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Steenbruggen, J.G.M.; Krieckaert, M.N.M.; Rietveld, P.; Scholten, H.J.; van der Vlist, M.

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Faculty of Economics and Business Administration

# The Usefulness of Net-Centric Support Tools for Traffic Incident Management

Research Memorandum 2015-8

John Steenbruggen
Maarten Krieckaert
Piet Rietveld[†]
Henk Scholten
Maarten van der Vlist

vrije Universiteit amsterdam

# *The usefulness of net-centric support tools for traffic Incident Management*
*Results of a field experiment in the Netherlands*

John Steenbruggen
VU University
Department of Spatial Economics
De Boelelaan 1105
1081 HV Amsterdam. The Netherlands
Phone: +31(0)152 75 7301
john.steenbruggen@rws.nl

Maarten Krieckaert
VU University
Department of Spatial Economics
De Boelelaan 1105
1081 HV Amsterdam. The Netherlands
Phone: +31(0)205 98 6090
m.n.m.krieckaert@vu.nl

Piet Rietveld † [1]
VU University
Department of Spatial Economics
De Boelelaan 1105
1081 HV Amsterdam. The Netherlands
Phone: +31(0)205 98 6090
p.rietveld@vu.nl

Henk Scholten
VU University
Department of Spatial Economics
De Boelelaan 1105
1081 HV Amsterdam. The Netherlands
Phone: +31(0)205 98 6090
h.j.scholten@vu.nl

Maarten van der Vlist
Ministry of Infrastructure and Environment.
Zuiderwagenplein 2,
8224 AD Lelystad. The Netherlands.
maarten.vander.vlist@rws.nl

***Abstract***
*In the last two decades traffic Incident Management (IM) has become an important tool to reduce and prevent congestion on the road network, especially in urban areas. IM involves the coordinated interactions of many public and private actors. To support their tasks in an effective way, information systems are becoming increasingly important. In particular, information and system quality and Situational Awareness (SA) have been identified as major hurdles for effective emergency response. This paper reports 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 16 participants. Data on the responses of the participants were collected through 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, how scenario complexity can affect the design principles of net-centric systems.*

***Keywords****:* Traffic Incident Management, Net-centric information systems, Common Operational Picture, Situational Awareness.

[1] Piet Rietveld passed away on November 1, 2013.

## 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 response time of the emergency services, 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, 2007). The basic idea is that fast clearance of the incident scene can help to reduce the incident-related congestion. Improving Situational Awareness (SA) for emergency services is crucial for the quick clearance of the incident scene. Klein (2000) 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 (questionnaires)?
- 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?

## 2. Assessing the effectiveness of net-centric information systems

### 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.* (2012a).

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.

**Table 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?<br>• What type of incident?<br>• What is the nature of the incident? | • Where is the congestion located?<br>• Where are the traffic jams?<br>• Where are the road users? | • Which emergency organizations are involved?<br>• 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?<br>• What is the number of injuries?<br>• Is there release of dangerous goods? | • What causes the congestion: incident, events, weather?<br>• What is the site accessibility for emergency services?<br>• How many people are in the area? | • How should we respond?<br>• 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?<br>• What risks are there for the surrounding area (e.g. chemical releases? | • What will they do (activity)?<br>• At what time will they be (t)here? |

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

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.

### 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 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 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<br>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) |

### 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 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) | |

## 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.

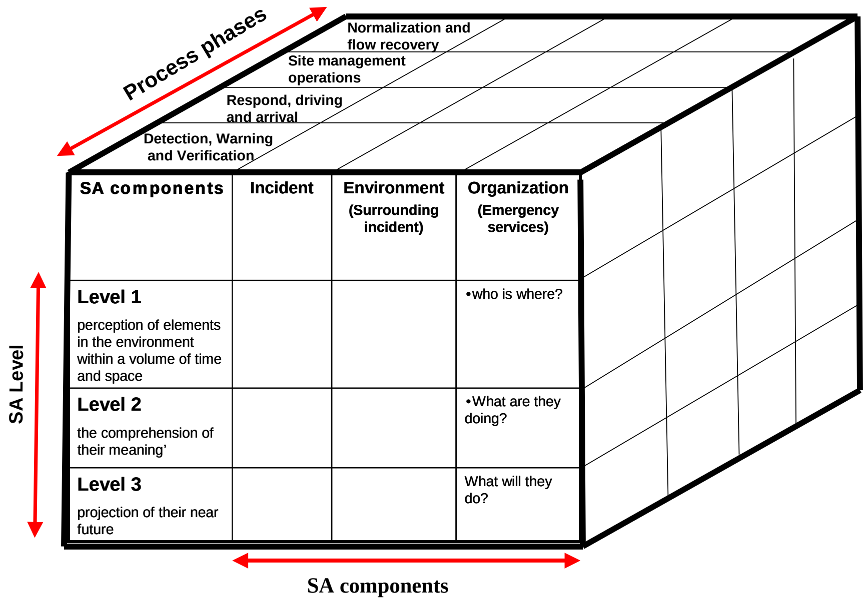


**Figure 1: 3D model for measuring Situational Awareness for traffic IM**

The 3D model in Figure 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.*, 2012a; 2012b; 2014).

## 3. Design of the experiment

### 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 Rijkswaterstaat works 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.

### 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.

### 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 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 2a: Centralist in action** **Figure 2b: Fieldworkers on the scene**

### 3.3.1. Participants

The demographics of the participants in the field exercise are shown in Table 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 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* | |
| *Emergency room ANWB* | 4 |
| *Towing services* | 3 |
| *Towing emergency room CMV* | 3 |
| *(trucks)* | 3 |
| *Towing emergency room LCM (cars)* | |
| | 1 |

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

### 3.3.2. 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).
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 are 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 and sitplots.

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'. 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 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.

### 3.3.3. 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, 2005) 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 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-1)** *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.*

### 3.3.4. 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 groups of participants: a test group that used the specially developed net-centric systems and a control group that used traditional systems (Figure 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 2b). For each group, the scenarios were facilitated by an exercise staff. 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.

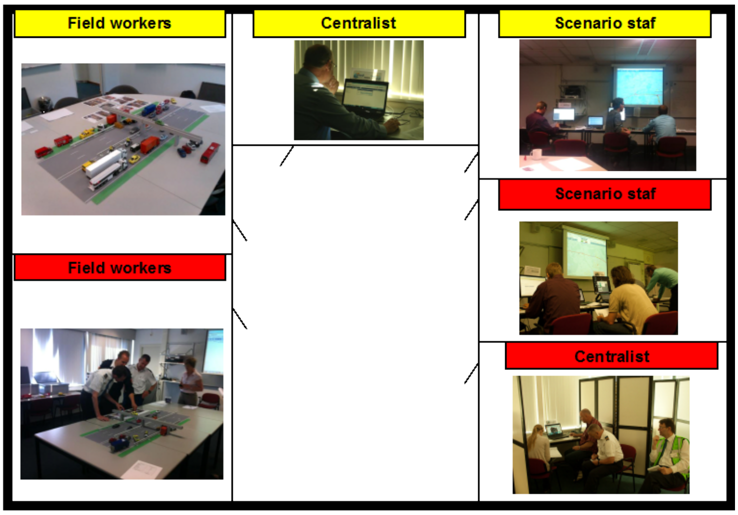


**Figure 3: Arrangements of participants**

We used different research methods to be able to analyse the results (see Figure 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.

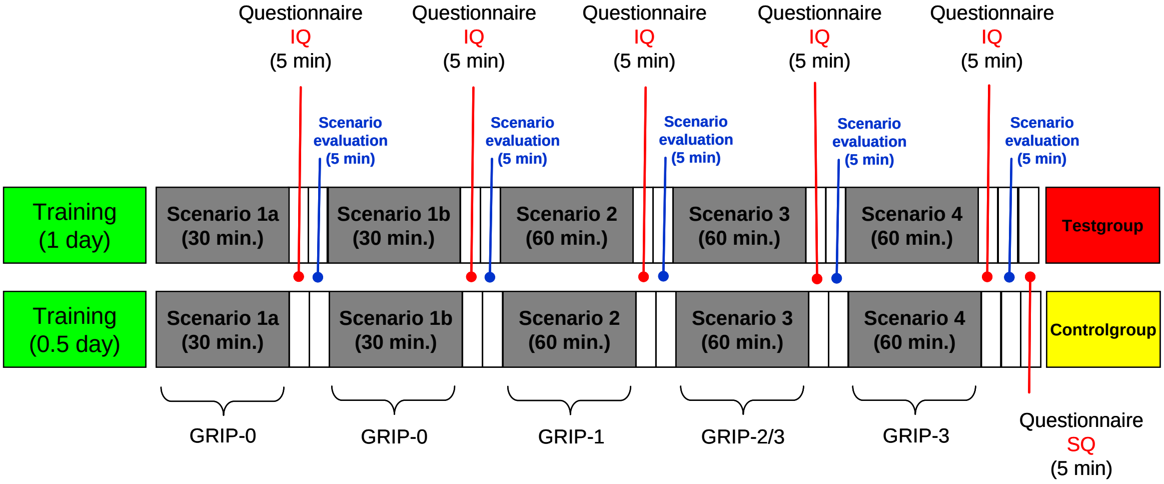


**Figure 4: Timelines representing the experiment protocol**

### 3.3.5. 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.

## 4. Results of the experiment

### 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 were 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 was 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: IQ 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 8: IQ 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 9: IQ 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 10: IQ 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 11: IQ 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.* (2012). The introductions 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 12: SQ 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.

## 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 | Control group | Test group | Control group | Test group | Control group | Test group | Control group | Test group | Control 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 |
| **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 *1 | 9 | 16 | 25 | 14 | 14 |
| Decision alternative routes | | | | | 15 *1 | 8 | 4 | 20 | 25 | 34 |
| **Organisation and coordination information** | | | | | | | | | | |
| Road Inspector at the incident location | 11 | 6 | 11 | - | 8 | 10 | 7 | 11 | 12 | 12 |
| RWS Officer of Duty at 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 *1 | | | 12 | 9 | 8 | 11 | 6 | 11 |
| Ambulance at the incident location | | | | | 12 | 9 | Nambulance | 18 *2 | 12 | 12 |
| Towing car at the incident location | | | 8 | - | 37 2e incid. | 29 *1 | 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 *2 | 17 *2 | 28 *2 (41) | Nhelicopter | | |
| Demand additional transport | | | | | 42 | 47 | | | | |
| Demand environmental expert | 9 | 23 | | | | | | | | |
| Demand for STI expert | | | | | 14 | 10 | | | | |
| First COPI meeting | | | | | No COPI | 21 | 34Motorkap | 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.
Note: *1 = not necessary, *2 not ordered, Nambulance = No ambulance, Nhelicopter = No helicopter., 2eincid. = Second incident.

### 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 netcentric 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.

## 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.

### 5.1. Communication, coordination, and performance of 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 14 provides an overview of the sum of minutes gained in the test group. In Scenario 3, only the Ambulance services were 3 minutes later at the incident location. This was based on a miscommunication between the fieldworkers and the Control Centre. This means that even with the right tools, it is the quality of information which is relevant. 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.

**Table 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.<br>Location : 17 min.<br>Type : 16 min.<br>Vehicles : 33 min.<br>Victims : 7 min.<br>Dangerous goods : 49 min. | WIS: 1 min.<br>OvD: 3 min.<br>Police: 11 min.<br>Fire Brigade: 9 min.<br>Ambulance: -3 min<br>Towing cars 13 min.<br>Towing trucks: 41 min.<br>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.

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 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 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 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.

**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 an information system 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 serious 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 an 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 *time 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.

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