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 (Harraald 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 Harraald 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 Frias-Martínez, 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 than 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 than 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 km². 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.

Another 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 to 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.