Table of Contents

1. Setting the Scene .................................................................................................................. 1
   1.1 Introduction ......................................................................................................................... 1
   1.1.1 Improved cooperation between the emergency services .............................................. 2
   1.1.2 Information and system quality ...................................................................................... 4
   1.2 The role of Situational Awareness ...................................................................................... 4
   1.3 New information concepts to support Situational Awareness .......................................... 5
   1.4 The use of telecom data to support Situational Awareness .............................................. 7
   1.5 Aims and objectives of the thesis ....................................................................................... 7
   1.6 Scope of the thesis ............................................................................................................. 10

2. Traffic Incident Management ............................................................................................... 13
   2.1 Introduction ......................................................................................................................... 13
   2.2 Incident Management defined .......................................................................................... 14
   2.3 IM developments in the Netherlands ................................................................................. 17
      2.3.1 Regulation on mobility and safety ............................................................................... 18
      2.3.2 Balance between policy and operation ......................................................................... 20
      2.3.3 Type and numbers of incidents ............................................................................... 22
      2.3.4 Economic costs and benefits of congestion ............................................................... 24
   2.4 IM as an actor network approach ..................................................................................... 24
      2.4.1 IM development stages .............................................................................................. 24
      2.4.2 Public IM actors .......................................................................................................... 27
      2.4.3 Private IM actors ........................................................................................................ 28
      2.4.4 The IM information chain .......................................................................................... 29
   2.5 European policy ................................................................................................................. 30
      2.5.1 IM regulation on mobility and safety ......................................................................... 30
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.2 EU road organizations</td>
<td>31</td>
</tr>
<tr>
<td>2.5.3 Road safety</td>
<td>33</td>
</tr>
<tr>
<td>2.6. EU framework for information services</td>
<td>35</td>
</tr>
<tr>
<td>2.6.1 Traffic IM</td>
<td>35</td>
</tr>
<tr>
<td>2.6.2 Geo-spatial initiatives</td>
<td>36</td>
</tr>
<tr>
<td>2.6.3 Interoperability</td>
<td>38</td>
</tr>
<tr>
<td>2.6.4 Standardization of sensors, identification and location technologies</td>
<td>40</td>
</tr>
<tr>
<td>2.6.5 Legal aspects</td>
<td>41</td>
</tr>
<tr>
<td>2.7 Discussion</td>
<td>42</td>
</tr>
<tr>
<td>3. A Common Operational Picture to Support Situational Awareness</td>
<td>45</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>45</td>
</tr>
<tr>
<td>3.2 The importance of IM and mobility consequences</td>
<td>47</td>
</tr>
<tr>
<td>3.2.1 Providing reliable travel times to road users</td>
<td>47</td>
</tr>
<tr>
<td>3.2.2 Increasing discrepancy between mobility and capacity</td>
<td>48</td>
</tr>
<tr>
<td>3.2.3 Costs of traffic jams and delays</td>
<td>50</td>
</tr>
<tr>
<td>3.2.4 Incident numbers and time reduction</td>
<td>51</td>
</tr>
<tr>
<td>3.2.5 IM Strategies and the importance of speed</td>
<td>52</td>
</tr>
<tr>
<td>3.2.6 Balancing between System Optimum (SO) and User Equilibrium (UE)</td>
<td>54</td>
</tr>
<tr>
<td>3.3 Information systems for traffic incident management</td>
<td>56</td>
</tr>
<tr>
<td>3.4 Net-centric-enabled capabilities for IM</td>
<td>58</td>
</tr>
<tr>
<td>3.5 Common Operational Picture</td>
<td>61</td>
</tr>
<tr>
<td>3.6 Context in a common operational picture</td>
<td>63</td>
</tr>
<tr>
<td>3.7 Situational awareness</td>
<td>67</td>
</tr>
<tr>
<td>3.7.1 Definitions and models for individual situational awareness</td>
<td>67</td>
</tr>
<tr>
<td>3.7.2 Definitions and models for shared situational awareness</td>
<td>69</td>
</tr>
<tr>
<td>3.8 A common operational picture for traffic IM</td>
<td>70</td>
</tr>
<tr>
<td>3.8.1 A COP within traffic IM</td>
<td>70</td>
</tr>
<tr>
<td>3.8.2 Measuring the value added service</td>
<td>73</td>
</tr>
</tbody>
</table>
4. Mobile Phone Data for Traffic Parameter and Urban Spatial Pattern Assessment

4.1 Introduction

4.2 Mobile phone data location methods

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

4.3.1 First attempts from the US

4.3.2 European efforts

4.3.3 Telecom companies projects

4.3.4 Recent projects outside Europe

4.3.5 Research on O-D matrix estimation

4.3.6 Research on urban behaviour

4.4 Illustrative application for Amsterdam

4.5 Main research issues

4.5.1 Lessons

4.5.2 Sample size, reliability and accuracy

4.5.3 Legal issues

4.5.4 The role of private mobile companies

4.5.5 The role of transportation agencies

4.6 Conclusions

5. Mobile Phone Data to Support Traffic Incident Management

5.1 Introduction

5.2 Electronic footprints

5.3 Space-time geography and digital data

5.4 Location-based services and context awareness

5.5 Collective sensing and security

5.6 Incident management and safety/security issues

5.7 Review of telecommunication research direction for IM
5.7.1 Security and safety for surrounding areas ................................................... 124
5.7.2 Incident detection ......................................................................................... 126
5.7.3 Prediction of flows and site accessibility of emergency services .................. 129
5.8 The Amsterdam telecom casestudy ............................................................... 130
5.8.1 Introduction .................................................................................................. 131
5.8.2 Normality maps for anomaly detection ......................................................... 133
5.8.3 Anomaly detection for traffic IM ................................................................. 134
5.9 Conclusion and further directions .................................................................... 136

6. Identification of Problems and Needs in Information Sharing .................... 141
6.1 Identification of the problems in the IM operations ........................................ 141
6.1.1 Results of the regional evaluation sessions .................................................. 141
6.1.2 Results of shadowing session of the traffic IM operations ......................... 142
6.2 Internet questionnaire ...................................................................................... 146
6.3 Information, communication, and coordination problems ................................ 151
6.4 Telephone communication ............................................................................. 152
6.5 Information needs ........................................................................................... 154
6.6 Information needs and system functionality .................................................... 156
6.7 Information quality ......................................................................................... 158
6.8 System quality ............................................................................................... 159
6.9 Information dependence ................................................................................ 160
6.10 Adoption rate of net-centric information systems .......................................... 165
6.10.1 Familiar with net-centric systems .............................................................. 165
6.10.2 Complexity .............................................................................................. 166
6.10.3 Relative advantage .................................................................................. 166
6.10.4 Compatibility .......................................................................................... 168
6.10.5 Visibility .................................................................................................. 169
6.10.6 Triability .................................................................................................. 169
6.11 Discussion ................................................................................................. 171
7. Effectiveness of Net-centric Support Tools for Traffic IM

7.1. Introduction

7.2 Assessing the effectiveness of net-centric information systems

7.2.1 Situation awareness

7.2.2 Information quality

7.2.3 System quality

7.2.4 Impact on the decision process

7.3 Design of the experiment

7.3.2 Hypotheses to be tested

7.3.3 Set-up of the experiment

7.3.4 Participants

7.3.5 Net-centric software tool

7.3.6 Scenario descriptions

7.3.7 The experiment

7.3.8 Limitations

7.4 Results of the experiment

7.4.1 IQ and SQ questionnaires

7.4.2 Shadowing and system logs

7.4.3 Scenario evaluation

7.5 Discussions

7.5.1 Communication, coordination, and the decision making process

7.5.2 Design principles of net-centric systems

8. Traffic Incidents and Mobile Phone Intensity

8.1 Introduction

8.2 Data sets used

8.2.1 Traffic incident data

8.2.2 Motorway car-traffic data

8.2.3 Mobile phone data
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANWB</td>
<td>The Royal Dutch Automobile Association</td>
</tr>
<tr>
<td>ATSSA</td>
<td>American Traffic Safety Services Association</td>
</tr>
<tr>
<td>BCR</td>
<td>Benefit/Cost Ratio</td>
</tr>
<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
</tr>
<tr>
<td>BSC</td>
<td>Base Station Controllers</td>
</tr>
<tr>
<td>CDT</td>
<td>Cell Dwell Time</td>
</tr>
<tr>
<td>CEDR</td>
<td>Conference of European Road Directors</td>
</tr>
<tr>
<td>COP</td>
<td>Common Operational Picture</td>
</tr>
<tr>
<td>DDDAS</td>
<td>Dynamic Data Driven Application Systems</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>ECTP</td>
<td>European Construction Technology Platform</td>
</tr>
<tr>
<td>EIF</td>
<td>European Interoperability Framework</td>
</tr>
<tr>
<td>EPC</td>
<td>Electronic Product Code</td>
</tr>
<tr>
<td>ERTRAC</td>
<td>European Road Transport Research Advisory Council</td>
</tr>
<tr>
<td>ETSC</td>
<td>European Transport Safety Council</td>
</tr>
<tr>
<td>FCC</td>
<td>Federal Communication Commission</td>
</tr>
<tr>
<td>FCD</td>
<td>Floating Car Data</td>
</tr>
<tr>
<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal High Way Administration</td>
</tr>
<tr>
<td>GHOR</td>
<td>Geneeskundige Hulpverlening Organisatie in de Regio</td>
</tr>
<tr>
<td>GMES</td>
<td>Global Monitoring for Environment and Security Program</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GRIP</td>
<td>Gecoördineerde Regionale Incidentbestrijdings Procedure</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>HCI</td>
<td>Human-Computer Interaction</td>
</tr>
<tr>
<td>HLR</td>
<td>Home Location Register</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>IDABC</td>
<td>Interoperable Delivery of European eGovernment Services to Public Administrations, Businesses and Citizens</td>
</tr>
<tr>
<td>IM</td>
<td>Incident Management</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardisation</td>
</tr>
<tr>
<td>IMOOV</td>
<td>Informatie Model Openbare Orde en Veiligheid</td>
</tr>
<tr>
<td>IR</td>
<td>Incident Response</td>
</tr>
<tr>
<td>ISA</td>
<td>Interoperability Solutions for European Public Administrations</td>
</tr>
<tr>
<td>ITS</td>
<td>Intelligent Transport Systems</td>
</tr>
<tr>
<td>IQ</td>
<td>Information Quality</td>
</tr>
<tr>
<td>KIM</td>
<td>Kennis Instituut Mobiliteit</td>
</tr>
<tr>
<td>KLPD</td>
<td>Korps Landelijke Politie Diensten</td>
</tr>
<tr>
<td>LBS</td>
<td>Location Based Services</td>
</tr>
<tr>
<td>LCM</td>
<td>Landelijk Centraal Meldpunt</td>
</tr>
<tr>
<td>LPR</td>
<td>License Plate Recognition</td>
</tr>
<tr>
<td>MSC</td>
<td>Mobile Switching Centre</td>
</tr>
<tr>
<td>MTS</td>
<td>Mobile Traffic System</td>
</tr>
<tr>
<td>NBD</td>
<td>Network Based Defence</td>
</tr>
<tr>
<td>NCO</td>
<td>Net-Centric Operations</td>
</tr>
<tr>
<td>NCMS</td>
<td>National Crisis Management System (LCMS - Landelijk Crisis Management Systeem)</td>
</tr>
<tr>
<td>NCW</td>
<td>Network-Centric Warfare</td>
</tr>
<tr>
<td>NDW</td>
<td>National Road Database</td>
</tr>
<tr>
<td>NEC</td>
<td>Network Enabled Capabilities</td>
</tr>
</tbody>
</table>
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 eXtensible Mark-up Language
List of Figures

Figure 1.1 Structure of the thesis.
Figure 2.1a Number of fatal casualties.
Figure 2.1b Policy goals related to fatal casualties.
Figure 2.2 IM development stages in the Netherlands.
Figure 2.3 Road deaths per million inhabitants in 2010 (with road deaths per million inhabitants in 2001 for comparison).
Figure 3.1 Different phases of the IM process.
Figure 3.2 Causes of the existing congestion.
Figure 3.3 Developments in vehicle kilometres and lane length in the Netherlands.
Figure 3.4 Relation between incident duration and response time.
Figure 3.5 New network categorization in the Netherlands.
Figure 3.6 Incident Management in relationship to other traffic management services.
Figure 3.7 Traffic management building blocks.
Figure 3.8 Network Enabled Capabilities (NEC) value chain.
Figure 3.9 Network-Centric Maturity Model.
Figure 3.10 3D cube of measuring Situational Awareness for traffic IM.
Figure 4.1 GSM network scheme.
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.
Figure 5.1 Categorization of tasks along place and time.
Figure 5.2 Estimated number of people are at the (incident) site.
Figure 5.3 Overview of Amsterdam test area.
Figure 5.4 Overview of telecom system architecture.
Figure 5.5  Number of SMS sent during New Year’s Eve.
Figure 5.6  Call intensity in different Amsterdam city areas.
Figure 5.7  Index of deviation of the Index of Human Activities before, during and after an incident.
Figure 6.1  Mean age of the different IM organizations.
Figure 6.2  Spread of age over the different IM organizations.
Figure 6.3  Spread of education level per organization.
Figure 6.4  Spread of mean education level per organization.
Figure 6.5  Years of experience in the current function.
Figure 6.6  Mean years of experience.
Figure 6.7  GRIP experience per organization.
Figure 6.8  Mean GRIP experience per organization.
Figure 6.9  Incident information notification issues.
Figure 6.10a Information problems per phase.
Figure 6.10b Coordination problems.
Figure 6.11 Problems with telephone communication per organization.
Figure 6.12 Mean values of telephone communication problems.
Figure 6.13 Information requirements on the incident.
Figure 6.14 Information needs on the environment.
Figure 6.15 Information needs of the IM organizations.
Figure 6.16 Desired system functionality per organization.
Figure 6.17 Mean scores of desired functionality.
Figure 6.18 Current information quality per organization.
Figure 6.19 Mean value of information quality.
Figure 6.20 Current system quality per organization.
Figure 6.21 Mean value for system quality.
Figure 6.22 Mean perceived value for how information systems support IM.
Figure 6.23 Familiar with net-centric systems.

Figure 6.24 Perceived complexity of net-centric systems.

Figure 6.25 Relative advantage of net-centric systems.

Figure 6.26 Value added services between different types of incidents.

Figure 6.27 Compatibility of innovation with existing values, past experiences, and adopter needs.

Figure 6.28 Visible results of net-centric systems.

Figure 6.29 Practical experience with net-centric systems.

Figure 6.30 Attitude to training with all IM organizations.

Figure 6.31 Willingness to participate in a net-centric field exercise.

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

Figure 7.2a Centralist in action.

Figure 7.2b Fieldworkers on the scene.

Figure 7.3 Arrangements of participants.

Figure 7.4 Timelines representing the experiment protocol.

Figure 8.1 Graphical representation of our research model.

Figure 8.2 Overview of the Amsterdam test area.

Figure 8.3a Variation of hourly traffic incidents.

Figure 8.3b Variation of daily traffic incidents over a week.

Figure 8.3c Variation of monthly traffic incidents.

Figure 8.4 Number of incidents on different types of infrastructure.

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

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

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

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).

Figure 8.9 Distribution of traffic incident with injuries.
List of Tables

Table 2.1 Differences in the definition of the traffic IM process phases.
Table 2.2a Number of traffic incidents in the Netherlands.
Table 2.2b Registered private cars.
Table 2.2c Registered trucks.
Table 2.3 Overview of IM organizations and their roles.
Table 2.4 Activities to support traffic IM within and between organizations.
Table 3.1 Comparison of traffic intensities between the Netherlands and surrounding countries.
Table 3.2 Time loss due to traffic congestion.
Table 3.3 Reduction of capacity (as a percentage of the original capacity) due to an incident.
Table 3.4 Services level emergency related driving times to incidents.
Table 3.5 Fundamental roles for an emergency management system.
Table 3.6 Examples of context variables contained in a COP.
Table 3.7 Relation between NEC value chain and the IM process phases.
Table 4.1 Summary of studies and field test deployments.
Table 4.2 Main field test project characteristics.
Table 5.1 SWOT Analysis of the GSM Technology applied to transport safety and security.
Table 6.1 Overview of the participants of the internet questionnaire.
Table 6.2 Information dependence on other organizations.
Table 6.3 Cross-information dependence.
Table 6.4 Own information that is valuable for other organizations.
Table 6.5 Cross information dependence.
Table 6.6 Definition of adoption factors.
Table 7.1 Measuring levels for SA and traffic IM information components.
Table 7.2 Most relevant information quality dimensions identified in the literature.

Table 7.3 Overview of the selected information quality dimensions.

Table 7.4 Overview of selected system quality constructs.

Table 7.5 Demographics of participants field exercise.

Table 7.6 Scenario descriptions.

Table 7.7 IQ results for scenario 1a.

Table 7.8 IQ results for scenario 1b.

Table 7.9 IQ results for scenario 2.

Table 7.10 IQ results for scenario 3.

Table 7.11 IQ results for scenario 4.

Table 7.12 SQ results for all scenarios.

Table 7.13 Sum of minutes gained in the test group in information-sharing and coordination for all scenarios.

Table 7.14 Current identified problems for communication and coordination for traffic IM.

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

Table 8.2 Description of the telecom counts used.

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

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

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

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

Table 8.7 Marginal effects for all 109 cells with different mobile phone variables and hourly interaction terms for mob$_a$.

Table 8.8 Marginal effects for the 109 cells with interaction terms for mob$_a$. 
Appendix

Appendix 1  Relation between incident duration and lost vehicle hours.

Appendix 2  Overview of the current identified problems during 10 regional evaluation sessions.

Appendix 3  Overview of involved emergency services clustered per incident type.

Appendix 4  Marginal effects analysis – Based on estimates of Table 8.6.

Appendix 5  Marginal effects for all the 109 cells on all incidents with different mobile phone variables.

Appendix 6  Marginal effects for the 109 cells with a distinction between the different incident types.