research was originally conducted in the area of military aviation safety in the mid-1980s in order to design computer interfaces for human operators (Endsley 1988 ; Dominguez *et al.*, 1994 ; Endsley, 1995). To define which context variables are relevant to define a COP for traffic IM, we build on existing theories (e.g. Dey, 2001; Dey and Abowd, 1999, 2000; Küpper, 2005). To ensure that the information needs of end-users are met, we integrate the concepts of Information Quality (IQ) and System Quality (SQ) to establish a COP which contributes to improving SA (e.g. Strong *et al.*, 1997; Perry *et al.*, 2004). The concept of 'quality' is often defined in terms of '*fitness for use*' '*fitness for intended use*', or '*fitness for purpose*'. The value of this thesis in relation to previous research, is that it applies these information concepts to traffic IM. As traffic IM can be seen as a special case of emergency response, to a certain extent these concepts can also be applied to design a traffic IM system. The underlying assumption is that the introduction of these concepts leads to an improved SA.

Further, we looked at new high spatio-temporal resolution data sets, such as mobile phone data, which enable us to extract vital information at a very fine-grained scale. Research on the use of mobile phone data has its origins in different domains: e.g. monitoring cities (Ratti *et al.*, 2006; Calabrese and Ratti, 2006; Reades *et al.,* 2007; Calabrese *et al.*, 2011a); land use patterns (Soto and Frıas-Martınez, 2009); social analyses and human dynamics (Barabási, 2005); human mobility patterns (Eagle and Pentland, 2006; Mateos, 2006; Shoval, 2007; Candia *et al.*, 2008); detection of social events (Calabrese *et al.,* 2010b); disaster management (Schoenharl *et al.*, 2006b; Madey *et al.*, 2006b; Pawling *et al.*, 2008b;

Vaidyanathan 2010a); and transportation (Yim, 2003; Rose, 2006; Caceres *et al.*, 2008; Fontaine, 2009). This thesis is the first study which explores the use of mobile phone data for traffic IM. Although the above mentioned studies demonstrate the potential use of mobile phone data in a broad range of applications, we can conclude that the use of such data is still in the research and development stage.

9.2 Conclusions of the explorative studies

Part I consisted of four explorative studies which defined the theoretical foundations of this thesis. In Chapter 2 we provided an extensive literature review on traffic IM and related mobility and safety issues. In an urbanized Europe with a dense transportation network, the professional development of IM technology is a prerequisite for sustainable urban development and related transportation strategies, because it is the main cost-effectiveness measure to handle and reduce irregular traffic jams caused by traffic incidents. Before 1975 there were a limited number of highways, and traffic jams did not lead to major problems in terms of mobility and safety on a nationwide scale. As a results of the increased traffic intensity and a vast number of road incidents, more public and private organizations have become involved which has led to the IM information network, where coordination of information and creating a shared understanding of the incident situation have become important constraints for effective IM handling. The cooperation between different organizations is clearly defined in Article 2 of the IM Policy Rules. This was the initial start of the IM network, which can be seen as a public-private partnership.

Chapter 3 focused on net-centric information services that are seen as an important instrument to improve cooperation, which is a basic constraint in achieving improved Situational Awareness (SA) based on a COP between the different IM organizations. The term '*net-centric*' can be defined as "*participating as a part of a continuously evolving, complex community of people, devices, information and services interconnected by a communications network to achieve optimal benefit of resources and better synchronization of events and their consequences*". A COP offers a standard overview of an incident, thereby providing incident information that enables organizations to make effective, consistent, and timely decisions. By compiling data from multiple sources and disseminating the collaborative information, a COP ensures that all responding entities have the same understanding and awareness of incident status and information when conducting operations. More simply, SA has been generally defined as "*knowing what is going on around you*". Net-centric systems and a COP are thus the basic ingredients to achieve an improved SA. There are three elements which define 'Situation' in order to support traffic IM: incident information; information specifically related to the environment of the incident; and information about the emergency organizations involved in dealing with the incident. The transfer of these concepts from their safety and combat origins to the complex, heterogeneous emergency management structure is exceedingly difficult, and short-term strategies based on the assumption that shared SA will be easily achieved are doomed to failure. Therefore, we conclude that these concepts need to be introduced in four different stages: user perspective; selection of IM actors; selection of minimal data set; and the ambition level based on a maturity model.

Chapter 4 analysed the use of telecom data for transportation management from a historical perspective. The use of wireless location technology and mobile phone data appears to offer a broad range of new opportunities for sophisticated applications in traffic management and monitoring, particularly in the field of IM. Indeed, because of the high market penetration of mobile phones, it allows the use of very detailed spatial data at lower costs than traditional data collection techniques. Travel speed and travel time are the most studied estimation issues for traffic management purposes. The adoption of GSM data is still limited, and it is a field still largely dominated by research and development. The technology is promising, but not yet developed to the degree necessary for large-scale utilization. Recent studies show more promising results, but the transportation agencies have historically not defined suitable performance requirements for wireless location systems, which may cause ambiguities in validation studies, which make it difficult to draw clear conclusions. Therefore, it is crucial that governments should be involved at an early stage in these innovation projects.

Finally, Chapter 5 provided an extensive review of the research on using mobile phone data to support traffic IM. The three most-promising applications are: support safety and security for surrounding areas; incident warning based on anomaly detection; and, prediction of flows and site accessibility for emergency services. It also provides the results of a first experimental case study, carried out in 2010, to detect traffic incidents from mobile phone data based on anomaly detection for greater Amsterdam. Indeed, these results confirm, on the basis of a limited number of selected traffic incidents, that mobile phone data can be used to detect traffic anomalies. It also provides a SWOT analysis of GSM technology applied to transport safety and security.

The extensive literature review demonstrated that net-centric systems has the potential to improve the cooperation between IM emergency services. However, this domain has a variety of research directions. To narrow down our scope, we introduce a two-level approach. Firstly, we analyse the current status and the future ideas of the IM information network in terms of information, communication, and coordination. Therefore, an Internet survey questionnaire was administered to stakeholders. The main goals of this questionnaire were to:

- identify the current information, communication, and coordination problems;
- gain knowledge of the main information needs;
- have insights about the current information quality (IQ) and System Quality (SQ);
- define the required system functionality;
- have insights into the information dependency between IM organizations, and;
- identify the willingness to adopt net-centric information systems.

The second level focused on an experimental net-centric field exercise. Based on the outcomes of this Internet questionnaire and a desktop analysis, a specific IM net-centric system was developed, and a two day field experiment was set up. The main research questions for this case study were:

- How has SA improved the performance of the decision-making process (outcomes)?
- What are the main issues using net-centric systems as experienced by end-users?
- What are the effects of scenario complexity on the benefits of net-centric systems?

The literature review on the use of wireless location technology and mobile phone data offered a broad range of new possibilities. Traditional measuring methods, such as road loop detectors, camera detection, or floating probe vehicles, are effective and precise. However, there are practical and financial limitations to their use. Detection loops installed under the road pavement are regularly installed on highways but their application in urban environments appears to be unfeasible, given the number of roads that need to be monitored and the complexity of installation. Moreover, only small part of the Dutch highway infrastructure (approximately 30 per cent) is equipped with detection loops. Similar concerns can be raised about detection cameras, which are a feasible option for a limited number of measurement points. There is, however, an increasing need for less expensive monitoring systems and effective and reliable information systems.

To narrow down our scope on telecom data for traffic IM, we defined the following main research questions which have been tested in an extensive case study in the area of greater Amsterdam.

- Can mobile phone data be used (as a predictor) to detect motorway traffic incidents?
- What is the relationship between motorway car traffic dynamics and traffic incidents?
- Are mobile phone variables a good indicator to estimate the probability of having a traffic incident?

9.3 Conclusions of the empirical studies

Part II contains three empirical studies related to SA and traffic IM: A) an Internet questionnaire administered to stakeholders; B) a field experiment to measure the effectiveness of net-centric support tools, and: C) a case study to analyze the usefulness of mobile phone data as a first attempt to create a early warning system for traffic IM. In the following sections we highlight the main findings.

9.3.1 Internet survey questionnaire

Chapter 6 provided an empirical analysis of the critical success conditions for effective IM in the Netherlands based on an Internet survey questionnaire administered to employees of the main IM stakeholders: The respondents to this questionnaire were the employees of the Rijkswaterstaat (RWS) (in particular RWS VCNL as the National Traffic Management Centre and RWS RTMC as the five Regional Traffic Management Centres), the Safety Regions (the Police, the Fire Brigade and the Ambulance service), the towing services (LCM and CMV), and the Royal Dutch Automobile Association (ANWB). The total number of respondents is 236 who represent about 50 per cent of the total population approached in this survey.

The main goals of this research are: to get a clear and critical overview of the main information, communication, and coordination problems; to gain knowledge of the main information needs of each IM organization; to evaluate the current appreciation of Information Quality (IQ) and System Quality (SQ); to gain insights into the desired system functionality; to estimate the willingness to adopt net-centric information systems; and to see what is the information dependency based on an actor-network approach.

The early and reliable detection and verification of incidents, together with integrated traffic management strategies, are important contributions which can improve the efficiency of the incident response. Currently, most problems occur in the first phases of the IM process. The coordination of IM measures also plays an important role. Organizations do not have a good overview of the activities of the other organizations. In order of importance, safety has a higher priority then smooth traffic flow. It is, however, surprising to see that the safety and status of potential victims both score lower than the other information categories. Location information has the highest score. Cargo information and dangerous goods also have a high priority. Nearly all the items score between 4 and 5 (on a 5-point Likert scale). This indicates that information about an incident has a high priority. The need for environmental information clearly has more variation in the scores. This group is considered to be important, but scores significantly lower than information about the incident. Organization information scores are approximately equal for all organizations, with the exception of the LCM. Within the Safety Regions (the Police, the Fire Brigade and the Ambulance service) the functionality to view the status and location of fieldworkers of other organizations already exists. For the RWS, ANWB, LCM, and CMV this functionality is not yet available. This could clearly improve the cooperation to create better organization awareness. The need for organization information is at approximately the same level as it is for environmental information.

The management of information is essential for the coordination of the emergency response. To measure SA, it is crucial to include the concept of ‘quality of information systems’. Information Quality (IQ) and System Quality (SQ) are both important requisites to achieve SA. Completeness, consistency, and knowledge of the reliability information score a few lower then the other IQ items. However, there is not a great variation between the scores (between 3 and 4). This means that the organizations concerned indicate that some significant improvements in IQ can still be made. By ‘information systems’ we mean all systems that are currently used to support the daily IM handling. The value of SQ scores lies around 3. Here we can conclude that there are some major improvements possible. However, the respondents indicated that the current systems support their own activities better than the cooperation between different IM organizations. In the current IM domain, most information is shared by telephone communication. We can conclude therefore, that respondents found that telephone communication alone is insufficient for the daily handling of IM, and does not sufficiently support the cooperation between IM organizations. There is clearly a need for additional communication tools.

Following this conclusion, we asked which functionality the organizations would like to have for the handling of incidents and to improve the cooperation between the emergency organizations. Hereby, we made a distinction between additional information sources (text messages, camera images, multi-media, social media, and mobile/porto phone) and system functionality (automatically push incident notifications; share messages at once with all organizations; filter that personalizes information; notification of information changes; and identification of the reliability of information). Based on my research, we can conclude that text messages, camera images, automatically push incident notifications, share messages at once with all organizations, filter that personalize information and, notification of information changes, are the functionalities that are most appreciated among IM organizations. These functionalities are integrated in the net-centric system for our field experiment.

9.3.2 Net-centric field experiment

To test the value-added services for traffic IM, we set up a field experiment. Chapter 7 reported the results of an empirical analysis of the effectiveness of net-centric information systems to improve the cooperation between public and private IM organizations. A set of controlled experiments were conducted with well-trained participants. This study is based on realistic traffic IM scenarios that cover a wide range of different types of incidents in terms of vehicles involved, casualties, and complexity. The participants were randomly assigned to one of two groups. The test group used the net-centric systems, while the control group used traditional tools for the daily handling of traffic incidents. During the experiments, data on the responses of the participants were collected by means of questionnaires and observer notes. The analysis focused on: a comparison of the tools tested; in terms of the appreciation of information and system quality; a comparison of the communication and coordination of a test group and a control group of the emergency workers; the value of SA in the performance of the decision-making process and its outcomes; and, how scenario complexity can affect the design principles of net-centric systems.

To determine whether the net-centric system functionality was able to establish a COP, which leads to better information sharing, we focused on System Quality (SQ) aspects. For the task-related SQ constructs, the test group scored significantly higher on *integration*, *memory,* and *SA*. Only the construct *format* scored significantly lower. This is strongly related to the IQ constructs *overload* and *verification*. *Personalization* seemed to be a key issue in an information-rich environment. For perceived operational satisfaction, we measured two constructs. The test group found the system complicated to use. The SQ construct *ease of use* scored significantly lower in the test group. However, a learning effect was visible. The test group started to perform relatively better after each scenario. *Usability* was scored significantly better in the test group. Here, we can conclude that the test group recognized the value-added service of a net-centric system, but that they still perceived it as complex to use.

To measure whether a COP leads to a better shared understanding (SA), we focused on Information Quality (IQ) aspects. We find that the internal consistency of the various items to measure IQ dimensions is, on average, satisfactory (Cronbach's alpha is larger than 0.7 in a clear majority of the cases). With the exception of Scenario 2, the test group reported higher information quality dimensions than the control group. However, given the small number of participants, the differences are in most cases not significant. *Timeliness* is the dimension with the best score in the comparison between the test group and the control group. In the more complex scenario's, information overload was the main issue. The test group had difficulties in using the predefined tools to filter relevant information. They also found it hard to verify shared information. However, the test group performed significantly faster than the control group. Eventually, it was clearly apparent that the test group were starting to have hands-on experience using the net-centric system. They scored better on all constructs, with the exception of *relevance*. This is mainly because the filters for personalization of information system were still too complicated to use.

To validate whether better SA, based on net-centric systems, improves the performance in the decision-making process of the emergency organizations, we focus on the speed of completeness of incident notification information, and how fast the emergency services arrive at the incident location. We compared the observed outcomes (by shadowing the participants) of each scenario in the test group and the control group. The average time gained by having incident information (first notification, location, incident type, involved vehicles, number of victims and dangerous goods) was, on average, 21 minutes faster in the test group. The emergency services of the test group also arrived approximately 10 minutes earlier at the incident location. Only the Ambulance service was 3 minutes later at the incident location in Scenario 3. This was based on a miscommunication between the fieldworkers and the Traffic Management Centre. This means that even with the right tools, it is the quality of information which is relevant.

Scenario complexity affects the design principles of net-centric systems. Most of the detected problems in our field exercise to measure IQ in the more simple GRIP0 scenarios, were related to *consistency* of information. This means that only a small amount of information was shared. However, the working memory of the participants could handle the information flow, and they could easily judge the (in)consistency of the data. Telephone communication still plays an important role here. In the more complex Scenarios (2, 3 and 4) the participants had most problems with *relevance*, *overload*, and *verification* of information. This is directly related to system quality constructs. Participants in the test group were pleased that the system supports the *accessibility* and *integration* of many data. They also scored higher in the task-related construct *memory*. However, the construct *format* was clearly not used and designed to avoid information overload, help their work memory, and support their attention. This is partly due the participants having little or no experience with net-centric systems. However, we did observe a learning effect during the scenarios. Clearly, more complex incidents need to have appropriate formats which are specially designed for different types of minor incidents (GRIP 0) and the more serious GRIP incidents (GRIP 1-4). These are the main reasons why the system is perceived as complex. This means that a net-centric system is perceived as *useful,* but clearly there is a need to improve some technical system functionality to support IQ for daily use.

9.3.3 Telecom case study

To test the value-added services for the use of telecom data, we set up a case study in the greater Amsterdam area. Chapter 8 reports the results of an empirical study to explore the relationship between motorway car intensity, traffic incidents, weather data and mobile phone use. By its very nature, Big data derived from various sources provides new sources of spatial data which have the potential to significantly improve the analysis, understanding, representation, and modelling of urban dynamics. The main research question of this case study was to examine whether we can use mobile phone data as a detector for motorway traffic incidents. The underlying goal was to explain which factors contribute to the mobile phone use.

The study area involved the city of Amsterdam and its surroundings, covering an area of about 1000 km^2. The mobile telecom data we utilize for our research was supplied by a major Dutch telecom operator and provided aggregated information about mobile phone use at the level of the GSM cells. In order to derive spatio-temporal information from a huge volume of raw mobile network traffic data, a semi-automated (geo-)processing workflow was developed. We selected only those cells that have a direct relation (overlap) with the highway infrastructure: in total 790,865 hourly measurements were selected, corresponding to 322 days and 7 hours, for each of the 109 telecom cells belonging to the area chosen for the investigation. The anonymized and aggregated volumes of traffic data included indicators for presence (Erlang, new calls, call lengths, SMS) and an indicator for movements (handover). For the purposes of this case study, we selected data from 1 January 2010 (00.00 hr.) through to 20 November 2010 (07.00 hr.). For this period there were, in total, 2382 traffic incidents. We used six different types of incident categories: object on the highway; accident with injuries; driver unwell; broken-down vehicle; accident with only material damage; and accident with fire. The hourly variation of incidents is characterized by some significant temporal signatures. During the rush hours there are significantly more incidents, with the highest peak in the evening. During the working days there are considerably more incidents than during the weekend. Traffic incidents may be sensitive to the different types of infrastructure where they occur. We can conclude that most motorway traffic incidents take place at the intersection point of highways, and at the exit and entry points of highways. It is important to realize that each of the six types of traffic incidents have a different impact on the smoothness of traffic flows. An important aspect is the duration of the handling of an incident. The mean duration varies between 16 and 71 minutes, depending on the type of incident. Parts of the Dutch road network, especially in dense urban areas, are equipped with a comprehensive monitoring system based on detection loops. For car flows, hourly data was extracted from the 'MTR+' detection loop application provided by the Dutch Ministry of Infrastructure and Environment. The *Meteorological* data (temperature, rain and snow), used for this case study, was obtained from the Royal Netherlands Meteorological Institute, KNMI (www.knmi.nl). All measurements are hourly averages and were measured by accurately calibrated weather stations used for regional weather forecasting by the regional environmental agency (based at Amsterdam Schiphol Airport).

The most important finding, based on OLS regression, is that mobile phone use, as reflected in erlang, new calls and call length, is positively related with motorway car traffic and traffic incidents. For example, an increase in car traffic of 1 per cent leads to an increase in new calls of 1.14 per cent. Similarly, an incident leads to an increase in new calls of 11.7 per cent. An interesting observation is that an incident has a lower impact on handover (5.5 per cent) than on the other mobile phone uses, which indicates that an incident makes traffic slower. The estimated effects of traffic incidents still have approximately the same values, both with and without using the car flow data (coefficients between 10-11).

In order to test whether the volume of car traffic intensity increases the probability of having a traffic incident, we used the probit models. The most important finding is that the coefficients for mobile phone use, in terms of erlangs, are positive and significant. When excluding car traffic, the spatial dummy variables of cell-id's (X_i) seemed to pick up this mobile phone use. One would expect that there would be a positive relation between the number of cars and the number of traffic incidents. However, the results show, when using hourly interaction terms for car flows, there is a negative but not significant relationship between the number of cars and the probability of having a traffic incident. This relationship is apparently strongly influenced by the specific hour of the day. The morning rush hours (between 6:00 hr. and 10:00 hr.) have more motorway traffic than the evening rush hours (between 16:00 hr. and 20:00 hr.). There are clearly more incidents during the evening rush hours, with less cars, than in the morning rush hours in which there are more cars on the road.

Next we analysed for all cells, the more specific role of mobile phone data and different weather conditions on the probability of having the different types of traffic incident. Therefore, we used marginal effects (ME) in combination with probit models. Even after controlling for hourly effects, the erlang, new calls, call lengths and sms are still positive and significantly related to traffic incidents. It should be noted that erlangs and call lengths are highly correlated. New initiated calls are more significant than the number of sms sent. This is plausible, people are assumed to find it easier to make phone calls than send an sms while driving. The categories accidents with injuries, driver being unwell, broken-down vehicles, and incidents with only material damage are all positive and significant. We find rather high effects for broken-down vehicles. There are a few possible reasons for this outcome. The A10 Amsterdam ring road has the characteristic that the number of cars during the day is close to its maximum capacity. For safety reasons, before 2011, the Traffic Management Centre strictly closed one driving lane for safety reasons to facilitate the delivery of emergency aid. This directly caused traffic jams, even just for broken-down vehicles. Since 2011, because of major congestion problems, that is after our study period, this policy has been changed.

Anther interesting finding is that temperature is only positive and significant for broken-down vehicles. We would have expected that low temperatures should also be significant. There is a logical explanation for this. In cold weather conditions, people are likely to have more problems with their batteries. These kind of problems occur when starting their cars just before leaving home. Cars will need to be repaired even before entering the highway. Rain is only positive and significant for material damage (collisions between cars). This means that wet weather conditions significantly influence the safety on the roads. Such weather conditions directly affects incidents with only material damage but has less influence on more serious accidents with injuries. The explanation is that drivers reduce speed so that serious accidents are less probable, but nevertheless the probability of less serious accidents increases.

9.4 Discussion (Relevance of findings)

In general, we can state that in the Netherlands, the application of IM is supported by very professional public and private organizations. In the operation or action phase (scene management), the cooperation between IM organizations is very effective. However, the results from the Internet questionnaire confirm that there is still a lot to gain from improving the information provision to support the IM process. Especially at the beginning of the IM process (detection, verification, and allocation of necessary resources), there are still many information, communication, and coordination problems. The most important contribution of this thesis is the quantification of the influence of new information concepts and Big Data to improve SA for traffic IM.

9.4.1 Situational Awareness and net-centric systems

This thesis confirmed that the introduction of net-centric information systems significantly improves SA to support effective decision making in traffic IM. Following a series of steps (literature review, questionnaires, field experiment, and shadowing), this dissertation has introduced new information concepts that ensure better information-sharing.

The current IT architecture in the IM domain is characterized by top-down information flows which are mono-disciplinary-based, and generate mainly static agency-specific operational pictures. The introduction of a net-centric system needs to critically redesign existing information systems, data management, and current work methods, which enable a collective intelligence to develop among the emergency services based on real-time information-sharing. On the basis of our field experiment, we can conclude that there is still some lack of knowledge, and special attention needs to be paid to the training of emergency workers.

The net-centric approach must further been seen as an additional information service to the traditional information channels such as (mobile) phone communication. As demonstrated in the field experiment, IQ and SQ are major constraints to establish a COP to reach the full potential of SA. SQ focuses more on system- and task-related features, and perceived operational satisfaction. IQ is more related the characteristics of information and how it meets the requirements of end-users.

Looking back to 2008, the Dutch IM Council stated that real-time information sharing between IM organizations had to be implemented within 2 years. If we look at the current situation, we can conclude that this goal has not been achieved. The literature on the introduction of net-centric systems, in the field of traffic IM, is scarce, and empirical case studies do not exist. However, within the disaster management environment, the Dutch Safety Regions (the Police, the Fire Brigade and the Ambulance service) already have some years' experience of introducing these concepts. This was also confirmed in the Internet questionnaire. However, the other IM organizations, including the RWS have hardly any such experience. We demonstrate that traffic IM, due its relatively limited complexity, should be a good starting point to introduce these concepts, especially because 100,000 incidents per year provides the opportunity for net-centric handling and thinking to become a daily routine. Special attention needs to be paid to the cognitive domain. Humans are limited by working memory and attention. New information from multiple sources must be integrated with other knowledge. How people direct their attention when acquiring new information has a fundamental impact on which elements are incorporated in their SA.

9.4.2 Situational Awareness and telecom data

Another contribution of this thesis is the use of mobile phone data to support traffic IM, which is a novel approach in the current literature. Chapters 4 and 5 provided an extensive literature review. In Chapter 8 we analyzed the relationship between mobile phone data, motorway car traffic, weather data and traffic incidents. Our study investigated the effects of hourly variations in mobile phone intensity on the number of traffic incidents on the highways of greater Amsterdam. The use of mobile phone data to support daily traffic management, and in particular traffic IM, seemed to be a promising solution. The findings of our case study have statistically confirmed the use of such spatio-temporal data. These data can be seen as an additional tool, in terms of collective sensing, to develop an early warning system to detect motorway traffic incidents. In a broader perspective, spatio-temporal data can be also used to develop more sophisticated tools for larger disasters and crisis management.

The high resolution of the mobile phone data could enable us to extract vital information at a very fine-grained scale. However, the temporal dimension used in our case study was limited to a 1 hour time interval. This 1 hour time interval need to be reduced down to 5 or 10 minutes. This would enable information to be provided which answers the required timelines of end-users in the RWS Regional Traffic Management Centers. As well as that, it would be very interesting to use a more sophisticated data sample of the mobile telecom network, such as OD matrices. They consist of ammonized phone records of individual subscribers, so more advanced analysis could be applied.

9.5 Policy recommendations and suggestions for future research

IM is one of the most important instruments of traffic management that reduces congestion and lost vehicle-hours of traffic jams. The main focus of this thesis was the quantification of the influence of new information concepts (net-centric information systems) and Big Data (mobile phone and weather data) to improve SA for traffic Incident Management. However, there are still many aspects which could be further explored as an extension to the current analysis, or as possible directions for further research.

9.5.1 Scientific recommendations

Firstly, the results could be used as a basis for developing net-centric information systems, which support the daily practice of IM, in a real proof of concept environment. The current case study was based on IM scenarios in a desktop simulation environment. The field test could be extended to support the handling of real traffic incidents. This would then make it possible to confirm and extend the findings of this thesis. Special attention needs to be paid in training emergency workers in net-centric thinking and handling. In addition, the transport infrastructure and traffic management are crucial to support emergency management in the event of large-scale disasters. The findings of this thesis could form the basis to develop information systems which support cooperation between daily traffic incident management and large-scale disaster management.

Secondly, the Internet questionnaire in Chapter 6 gave a clear view of the information needs of users from different organization perspectives. This provided the confirmation of existing data needs and also of new data sources, such as the social media and the sharing of camera images among the different IM organizations. More data, however, does not necessarily mean better information. This direction could be further explored, with a special emphasise on *format, personalization*, and *system complexity*.

Thirdly, the use of telecom data to support traffic management, and in particular traffic IM, seems to be a promising development in terms of collective sensing. The high spatio-temporal resolution of the mobile phone data will enable us to extract vital information at a very fine-grained scale. However, the temporal dimension used in our case study was limited to a 1-hour interval. This case study could be extended in three directions. The 1 hour time interval should be reduced to 5 or 10 minutes. In addition, it would be very interesting to use a more sophisticated data sample of the mobile telecom network. This consists of ammonized phone records of individual subscribers. This would make it possible to provide information which answers the required timelines of end-users. In addition, the data quality of the mobile telecom network could be further explored. The telecom network consists of a complex structure to extract information. A valuable exercise would be to compare the different approaches which currently dominate the literature, such as rasterisation, veronoi diagrams, and spatial signatures.

Fourthly, the process of data fusion, which combines information originating from multiple sources, could also be further explored. Overlapping information could be used to detect, identify and track relevant objects in a region to support SA for traffic IM. Telecom data have a location component but lack context information. The use of social media data could provide context information to traffic IM. However, most social media data lacks this location component, with the exception of geo-located tweets. The combination of different social data sets could provide a value-added service related to the fine grade spatio-temporal telecom data. Hereby, the government not only is the provider of information but could also benefit from the content which is generated by (road) users.

Finally, concepts such as ‘Dynamic Data Driven Application Systems’ (DDDAS) could be a useful contribution. These systems enable real time data flows to be handled from different data sources. This could be used to develop simulation systems for evacuation, and to study the effect of different emergency scenarios and types of agent behaviour.

9.5.2 Policy recommendations

The Internet research also focussed on the willingness to adopt net-centric information systems. Net-centric information systems are relatively new to the traffic IM domain. Implementing these systems is a complex undertaking and can be considered as a major innovation in the daily IM operations. According to Everett Rogers (1995), there are five qualities which determine between 49 and 87 per cent of the variation in the adoption of new products or services. These are: relative advantage, compatibility, complexity, triability, and visibility. Less than half of the respondents had no experience using these information concepts and were not familiar with net-centric information systems. However, there is a significant difference in knowledge between the organizations. The Safety Regions and the ANWB score much higher than the other organizations. Within the RWS there is relative little knowledge. This is a clear indicator that introducing these concepts needs to be carefully managed, especially because the RWS Regional Traffic Management Centre is the key IM player. There is no significant difference in the perceived complexity between organizations. The scores lie approximate around 3. This also confirms that the introduction of net-centric systems needs to be carefully managed. It is interesting to see that, even thought net-centric systems are not well known, there is a relatively strong perceived usefulness of such systems. The average value lies between 3 and 4. This is a clear indicator that net-centric systems have the potential to be adopted within the IM domain. All organizations clearly indicated that net-centric systems have a strong value for all incident types with the exception of the towing organization LCM. This is also a strong indicator that net-centric systems actually have their roots in the military domain. The respondents indicated that these systems also support daily traffic incidents and not merely the more complex disaster management events. All organization consider net-centric systems to be more or less compatible with their existing IM systems. The scores lie between the 3 and 4. This is also a strong indicator that net-centric systems fit well within the IM operations and are a next logical step in a new generation of IT solutions. *Visibility* is a strong indicator in the discussion on, and the acceptation of, new technology. The results are slightly below 3. This means that special attention needs to be given to this indicator. If an idea can be tested in a conditioned environment, there is a higher chance that the innovation will be accepted faster. It is therefore crucial to give potential end-users the chance to have experience with net-centric systems. 101 of the 162 participants had never worked with these systems. 145 of the 162 participants thought that cooperative training helps to improve the quality of information sharing. This is a strong indicator that organizing periodic training sessions is very relevant to the adoption of net-centric systems. Finally, 141 of the 162 participants were willing to participate. We can therefore conclude that the respondents are keen to improve the daily handling of traffic incidents. This means that in the Netherlands, there is clearly a positive attitude to improving IM, and particularly with regard to information-sharing between the emergency services.

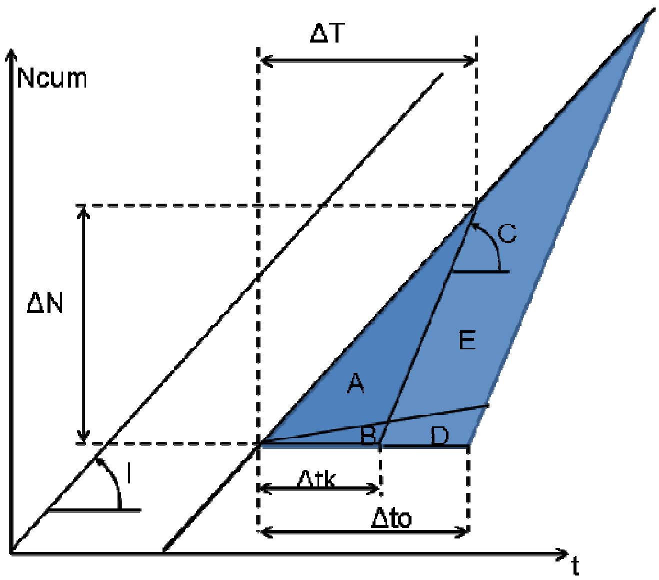
In general, we can conclude that the willingness to adopt these systems among the different IM actors is high, but their implementation needs to be carefully managed because of the lack of net-centric knowledge and experience in some IM organizations, and the complexity of changing existing information systems and existing working methods. However, it is appropriate to note that these findings are based on respondents with operational tasks. Rogers theory assumes that respondents are also able the make their own decisions. In our case, this responsibility lies with the management. For example, in the Dutch Safety Law (2010), net-centric working has been stated as a constraint for improving information-sharing in crisis situations. This legal basis made it possible that for employees of the Safety Regions (the Police, the Fire Brigade and the Ambulance service) to have the opportunity to acquire some practical experience. However, this is not the situation for the other IM organizations. We can thus conclude that the adoption of these concepts needs strong involvement of the management.

All organizations play an important role in the cooperation of the IM network. However, some organizations, such as the Police and the RWS Regional Traffic Management Centres are the dominant players in terms of information provision. This is an important constraint for introduction of net-centric systems. To understand the network operation, it is important to understand the inter-organizational strength in terms of information dependency, which provides a good guidance for developing new information systems to support traffic IM.

Finally, the use of sensor concepts, such as mobile phone data, are a promising concept. Traditional measuring methods, such as road loop detectors, camera detection, or floating probe vehicles, are effective and precise, but there are practical and financial limitations to their use. The results from our study could be a starting point for the research and development of less expensive monitoring systems. These new data sets could be integrated in a more sophisticated COP, which would lead to enhanced SA.

Appendix 1: Relation between incident duration and vehicle lost hours

There is a strong quadratic relationship between the duration of an incident and the response time required from the traffic management centre and the emergency services. The formula based on Figure 1 shows that the consequences of an incident are proportional to the square of the accident duration. The value of the factor depends on the capacity (C) and the load on the road section concerned (I). Thus, the number of lost vehicle-hours as the result of an incident depends on the time required to clear the road for traffic following an accident, the road capacity, and the extent to which the road capacity is filled. The basic idea is that fast clearance of the incident scene can help to reduce the incident-related congestion.



$$A+B+E+D = \frac{\Delta t_o^{2} * I}{2 * (1 - I/C)}$$

Figure 1: Quadratic relationship between the duration of an incident and the response time

Highways with a high impact factor (I/(1-(I/C)) are potential vulnerable road segments. To demonstrate this factor, we provide two real examples of the highways Amsterdam A10 (3 lane road) and the Groningen A28 (2 lane road). The hourly incoming capacity was obtained from the detection loop data base of Rijkswaterstaat. A three lane highway has a capacity of 7250 cars per hour (A10) and a two lane highways has a capacity of 4650 cars per hour (A28). The Amsterdam A10 has during the day an incoming capacity which is close to the maximum road capacity of a three lane highway. This results directly in a high impact factor. The results are presented in Figure 2.

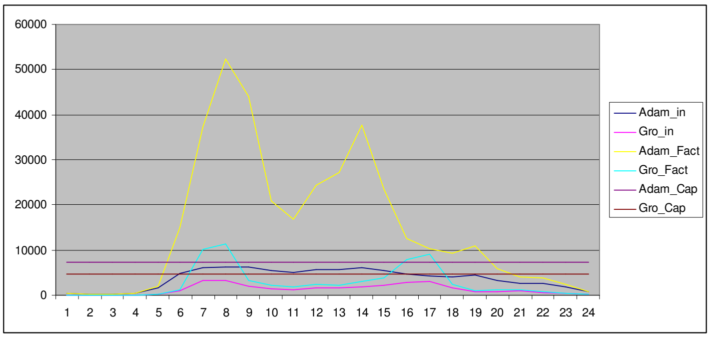


Figure 2: Influence of cars intensity on impact factor

To demonstrate the effect of this impact factor, we calculate for the two highways the number of vehicle lost hours which can be saved by reducing the minutes gained in a faster handling of the traffic incident (range form 1 till 10 minutes on a traffic jam of 1 hour) for both roads. The values are calculated for four time intervals of the day: 8:00, 12:00, 16:00 and 24:00. The results are presented in Figure 3a and 3b. The incoming car traffic is strongly depending on the hour of the day which directly influence the number of vehicle lost hours depending on the before explained impact factor.

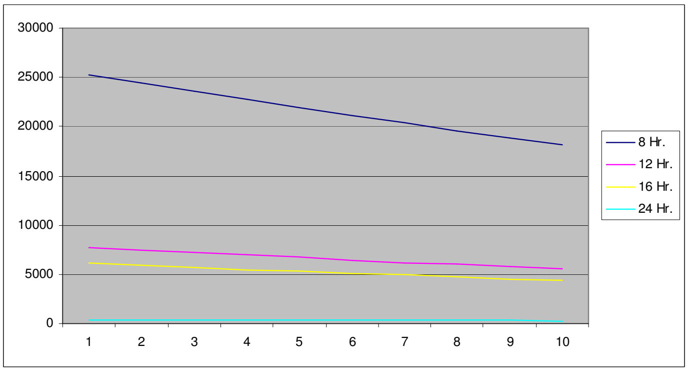


Figure 3a: Amsterdam A10, saving of relative vehicle lost hours (3 lane highway)

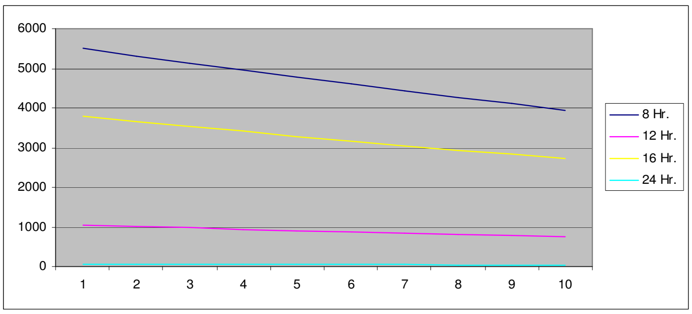


Figure 3b: Groningen A28, saving of relative vehicle lost hours (2 lane highway)

It is important to notice that due the quadratic effect of time, the reduction of vehicle lost hours has a non linear relation. This is not directly visible in Figure 3a en 3b. This because the effect is only visualized for the first 10 minutes of an incident with 1 hour duration. When we do the same exercise with steps of 5 minutes interval, this will demonstrate this effect for the Amsterdam A10.

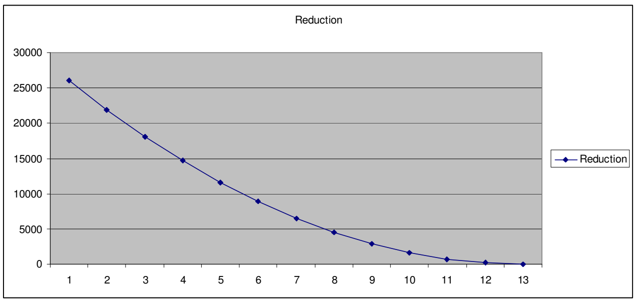


Figure 3b: Amsterdam A10, saving of relative vehicle lost hours with 5 minutes interval (at 8:00 Hr.)

Another factor which influence the vehicle lost hours is the number of outgoing cars. This impact is demonstrated for the A10 with intervals of 500 cars per hour where the time interval is 5 minutes reduced. This is presented in Figure 4. The number outgoing of cars have relatively a small impact on the number of vehicle lost hours.

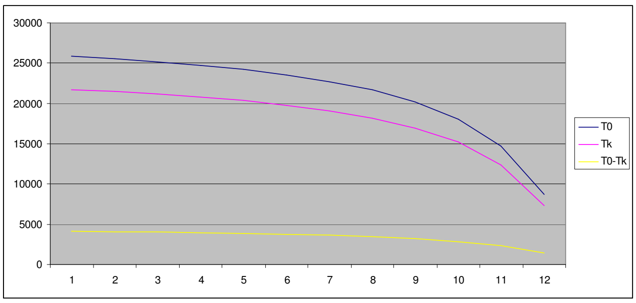


Figure 4: Impact of outgoing cars on vehicle lost hours (Amsterdam A10 at 8:00 Hr.)

Summarized, we can conclude that time has a significant impact on the vehicle lost hours. Highways with a high impact factor (I/(1-(I/C)) are potential vulnerable road segments. Rush hours have by nature high impact factor and the number outgoing of cars have relatively a small impact. Therefore, the application of traffic IM, in terms of improving cooperation between emergency organization, significantly improve the transportation system in dense urban areas.

Appendix 2: Overview of the current identified problems during 10 regional evaluation sessions

Incident information

relatively large number of false incident notification
wrong location information
wrong information about number of casualties involved
wrong information about number of vehicles involved
incomplete or wrong information about dangerous goods
information notification provided by the Police is often lacking details

Environment information

wrong information about number of lanes closed
real-time traffic information not used
information about best driving route not available
better area knowledge can provide more effective alternative routes
actual weather information is often not used
no overview available of number of people who are in the risk area of incident

Organization information

no (time) information available when emergency services arrive at incident
knowing status and real-time location of emergency services
not always resource information available of towing services for RWS

Technology problems

different detection methods identified by multiple sources creates inconsistency
communication only by phones causes misinterpretation
mobile phones sometimes fail owing to system problems (coverage/capacity/battery)
webcam /video images could provide useful information for all actors

Registration problems

no uniform incident definition and registration
sometimes no registration, Road Inspector needs to explain situation multiple times
same incident registered independently by all involved organization

incident evaluation difficult owing to incomplete and inconsistent registration

Coordination problems

relatively many unnecessary towing trips (false incident notification)
searching for the right incident location can be time-consuming
wrong information about site accessibility can be time-consuming
allocation of resources based on wrong information can be time consuming
upscaling (escalating) is time-consuming if incident category is initially wrong
112 informs the different centres which start separate uncoordinated processes
different centralists do not communicate with each other
more and better information sharing during the driving phase
KLPD communicate with region Police by 112 control room
sometimes fire brigade is informed too late
information about incident is sometimes communicated (too) late to the RWS
incident detection via (0900-8844) not always known by RWS Traffic Management Centre
communication between Road Inspector and Duty Officer not optimal due capacity problems
constructor gives wrong feedback about which lanes/roads are closed
miscommunication about opening closed or blocked lanes (Police – RWS)
no clear communication about which lanes / roads are closed
sometimes first safety measure not appropriately applied
direct involvement of the RWS helps to ensure safety in the incident location
information to RWS is sometimes wrong, incomplete, and unclear
only relevant information should be communicated to the emergency services
information WvL-> Road Inspector/Duty Officer sometimes incorrect and own interpretation

Appendix 3: Overview of involved emergency services clustered per incident type

Incident type	Involved emergency services
Object on the highway	RWS Regional Traffic Management Centre (Always) Road Inspector (Always) RWS National Traffic Management Centre (Sometimes) Safety Region (Regional police) (Sometimes)
Broken-down vehicle	RWS Regional Traffic Management Centre (Always) Road inspector (Always) RWS National Traffic Management Centre (Sometimes) LCM / CMV (Most of the time) Towing services (Always) ANWB (Frequently)
Incident with only material damage	RWS Regional Traffic Management Centre (Always) Road Inspector (Always) RWS National Traffic Management Centre (Sometimes) LCM / CMV (Always) Towing services (Always)
Incident with injuries	RWS Regional Traffic Management Centre (Always) Road Inspector (Always) RWS National Traffic Management Centre (Frequently) LCM / CMV (Always) Towing services (Always) Safety Region (Regional Police, Fire brigade, Ambulance service) (Most of the time)
Other (driver unwell, animal on the road, fire, dangerous goods)	Regional traffic management centre (Always) Road Inspector (Always) RWS National Traffic Management Centre (Sometimes) LCM / CMV (Sometimes) Towing services (Sometimes) Safety region (Regional Police, Fire brigade, Ambulance services) (Frequently)

Appendix 4: Marginal effects analysis – based on estimates of Table 8.6

VARIABLES	(1) incident	(2) incident	(3) incident	(4) incident	(5) incident	(6) incident
ln(cars)	-0.00293	0.00106	-	-	-	-
	(-3.292)***	(0.754)	-	-	-	-
ln(erlang)	0.000624	0.000412	0.000644	0.00133	0.000609	0.000582
	(2.101)**	(2.511)**	(2.136)**	(1.335)	(12.29)***	(3.182)***
temperature	1.95e-06	9.46e-07	2.15e-06	1.81e-06	1.32e-06	1.42e-06
	(0.873)	(0.830)	(0.950)	(1.173)	(2.826)***	(2.997)***
rain	5.66e-05	2.72e-05	7.54e-05	5.22e-05	0.000188	0.000185
	(0.155)	(0.147)	(0.206)	(0.210)	(2.461)**	(2.384)**
snow	0.00179	0.000980	0.00358	0.00249	-0.000214	-0.000231
	(1.402)	(1.423)	(2.373)**	(2.339)**	(-0.922)	(-0.985)
Hourly dummies (23)	Included	Included	Included	Included	Included	Included
Work day dummies (4/6)	Included	Included	Included	Included	Included	Included
Zone dummies (6/108)	Included	Included	Included	Included	Included	Included
Interaction terms	No	Yes	No	Yes	No	Yes
Observations	38,921	38,921	38,921	38,921	790,865	790,865

z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Note: Effects based on reference: 12:00 Hr., Hourly interaction terms H*ln(cars) and H*ln(erlang)

Appendix 5: Marginal effects for all the 109 cells on all incidents with different mobile phone variables

VARIABLES	(1) incident	(2) incident	(3) incident	(4) incident
ln(erlang)	0.000609			
	(12.29)***			
ln(new_calls)		0.000423		
		(9.419)***		
ln(sms)			0.000316	
			(6.857)***	
ln(handovers)				0.000470
				(8.294)***
Temperature	1.32e-06	1.20e-06	9.84e-07	1.32e-06
	(2.826)***	(2.505)**	(2.040)**	(2.736)***
Rain	0.000188	0.000197	0.000194	0.000198
	(2.461)**	(2.507)**	(2.443)**	(2.513)**
Snow	-0.000214	-0.000225	-0.000213	-0.000181
	(-0.922)	(-0.942)	(-0.881)	(-0.746)
Hourly dummies (23)		Included		
Work day dummies (6)		Included		
Zone dummies (108)		Included		
Observations	790,865	790,865	790,865	790,865

z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Note 1: Effects based on reference: 12:00 Hr.

Note 2: corresponds with column 5 in Table 8.6.

Appendix 6: Marginal effects for the 109 cells with a distinction between the different types of incidents

VARIABLES	(1) Object on the highway	(2) Accident with injuiries	(3) Driver unwell	(4) Broken down vehicle	(5) Only material damage	(6) Fire
ln(erlang)	-1.09e-05	5.10e-05	6.23e-05	0.000328	0.000297	-1.65e-06
	(-0.475)	(2.394)**	(3.518)***	(9.146)***	(9.144)***	(-0.112)
Temperature	2.05e-07	2.65e-07	2.67e-07	1.24e-06	-3.57e-07	1.97e-07
	(0.864)	(1.251)	(1.800)*	(3.761)***	(-1.181)	(1.276)
Rain	-3.76e-05	-2.07e-05	-4.81e-05	-1.85e-05	0.000293	-2.14e-05
	(-0.959)	(-0.622)	(-1.869)*	(-0.345)	(5.735)***	(-0.877)
snow	-0.000186	-5.00e-06		6.47e-05	-0.000123	
	(-1.542)	(-0.0459)		(0.365)	(-0.894)	
Hourly dummies (23)				Included		
Work day dummies (6)				Included		
Zone dummies (108)				Included		
Observations	579,431	213,278	139,232	739,833	717,952	49,137

z-statistics in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Note: Effects based on reference: 12:00 Hr.

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Samenvatting

Wegverkeer Incident Management en Situatie bewustzijn

1. Samenvatting

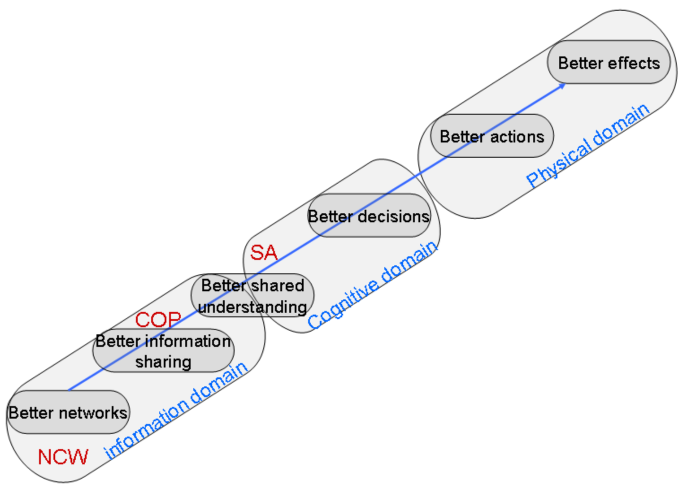
Het grote aantal weggebruikers op het druk bezette Nederlandse wegennet leidt dagelijks tot aanzienlijke files. Deze treden voornamelijk op bij knooppunten en in stedelijke gebieden en veroorzaken naast de dagelijkse congestie, reistijdvertragingen, brandstofverspilling, toenemende luchtvervuiling en voertuigverliesuren. Eén van de oorzaken van deze dagelijkse files zijn incidenten met blikschade, gewonden en mogelijk dodelijke slachtoffers en de verkeersveiligheid van de overige weggebruikers is in die situaties eveneens in het geding.

Op jaarbasis zijn er meer dan 100.00 incidenten, dat wil zeggen ongeveer 270 incidenten per dag. Ongeveer 13 procent van de dagelijkse files wordt veroorzaakt door verkeersongelukken, zoals incidenten met alleen materiële schade, incidenten met dodelijke slachtoffers en gewonden, en incidenten met afgevallen lading. Incident Management (IM) is één van de belangrijkste maatregelen in het huidige verkeersmanagement om dergelijke incidenten af te handelen. Deze afhandeling is het onderwerp van mijn dissertatie, waarbij ik me richt op het gebruik van informatiesystemen en –concepten, zoals situatiebewustzijn, met als vraag welke bijdrage deze kunnen leveren aan de organisatie en de snelheid van de afhandeling.

De centrale onderzoeksvraag in deze dissertatie luidt: kan situatiebewustzijn het dagelijkse management van verkeersincidenten verbeteren? De beschikbare wetenschappelijke literatuur richt zich op diverse aspecten van situatiebewustzijn, zoals gebruikersgericht ontwerp, datamanagement, nieuwe informatieconcepten, zoals net-centrische werken en common operational picture en de specifieke informatiebehoefte voor de ontwikkeling van verbeterde informatiesystemen welke ondersteunend zijn aan duurzaam mobiliteitsmanagement in dichtbevolkte gebieden zoals Nederland. Situatiebewustzijn is gericht om een gedeeld begrip van een bepaalde situatie; gedeeld tussen diverse partijen. Dit concept is interessant omdat bij de afhandeling van incidenten diverse partijen betrokken zijn op diverse locaties die moeten samenwerken om tot een adequate en snelle acties te komen. Om het informatiedomein ten behoeve van situatiebewustzijn te ordenen zijn twee concepten nader onderzocht: net-centrisch werken en common operational picture. Waarbij net-centrische werken de informatie van diverse relevante partijen met elkaar verbindt en een common operational picture het mogelijk maakt om informatie met elkaar te delen op een vooraf afgesproken wijze.

De belangrijkste doelstelling van deze dissertatie is het kwantificeren van de rol van situatiebewustzijn, met behulp van deze nieuwe informatieconcepten: net-centrisch werken en een Common Operational Picture (verder COP; gezamenlijk operationeel beeld), met het oog op het verbeteren van de dagelijkse afhandeling van verkeersincidenten en het doen van aanbevelingen voor de ontwikkeling van nieuwe informatie systemen voor Incident Management.

In Figuur 1 is aangegeven op welke wijze de nieuwe informatieconcepten onderling samenhangen. In het informatiedomein zijn net-centrische systemen (NCW) de basis om een COP vorm te geven. In het cognitieve domein leidt dit op basis van een beter inzicht van de situatie (situatiebewustzijn) tot een betere operationele besluitvorming. In het fysieke domein leidt dit uiteindelijk tot een betere afhandeling (performance). Ten minste dat is de veronderstelling. De centrale parameter is de snelheid van afhandeling van het incident, dat direct gerelateerd is aan betere verzorging gewonden en afname voertuigverliesuren.



Figuur 1: Relatie tussen de verschillende informatieconcepten.

De bevindingen uit dit onderzoek zijn dat een COP inderdaad leidt tot een beter inzicht van de incidentsituatie[21], er een betere samenwerking tot stand komt tussen de diverse IM organisaties, wat uiteindelijk leidt tot een betere besluitvorming. Deze betere besluitvorming verbetert de IM prestatie in termen van reactie tijd dat wil zeggen snelheid van de incidentafhandeling wat uiteindelijk leidt tot het verminderen van fileduur en het reduceren van voertuigverliesuren.

Het onderzoek heeft in eerste instantie de bestaande data van de diverse partijen als vertrekpunt genomen. Deze data kennen echter als gevolg van de inwinning een bepaalde tijd- en ruimteschaal. Daarom is in deze dissertatie ook gekeken naar het gebruik van andere data die een grotere mate van detail kennen zowel in tijd als in ruimte met als achterliggende gedachte niet alleen de afhandelingsnelheid te verminderen maar om te kunnen voorspellen waar zich incidenten kunnen voordoen. Telecom data worden gebruikt voor het monitoren van events (gepland of ongepland) in steden, herkenning van ruimtelijke patronen van landgebruik, en de analyse van mobiliteitsproblemen, verkeersmanagement en crisismanagement. Het nut van deze mobiele telefoongegevens is echter nog niet vanuit het gezichtpunt van incidentmanagement bestudeerd. Dit onderzoek is één van de eerste studies welke een verkenning uitvoert naar het gebruik van mobiele telefoondata voor IM. Het gebruik biedt zeker perspectieven, zoals het kunnen voorspellen waar zich mogelijk verkeersincidenten zullen voordoen, maar we moeten concluderen dat het gebruik van dergelijke data zich nog steeds in de fasen van onderzoek en ontwikkeling bevindt.

2. Conclusies van de explorerende studies

De vier uitgevoerde explorerende studies vormen met elkaar het theoretische fundament van deze dissertatie. In Hoofdstuk 2 vindt een uitgebreide verkenning van de literatuur plaats waarin de kenmerken van incident management en de daarmee samenhangende mobiliteits- en veiligheidsissues worden behandeld. De belangrijkste conclusie is dat door een toenemende congestie op het drukbezette Nederlandse wegennet er steeds meer incidenten plaats vinden en er steeds meer organisaties betrokken zijn geraakt bij de professionele afhandeling van deze incidenten. Organisaties werden qua uitvoering steeds meer afhankelijk van elkaar wat uiteindelijk heeft geleid tot het informatienetwerk. Hoofdstuk

[21] Situatiebewustzijn richt zich op informatie van het incident, de omgeving en de betrokken organisaties.

3 gaat meer in op de nieuwe informatieconcepten net-centrische informatiediensten en het common operational picture. Deze concepten vinden hun oorsprong in het militaire domein en zijn later geadopteerd in crisis management. De conclusie is dat de introductie van deze concepten binnen incident management moet plaats vinden in verschillende stappen: keuze gebruikersperspectief; selectie betrokken actoren; keuze minimale dataset; en ambitie niveau volwassenheidsmodel. Hoofdstuk 4 analyseert het specifieke gebruik van mobiele telecomdata voor verkeersmanagement vanuit een historisch perspectief. Tot slot biedt Hoofdstuk 5 een uitgebreide beschrijving van mogelijke onderzoeksrichtingen voor het gebruik van mobiele telefoondata ter ondersteuning van het IM proces.

3. Conclusies van de empirische studies

In deze dissertatie zijn drie empirische studies uitgevoerd gerelateerd aan situatiebewustzijn en incident management:

1) een landelijke internetenquête gehouden onder IM-organisaties,
2) een veldexperiment voor het meten van de effectiviteit van net-centrische ondersteuningstools,
3) een casestudie waarin de mogelijkheden worden geanalyseerd van de bruikbaarheid van mobiele telefoon data voor het creëren van een meldingssysteem voor IM.

A: Internet enquête

In hoofdstuk 6 is met behulp van een internet enquête een empirische analyse uitgevoerd naar de mening van mensen die werkzaam zijn in het incident management proces over de belangrijkste problemen en succesfactoren van het huidige incidentmanagement. De respondenten van deze enquête zijn medewerkers van Rijkswaterstaat (VCNL als Nationale verkeersmanagement centrale en de 5 Regionale verkeersmanagement centrales), de veiligheidsregio's (Politie, Brandweer en Ambulance), de bergingsorganisaties (LCM en CMV), en de Algemene Nederlandse Wegenwacht Bond (ANWB). In totaal hebben 236 respondenten (ongeveer 50% van de populatie) de enquête ingevuld.

Uit de enquête blijkt dat naar de mening van de respondenten een vroegtijdige en betrouwbare detectie en verificatie van incidenten, in combinatie met geïntegreerde verkeersmanagement strategieën, van groot belang is voor een effectief Incident Management. Op dit moment doen zich, aldus de respondenten, de meeste problemen voor in de eerste fasen van het IM proces. Ook is er een grote behoefte aan een goed zicht op de coördinatie van IM maatregelen. Het blijkt dat organisaties geen goed overzicht hebben van de activiteiten van andere organisaties. Ook is gevraagd of respondenten verkeersveiligheid belangrijker vinden dan de doorstroming van het verkeer. Het is echter opmerkelijk dat de verkeersveiligheid en de status van potentiële slachtoffers qua informatiebehoefte door respondenten lager wordt gescoord dan andere informatiecategorieën van een incident. Locatie informatie scoort het hoogst. Ook lading van het voertuig en de aanwezigheid van gevaarlijke stoffen scoren hoog. Dit betekent dat de informatie van het incident (locatie, kenmerken) een hoge prioriteit heeft bij alle partijen die betrokken zijn bij incidentmanagement.

De behoefte aan omgevingsinformatie heeft duidelijk meer variëteit. Dit hangt ondermeer samen met de informatie die diverse partijen denken nodig te hebben en of zij daarover al zelf beschikken. Bij de veiligheidsregio’s (Politie, Brandweer en Ambulance) is de functionaliteit om de status en locatie van veldmedewerkers te volgen al beschikbaar. Voor de Rijkswaterstaat, ANWB, LCM en CMV bestaat deze functionaliteit nog niet. Als ook deze partijen over deze functionaliteit zouden kunnen beschikken zou dat tot een belangrijke verbetering van het situatiebewustzijn kunnen leiden. Het managen van deze informatie is essentieel voor de coördinatie van hulpverleners.

Om het situatiebewustzijn te kunnen meten is het van belang om zowel de kwaliteit van de informatie als zodanig als van de (informatie-)systemen te beoordelen. Informatie kwaliteit (IQ) en Systeem Kwaliteit (SQ) vormen een belangrijke voorwaarde voor het verkrijgen van een verbeterd situatiebewustzijn. Hierover zijn de respondenten door middel van de internetenquête vragen voorgelegd. Compleetheid, consistentie en inzicht in de betrouwbaarheid van de informatie scoren iets lager dan de overige items, zoals bijvoorbeeld, tijdslijnen, correctheid en hoeveelheid van informatie. De verschillen tussen de scores zijn echter beperkt. De respondenten geven aan dat er nog een significante verbetering voor informatiekwaliteit mogelijk is. Met informatiesystemen bedoelen we alle systemen die op dit moment bij organisaties wordt gebruikt ter ondersteuning van het IM proces. De scores van systeem kwaliteit liggen rond de 3 (op een schaal van 5). Ook hier geven de respondenten aan dat er nog aanzienlijke verbeteringen te realiseren zijn. Het is echter belangrijk om op te merken dat de respondenten aangeven dat de beschikbare systemen beter hun eigen activiteiten ondersteunen dan de samenwerking met andere organisaties. Op dit moment wordt informatie vooral gedeeld door telefonische communicatie. Veel respondenten zeggen echter ook dat uitsluitend telefonische communicatie ontoereikend is voor de dagelijkse afhandeling van verkeersincidenten en op een onvoldoende wijze de samenwerking tussen organisaties ondersteund. Hier bestaat een duidelijke behoefte aan additionele tools.

Gebaseerd op mijn onderzoek kunnen we concluderen dat ‘tekst berichten’, ‘camerabeelden’, ‘automatisch doorzetten notificaties’, ‘gelijktijdig delen berichten’, ‘filter voor gepersonaliseerde berichten’ en ‘notificatie van informatieveranderingen’ door de betrokken organisaties het hoogst worden gewaardeerd om de afhandeling van incidenten te versnellen en de operationele samenwerking tussen organisaties te verbeteren.

Op basis van de uitkomsten van deze internetenquête ten aanzien van de informatie en systeem verbetering van het incidentmanagement is een net-centrisch systeem ontwikkeld voor een veldexperiment met deze gewenste functionaliteiten.

B: Veldexperiment net-centrisch werken

Voor het testen van de toegevoegde waarde van dit net-centrische systeem, hebben we een veldexperiment opgezet met publieke en private hulpverleners die actief zijn bij het incidentmanagement. Hoofdstuk 7 bevat de resultaten van dit experiment. Tijdens het experiment is een set van gecontroleerde experimenten uitgevoerd met ervaren en goed getrainde deelnemers. Het onderzoek is uitgevoerd met realistische scenario’s, dat wil zeggen scenario’s die ontleend zijn aan de praktijk van het incidentmanagement. De scenario’s bevatten een scala van verschillende type incidenten in termen van betrokken voertuigen, slachtoffers en variëren in de mate van complexiteit. De scenario’s zijn steeds uitgevoerd door een groep die ondersteund werd met net-centrische informatiesystemen – de testgroep - en een groep die met de huidige instrumenten incidenten afhandelt, de zogeheten controle groep.

Gedurende het experiment zijn data verzameld met observaties, na het experiment zijn data verzameld door de deelnemers vragenlijsten te laten invullen. De analyses richten zich op een vergelijking tussen de gebruikte tools in termen van:

- de waardering van informatiekwaliteit en systeemkwaliteit;
- een vergelijking van de communicatie en coördinatie;
- de toegevoegde waarde van SA in de afhandeling, het besluitvormingsproces en de resultaten;
- en hoe scenariocomplexiteit de ontwerpprincipes beïnvloedt van net-centrische systemen.

Om te bepalen of de net-centrische functionaliteit, op basis van een COP, leidt tot betere informatiedeling is de systeemkwaliteit geëvalueerd. Voor de taak gerelateerde SQ items, scoorde de testgroep significant beter op *integratie*, *geheugen* en *situational awareness*. Alleen op *format* scoorde de testgroep significant lager. 'Format' is sterk gerelateerd aan de IQ aspecten *informatiehoeveelheid* en *verificatie*. Dit hangt samen met personalisatie van informatie; een sleutel element in een informatierijke omgeving.

Voor de waargenomen operationele tevredenheid zijn twee items gemeten. De testgroep vond het systeem erg gecompliceerd in het gebruik. Het SQ aspect *gebruikersgemak* scoorde significant lager in de testgroep. Tijdens de uitvoering van de scenario's deed zich echter een leereffect voor. De testgroep slaagde er in om na ieder scenario beter te presteren. *Bruikbaarheid* van het systeem scoorde significant hoger in de testgroep. We kunnen op basis hiervan concluderen dat de testgroep de toegevoegde waarde van het net-centrisch systeem onderkend maar dat het gebruikersgemak aandacht behoeft.

Om vast te kunnen stellen of een COP ook leidt tot een beter gezamenlijk begrip, zijn de informatie kwaliteitsaspecten (IQ) met de vragenlijst gemeten. De interne betrouwbaarheid voor het meten van de verschillende informatie kwaliteitsaspecten scoorde gemiddeld goed (Crombach's alpha is in de meeste gevallen hoger dan 0.7). Met uitzondering van scenario 2 scoorde de testgroep hoger op de verschillende kwaliteitsdimensies. Gezien de kleine groep participanten waren de verschillen in de meeste gevallen niet significant. In de meer complexe scenario's was de hoeveelheid van de aangeboden informatie het grootste probleem. De testgroep ondervond vooral moeilijkheden in het gebruik van de van te voren gedefinieerde tools om informatie te kunnen filteren. Ze ondervonden ook problemen om de betrouwbaarheid van gedeelde informatie te verifiëren. Ondanks deze problemen was de afhandeling significant sneller dan de controlegroep. In het laatste meest complexe scenario was duidelijk meetbaar dat de testgroep ervaring begon te krijgen in het werken met het net-centrische systeem. Zij scoorden beter op alle informatie kwaliteitsaspecten met uitzondering van *relevantie* van informatie. Dit werd vooral veroorzaakt doordat de filters voor gepersonaliseerde informatie nog steeds als te complex voor gebruik werden ervaren.

Om te valideren of een beter situatiebewustzijn, gebaseerd op net-centrische systemen, de afhandeling in het besluitvormingsproces verbetert, richten we ons specifiek op de snelheid van het compleet krijgen van incidentmeldingen en hoe snel hulpverleners arriveren op de incidentlocatie. De gemiddelde tijd die gewonnen wordt bij incidentinformatie (eerste melding, locatie, incident type, betrokken voertuigen, betrokken slachtoffers en ladinginformatie) was over alle scenario's gemiddeld 21 minuten sneller beschikbaar in de testgroep. Ook waren de hulpverleners van de testgroep gemiddeld 10 minuten eerder op de incidentlocatie aanwezig. Alleen de Ambulance arriveerde in scenario 3 ongeveer 3 minuten later op de locatie. Dit werd veroorzaakt door miscommunicatie tussen de veldmedewerkers en de centralisten.

Scenariocomplexiteit heeft ook invloed op de ontwerpprincipes van een net-centrisch systeem. De meest gedetecteerde informatie kwaliteitsproblemen bij de meer eenvoudige scenario's in het veldexperiment hadden betrekking op de *consistentie* van informatie. Dit betekent dat slechts een beperkte hoeveelheid informatie werd gedeeld. Het geheugen van de deelnemers was vrij eenvoudig in staat om de aangeboden informatie te verwerken en de deelnemers waren in staat om inconsistente informatie te beoordelen. Telefonische communicatie speelde hierbij een belangrijke rol.

Echter in de meer complexe scenario's (2, 3 en 4), hadden de deelnemers problemen met *relevantie*, *hoeveelheid* en *verificatie* van informatie. Dit is direct te relateren aan systeem kwaliteitsaspecten. Deelnemers in de testgroep waarderen dat het systeem voorziet in de toegang en integratie van data. De testgroep scoorde ook hoog voor het taakgerelateerde item *geheugen*. Hoewel, het item *format* was duidelijk niet ontworpen om de informatie hoeveelheid en het geheugen op een goede wijze te ondersteunen. De geringe ervaring van de deelnemers is hiervoor een belangrijke verklaring. Er was echter wel een leereffect waarneembaar gedurende de scenario's. De verschillende incidenttype hebben op maat gemaakte formats nodig welke specifiek zijn ontwikkeld voor de eenvoudige incidenten (GRIP0) en de meer serieuze incidenten (GRIP 1-4). Dit is één van de belangrijkste reden waarom het systeem als complex werd ervaren. Dit betekent dat een net-centrisch systeem als bruikbaar wordt ervaren maar dat er nog wel enkele technische functionele systeemaanpassingen moeten worden ontwikkeld voor de aansluiting op het dagelijks operationeel gebruik.

C: Telecom case studie

Om de toegevoegde waarde van het gebruik van telecom data ten opzichte van de nu gebruikte data te testen, is er een case studie voor Amsterdam gedaan. Hoofdstuk 8 beschrijft de resultaten van deze empirische studie waarin de relaties tussen de thans gebruikte gegevens over voertuigintensiteit, incident, weersgesteldheid worden vergeleken met data van het mobiele telefoonverkeer. Het studiegebied betreft groot Amsterdam met een oppervlakte van 1000 km^2.

Gedurende de spits zijn er significant meer incidenten. De hoogste piek is in de avondspits. Op werkdagen gebeuren er meer incidenten dan gedurende het weekend. Ook hangt het voorkomen van verkeersincidenten samen met karakteristieken van de infrastructuur. Zo vinden op kruisingen van snelwegen en bij op- en afritten de meeste incidenten plaats. In het incident management worden 6 type incidenten (he dat is helemaal nieuw, welke zes en is dat hier belangrijk, zo ja, dan even benoemen) onderscheiden die een verschillende impact hebben op de doorstroming van het wegverkeer. Deze incidenten verschillen sterk ik de duur van afhandeling, variërend van 16 tot 71 minuten.

De belangrijkste bevinding, gebaseerd op OLS-regressie, is dat het gebruik van mobiele telefoons, positief gerelateerd is met de het voertuigverkeer in zijn algemeenheid en verkeersincidenten in het bijzonder. Zo leidt een toename van het voertuigverkeer met 1 procent tot een toename van nieuwe telefoongesprekken met 1,14 procent. Bij incidenten neemt het aantal nieuwe gesprekken zelfs toe met 11,7 procent. Ook het feit dat een incident een lagere impact heeft op de *handovers*[22] (5,5 procent) dan op de andere mobiele telefoonindicatoren, is een aanwijzing dat het incident de rijsnelheid doet afnemen.

Is er nu ook een verband tussen de voertuigintensiteit en de kans op een incident? Om dit verband te testen hebben we probit modellen gebruikt. De resultaten laat zien dat er geen lineaire relatie bestaat tussen het aantal aanwezige voertuigen en de kans op een verkeersincident. Deze relatie wordt echter sterk beïnvloed door het specifieke uur van de dag. De ochtendspits (tussen 6:00 Hr. Tot 10.00 Hr.) toont meer voertuigverkeer dan de avondspits (tussen 16hr.-20hr.). Er zijn echter duidelijk meer incidenten tijdens de avondspits, met minder voertuigen, dan in de ochtendspits met meer voertuigen op de weg.

Vervolgens zijn voor alle cell-id's de meer specifieke rol van de gsm-gegevens en de verschillende weersomstandigheden geanalyseerd op de kans van het optreden van verschillende type incidenten. De categorieën ongevallen met letsel, onwelwording, en incidenten met slechts materiële schade, zijn allemaal positief en significant. We vinden vrij hoge relaties voor gestrande voertuigen. Een andere interessante bevinding is dat de temperatuur alleen maar positief en significant is voor de gestrande voertuigen. We zouden verwachten dat lage temperaturen ook een belangrijke invloed hebben, maar dit blijkt niet het geval. De logische verklaring is dat bij koud weer er zich meer accuproblemen voordoen. Dit soort problemen doen zich voor bij het starten van auto's bij vertrekt van huis. Auto's worden hersteld, voordat ze op de snelweg zijn. Regen is alleen positief en significant voor incidenten met materiële schade. Dit houdt in dat natte weersomstandigheden een significante invloed hebben op de verkeersveiligheid. Het beïnvloedt alleen incidenten met materiële schade, maar er is geen relatie met zware ongevallen met verwondingen of fatale afloop. De verklaring is dat automobilisten hun snelheid aanpassen aan de weersomstandigheden, zodat ernstige ongevallen minder waarschijnlijk zijn, maar de kans op minder ernstige ongevallen toeneemt.

4 Discussie (Relevantie van bevindingen)

In Nederland wordt, vergeleken met andere landen, de toepassing van IM ondersteund door zeer professionele publieke en private organisaties. De resultaten van de internetenquête

[22] verplaatsing tussen mobiele telefoon cellen

bevestigen dat er vooral aan het begin van het incident afhandelingsproces nog veel te winnen is aan de verbetering van de informatievoorziening.

A. Situatie bewustzijn en net-centrische systemen

De resultaten van het veldexperiment bevestigen dat de invoering van de net-centrische informatiesystemen het situatiebewustzijn aanzienlijk verbetert in het IM domein. De huidige IT architectuur in de IM domein worden gekenmerkt door top-down informatiestromen die ‘monodisciplinair’ zijn georganiseerd en voornamelijk statische informatie *(ex post)* genereert. De net-centrische werkwijze moet worden gezien als een extra informatiedienst naast de bestaande informatiekanalen, zoals telefonische communicatie. De invoering van net-centrische werken vereist een kritisch herontwerp van bestaande informatiesystemen, data management, en de huidige werkwijze, waarbij een collectieve intelligentie tussen hulpdiensten wordt ondersteund met het real-time kunnen delen van informatie. Op basis van het uitgevoerde veldexperiment, kunnen we concluderen dat onder de medewerkers er nog steeds een gebrek aan kennis en praktische ervaring bestaat in het gebruik van dergelijke systemen. Er zal speciale aandacht moeten worden besteed aan de opleiding en training van IM hulpverleners. Zoals aangetoond in het veldexperiment, zijn informatiekwaliteit en systeemkwaliteit belangrijke voorwaarden om een COP ten volle te benutten en het situatie bewustzijn tussen organisaties te verbeteren.

Het Nederlandse IM-beraad verklaarde in 2008 dat binnen twee jaar real-time informatie-uitwisseling tussen IM organisaties moest zijn geïmplementeerd. Anno 2013, kunnen we concluderen dat dit doel nog niet is bereikt. Binnen het crisismanagementdomein, wordt door de Nederlandse veiligheidsregio's (de politie, brandweer en GHOR) al een aantal jaar ervaring opgedaan met de introductie van deze concepten. Dat kwam ook terug in de antwoorden op de internetenquête. Echter, buiten de organisaties die samenwerken in de veiligheidsregio’s, hebben de andere IM organisaties, waaronder Rijkswaterstaat nog nauwelijks ervaring met net-centrisch werken. Incidentmanagement als werkveld biedt vanwege de relatieve complexiteit, goede kansen voor de invoering van dergelijke systemen.

B. Situatie bewustzijn en mobiele telefoondata

Een andere bijdrage van dit proefschrift is het gebruik van de mobiele telefoondata bij IM, een relatie waarover nog niet is gepubliceerd in de wetenschappelijke literatuur. Het gebruik van de mobiele telefoongegevens ter ondersteuning van het dagelijkse operationele verkeersmanagement, en vooral IM, is veelbelovend. De bevindingen van de casestudie bevestigen de positieve statistische relatie tussen mobiele telefoondata en aspecten van het wegverkeer. Het kan een belangrijke aanvullende bron van informatie worden, vooral als het gaat om anomalie detectie van het mobiele telefoonnetwerk gerelateerd aan verkeersincidenten. Vanuit een brede perspectief, kunnen deze big data ook worden gebruikt om de meer geavanceerde tools te ontwikkelen voor grotere rampen en crisisbeheersing.

5. Aanbevelingen en vervolgonderzoek

IM is één van de belangrijkste instrumenten van modern verkeersmanagement dat congestie en voertuigverliesuren van files vermindert. Het belangrijkste doel van dit proefschrift was het kwantificeren van de invloed van nieuwe informatie concepten (net-centrische informatiesystemen) en Big data (mobiele telefoon en weergegevens) om situatiebewustzijn te verbeteren bij Incident Management op de weg en vooral de afhandelingstijden van diverse typen incidenten te verminderen. Maar voordat tot daadwerkelijke introductie in de praktijk van het IM kan worden overgegaan moeten nog een aantal zaken verder worden uitgezocht.

5.1 Wetenschappelijke aanbevelingen

Ten eerste kunnen de resultaten uit deze dissertatie worden gebruikt als basis voor de verdere ontwikkeling van net-centrische informatiesystemen in de vorm van een ‘proof of concept’ in dagelijkse IM praktijk. Daartoe kan het voor dit proefschrift gebruikte veldexperiment worden uitgebreid voor de afhandeling van echte verkeersincidenten. Speciale aandacht dient daarbij te worden besteed aan de opleiding van hulpverleners in het net-centrisch denken en handelen. Daarnaast is het denkbaar dat deze net-centrische systemen niet alleen van nut zijn voor het incident management maar ook in gevallen van crisisbeheersing bij grootschalige rampen. Deze extra mogelijkheid dient nader doordacht te worden.

Ten tweede, hoofdstuk zes (internetenquête) geeft een duidelijk beeld van de informatiebehoeften van de gebruikers van de verschillende organisatie. Nieuwe gegevensbronnen, zoals sociale media en het delen van camerabeelden tussen de verschillende IM organisaties, zijn nuttig. Maar meer gegevens betekent nog niet dat er betere informatie ontstaat. Het gebruiksgemak van deze systemen zal moeten worden verbeterd door te onderzoeken hoe met de hoeveelheid informatie, de personalisering en de systeemcomplexiteit kan worden omgegaan.

Ten derde, de hoge resolutie van mobiele telefoondata maakt het mogelijk om analyses uit te voeren op een zeer gedetailleerde tijdruimtelijke schaal. Daarnaast is het zeer interessant om een meer geavanceerde steekproef te gebruiken, zoals bijvoorbeeld OD Matrices. Deze bestaat uit geanonimiseerde telefoongegevens van de individuele abonnees, zodat meer geavanceerde analyse kunnen worden gemaakt. Ook de kwaliteit en betrouwbaarheid van de gegevens van het mobiele telecom netwerk kan verder worden onderzocht. Het mobiele netwerk bestaat uit een complexe structuur van geografische cellen op verschillende frequenties. Een zinvolle vervolgstap is het vergelijken van de verschillende benaderingen zoals rasterbenadering, Veronoi diagrammen, best serving cell mappen en ruimtelijke signaturen.

Ten vierde, ook het proces van data-integratie van verschillende informatiebronnen kan verder worden onderzocht. Overlappende informatie kan worden gebruikt voor het detecteren, identificeren en volgen van relevante objecten ter ondersteuning van situatiebewustzijn voor IM. Mobiele telefoon gegevens hebben een locatie component, maar het ontbreekt aan context informatie. Het gebruik van bijvoorbeeld gegevens van de sociale media zou aanvullend kunnen worden gebruikt voor het bieden context informatie voor Incident Management. Hierbij is de overheid niet alleen de aanbieder van informatie, maar kan ook profiteren van inhoud die wordt gegenereerd door (weg) gebruikers.

Ten slotte kunnen 'Dynamic Data Driven Application Systems' (DDDAS) een nuttige bijdrage leveren. Deze laten het beheer toe van real-time gegevens afkomstig uit verschillende gegevensbronnen. Dit kan bijvoorbeeld worden gebruikt om simulatiesystemen voor evacuatie te ontwikkelen en het effect van verschillende noodscenario's en organisatie gedrag te analyseren.

5.2 Beleidsaanbevelingen

De internetenquête heeft ook specifiek aandacht besteed aan de adoptiebereidheid van net-centrische systemen. Net-centrische informatiesystemen zijn relatief nieuw voor het IM domein. Volgens Everett Rogers (1995), zijn vijf specifieke adoptiekenmerken bepalend in 49 tot 87 procent bij de acceptatie van nieuwe producten of diensten. Dit zijn *relatieve voordeel*, *compatibiliteit*, *complexiteit*, *probeerbaarheid* en *waarneembaarheid*. Minder dan de helft van de respondenten heeft kennis over deze informatieconcepten en is nauwelijks vertrouwd met net-centrische informatiesystemen. Er is echter een significant verschil in kennis tussen de organisaties. De veiligheidsregio's en de ANWB scoren veel hoger dan de andere organisaties. De onderzoeksresultaten laten zien dat de invoering van de net-centrische systemen zorgvuldig moet plaats vinden. Alle organisaties (behalve LCM) geven aan dat net-centrische systemen een toevoegde waarde hebben voor alle soorten incidenten Dit is tevens een sterke indicator dat alhoewel net-centrische systemen hun roots hebben in het militaire domein, de respondenten aangeven dat deze systemen zinvol zijn voor de dagelijkse incidenten. Alle organisatie geven aan dat net-centrische systemen min of meer verenigbaar zijn met hun bestaande IM systemen. Ook een sterke indicator dat de net-centrische systemen goed aansluiten binnen IM en een logische volgende stap zijn in de ontwikkeling van een nieuwe generatie van IT-oplossingen. Het onderzoek laat zien dat het van cruciaal belang is om de potentiële eindgebruikers de kans te geven om ervaring op te laten doen. 101 van de 162 deelnemers hebben nog nooit gewerkt met dergelijke systemen. 145 van de 162 deelnemers denken dat gezamenlijke training helpt bij het verbeteren van de kwaliteit van informatie-uitwisseling. Dit is een sterke aanwijzing dat het organiseren van periodieke trainingen zeer relevant zijn voor de adoptie van net-centrische systemen. Tot slot, is het positief dat 141 van de 162 deelnemers bereid zijn om daadwerkelijk aan een oefening deel te nemen. In het algemeen kunnen we concluderen dat de adoptiebereidheid van hulpverleners van organisaties om deze systemen te gebruiken hoog is, maar dat invoering zorgvuldig dient te gebeuren. De veiligheidsregio’s maken ook stappen op dit terrein. In de Nederlandse Veiligheidswet (2010), is expliciet vastgelegd dat net-centrische werken de basis is voor het verbeteren van de informatie-uitwisseling in crisissituaties. Deze rechtsgrondslag maakt het mogelijk dat de medewerkers van de veiligheidsregio's (de politie, brandweer en GHOR) de gelegenheid hebben om praktische werkervaring op te doen. Voor het IM domein bestaat dergelijke regelgeving niet. Sterke bestuurlijke betrokkenheid bij de andere IM organisaties is derhalve nodig.

Tenslotte is het gebruik van nieuwe sensordata, zoals de mobiele telefoondata, veelbelovend. Traditionele meetmethoden, zoals weg lusdetectoren, cameradetectie of floating car sensor, zijn effectief en precies, maar kennen praktische beperkingen en zijn relatief duur. De resultaten van deze studie kunnen een startpunt zijn voor een verder onderzoek naar en ontwikkeling van de minder dure controlesystemen.