Crowdsourced Disaster Response for Effective Mapping and Wayfinding

Lucy T. Gunawan

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Proefschrift

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For my dearest Dad.

You attend the funeral, you bid the dead farewell.
You grieve. Then you continue with your life.
And at times the fact of his absence will hit you like a blow to the chest,
and you will weep.
But this will happen less and less as time goes on.
He is dead.
You are alive.
So live.

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Lucy Gunawan (Nike)
Rotterdam, December 2012

Summary

The research focuses on guiding the affected population towards a safe location in a disaster area by utilizing their self-help capacity with prevalent mobile technology. In contrast to the traditional centralized information management systems for disaster response, this research proposes a decentralized computer-supported management system in which affected people can lead themselves to safety and simultaneously serve as field sensors that share information about the disaster situation.

A literature study together with contextual inquiries (field observations) were first conducted to analyse and identify existing problematic areas in order to envision a feasible, efficient and effective system. Based on literature from the field of disaster sociology and humanitarian operation experience, it was clear that the affected people in a disaster are not simply helpless victims; instead, they consist of capable human beings who tend to act rationally and proactively in a united and helpful manner. In times of collective stress, they are even able to creatively use whatever means of technology are at hand. This group forms the majority of the population that is affected by a disaster. They are distributed over the disaster area and witness the disaster first hand. As a result, these individuals form a massive potential resource for collecting first hand knowledge about the disaster. Field observations indicated that tailored mobile navigation support is lacking. Likewise, situation map-mapping support has appeared to be limited, fragmented, and funnelled to one "plotter".

The literature and field observations showed that there is a need for (1) navigation support of the affected people, (2) collaborative map-making

support, and (3) the integration of these support functions into one information system to establish a harmonized, effective, and safe, disaster response. As part of the research, prototypes of these two support functions and the integrated system were developed and tested in both controlled environments and out in the field.

Major disaster events can significantly change an area, render earlier geographical data obsolete, and make damaged infrastructure hazardous to the affected people. In order to minimize public exposure to such dangerous conditions, which prevail in disaster areas, the affected people need to be guided to a safer location. Thus, a navigation system that provides sufficient and flexible guidance given the altered environment in the disaster area is critical in these situations.

The first study was a field experiment, tested a handheld navigation solution that pointed toward the direction of a destination and elementary navigational cues. The results suggested that a rudimentary navigation cue in the form of an arrow was sufficient to guide an individual towards a specific destination. Moreover, additional navigation cues such as the distance or the time to a destination gave additional support by making it easier for a person to follow the guidance. However, in order to provide adequate navigational support, an up-to-date presentation of the post-disaster situation is desirable. Especially as a map is usually needed to represent complex situations. For example, during the field observations of USAR.nl in the Czech Republic, the rescuers sketched and updated a map (drawn on the wall) with a spray can to represent the rescue situation and their activity outcomes over time. The command post was informed about the situation however by audio (telephone) communication. In a disaster with widespread damage, the disaster situation needs to be rapidly assessed. However, the traditional centralized mechanism of gathering this kind of information is regarded as inefficient and can result in an inaccurate and outdated situation map. These inefficiencies stem from: (1) the use of an unsuitable communication modality to relay spatial information (e.g. audio), (2) limited emergency resources that collect this kind of information, and (3) the hierarchical and chain reporting structure in the organization of the map-making process. To overcome these inefficiencies, this research also focuses on a distributed approach that utilizes the affected people for collecting situation data in the field and using additional modalities of communication.

This led to the second study, which investigated the construction of a shared situation map using a collaborative mechanism. This study was conducted in a controlled laboratory environment. The first results demonstrated that if the contribution from each individual is not balanced then collaborative

map-making can result in a joint map that is worse than the underlying individual maps. Based on this result, a method of explicitly showing confidence information was prototyped in the subsequent experiment. The results showed that the quantity and quality of the information in the collaborative maps was better than the individual maps. It was concluded that a visual shared map can complement the auditory communication during situation map-making and that explicitly rating objects and events in the map with a confidence level significantly enhanced the discussion process.

FINALLY, the third empirical study was an extensive controlled field study where Delft was converted into a disaster playground. Several participants played simultaneously different roles (the affected people and the operator) located at multiple locations (in the field and in the information center) while using multiple devices (mobile phone, desktop computer) and applications (mobile client, server, and simulation). The aim of this study was to compare the proposed system with the traditional centralized system. The result of this study demonstrated that the proposed system was superior in (1) guiding the affected people safely to their destination, (2) helping operators in achieving a higher situational awareness, and (3) lowering operator workload.

To conclude, this research proposes a participatory distributed mechanism which involves the affected people to improve the disaster response. The system harvests the capabilities of the affected people as distributed active sensors for assessing disaster situations. In this way, they can help themselves to safety while helping to rapidly construct a clear image of the disaster without burdening the already overwhelmed rescue services. The study showed that this mechanism might reduce the workload of the disaster responders and may improve the effectiveness of the disaster response process. With better situational awareness of the disaster area, humanitarian aid and rescue activities can be conducted more effectively and victims can be saved faster than before. Thus, the proposed system in this thesis can form the foundation of an efficient next generation disaster response system.

Samenvatting

Het onderzoek richt zich op de vraag hoe mensen die door een ramp getroffen zijn naar een veilige locatie kunnen worden begeleid door gebruik te maken van hun zelfredzaamheid en de beschikbare mobiele technologie. In tegenstelling tot traditionele gecentraliseerde rampbestrijding systemen, stelt dit onderzoek voor om gebruik te maken van een gedecentraliseerd systeem. Daarbij kunnen de mensen in het getroffen gebied zichzelf naar een veilige omgeving leiden en tegelijkertijd dienen ze als veldsensoren om informatie over de rampsituatie te delen.

Om probleemgebieden van bestaande systemen te identificeren en te analyseren is er eerst een literatuurstudie en een veldonderzoek uitgevoerd. Aan de hand van de bevindeningen is een haalbaar, efficient en effectief systeem voorgesteld. Uit de literatuur op het gebied van katastrofesociologie en uit ervaring van noodhulpacties blijkt dat mensen in een rampgebied geen hulpeloze slachtoffers zijn. Het zijn capabele personen die rationeel en proactief opereren op een samenhorige en behulpzame manier. Ze zijn zelfs in staat om ten tijde van een crisissituatie creatief om te gaan met alle voorhanden zijnde technologieen. Deze personen, welke verspreid zijn over het rampgebied en ooggetuigen van de ramp zijn, vormen de grootste groep in het getroffen gebied. Hierdoor vormen deze personen een groot potentieel als hulpmiddel om eerstehands informatie over de rampsituatie te verzamelen. Veldonderzoek lieten ook zien dat er een gebrek is aan opmaat gemaakte ondersteuning voor mobiele navigatie. Ook bleken dat ondersteuning voor het maken van een situatiekaart, beperkt en gefragmenteerd was. Daarnaast is het proces trechtervormig doordat één persoon de situatiekaart samenstelt.

De literatuurstudie en het veldonderzoek lieten zien dat er behoefte is aan (1) ondersteuning van de navigatie van de getroffen bevolking uit het rampengebied, (2) ondersteuning voor het maken van een gezamenlijke situatiekaart, en (3) integratie van deze ondersteunende functies in één samenhangend systeem om de effectieve en veilige van de rampbestrijding te bewerkstelligen. In het onderzoek zijn prototypes van deze drie functies ontwikkeld en vervolgens getest onder zowel laboratoriumcondities als in het veld.

Grote rampen kunnen een gebied zodanig veranderen dat bestaande geografische data niet meer van toepassing is en de infrastructuur dusdanig beschadigd raakt dat er gevaar ontstaat voor de getroffen bevolking. Blootstelling aan zulke gevaarlijke condities, moet geminimaliseerd worden door de getroffen bevolking zo snel mogelijk naar een veilig gebied te begeleiden. Derhalve is een navigatiesysteem dat voldoende en flexibele begeleiding biedt, ondanks de veranderde omgeving in het rampgebied, cruciaal in deze situaties.

De eerste studie was een veldexperiment dat een mobiel navigatiesysteem testte dat de richting van de bestemming aangaf en eventueel elementaire navigatie aanwijzingen verschafte. De resultaten tonen aan dat een rudimentaire navigatie aanwijzing in de vorm van een pijl voldoende is om personen naar een specifiek bestemmning te leiden. Bovendien konden additionele navigatie aanwijzingen zoals afstand of tijd tot aan de eindbestemming, ondersteuning bieden om de richting te volgen. Echter, om adequate navigatie ondersteuning te bieden en om deze complexe situatie weer te geven is een bijgewerkte situatiekaart gewenst. Ter illustratie, tijdens het veldonderzoek van USAR.nl in Tsjechië had de hulpdiensten een kaart op de muur gespoten met verf en werkten deze steeds bij om de reddingssituatie en resultaat in tijd uit te zetten. De commando posten werden echter telefonisch ingelicht over de situatie. In een ramp met wijdverspreide schade dient de situatie snel beoordeeld te worden. Echter, de traditionele, gecentraliseerde mechanismen om dit soort informatie te verzamelen, kan bestempeld worden als inefficient en kan resulteren in een inaccurate en verouderde situatiekaart. Deze inefficientie wordt veroorzaakt door: (1) het gebruik van ongeschikte communicatie modaliteiten om ruimtelijke informatie te rapporteren (gebruik van audio), (2) een beperkt aantal hulpdiensten die deze informatie verzamelt, en (3) de hierarchie in de organisatie en de vele schakels in het rapportageproces om een situatiekaart te maken. Om deze inefficiente werkwijze te overwinnen richt dit onderzoek zich op een gedistribueerde benadering die gebruik maakt van enerzijds de getroffen bevolking om uit het gebied situationele gegevens te verzamelen en anderzijds door gebruik te maken van additionele communicatiemodaliteiten.

Dit leidde tot een tweede studie welke zich richtte op de manier waarop samenwerkende personen een gezamenlijke situatiekaart constructueren. Deze studie is uitgevoerd onder laboratorium condities. De eerste resultaten tonen aan dat wanneer individuen in ongelijke mate bijdragen aan de kaart, dit kan resulteren in een gezamelijke situatiekaart met meer fouten dan de oorsprongelijke losse, indivuduele situatiekaarten tezamen. Voortbordurend hierop is een prototype ontwikkeld waarbij de individuele bijdragen met een zekerheidsindicatie worden aangegeven. De onderzoeksresultaten tonen in dit geval aan dat de kwantiteit en kwaliteit van de informatie in de gezamenlijke situatiekaart beter was, dan de inidividuele kaarten. Geconcludeerd mag worden dat bij de ontwikkeling van een situatiekaart een visueel gedeelde kaart de audiocommunicatie ondersteunt en dat het toevoegen van de zekerheidsindicatie het discussieproces significant verbetert.

Tenslotte, de derde empirische studie was een uitgebreide gecontroleerde veldstudie waarbij een ramp in Delft werd nagebootst. Meedere deelnemers speelden op verschillende locaties (in het veld en in het informatiecentrum) tegelijkertijd verschillende rollen (de getroffen bevolking en operatoren), terwijl ze gebruik maakten van verschillende hulpmiddelen (mobiele telefoon, desktop computer) en applicaties (mobile client, server en simulatie). Het doel van deze studie was om het voorgestelde systeem te vergelijken met een traditionele gecentraliseerde systeem. De resultaten van deze studie tonen dat het voorgestelde systeem superieur was aan het traditionele systeem in (1) het veilig begeleiden van de getroffen bevolking naar de bestemming, (2) het helpen van de operatoren om een beter bewustzijn van de situatie te bewerkstelligen en (3) het verlagen van de werkdruk van de operatoren.

Samengenomen, dit onderzoek stelt een gedistribueerd mechanisme voor die de getroffen bevolking betrekt om de reactie op een ramp te verbeteren. Het systeem maakt gebruik van het potentieel van de getroffen bevolking om als gedistribueerde, actieve sensoren de rampsituatie te beoordelen. Op deze wijze kunnen ze zichzelf in veiligheid brengen, terwijl ze helpen om snel een duidelijk beeld van de ramp te vormen zonder de reeds hoge werkdruk van de hulpdiensten te verzwaren. De studie toont aan dat dit mechanisme in staat is om de werkdruk van de hulpdiensten te verlagen en om de effectiviteit van rampbestrijding te verbeteren. Door betere situatiebewustzijn van het rampgebied, kunnen humanitaire hulp en reddingsactiviteiten effectiever uitgevoerd worden waarbij slachtoffers sneller dan voorheen gered kunnen worden. Derhalve kan het in dit proefschrift voorgestelde systeem de basis vormen voor een volgende generatie rampenbestrijdingssystemen.

Table of Content

Chapter 1. Introduction

Large sudden natural disasters such as earthquakes, tsunamis, and hurricanes, can cause massive destruction on impact, and result in tremendous disruptions to human life. As the world population continues to grow and more complex infrastructures are being built, natural disasters have a growing potential to affect bigger populations, thus inflicting even more damage. The year 2011 was the most expensive year on record when it comes to natural disasters, it accounted for US$ 380 billion in losses, caused mainly by two huge earthquakes in Japan and New Zealand (Munich Re, 2012). Further, the recent 2010 earthquake in Haiti killed over 20 thousand people and affected around 3.7 million people, while the earthquake in Wenchuan, China in 2008 killed over 87 thousand people and affected approximately 46 million people (CRED, 2012).

When responding to such devastating situations, the priority is usually given to rescue as many human lives as possible and to protect them from subsequent harm. In order to have an effective and efficient response to a disaster, the situation in the disaster area needs to be acquired rapidly. This, for example includes: identifying the extent of the damage, potential hazards, dangerous and safe areas, passable route networks, the casualties, and the availability of emergency facilities. Without awareness of the situation, any deployment or mobility in the area of disaster can be dangerous (as the area may contain various hazards) and ineffective (as it may cause delays to the relief efforts). (U.S. House of representative, 2006a, U.S. The White House, 2006).

However, it is a complicated and lengthy task to acquire comprehensive knowledge of a disaster area, especially on a complex and large-scale disaster area with widespread damage. Often, the entire scope of the disaster can only be understood after several days. This delay is commonly caused by: (1) inadequate information about the situation, (2) the dynamic nature of the event, and (3) slow situation assessment. The slowness of situation assessment is party caused by the centralized and hierarchical structure of the disaster management model that is commonly adopted worldwide (Kean & Hamilton, 2004, Ramaswamy et al., 2006, Tierney, 2006). This model, not only puts burden on the limited and overwhelmed emergency services for the rescue actions (Schneider, 2005), it also makes them responsible for acquiring and verifying information on the ground. This adds an additional strain and workload on emergency services thus further delays situation assessment. Additionally, the information gathered on the field is relayed through extended hierarchical information chains (Drabek, 1985, U.S. House of Representatives, 2006b, U.S. The White House, 2006). This not only delays the update of information about the situation, but may also result in information corruption as data transmitted up the hierarchy (as commonly demonstrated in the colloquial "telephone" game amongst friends or Chinese whisper game) (Buckner, 1965). As a result, the knowledge of disaster situation often tends to be incomplete, scattered, and outdated (U.S. House of Representatives, 2006a).

In the meantime, there is a massive untapped resource in the disaster area itself which can potentially help in the assessment of a disaster situation: the affected population. The study of how humans behave during times of collective stress shows that the affected population in a disaster area are not helpless victims, they are actually capable humans who tend to act rationally and exhibit a great deal of pro-social behaviour (Quarantelli, 1986, Lomnitz, 1999). They are likely to be proactive, united, and are usually the first to provide help on the ground during a time of collective stress (Wenger et al., 1986, WHO, 1989, Quarantelli, 1999, Tierney et al., 2001, Kean & Hamilton, 2004, McEntire, 2006a). Despite the growing awareness of their untapped potential in a disaster situation, the affected population is typically overlooked as a potential asset, and their inclusion in a disaster management system is still limited.

The current challenge and possible solution to understand the impact of a disaster and the resulting situation is analogous to the story of the blind men and the elephant. In the story, a group of blind men touch an elephant to understand its physical shape. Each one feels a different part, but only one part, such as the trunk, the tusk, or the tail. When they compare what they have experienced and learned they are in complete disagreement, leaving them with an inaccurate mental model. Now, imagine if these blind men were equipped with 3D tracking and positioning system while feeling the elephant's shape. If they were also allowed to communicate and combine their findings, and were provided with a computer numerical control (CNC) machine to print the resulting 3D shape (such as RepRap), they can print a miniature of the elephant which resembles the real elephant, resolving their previous disagreements. By using the same analogy, it may be useful to use the affected people, as distributed reporters, across the disaster area, who are experiencing the disaster first hand. In addition, utilizing advances in smart-phone technology, with GPS and data connectivity, makes the affected population a potentially vital element in a system that can construct an emerging overview of the disaster.

Therefore, the aim of this study is to utilize the potential capacity of affected people by providing them with a way to lead themselves to safety while, at the same time, empowering them to serve as distributed active sources of information for other affected people and rescue services. This way, the people will be better off in a safer place which they were able to reach by themselves, while at the same time help to rapidly construct a clear image of the disaster situation without burdening the already overwhelmed emergency services. With better knowledge of the disaster situation, the humanitarian aid and rescue activities can be assisted more effectively and the injured can be rescued in shorter time.

1.1. *Research Questions*

Based on the motivations above, the main question addressed in this thesis is as follows:

> *Can affected populations be effectively and efficiently guided to safety in a disaster area through a participatory mechanism by collaboratively sharing spatial information among professional and nonprofessional actors during the disaster response?*

In this research question, the affected population is defined as people who are adversely affected by a disaster, and may require humanitarian assistance, e.g., requiring basic survival needs such as food, water, shelter, sanitation or simple medical assistance (WHO, 2012, CRED, 2012). This category usually includes 94% of the population (Guha-Sapir, 2011).

In pursuit of basic assistance, physical movement and wayfinding is required. Therefore, some sort of guidance is necessary to minimize exposure to dangerous conditions that may prevail in disaster areas. The participatory mechanism is a method in which the affected population participate as active sensors that share observations of the disaster area while finding their way to safety.

Disaster response is a phase in the disaster management cycle that includes actions immediately prior to impact, as well as during and after the disaster event, that aims to reduce human and property losses. The physical movements of citizens and emergency services happen during the response phase while simultaneous activities such as situation analysis, evacuation, search and rescue, and humanitarian assistance are taking place.

This study focuses on the response phase of natural disasters that strike without warning (such as earthquakes), because these are usually the worst natural disasters in terms of casualties and cannot yet be prevented. Human survival after a disaster is sometimes a race against the time if rescue or medical assistance is needed. The golden hours is a term given to the period in which humans may still survive before being rescued while they are trapped under rubble or debris. Within this limited time frame, the affected people should give first assistance, as help from outside will likely come too late. Therefore it is important to empower the affected people to help each other. It will not only save more lives, but it can potentially lighten the workload of the emergency services, thus making the disaster response more effective and efficient.

From the main research question, three hypotheses are defined to investigate the contribution of information and communication technology to the enhancement of disaster response:

1. *In a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues.*

2. *Using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map.*

3. *By collaboratively sharing spatial information between the affected population and professional actors on-and-off location: (a) the affected population will be guided in a safer manner and (b) a more accurate disaster situation map will be constructed, which in turn will better facilitate the relocation of the affected population, in comparison to the commonly used system.*

Major disaster events, such as earthquakes, tsunamis, and tornadoes, may change the area significantly and cause extensive damage to the infrastructure (buildings collapsed or severely damaged, and road networks blocked or destroyed). This renders earlier geographical data, such as maps, less useful (van der Walle et al., 2010). As common navigation technologies such as turn by turn instruction will not work in this kind of situation, a navigation technology that is less dependant on an underlying map is needed. Therefore, the direction arrow was chosen as the navigation tool when a map is unavailable. By having a mobile technology that shows the destination, the affected population can guide themselves to safety while avoiding blockades and dangerous areas. An illustration of this process can be seen in Figure 1.1.

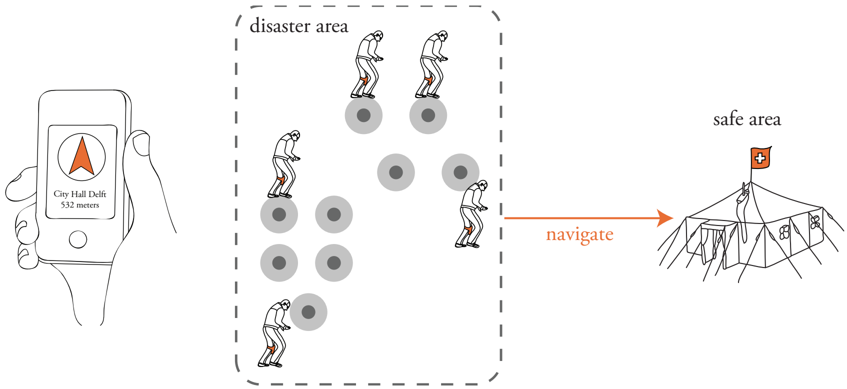


Figure 1.1. Illustration of the first hypothesis, the affected people are guided to reach a safe area, using mobile navigation technology that shows an arrow which points to the direction of the destination and elementary navigational cues shown such as distance to destination or estimated time to arrival.

Once the affected people are provided with navigation technology to help them reach safety, the same tools can be extended with communication mechanisms. This allows the affected people to be connected to a network of information, allowing them to function as distributed active sensors in the disaster area. A passable road network may emerge from the digital trails left by affected people. Additionally, it can be supplemented with reports from the field, such as dangerous areas and potential hazards. Thus making the disaster map more accurate. Figure 1.2 illustrates how such a process can work.

Collaboration between the emergency services and the affected people, during the disaster response can be beneficial for the efficiency and effectiveness of the disaster response. This is due to the different type of information both parties possess. The affected population has the knowledge of what is going on in the field, while the emergency services have the knowledge of how to cope with the circumstances; such as predictive disaster development, vulnerable infrastructure, emergency services, etc. By enabling them to share information, resources, activities, and capabilities, they can jointly achieve an outcome that could not be achieved by each party separately. See Figure 1.3 for an illustration of this process.

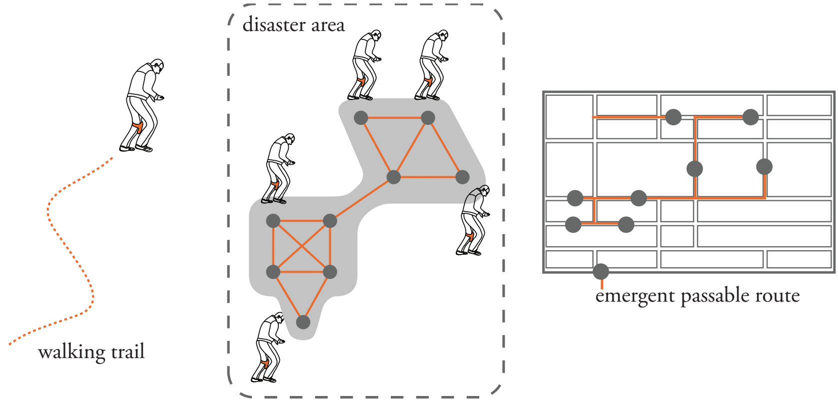


Figure 1.2. Illustration of the second hypothesis. The connected affected people can form an emergent passable road network in the disaster area.

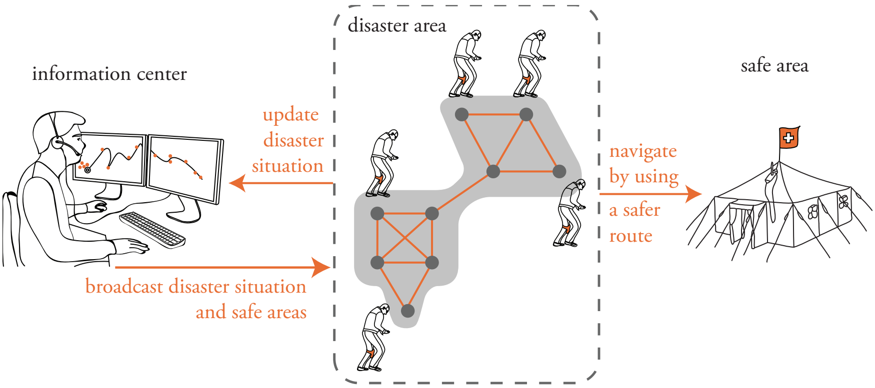


Figure 1.3. Illustration of the third hypothesis. The collaboration between the affected people and emergency services off and on location can enhance the effectiveness and the efficiency of disaster response.

1.2. Methodology and thesis structure

As a first stepping stone towards answering the research questions and the three defined hypotheses, the idea that affected people are not helpless victims must be supported. The support for this is formed by studying findings in the field of disaster sociology and experiences from past humanitarian operations during disaster response. Further, the potential role of the affected population and the advances in prevalent mobile technology is examined to get a general idea of the envisioned system. The three hypotheses are then substantiated through a critical analysis of the relevant available literature to support the main hypothesis. The literatures study as a theoretical framework is described in Chapter 2.

The first direct support for the three hypotheses was done by observing and understanding the current practises in disaster management. This was done by using the contextual inquiry method in three occasions: (1) observing the operations of a disaster management team at a command centre, (2) observing the operations of search and rescue teams in the field, and (3) doing interviews with a fire fighter officer regarding the use of communication media to support his work. The findings from these contextual inquiries, is presented in the first section of Chapter 3, confirming in practise what has been reported in literature.

After the theoretical framework has been formed and the first direct support of the hypotheses is established, an envisioned technological solution will be proposed. The technological solution presented in this thesis is to improve the effectiveness and efficiency of the current practises. A scenario was created to put the envisioned technology, its interactions with the users, and the users' connectivity in context. This can be found in the second section of Chapter 3.

In order to support the first hypothesis, a controlled field experiment was done. The experiment evaluates the use of a mobile navigation support technology without a map interface. Instead, it incorporates an arrow that points to the direction of the destination, and shows different elementary navigational cues such as: landmark's, name of the destination, time to destination, and distance to destination. This empirical study is described in Chapter 4.

Support for the second hypothesis is established by a controlled laboratory experiment. The empirical study aims to test the possibility of constructing a shared situation map using a collaborative distributed mechanism. In this study, pairs of participants collaborate to make a situation map together using different kind of modalities. This empirical study is described in Chapter 5.

Chapter 6 supports the third hypothesis through a controlled field experiment where several participants simultaneously play different roles (the operator and the affected persons). This experiment aimed to compare the new protocol proposed in this thesis with the traditional centralized protocol that is commonly used.

Finally in Chapter 7, the study is concluded with a summary of the important findings, reflections, and contributions.

Chapter 2. Theoretical Framework

Some material presented in this chapter has been published in:

Utilizing the Potential of the Affected Population and Prevalent Mobile Technology during Disaster Response: Propositions from a Literature Survey (2012)
Lucy T. Gunawan, Siska Fitrianie, Willem-Paul Brinkman, and Mark A. Neerincx
Proceedings of the 9th International Conference on Information Systems for Crisis Response and Management ISCRAM2012.

In order to establish background support for all hypotheses introduced in Chapter 1, it is important to first understand that the affected population is often not a group of helpless victims. Instead, *the affected population are often capable humans beings, who are able to a large extent, to take care of themselves and help others during time of collective stress.* They also possess unique characteristics which can serve as a valuable resource during disaster response. The notion that affected population are capable persons is supported from the field of disaster sociology and the experience of the past humanitarian operations. It has been shown that the affected population consistently behave cohesive, calm, and helpful during time of collective stress (Quarantelli, 1986, Lomnitz, 1999, Kean & Hamilton, 2004, McEntire, 2006). They are the first to help themselves and others (Wenger et al., 1986, Quarantelli, 1999, Tierney et al., 2001). Additionally, by analysing the facts, figures, and experience from past disasters, it becomes apparent that the affected population is a massive potential resource, accounted for 94% of the population (Guha-Sapir, 2011). Furthermore, by being distributed all over the disaster area and witnessing the disaster themselves, they are a valuable resource to collect first hand information about the disaster. Therefore, the first section of this chapter forms the stepping-stone of all hypotheses explored in this thesis: it is devoted to the examination of the characteristics of the affected population and their potential role in the disaster response.

The first hypothesis states that *in a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues.* As there is no direct empirical support for this hypothesis, support for it will be explored by looking at psychological state of the affected people, looking at how people use and adopt technology during a disaster situation, examining the prevalent and suitable mobile technology, reviewing possible technological issues and solutions, and finally by examining successful navigation technology used by less technology adept or handicapped individuals such as the cognitively impaired (Liu et al., 2006, Fickas et al., 2008, Chang et al., 2010) and elderly (Goodman et al., 2004, Kawamura et al., 2008). If it is technically possible to have a mobile navigation device to successfully guide such users, then it should also be possible to use similar systems for guiding the affected population.

In order to make navigation technology work more effectively and efficiently in disaster response, an up-to-date representation of the post impact situation is required, especially in the case when the environment is altered in a way that renders the existing maps less useful. The traditional centralized mechanism of gathering this kind of information might not be efficient due to limited emergency resources that collect this information (Schneider, 2005) and the hierarchical reporting structure in command-and-control organization of disaster management (Drabek, 1985, Kean & Hamilton, 2004, Ramaswamy et al., 2006, U. S. House of Representatives, 2006b). Therefore, a distributed approach that utilizes the affected population for collecting situation data in the field is arguably more effective and efficient. The mechanism to do so, in a distributed manner, is outlined in the second hypothesis. It claims that *using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map.* Support for this hypothesis will be argued by considering the theory of rumour transmission, where communication in a network structure is superior to the chained structure (such as in the Chinese whisper game) due to the cross verification of transmitted information (Buckner, 1965). To argue that map and GPS coordinates could be better at pinpointing exact locations, examples of current inefficient practises in sharing spatial information through the exclusive use of voice communication will be studied. In the examples, emergency services were sent to the wrong address which could have led to terrible consequences (Udtke, 2008, Herald Canada, 2008). Additionally, examples of collaborative map-making for disaster response will be discussed, such as OpenStreetMap for the Haiti earthquake (Goodchild, 2007).

Good coordination is needed for an effective response (Gao et al., 2011). Even though the command and control model was criticized by disaster sociologists for its inflexibility (Comfort, 1985, Neal & Phillips, 1995), this thesis does not dismiss its eminent role. However, it seeks to enhance the effectiveness of the model by proposing a more proactive role for the affected population. This leads to the third hypothesis, *by collaboratively sharing spatial information between the affected population and professional actors on-and-off location: (a) the affected population will be guided in a safer manner and (b) a more accurate disaster situation map will be constructed, which in turn will better facilitate the relocation of the affected population, in comparison to the commonly used system.* The collaboration between the emergency services and the affected population is necessary. This is due to two different kinds of information that both parties posses that may complement each other: (1) the affected population has the knowledge of what is going on in the field, while (2) emergency services have the knowledge of: population data, emergency facilities, shelter locations, and vulnerable infrastructures. Support to this claim will be provided by looking at crowdsourcing systems through popular and social media (Gilmor, 2004, Palen & Liu, 2007) and cross-sector collaborations (Simo & Bies, 2007, Maon et al., 2009, van der Vijver et al., 2009)

This chapter is organized as follow: the first section of this chapter will make the argument that the affected population are capable human beings who can potentially help themselves and others during disaster response. The second section supports the first hypothesis indirectly, describing the need for mobility during disaster response and available navigation technology for people with special needs; The third section substantiates the second hypothesis, highlights the need for distributed collaborative sensemaking for disaster response, where the disaster situation awareness is often difficult to be acquired; and finally the fourth section gives substance to the third hypothesis, which argues that crowdsourcing can be a powerful mechanism for gathering information from the field, and a cross-sector collaboration is needed. This chapter ends with a conclusion of all the indirect evidence supporting the main thesis and outlines the scheme of succeeding empirical studies for support of the hypotheses directly.

2.1. The affected population as capable human beings

The affected population are often capable humans beings, who are able to a large extent, to take care of themselves and help others during time of collective stress

There are a number of preconceptions by the general public and members of the emergency services regarding how people behave in times of disaster. These preconceptions are that in times of emergencies, human behaviour is unalterably changed and these changes are not for the better. They include the assumptions that people are gripped by a sense of helplessness, they panic and act irrationally, they look after themselves with little or no regard for others, they are in a continuous state of shock, engage in chaotic mass evacuations, and exhibit increasing anti-social behaviour (Thristan, 1995, McEntire, 2006). It is therefore striking, that evidence gathered from the reviews of human responses to disaster over five decades, shows that those responses are actually overwhelmingly adaptive and positive (Quarantelli, 1999). Still, despite what is known, myths about disaster behaviour persist. These myths seem mainly sustained as a result of: (1) the consequences of used disaster management that is based on the command and control centralized management model, and (2) the influence of Hollywood movies and mass media in depicting disaster.

2.1.1. THE CENTRALIZED DISASTER MANAGEMENT SYSTEM

Many disaster management practices worldwide are adapted from various derivations of the command and control approach (Neal & Phillips, 1995). It is based on a series of rational bureaucratic principles and relies on a command-and-control model, where a designated authority controls personnel and resources in a hierarchical reporting structure for the purpose of executing a mission. This approach was often chosen due to its foreseen benefit of distinct authority and responsibility (Cronan, 1998, Tierney, 2006). These approaches assumed that the scene of the disaster is engulfed in chaos, and that the most important task after disaster impact is to establish control over a chaotic situation as soon as possible (Dynes, 1994). This assumption infers that the affected population is part of this chaos, making it necessary to remove them from the disaster area in order to establish control and restore order (Tierney, 2006). This assumption is often worsened by another assumption that the affected population that has to be rescued, is subjected to terrifying experience and trauma, leading to a reduced capacity of these individuals to cope with or respond to the situation (Dynes, 1983, 1994). As a result, the affected population is mostly treated as helpless and dependent human beings, who can not help themselves (Cronan, 1998). In spite of its popularity, the centralized disaster management approach has been criticized heavily by disaster sociologists due to the model's ignorance and misinterpretation to research literature that discredits disaster myths. Further, this model also overlooks the emergent phenomena of individuals and groups during a disaster (Britton, 1989, Wenger et al., 1990, Dynes, 1994, Drabek

& McEntire, 2003). It is regarded by disaster sociologists as strict, rigid, centralized, and a bureaucratic military approach to disaster management (Comfort, 1985, Neal & Phillips, 1995).

2.1.2. MEDIA INFLUENCE

To a large extend, the popular view of the affected population as helpless victims and people's misconceptions about human behaviour in a disaster comes from Hollywood movies and the mass media (Fisher, 1998, Mitchell et al., 2000, McEntire, 2006a, Tierney, 2006). Quarantelli (1985) argues that most people never experience a disaster themselves, the knowledge of how people behave in a disaster comes from popular culture. Unfortunately, the information presented in movies is usually only meant to entertain and stimulate excitements. A healthy suspension of disbelief is required to maximize enjoyment. Disaster movies often do not reflect disaster reality. From disaster movies analysed by Quarantelli (1985) and Mitchell et al. (2000), human are generally shown to be powerless in the face of events that are unpredictable. McEntire (2006a) argues that the same is true for the information conveyed by reporters, who focus on sensational and unusual stories to make the news more interesting. Media reports about disaster impacts are often exaggerated, have the tendency to suggest that victims cannot care for themselves. This viewpoint may serve the purpose for fund raising, for help. Although some victims may be overwhelmed or otherwise incapacitated due to the disaster, most are not helpless (McEntire, 2006a). Thus, because of these exaggerations in both Hollywood movies and the mass media, make the disaster movies are: (1) often incorrectly or inaccurately portray human behaviour in disasters (Lomnitz, 1999, McEntire, 2006a, Tierney, 2006), (2) untrue or may not representative (Quarantelli & Dynes, 1972), and (3) not empirically valid (Wenger et al., 1975).

2.1.3. WHAT IS ACTUALLY OBSERVED

Contrary to the belief that disaster victims are helpless, the reality of disaster behaviour is quite different. This has been argued for many years by disaster sociologists who have observed human behaviour during emergencies. The affected population in a disaster are actually capable humans. People tend to act logically and rationally with calm behaviours (Quaratelli, 1986, Lomnitz, 1999). For instance, while the World Trade Center towers burned out of control during the September 11, 2001 (9/11) terrorist attack, people were seen walking calmly out of the building as if they were reacting to a fire drill (McEntire, 2006a). Panic flight is rare, occurring only when there is an imminent threat to the well-being of the person or people evacuating (Drabek, 1986, Tierney, 2006). Evidence suggests that victims exhibit shock symptoms in a minority of disaster cases. Most victims do not have long-lasting mental health effects. According to Tierney et al. (2001), the congregate care utilization, the facility utilization where shelter and food is provided to evacuees, is likely to be in the range of 5-15%. Disaster victims are more immune to the disaster shocks, more innovative in resolving their problems and more resilient in the wake of severe challenges that they are given credit for (Quarantelli & Dynes,1972, Fisher, 1998).

Generally, those affected by disaster are most likely to be proactive, rather than wait for emergency personnel to arrive at the scene, they take care of themselves and others (Quarantelli, 1999, Wenger et al., 1986, Tierney et al., 2001, McEntire, 2006) and exhibit a great deal of pro-social behaviour (Lomnitz, 1999). Although anti-social behaviours, such as looting, violence and price gauging, do occur, research showed that they are likely exception rather than the norm (Quarantelli, 1965, Bryan, 1982). Instead of reacting in an anti-social manner, individuals form groups and typically become more cohesive and unified during collective stress. (Quarantelli, 1986, Drabek & McEntire, 2003). For instance, affected persons, organizations and communities are the first to help themselves after disaster impact (Wenger et al., 1986, Quarantelli, 1999, Kean & Hamilton, 2004). During and immediately after the emergency, an immense feeling of community spirit is usually evident, with people helping each other who, prior to the event, did not even know each other. Mental barriers are broken down by the need for self-survival and assistance of others (Thristan, 1995).

This phenomenon has also been verified by experience drawn from humanitarian aid organizations (WHO, 1989). Instead of being too shocked and helpless to take responsibility for their own survival, the affected population, finds strength during an emergency, as evidenced by the thousands of volunteers who spontaneously unite to sift through rubble in search of victims after an earthquake. Volunteers have always been an essential component of community resources (fire brigades, Red Cross, and faith-based organizations) which provide assistance to disaster victims as well as emergency services (Waugh & Streib, 2006). It also discredits the myth that disaster brings out the worst in human behaviour by showing the reality while isolated cases of antisocial behaviour exist, the majority of people respond spontaneously and generously. Additionally, most of the time, the local population almost always covers immediate lifesaving needs.

2.1.4. AFFECTED POPULATION AS POTENTIAL RESOURCE

The total affected population excluding those who are injured, usually form the largest group of people involved in a disaster. For example, in the Haiti earthquake of 2010, the total affected accounted for 92% of the population and the 2008 China-Sechuan earthquake had affected 99% of the population (CRED, 2012). Of the affected who are injured, the majority are the walking wounded. The walking wounded are those victims who suffer from relatively minor injuries, and, are still physically capable of walking. The 2005 London bombing produced the largest number of mass casualties in the UK since World War II. Of the injured, 86% was categorized as walking wounded (Aylwin, et al., 2007). Around 78% of the injured during the 2004 Madrid commuter train bombing, who were treated at the Gregorio Maranon University General Hospital, were reported to be walking wounded (de Ceballos, et al., 2005). Likewise, the September 11, 2001 New York terrorist attack counted 85% of its injured victims as walking wounded (Cushman, et al., 2003).

With this amount of capable human beings, the affected people are a massive potential resource to help in disaster response. Furthermore, by being distributed over the disaster area and witnessing the disaster themselves, the affected people is an invaluable resource to collect first hand information about the disaster.

Having established the potential of affected people in this first section, it forms the foundation of all hypotheses, that will be further substantiated in the next sections.

2.2. *Navigation technology for disaster response*

Hypothesis 1: in a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues.

2.2.1. PHYSICAL MOVEMENT IN DISASTER AREA

Most physical movement after disaster impact, according to Provitolo et al. (2011) is to ensure the protection and survival of oneself or close relatives. Some other motivations for civilian physical movement in the disaster area include: travel to get home or get to shelter, collecting of close relatives (generally within a short radius), curiosity, grouping, assistance, and rescue. Members of the affected population often travel in groups, sometimes under the authority of a leader or by individual actions (Provitolo et al., 2011). As social studies show, during a disaster, individuals and groups at a local level typically become more cohesive and unified (Quarantelli, 1986, Drabek & McEntire, 2003), they naturally pull together and form small support groups and function in response to disasters (Wenger et al., 1986, Quaranteli, 1999, Kean & Hamilton, 2004). These groups usually consist of family, friends, neighbours, coworkers and other people, who happen to be at or near the scene at the time of disaster impact (Quarantelli & Dynes, 1972, Drabek et al., 1975, der Heide, 1996).

The physical movements of citizens and emergency services typically happen during the disaster response phase of the disaster management cycle. The response phase is one of the four phases of emergency management: mitigation, preparedness, response, and recovery (Drabek, 1990, Turoff et al., 2009) as seen in Figure 2.4. The mitigation and preparedness occur pre-disaster, while response and recovery occur post-disaster (Drabek, 1990). The response phase includes actions taken immediately prior to impact, as well as during and after the disaster event, that help to reduce human and property losses. Examples of such activities include: situation analysis, construction of a crisis map, evacuation, search and rescue, managing and re-establishing logistical routes, provision of humanitarian assistance (medical services, basic need supply, shelters), mobilizing emergency responders and services, and an initial damage and needs assessment (Turoff, 2009, Baird, 2010, van der Walle et al., 2010, Piper, 2012). However, disaster sites may become inaccessible to responders and recovery forces due to obstruction, hazardous conditions, or remote location, making on-the-ground observation difficult

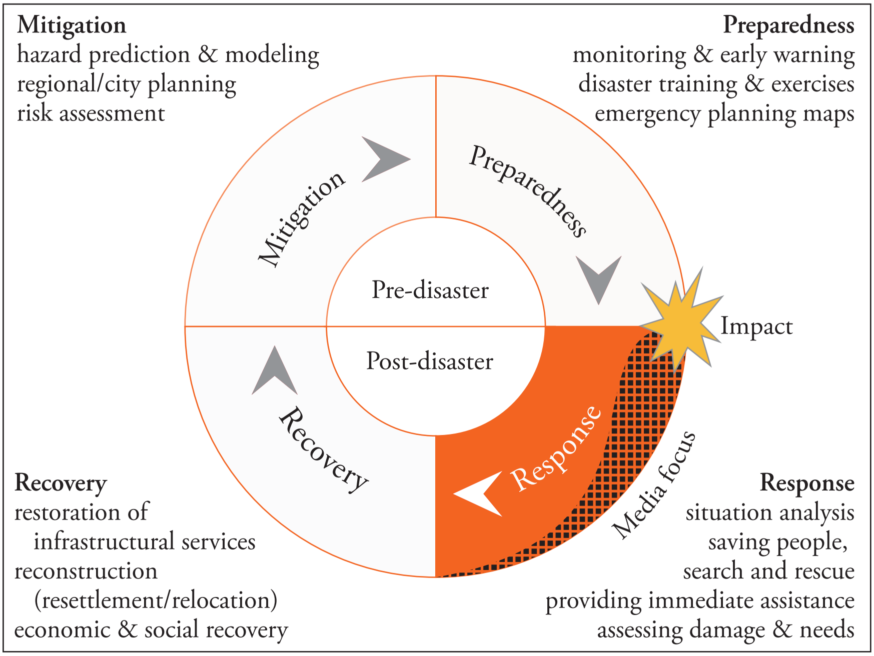


Figure 2.4. Disaster management cycle. This figure is based on the disaster management cycle adapted from Australian Development Gateway.

or impossible. Additionally, major events (such as earthquakes, tornadoes, explosions, and fires) may have significantly changed the area. As a result, extensive damage may be caused to infrastructure, such as collapsed or severely damaged buildings and blocked or destroyed road networks. Consequently, this renders earlier geographical data obsolete (van der Walle et al., 2010).

2.2.2. PEOPLE AND TECHNOLOGY IN DISASTER SITUATION

Not everyone is equally affected by a disaster, and not all disasters are equally devastating in psychological terms. Some types of disasters may result in less adverse psychological effects than others. In general, the psychological consequences of purely natural disasters (e.g. earthquake, tornado, flood) have less likelihood of producing adverse effects compared to those disasters produced by unintentional human activities (e.g. airplane crashes, industrial explosions) and intentional disasters which are inflicted by others (e.g. assaults, terrorist attack, war) (Becker et al., 2008). Tyhurst (1957) and Edwards (1976) describe two important phases of a survivor's psychological phenomena immediately after disaster impact: (1) the period of impact, and (2) the period of recoil. During the period of impact, which may vary between three to five minutes up to one hour, about 12-25% of people retain their awareness, appraise the situation, can formulate a plan of action, and are able to see it through. About 75% of survivors shows signs of emotional disturbance, which should be considered as normal, transient, recovering spontaneously, or responding quickly with the help of sympathetic support. The remaining 10-25%, shows responses of confusion, paralysing anxiety, crying, and screaming. During the period of recoil, which begins when the initial stress has ceased and lasts from several hours to a day or two, there is a gradual return of awareness, recall, and emotional expression. The majority of survivors seek shelter, move into homes of friends or relatives, obtain temporary shelter or care, or give an account of their experiences for the first time. Survivors need to be with others and have a desire to ventilate their feelings.

Recent crisis events have shown that people who are caught in an emergency or disaster use whatever means of technology that are available to them to fulfil their needs, especially for information seeking (Boyle et al., 2004). They are able to creatively utilize familiar technology, or quickly adopt new unfamiliar ones for their purpose, such as: the use of text messaging, mobile phones, Twitter, blogs, conference calls, photo and video sharing, and forums (Fox et al., 2002, Procopio & Procopio, 2007, Hughes & Palen, 2009, Shklovski et al., 2010). These examples illustrate that disaster events catalyse the creative use of available technologies.

It is clear that mobile technology is becoming increasingly prevalent among the world's population. Mobile cellular subscriptions in 2010 amounted to 76.2% of the world's population with 13.6% of users having mobile broadband subscriptions (ITU, 2011). It is estimated that the global penetration of 3G broadband handsets will reach 43% by 2014 (Meeker et al., 2010). Mobile market researchers predict that GPS functionality will be incorporated in 79.9% of mobile phones shipped in the 4th quarter of 2011 (Rebello, 2010). Likewise, camera-phone shipments are predicted to reach 74% of all handsets sold in 2011 (Ben-Aaron, 2011).

Disaster motivates technology users to adopt technologies that afford a higher mobility such as mobile phone and laptop (Shklovski et al., 2010).For more than a decade, scientists have reported the great interest that police departments, firefighters, and paramedics have showed in utilizing handheld communication devices for quick and efficient exchange of information in control rooms, headquarters and hospitals (Mikawa, 2006).

As with any mobile technological solutions, mobile GPS devices are dependent on local power and data networks. As such, their functionality can be interrupted if any of these vital infrastructures are disrupted. However, there are many technological solutions that have been developed to make such devices resilient in the face of limited resources. For example, alternative power sources have already been used to power electronic devices where no electric networks are available. Products such as the Solio are already available in the market and capable of charging mobile phones using solar energy (Solio, 2012). The famous wind-up radio, invented by Trevor Graham Baylis, represents another route to tackle this problem. Alternatively, developments in battery technology promise longer battery lives and shorter charge times (Garche, 2009, Kang & Ceder, 2009, Scrosati & Garche, 2010).

Some mobile carriers, such as AT&T have developed the mobile ad-hoc network (MANET) for rapid deployment of small cell sites in areas where a disaster has knocked down communication channels. It can be packed in a suitcase (extend connectivity up to 0.8 km in any direction) (AT&T, 2011). The architecture of MANET employs a peer-to-peer wireless network between handheld devices that does not require the use of a central base station (Mahaptra et al., 2010). In the UK flood in 2007, ad-hoc networks from ISPs were deployed with borrowed generators and re-routing facilities to offer limited access for some users in the affected communities. In addition, many telecommunications companies were surprised by the resilience of networks that continued to function even in areas of considerable flooding. It turned out that the increasing use of optical fiber, rather than copper cabling, was an important factor in explaining why some communities continued to access the digital infrastructures (Johnson, 2009). After the impact of Hurricane Katrina, it was possible to rapidly re-establish communication using the mobile infrastructure by (partially) replacing components that were damaged during the disaster (Rao et al., 2007).

2.2.3. ASSISTIVE NAVIGATION DEVICE

Several studies have reported the use of mobile devices for navigation assistance, implemented for individuals with cognitive impairments and the elderly. A handheld navigation device functioning as a pedestrian route finding device in the form of a personal digital assistant (PDA) guided adults with cognitive impairments such as Traumatic Brain Injury (TBI), mental retardation (Downs Syndrome), and Cerebral Palsy (CP). Both indoor (Liu et al., 2006, Chang et al., 2010) and outdoor (Fickas et al., 2008) implementations showed that all users were able to follow the directions to reach their destination. Another study with CP patients used a wheelchair with assistive navigation. It allowed users to select arbitrary local destinations through a tactile screen interface. All CP users were able to carry out the navigation mission along the circuit with relative ease (Montesano et al., 2010). Furthermore, Goodman et al. (2004) showed that an electronic handheld pedestrian navigation aide based around landmarks was more effective for older people than an analogous paper version. Another study showed that a mobile navigation system for urban environment for the elderly that employs cellular phones equipped with GPS for urban environment is useful for them to go out into society (Kawamura et al., 2008). In some aspect, the diminished capacity of cognitive impaired and the elderly might be analogous or worse than the decreased cognitive abilities of the affected population under the stress of the disaster situation. If so then these studies show that such a system for guiding the affected population might be useful in a disaster.

2.3. Collaborative situation-map making

Hypothesis 2: Using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map.

2.3.1. DISTRIBUTED SENSEMAKING

In order to make navigation technology operate more effectively and efficiently, an up-to-date model of the disaster environment is required. In such a situation, the environment is altered, rendering existing maps useless. Thus, there is a great need for constructing a new map that is representative of the post impact disaster situation in a rapid, accurate, and continuous process. The action of continuously gathering up-to-date information and making sense of the disaster situation is known as sensemaking (Weick, 1995), while the resulting output is known as situation awareness (Endsley, 1995). The situation map is one of the products of situation awareness. This map is essential for the mobilization of affected people and emergency services at the disaster site, in the disaster response phase (Figure 2.4). Without awareness of the situation, any deployment or mobility in the area of disasters can be dangerous since the areas may contain hazards and potential threats, and it may cause delays to the relief efforts as well (U.S. House of Representatives, 2006a, U.S. The White House, 2006).

Unfortunately, it is difficult to acquire and to maintain situation awareness, especially on a complex and large-scale disaster area with widespread damage. This is not only caused by the dynamic nature of the event, but also, and to a large extent, by the inefficient organization model of crisis management in obtaining and making sense of disaster situation that is geographically distributed across the disaster area (Kean & Hamilton, 2004, Ramaswamy et al., 2006, Tierney, 2006). With a hierarchical reporting structure and a military type command-and-control model, it is difficult and time consuming to continuously collaborate and verify the obtained information (Drabek, 1985, U. S. House of Representatives, 2006b, U. S. The White House, 2006). The limited emergency services are overwhelmed (Schneider, 2005) and linear chains of information transmission can leave incorrect information unnoticed (Buckner, 1965) and cause delays in relaying updates (Sobel & Leeson, 2005), thus rendering the situation awareness not only not up-to-date but also inaccurate (U.S. House of Representatives, 2006a).

Therefore, a distributed approach that utilizes the affected population for collecting situation data in the field is arguably more effective and efficient. As argued previously, the affected people are capable human beings who are able to creatively use technological support. They are distributed spatially and temporally over the disaster area, experiencing disaster first hand, making them valuable reporters of what is going on in the field (Palen & Liu, 2007). The reports can be environment related (damaged, unstable, and dangerous infrastructures), places where immobilized victim need to be rescued, or simply automatically sending the used route through the disaster area (METI, 2011). With enough people in this process, the disaster situation and passable road networks can emerge in a shorter amount of time compared to time needed for the limited number of emergency workers to survey the disaster area (Utani et al., 2011).

2.3.2. THE SHARING OF DISTRIBUTED OBSERVATIONS

Maps can be considered as the best medium for displaying spatial information, while GPS coordinates might be the best way to relay that information. Situation maps are demonstrated to be an essential collaboration tool in crisis situations (MacEachren, et al., 2005). Yet, the current practices heavily depend on the sole use of voice communication through conventional pathways (landlines, airways, and satellite links) (Garshnek & Burkle Jr., 1999, Chan et al., 2004), and text messages (pager) to relay location data, which can, very predictively, lead to errors with terrible consequences. For example, a German fire brigade was directed to the right address but in the wrong city (Udtke, 2008) and an ambulance was sent to the wrong address (Herald Canada, 2008). Location information is not only important for pinpointing addresses, but also for coordinating emergency personnel and ensuring that the right action is performed in the right location (Schoning et al., 2009). The emergency services is to be in a hazardous areas, such as in a city after being hit by a major earthquake that has unstable infrastructures, or a chemical leak resulting from a derailment of a cargo train. In such situations, graphics and maps are valuable assets in addition to verbal communication. Spatial information provides effective situational awareness through a common operating picture that presents information in a spatial context. It aids thinking and prompt decision-making since humans can process visual data more efficiently than textual data (Kraak, 2001).

Considering the dynamic nature of disaster situations, information accuracy is one of the key aspects that needs to be taken into account. It is argued that with a distributed network pattern of information sources (Buckner 1965), with many people contributing and verifying information, an accurate situation map will emerge. Additionally, with the rapid speed of information update, it seems to be better suited for dynamic environments. Wikipedia.org illustrates the successful power of participation (Bryant et al., 2005). Individuals around the globe came together, unsolicited, to contribute their knowledge and provide volunteer editorial services to create a high-quality freely accessible information resource. It is counter intuitive that an encyclopaedia, where anonymous contributions are accepted, that can be edited at anytime and anywhere, could be accurate by any standards.

2.3.3. DISTRIBUTED COLLABORATIVE MAP MAKING

In the Great East Japan Earthquake and Tsunami of 2011, traffic information maps based on real-time passable route data was collected via navigation systems and used to generate maps to assist people inside the impacted area (METI, 2011). In the Haiti Earthquake of 2010, OpenStreetMap (Goodchild, 2007) was used substantially for a massive mapping in a very short time since Haiti did not have a digital map before the disaster. It was reported that within 48 hours after the earthquake, a complete map of Port-Au-Prince and Carrefour was drawn by collaboration of hundreds of volunteer mappers around the world using the post-quake aerial imagery (ITO-World, 2010). The resulting digital map was used extensively for the disaster response, damage reports and transportation purposes by emergency services, humanitarian organizations, and search and rescue missions.

2.3.4. PARADIGM SHIFT TOWARD DISTRIBUTED PARTICIPATORY MECHANISM

As mentioned above, the centralized disaster approach is based on a military operational management model. However, even here, the advantages of collaborative information sharing and distributed participatory mechanism have not gone unnoticed. In the past decade, the military institutions in some countries, such as: the U.S.A, the United Kingdom, Australia, Canada, and Sweden, have started to transform their organization and concept of operation to a network-centric model that allows nonlinear interaction, decentralization, and self-organization (Australian Government Department of Defence, 2002, Michell, 2009, Perry et al., 2004, Ministry of Defence UK, 2009, Wilson, 2007). Thus, there is a movement from a hierarchical mode of thinking to a model powered by collaborative (human) networks. This paradigm shift was pioneered by the USA around 1998 by a new military doctrine, which is now commonly called Network-Centric Warfare (NCW). NCW is a theory which proposes to translate information advantage to speed communication and increase situation awareness through networking of well informed geographically dispersed forces. The NCW theory is aimed to increase mission effectiveness by: a networked force to improve information sharing, information sharing that enhances the quality of information and shared situation awareness, and a shared situation awareness which enables collaboration and self-synchronization and further enhances sustainability and speed of the command structure. The Network-Centric Operation has been successfully deployed by the U.S.A. in Afghanistan and in Iraq during Operation Iraqi Freedom (OIF) (Cebrowski, 2005).

2.4. Crowdsourcing and cross-sector collaboration

Hypothesis 3: By collaboratively sharing spatial information between the affected population and professional actors on-and-off location: (a) the affected population will be guided in a safer manner and (b) a more accurate disaster situation map will be constructed, which in turn will better facilitate the relocation of the affected population, in comparison to the commonly used system.

2.4.1. THE POWER OF CROWDSOURCING

The popularity and accessibility of social media tools and services open up more opportunities for community collaboration through crowdsourcing. Journalism activities by citizens bring the use of Internet and mobile phones together to communicate disasters through popular media (Gilmor, 2004, Palen et al., 2009). During the Indian Ocean Tsunami 2004, the Hurricane Katrina 2005 and the Haiti earthquake 2010 disasters, people used social networks, Wikipedia, blogs, photo and video sharing, and websites to report the situations and offer of shelter, jobs, and emotional support (Laituri & Kodrich, 2008, Gao et al, 2011). Microblogging (Twitter) was used as a medium to harvest information during Oklahoma Grassfire 2009 and Red River Flood 2009 (Vieweg et al., 2010). SMSs have been used extensively during the China SARS epidemic in 2003 to inform others about the physical locations of apparent SARS victim (Law & Peng, 2004). In addition, after the underground bombings in London, UK, citizens use camera phones with MMSs to capture photos and videos of structural damage in specific places of underground surroundings. In Hurricane Katrina 2005, emergent shelter call centers and web sites appeared to provide virtual information exchange, such as places for people who need to be rescued, missing persons, support or help offers and questions about relief assistance (Palen & Liu, 2007).

Two examples of major crowdsourcing systems that have been deployed in several countries are Ushahidi and Sahana. Ushahidi (2008) is a disaster map platform that can integrate data from various resources, such as phones, web applications, e-mail, and social media sites. It has been deployed in many countries, including Kenya, Mexico, Afghanistan, and Haiti. The platform uses the concept of crowdsourcing for social activism and public accountability to collectively contribute information, visualize incidents and allow cooperation among various organizations. Sahana (2009) is an open source disaster management system that provides a collection of tools to help manage coordination and collaboration problems resulting from a disaster (Samaraweera & Corera, 2007). The major functions are support for the search for missing persons, coordination of relief efforts, matching donations to needs, tracking the status of shelters, and reporting news. Additionally, Sahana facilitates the management of volunteers by keeping track of their skills, availability, allocation, etc. These two examples show the new movement in the disaster response. It recognizes the power of the crowd in supplying data of a disaster situation. As it has already been deployed to assist humanitarian operations in several major disasters, it shows the feasibility of this kind of system to be used in disaster situations.

2.4.2. THE NEED FOR COORDINATION AND COLLABORATION BETWEEN PROFESSIONAL AND NONPROFESSIONAL ACTORS

Although crowdsourcing applications can provide relatively accurate and timely information, Gao et al. (2011) and Romundstad, et al. (2004) pointed out that the lack of collaboration and coordination between emergency services, the affected population, and other response sectors may cause unevenness of effort and logistics. For example, since most initial casualty transport is carried out by the survivors, most disaster casualties end up at the closest hospital while other hospitals in the area wait for patients who never arrive (der Heide, 1989). Further, in U.S. Hurricane Katrina 2005, 60% of the material that was ordered ended up unused by the Federal Emergency Agency (USD 900 million in manufactured homes and 110 million pounds of ice), while many suffered in desperate need of housing and relief from the heat (U.S. House of Representatives, 2006a).

If the emergency services are not ready for collaboration and incorporating citizen's report in the process and organization, they will further overburden themselves. For example in the current bureaucratic practice, verification of citizen's reports is often a lengthy process. By having multiple message verifications and multiple steps to prioritise the response, the response time is delayed (Gates, 2007, Marlar, 2007). Such a protocol adds extra pressures and workloads on the emergency services, especially in mass-casualty disasters, when the information center is usually already overloaded with flood of inputs and questions (Kean & Hamilton, 2004). This not only makes the information center slower in understanding the disaster situation but also makes their situational awareness often incomplete and outdated.

Therefore, a collaboration between the emergency services and the affected population is necessary. The concept of citizen participation based on their geographic location in collaboration with the professional services, has been studied and acknowledged for decades. Some public policing researchers (Ostrom et al., 1978, Whitaker, 1980, Bayley & Shearing, 1996) argue that the production of local safety should be conceptualized as a joint operation or co-production between police and citizens. This way, citizens are not regarded as passive 'objects' of safety policies but rather as active 'coproducers' of these policies. Cross-sector collaboration is increasingly recognized as an important vehicle for strategically managing responses to public problems that require contributions from different sectors of society (Bryson et al., 2011). Bryson et al. (2006) defined cross-sector collaboration as "partnerships involving government, business, nonprofit and philanthropies, communities and/or the public as a whole". This way, they can share information, resources, activities, and capabilities by organizations in two or more sectors to achieve jointly an outcome that could not be achieved by organizations in one sector separately. Cross-sector collaboration is increasingly assumed to be a series of strategies for dealing with most difficult public challenges in current society, such as natural disasters and emergency management.

Attempts have been made to apply cross-sector collaboration, such as in the field of transportation, employment, GIS, and lead-agencies, self-governing, and partnership administrative organization governance systems (Provan & Kennis, 2007). For example, MetroGIS is a geospatial collaborative organization serving in the Minneapolis-St. Paul metropolitan area (MetroGIS, 2012). It has provided a regional forum to promote and facilitate widespread sharing and use of spatial data of multiple metropolitan areas. It is coordinated and staffed by the regional government involving over 300 local volunteers and regional governments, partners in the state and federal governments and academic institutions, nonprofit organizations, and business. In the field of disaster management, cross-sector socially oriented partnerships between nonprofit, businesses and government have been applied in the disaster relief field focusing on humanitarian work and logistics (Simo & Bies, 2007, Maon et al., 2009). For example, the relief phase of Hurricane Katrina disaster has mobilized collaboration of multiple government agencies, such as emergency management, law enforcement, transportation, public health, housing and welfare, and so on, and non-governmental agencies such as volunteer organizations, local religious institutions, businesses and individuals.

In the Netherlands, this concept has been implemented recently: Burgernet (van der Vijver et al., 2009), SMS-Alert (Korteland & Bekkers, 2007), AMBER Alert (amberalertnederland.nl), and the most recent 'Politie App' (den Elt, 2011). Burgernet, and SMS-Alert is a partnership between citizens, municipalities, and police using voice communication through (mobile) phones to promote improvement of safety in the home and work environment. It uses a citizen as sensor network, being the eyes and ears of the police in the neighbourhood, citizens become engaged in the attack and prevention of local crime, such as theft or burglary, violence, or search for a missing person. AMBER Alert is a national alert system for missing children and children abduction. It works within 10 minutes in which the picture of the missing or abducted child is being distributed and shown via mobile phones, TV, PC, Facebook, Twitter, iGoogle, website's, highway signs, TV screens in buses, supermarkets, and cinemas. The recent 'Politie App' for iPhone and Android that was launch in mid November 2011, allows photos and videos of serious crimes to be sent directly to the police. By including citizen participation in the early stages of the incident, citizens can either report incidents or volunteer to be contacted for help if an incident takes place in their vicinity in real time (van der Vijver et al., 2009, Meijer, 2010).

2.5. Conclusion

This chapter contained a literature study investigating the indirect evidence for supporting the main thesis hypothesis, and its three sub-hypotheses. The main hypothesis claims the affected population in a disaster can safely travel through a disaster area effectively and efficiently through a participatory mechanism by collaboratively sharing spatial information among professional and nonprofessional actors during the disaster response. A critical analysis of relevant literature and examples for each sub-hypothesis, substantiated the evidence to support the main hypothesis indirectly. Therefore, this chapter forms the theoretical foundation for this thesis.

Studies have shown that the affected population in a disaster consists of capable human beings who form an enormous potential resource for helping disaster response. It was apparent that they are able to use technology at hand creatively, both familiar and unfamiliar ones. At the same time, the mobile phone becomes prevalent, not only equipped with GPS but also cameras and mobile data access. The combination of distributed affected population, witnessing the disaster first hand, and prevalent technology, makes the affected population seems to be valuable active sensors to emergent situation awareness. Finally, it was shown from lessons learned from past disasters that collaboration between professional and nonprofessional actors in disaster response can make the disaster response more efficient and effective. By having this evidence, it seems to be worthwhile endeavour to further study the topic in more detail. This chapter supports the main thesis hypothesis indirectly through comprehensive literature reviews. The next chapters will provide direct support, where each sub-hypothesis will be further substantiated through series of contextual inquiries of the state-of-the-art system, interviews, and controlled experimental studies.

Chapter 3. Current situations and the Envisioned System

Some material presented in this chapter has been published in:

Envisioning Collaboration at a Distance for the Evacuation of Walking Wounded (2007)
Lucy T. Gunawan, Martin Voshell, Augustinus H. J. Oomes, and David D. Woods
Proceedings of the 4th International Conference on Information Systems for Crisis Response and Management ISCRAM 2007, pp. 431-437.

Collaboration-Oriented Design of Disaster Response System (2008)
Lucy T. Gunawan
Proceeding of Computer Human Interaction, CHI 2008, pp. 2613-2616, ACM New York, NY, USA.

While Chapter 2 provided support for the hypotheses indirectly through comprehensive literature reviews, this chapter provides support for three hypotheses directly by observing and understanding the current practises in disaster management. This was done by using a contextual inquiry method in three occasions: (1) observing the operations of a disaster management team at a command center, (2) observing the operations of search and rescue teams in the field, and (3) conducting interviews with a fire fighter officer regarding the use of communication media to support his work. The findings from these contextual inquiries confirmed what has been observed from the literature: (1) that chains of information can result in an outdated situation map and (2) conveying spatial information through the sole use of voice communication may lead to inaccurate position information. The contextual inquiry at the worksite also showed that maps are often needed to understand and explain a complex situation, and that the affected people can be a useful source of information for search and rescue teams.

The first section of the chapter describes the contextual inquiries and the interviews done in order to understand the current practises of disaster management. After problems and issues are identified, focus will be placed on how technology can address these shortcomings. The second section of this chapter describes the envisioned technological solution to improve the effectiveness and the efficiency of the current practises.

3.1. Current situation

To understand and experience the dynamics of disaster management, the interactions among involved actors and their activities, several different contextual inquiries were conducted, both in the command center and on the rescue worksites. Two contextual inquiries in the command center were conducted during local and nation-wide disaster management exercises in Rotterdam, the Netherlands. The field observations on a rescue worksite, was conducted during a four-day exercise in the Netherlands' Urban Search and Rescue (USAR.NL) in Ostrava, Czech Republic. Additionally, an interview about communication media used by fire fighters in the Netherlands was conducted with a fire fighter officer in Rozenburg, the Netherlands.

3.1.1. METHODOLOGY: CONTEXTUAL INQUIRY

The methodology used for all the field observations is a contextual inquiry (Beyer & Holtzblatt, 1995, 1999). Contextual inquiries are conducted to understand the working of specific roles or tasks, to learn their responsibilities and the structure of the roles, and to learn the details necessary to support a task in the context (or workplace). It is a user-centered design ethnographic method, where the researchers collaborate with users to understand the user's work by alternating between observing the user activities and discussing what the user did and why. The researchers share their interpretations and insights with the user during the interview. The user may expand or correct the researcher's understanding. In addition, the researcher gathers detailed retelling of specific past events when they are relevant to the project focus. Actions, events, conversations, and interesting findings are thoroughly noted and photographed. The most interesting findings occur when a problem is encountered or when things go wrong. Following the contextual inquiry field interview, interpretation sessions are conducted as a way to analyse the data. In an interpretation session, usually 2-4 team members gather together to hear the researcher re-tell the story of the interview in chronological order. As the interview events are listed, the team adds individual insights and facts as notes. Further, weaknesses in the process are examined to understand the possible causes and compare it with what have been found in the literature. After patterns of data are analysed, the issues are formulated as findings or assertions.

3.1.2. CONTEXTUAL INQUIRY IN A COMMAND CENTER

The contextual inquiries in the command center related to disaster management were done in the Safety Region (veiligheidsregio) of Rotterdam-Rijnmond, The Netherlands. This safety region organizes the crisis and disaster management in the Rotterdam area of the Netherlands. The participating agencies are municipalities, the fire brigade, the ambulance service, the medical emergency service, the police, the dispatch center, the Rotterdam port authority, and the environment protection agency.

Observations and interviews were collected of the work of the team in two exercises: (1) at the regional level and (2) nationwide. In the regional exercise, an accident involving explosion in one of the chemical storage tanks in the Rotterdam harbour was simulated, together with a plane crash in the Rotterdam city center. The one-day observation was performed on 10 July 2008. The national level exercise observed was 'Waterproef', the first nationwide

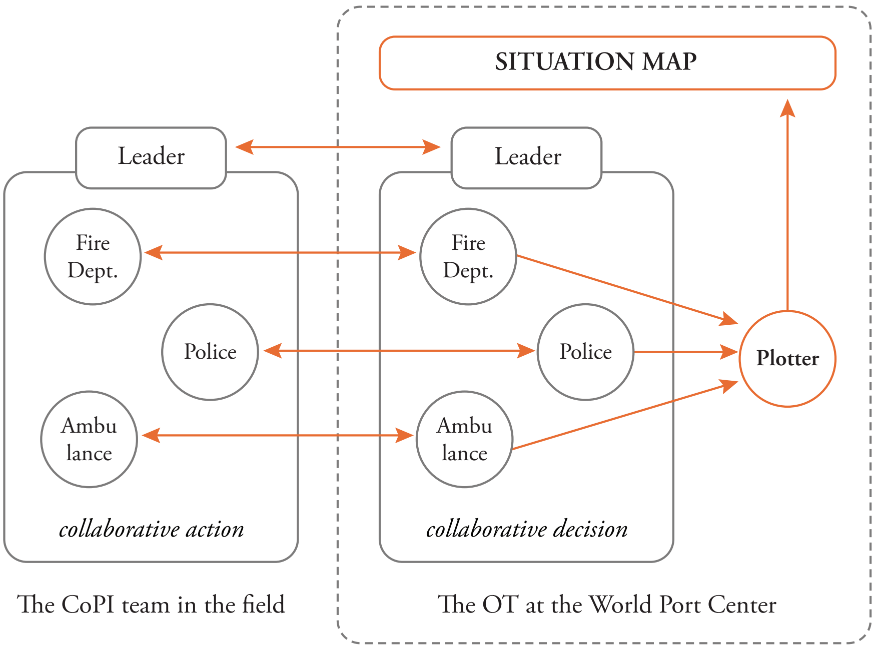


Figure 3.1. The information flow and sharing between OT and CoPI teams. The collaborative agents are not limited to the fire service, the police, and the ambulance service, but also include municipalities, the medical emergency service, the dispatch center, the Rotterdam port authority, and the environment protection agency.

disaster exercise in which an extreme flood situation in the Netherlands was simulated. This exercise was held from 30th October to 7th November 2008 and observations were performed over two days of the total exercise. In total, around 25-30 personnel from all agencies involved took part within each exercise in the command center. For both of the exercises, the collected observations focused on the process of the situation-map making.

Determining the scale of an incident or disaster is regulated by a national agreement called the Coordinated Regional Incident Control Procedure (GRIP: Gecoördineerde Regionale Incidentbestrijdings Procedure). GRIP stages regulate the structure of collaboration of the agencies, based on the scope of the incident. The two main groups are the Incident Command Post (CoPI) and the Operational Team (OT). The CoPI works at the location of the incident while the OT works at the command center in the World Port Center Rotterdam. The CoPI reports the development of the situation to the OT, and the OT updates any strategy changes during the incident. The internal structure of the CoPI and the OT is similar, consisting of representatives from the agencies mentioned above.

3.1.2.1. The Information Sharing

ALTHOUGH members of the CoPI team worked together closely and shared information, they only reported back to their own superior in the OT. For example, the police officer in the CoPI reported to his police superior in the OT. The reporting was mainly done by phone. Any spatial information re-

Figure 3.2. Several systems that were used by the plotter to support his tasks

ceived by the OT member was drawn on a paper map. These maps were collected by a plotter, a person who draws and maintains a shared situation map, that could only be shown among the OT. The information sharing of the OT and CoPI teams can be seen in Figure 3.1.

3.1.2.2. The Problems with the information sharing

The plotter often encountered difficulties submitting reports from the field into the system. According to the plotter, this was mainly caused by the complexity of the system. The system consisted of several unconnected geographic information applications running on different terminals, as shown in Figure 3.2.

The plotter reported that several hours of training is needed before one could use the system optimally. It is hard to maintain a high performance level due to the infrequent use of the system. This, was also confirmed by Cutter (2003), who reported that many geographic information systems are actually too complicated to be used without prior training.

When the plotter was asked about using such a system in the field for the CoPI team, the plotter replied that according to them the use of this system in the field was considered not an option due to its complexity. Another reason was that several location errors were made by other members of the OT, due to the use of verbal communication to convey the spatial information. This resulted in the need to constantly update and revise the map.

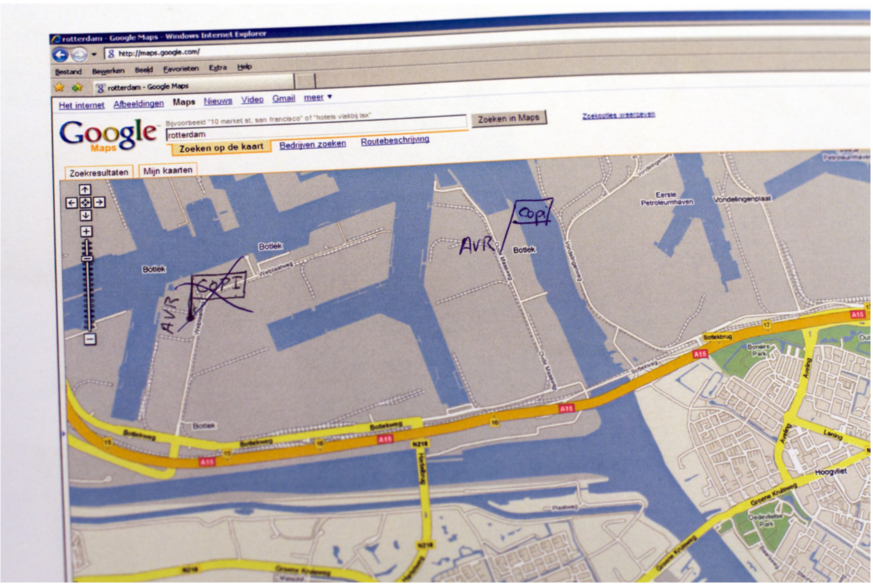


Figure 3.3. Error and correction on a paper map due to conveying geo-information over verbal communications

For example, as shown in Figure 3.3, the location of the CoPI team on the paper map was first drawn incorrectly, and then a correction was made. It was an error in distance of around 2.75 km. In some cases, information from the CoPI team did not flow to the plotter, and got stuck at one person in the information transmission chain. For example, when members of the OT were heavily occupied with their activities, they sometimes forgot to relay any spatial information updates to the plotter, which resulted in outdated and delayed information being shown in the situation map.

3.1.2.3.Discussions

Four important issues were identified from the observations. The first is the use of an improper modality for a specific task, in this case the sole use of verbal communication to relay spatial information among distributed team members. Since it is difficult to pinpoint an exact location using verbal descriptions, this often results in an inaccurate exchange of location information. This confirms the findings in Chapter 2 Section 2.3.2, which stated that most emergency services heavily depend on the sole use of voice communication to relay location data, which can lead to mistakes such as delayed response due to the rescuers being initially directed to an incorrect address (Udtke, 2008, Herald Canada, 2008).

Secondly, since the situation map was not shared across the distributed team members, errors made as a result of the above-mentioned problem are not quickly detected or resolved. Thirdly, due to many corrections from the previously mentioned inaccurate information, the workload of the plotter increases, which forms a bottleneck in the process of updating the situation-map. The fourth issue results from the information having to pass through chains in the hierarchy since some nodes in the chain occasionally omit to forward important information to the map plotter. This, also confirms the findings in Chapter 2, Section 2.3.1 which stated that linear chains of information can leave incorrect information unnoticed (Buckner, 1965) and can cause delays in relaying updates (Sobel & Leeson, 2005), thus rendering the situation awareness not only out-of-date, but also inaccurate (U.S. House of Representatives, 2006a).

3.1.3. CONTEXTUAL INQUIRY WITH USAR.NL

The contextual inquiry at the worksite (rescue site) was done by observing the Dutch USAR team (USAR.nl) during their international exercise in Ostrava, Czech Republic. The task of the USAR team is to rescue trapped victims under rubble after an earthquake. The exercise covered a complete USAR operation, as if it was dispatched for a real disaster, including logistics for the actual search and rescue activities (in total around 60 personnels and 30 cubic meter of materials were transported to Czech Republic). This exercise was held on 26th - 29th May 2008. The whole exercise was prepared completely by the Czech USAR teams who, for three weeks, had converted an abandoned steel factory into a disaster area complete with rubble, obstacles, and both fake and real human "victims". A total of 4 observation sessions were conducted over two days at the worksite while working in different time shifts and different rescue groups. Observations were also collected during shift changes of groups. The USAR operation has two locations: (1) a "base camp" for resting, medical, and logistics storage facilities and a command post; and (2) worksites at which the search and rescue activities are located. The USAR organization consists of a command group, a staff group, a support group, and a number of rescue groups (de Greef, et al., 2009). Operations took place 24-hours a day through the entire duration of the exercise, with four rescue groups working in rotating shifts. Each rescue group consisted of eight to ten people with specialized functions from different emergency services, usually 4 to 7 rescue workers (fire fighters), 1 or 2 dog handlers (police officer), a paramedic, and a commander (fire fighter officer). The commander is in charge for the team's operation on-site and responsible for the communication to the higher command.

3.1.3.1.Information sharing

Since understanding communication and the use of communication technology at the worksite is the aim of this study, the collected observations focused on the communications of the rescue group commander. Communicating with the higher command in the command post was achieved through satellite phone, while the communication within the rescue group was done face-to-face and through radio. There were no GPS devices used in this mission.

As for communication to higher command, there were no observable problems during the communication with the command post. Usually, the communication with the command post took place approximately every 30 minutes, at which time the group commander gives a summary of the number of located and rescued victims (but it was not necessary to report the detailed locations of each victim). There were also requests for logistics, such as clean masks and extra water due to the extremely dusty environment. Subsequent interviews with the command post personnel revealed that the command post only knew the total number of victims and how many of them were rescued, but were unaware of details concerning the level of progress of the rescue group at their assigned location/building.

Interesting findings were made in the internal communication and collaboration within the rescue group at the worksite. During one of the shift, immediately after saving one of the three located victims, the commander started to sketch a map of the building on the wall using spray paint. When the commander was asked for the reason behind his actions, he replied that he needed to brief and assign tasks to his team and that it made it easier to identify the exact location when more victims were found. The commander added that it also served him to understand the scope of the situation better. As the search and rescue operations unfolded, the commander kept adding new information, extending the scope of the map, and revising the location. He briefed his team members using this map, dividing them in smaller teams to rescue the victims in parallel.

The sole voice communication between the commander and the team often did not work well enough to convey the situation information. This was apparent when from time to time, the commander had to physically visit the small teams inside the building to understand the situation, reconstruct his situation awareness, or to find solutions to specific problems (e.g. need to make a bridge to pass a collapsed floor).

During the rescue group's shift change, the commander had to brief the new group that just arrived on the scene. The knowledge of the rescue progress and situation at that moment needed to be transferred to the new group before this new group could continue the work. The commander used the map he created on the wall to explain the situation in detail. It was useful to explain the complicated rescue situation.

3.1.3.2. The affected people participation

During the exercise, after a conscious victim has been rescued, the commander tried to get information from the victim by questioning him. The commander asked the victim whether he knew where anybody else was, the condition of the environment, and the location where dangerous materials or goods are stored. One victim explained that while he was working a night shift in a factory with two colleagues, there was an explosion of nitric acid and he did not know where they were gone after the explosion.

When the interviewer inquired about prior experiences, some rescuers who were deployed during a real mission after an earthquake in Pakistan in 2005, mentioned that the affected people had a helping role in their search and rescue mission. As the USAR operation moved from one collapsed building to another, the survived inhabiters usually stayed around the building that was once their home and the USAR team typically first asked them for information such as how many people were possibly under the rubble, how the building looked like before, and whether there was a basement. This kind of information was useful to understand the building structure and the likely locations of safe voids where survivors can be found.

Figure 3.4. The group commander draws the map of the building and locations of victims found

Figure 3.5. The group commander briefs his team member on how to rescue the victims

Figure 3.6. The rescue operation

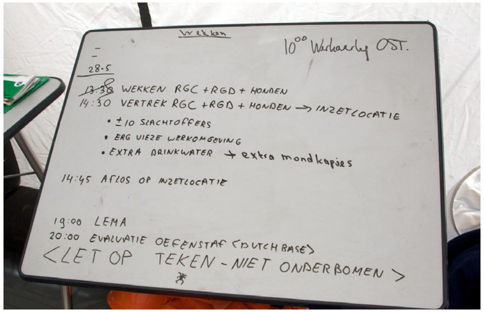


Figure 3.7. The situation board at the command post

Figure 3.8. A more complete map of the building developing over time

Figure 3.9. The group commander explaining the situation to a new team arriving at the worksite

3.1.3.3.Discussion

To summarize the observations at the worksite: as more victims were found new rooms were explored, and the situation of the operation became more complex, there was a need for the commander to visualize this situation. The sketch map was used not only to understand the situation, but also to share the situation among the distributed team and to coordinate team actions. This shows that a map is intuitively used to represent a complex situation with multiple events that are scattered in different locations. Additionally, this also shows that voice communication by itself is not sufficient to convey situation information, as illustrated by the need for the commander to occasionally go in and see the situation by himself. However, the sketch map was cluttered and not standardize, making it difficult to understand by another person once the situation became too complicated. Additionally, any technological solution that is able to support the work of this team should be usable in a dark and dirty environment and operable while using gloves.

The affected people, or the rescued victims, can be helpful for the USAR operation (as experienced during real USAR mission in Paskistan) by providing information on what they know about the environment and other possible victims.

3.1.4. CONTEXTUAL INQUIRIES WITH FIRE BRIGADE

Two contextual inquiry interviews were conducted with a fire fighter officer. The first contextual inquiry was conducted on 18th July 2008 where the officer explained and demonstrated the use of communication media and technology used by fire services. The interviews lasted around 2 hours each and took place in the fire fighter office in Rozenburg, the Netherlands.

The fire brigade mainly used the C2000 network, a closed private communication network specifically used by police, fire brigade, ambulance, rescue squad, customs, and royal military police. It is based on the TETRA standard (Terrestrial Trunked Radio), a standard for mobile communication for the public security services. It was intended to integrate the communication between all emergency services and to replace the national analog radio system. The digital network is encrypted, thus unable to be listened in on by a third party. Still, some emergency services (such as fire fighters) use analog radios because of operational problems such as loosing the C2000 signal inside a building and the compromised capacity of C2000 towers in some locations (a result of budget limitations). C2000 consists of three components: T2000 (encrypted voice and data communication), P2000 (paging) unencrypted warning network, and M2000 integrated Public Safety Answering Point (PSAP) dispatch center.

Figure 3.10. TETRA Mobile Data Terminal (MDT) and hand-portable radio terminal installed in a Communication and Control Vehicle.

Figure 3.11. Digital TETRA mobile radio terminal and mobile analog radio terminal.

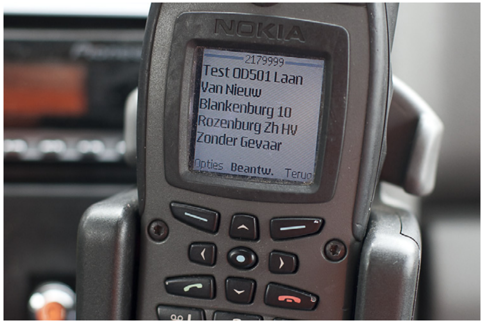


Figure 3.12. A hand-portable radio terminal displaying an incident message.

Figure 3.13. The same incident message in Figure 3.12 was also sent to the pager using P2000 one-way communications network.

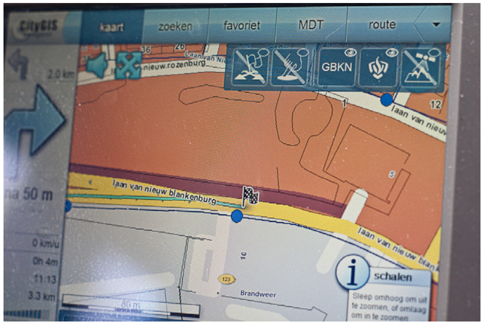


Figure 3.14. The MDT shows the navigation route and place of incident on the map.

Figure 3.15. The MDT can also show additional information such as water outlets, road markings, etc.

The fire fighter officer demonstrated four communication tools in the Communication and Control Vehicle (VC3) that use the C2000 network: a Mobile Data Terminal (MDT) and a handportable radio terminal as seen in Figure 3.10, as well as a mobile radio terminal (Figure 3.11, above) and a pager (Figure 3.13).

Beside this, a mobile analog radio terminal is used (Figure 3.11, below). A MDT is an in-vehicle device used to display mapping (Figure 3.14) and information relevant to the tasks and actions performed by the vehicle such as showing water outlet and safety information (Figure 3.15). It should be noted that although conveying GPS coordinates using MDT is considered useful, most fire fighter vans do not have access to this tool due to budget limitations. The fire fighter officer demonstrated what would happen if an incident report was received from the dispatch center, all the four communication tools showed the information directly as seen in Figure 3.11, Figure 3.12, and Figure 3.13.

The second visit, that was conducted in 2009, revealed that voice communication barely works when the incident location is very noisy. For example, on 13^{th} February 2009, there were explosions followed by an enormous fire and noise in the refinery of Q8 petroleum in Europort, Rotterdam. The crew of the four fire engines that were deployed surrounding the incident could not communicate with each other directly to get situation updates due the noise despite of their relatively close proximity. Instead, they had to communicate with difficulties through the dispatch center.

3.1.5. DISCUSSIONS

From the contextual inquiries and interviews with the emergency services and rescue workers, the direct support of the thesis hypotheses was found.

Based on the story of the real USAR.nl mission dispatched in Pakistan 2005, the affected people helped the rescue workers during the real rescue action at the worksite by informing them about the conditions of their houses before the disaster happened and also whether they had any missing family members. This confirms the stepping stone claim that the affected population are capable human beings as argued in Chapter 2, Section 2.1.

The necessity of conveying spatial information through a map was recognized by the emergency services. This was confirmed by the USAR group commander action of drawing a situation map of the worksite, and also the use of MDT. The observations in the command center showed that chains of information can result in an outdated situation map and that conveying spatial information through the sole use of voice communication may lead to inaccurate position information. Further, the use of audio communication was also reported to be unusable in a noisy environment. Thus, these findings seem to support the second hypothesis as was argued in Chapter 2, Section 2.3. It is found that there is a need for collaboration between the emergency services and the affected people during the rescue operation. The affected people have the knowledge of the situation before the disaster and are more familiar with the area, while the rescue workers need this information to best carry out the rescue operation. This supports the third hypothesis as argued in Chapter 2, Section 2.4.

3.2. The Envisioned System

As the emergency services are limited during disaster response, while the affected people are capable human beings who are shown to be able to help themselves and others during a disaster, these victims should be included actively in the response operation. Thus the proposed system supports the affected people as active sensors in a disaster area that report the situation on the ground. While at the same time, the system should help these people to reach safety.

It was shown in the previous section, that information sharing seems to be inefficient due to the existence of chains in information processing. This resulted in information sharing delays and unshared situation maps among the collaborative team members. Therefore, there is a need for tools that facilitate collaborative mapping among teams. This research assumes that targeting the collaboration activities will result in a more effectively shared map than one generated with the support systems currently in use.

When it comes to the command center, relaying information solely on voice communication is sometimes inefficient, it may be useful to test the effectiveness of other forms of communication modalities (i.e., visually through a map) to improve the process of creating a situation map. In addition, sharing the map across collaborators may help improve the overall situation awareness. Therefore, one option is to alter the way the maps are currently created (by a single map plotter) into a collaborative system where multiple actors at different places can continuously check the accuracy of the map and make corrections when needed.

The main goal behind the design of the proposed system is to help users to go to a safer location. The system aims at offering a compact and simple interface design to support interactions and equipped with features for: (1) supporting the navigation of affected people to a certain destination, (2) sending useful incident field reports, (3) sharing up-to-date information about the current situation with other users, and (4) marking dangerous areas based on the incident field reports.

The hypothetically envisioned system consists of two main devices which are connected wirelessly to each other:

1. A handheld device equipped with GPS, which serves as: (1) navigation device, (2) display device for the map of the situation, and (3) reporting device.
2. An information center which gathers and broadcasts information to all the mobile devices

The difference of process and expected outcomes between the currently used system and the envisioned system scenario can be seen in Figure 3.16.

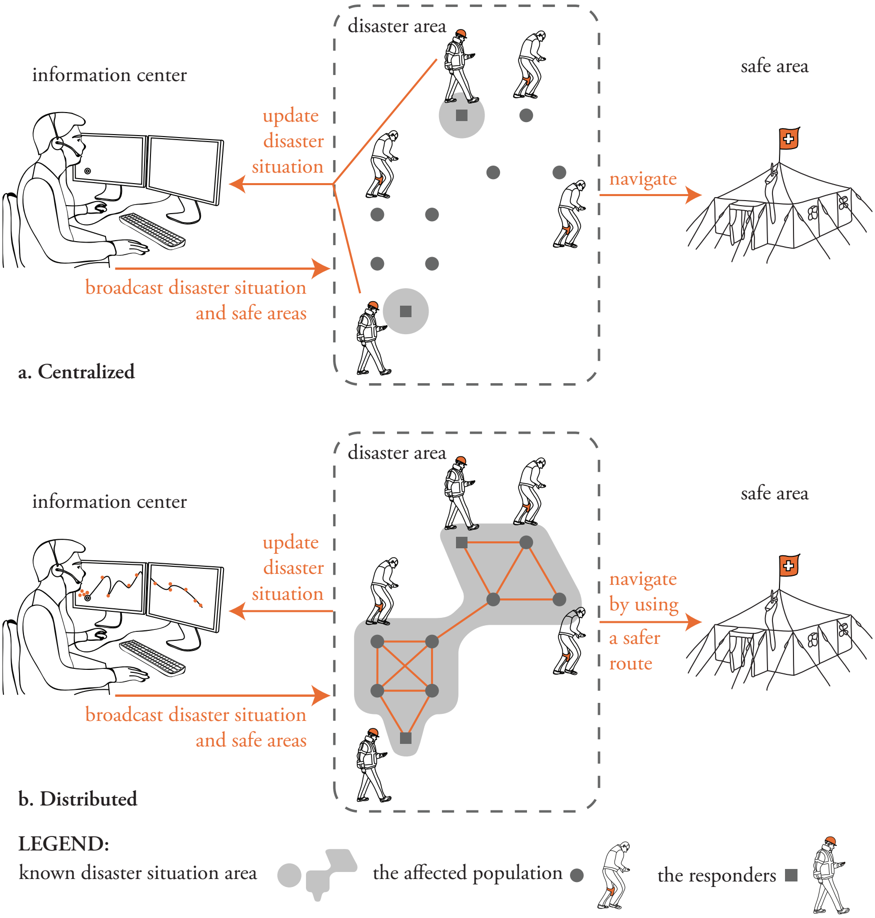


Figure 3.16. Comparison of the outcomes of centralized and distributed systems to situations of a disaster area; (a) knowledge about the disaster situation only known if the emergency services are present and (b) achieve a bigger coverage of the knowledge by sharing information among civilians and emergency services in the field and operators in the information center.

The user of the mobile device can be either the affected person, or a member of emergency services in the field. The user of the information center is an operator, who manages information from the mobile devices. Additionally, the operator is able to add other type of information from other sources, for example: locations of vulnerable buildings (nuclear reactor, gas station, chemical factory, etc.).

The proposed system consists of a server located in the information center and a number of mobile application clients on handheld devices. The system supports two way context sensitive data exchange by utilizing observation maps. These maps allow the user to attach information relevant to a particular location of a disaster event, including the automatic tracking of the user's location using GPS. The system is therefore designed to display and track the user's approximate locations, and to share this data with the information center. At the same time each mobile device receives route trails and incident reports which are gathered by the information from all other users.

The proposed system is designed to enable affected people to use their handheld device for navigating to a safe location during a disaster event. At any point in time, the affected people are associated with a spatial location. Affected people who witnessing the situation first hand now become effective distributed reporters in the field. The possible destruction of paved routes might force affected people to find alternative routes to safety. While on the move, they may report the state of their surroundings, including what they see, hear, smell, or experience, which can be transformed into reports used by others. Following this scenario, all data from the affected people's handheld devices (including the automatic tracking of their walking routes) arrives at the information center where it can be acknowledged and used for marking specific areas, broadcasting the data to all affected people, and updating the system installed on their handheld devices. Such real-time communication and information sharing supports the immediate usage of newly found routes to safety as they emerge and is useful not only for affected people but for emergency services, humanitarian organizations, and search and rescue missions as well.

A novel aspect of the proposed system is the human participatory evacuation protocol. Besides supporting fast and easy interactions, the system also offers a unified representation facilitating the exchange of information. Additionally, by involving the participation of the affected people as distributed active sensors and due to the constant flow of (redundant, and thus intrinsically verifiable by multiple sources) data, it is expected that situation awareness can become more accurate and be available in nearly real time.

3.2.1. SCENARIO

Scenarios help to put the envisioned technology, its multiple views of interactions with the users, and user' connectivity in context (Carroll, 1999; Rosson & Carroll, 2002). In Figure 3.16.b, it is shown that there are three kind of users that can use this system: the affected people in the disaster area, the operator of the information center, and the emergency services on the ground who are doing response operation. Below is the scenario which describes interactions between different type of users and the envisioned system.

> *An enormous earthquake has struck Delft registering at 9.2 on the Richter scale. Many affected people are alive and uninjured. However, Delft as a city is devastated with unimaginable damage. There are huge cracks on the roads, buildings collapsed or have become unstable, and many fires have been ignited around the city. It is not safe for the affected people to stay too long in the disaster area, so they need to go to temporary evacuation shelters which the authorities constructed to help the affected population. In order to go to the temporary shelter, the route is not straightforward. Although the affected people probably know their way around, the condition on the ground changed considerably after the disaster. Therefore, they may need to take several detours on their way to the destination*
>
> *Bob is one of the persons who are affected by the disaster. He is initially shocked of what happened, but he recovers quickly, and tries to gather his family. His family consists of five members, his wife, his two children and his father. They were lucky that none of his family members are missing. Bob tries to understand of what is happening. He can not turn on the television to see news, since the electricity is cut off and he does not have a radio. Bob and his family go out of their home and join the neighbours who are also curious of what is happening. He activates his smartphone, but the communication network has also been cut. Then he remembers that he has a crowdsourcing application developed for emergency which works on mobile ad-hoc networks. It is soon apparent to him that the earthquake has destroyed the city, and staying where he is, is not safe. He needs to lead his family and some of his neighbours to a safer place. The crowdsourcing application shows him the nearest safe place, complete with guidance to go there. The walking routes of Bob (who uses the system) are sent to the information center. On his way, he cannot pass a broken bridge, he sends this information (with photo of the incident) accordingly. He also receives all other incident reports from others, making him more aware of dangerous area around. Now, he has to find another route to go to his destination. He checks the map on his mobile phone, and makes*

use of the passable routes walked by others. On the way, he meets another affected person who has the same destination, they walk together to the same shelter.

Ian and Jane are police officers, they are on duty helping and securing the disaster area. Their role as responders are not to verify the affected population reports, instead they act on the information and also put information when it is needed. They see that a building almost collapses, and use the system to report this situation.

In the meantime, in the information center, walking routes and reports sent by affected population and responders are collected. Gradually, an overview of the disaster situation and passable routes in the disaster area emerge. The operator, Sarah, is able to group similar incident reports and mark dangerous areas, and sends this information to all affected people, so that they can avoid getting into dangerous areas. The information gathered from the responders are clearly visible, as information is marked depending on the source of the information. Additionally, she receives and displays information about vulnerable and high risk buildings in the disaster area from the geographic information system of the Delft municipality.

3.3. Conclusion

In the first section of this chapter, the challenges of creating a disaster situation map during team exercises were observed. From contextual inquiries, it was found that the inefficiency of the situation-map making process could result in an inaccurate and outdated situation map. These inefficiencies seem to stem from the hierarchical organization setup of the map-making process, such as: an unshared map across distributed team and many information chains before information can be drawn on the situation map. Additionally, the inefficiencies are also caused by the use of an improper communication modality to relay spatial information. These findings confirm and support the hypotheses as discussed in Chapter 2. Therefore, together with Chapter 2, the findings from the contextual inquiries motivate the two empirical studies in Chapter 5 and Chapter 6.

The envisioned system and the scenario, that were presented in the second section of this chapter, are used to direct all empirical studies that will be described in Chapter 4, Chapter 5, and Chapter 6.

Chapter 4. Navigation

Some material presented in this chapter has been published in:

Navigation Support for the Walking Wounded (2009)
Lucy T. Gunawan, Augustinus H.J. Oomes, and Zhenke Yang
Lecture Notes in Computer Science, Universal Access in Human-Computer Interaction. Applications and Services 13th HCI International 2009, pp.197-206, Springer-Verlag Berlin, Heidelberg.

Evacuation Coordination Support System (2007)
Lucy T. Gunawan and Augustinus H.J. Oomes
Lecture Notes in Computer Science, 12th HCI International 2007, pp. 1441-1444, Springer-Verlag Berlin, Heidelberg.

In chapter 2, the argument that it should be possible to guide the affected people by a mobile navigation device was supported by literature, but there was no direct empirical support. Therefore, the aim of this chapter is to empirically investigate the possibility of guiding the affected population using a mobile navigation device when the map of the area is unavailable or rendered useless (for example, when the area is destroyed). More specifically, this chapter test the second main hypothesis of the thesis using a controlled experiment:

> *In a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues.*

Three studies were conducted to test this hypothesis: two explorative studies and one controlled experiment. The first two studies explored the idea of navigating using only an arrow showing the direction to a specific destination. They were conducted in the field, first by using a compass and then using an existing GPS device designed for hiking. Since these two studies showed promising potential for the idea, a third controlled experiment was conducted that used a mobile GPS device specifically developed for this task. The third study is the main study in this chapter, it is a controlled field experiment that was conducted to measure the effectiveness of the direction arrow and the usefulness of different elementary navigation cues, such as distance-to-destination, time-to-destination, and names of landmarks. The participants were equipped with a smartphone that had GPS capability to show them the destinations. It was found that a navigation based on a direction arrow provided sufficient guidance for short distance navigation. However, providing additional navigation cues displaying progress could increase the user's confidence level in the guidance direction.

This chapter describes the two explorative studies, the controlled experiment designs, implementation, methodology and analysis. It ends with a discussion and conclusion derived from these studies.

4.1. Explorative Studies

The goal of these explorative studies was to see whether the idea of navigating based only on direction to destination has potential to help an affected person in a disaster area when a map is unavailable.

4.1.1. THE FIRST STUDY: COMPASS NEEDLE

To quickly test the idea of a direction arrow using readily available tools, a compass was used (Figure 4.1). A compass has a needle that points to the North and the South. Seven participants were asked to follow the compass needle from the Electrical Engineering, Mathematics and Computer Science (EECMS) faculty building until they reached the North campus border (the cemetery). As the compass needle pointed toward the North point, the participants were asked to use its direction in stages. First, they used the arrow to walk to the farthest visible obstacle on their way to destination. When they reached this obstacle, they needed to check the compass again to orient themselves and go around it. In this experiment, the participants' behaviours were observed and their experiences were written down.

Figure 4.1. The compass used for the experiment

The experiment was conducted in two days on the

22nd and 23rd of February 2007. The participants consisted of two females and five males, between the age of 24 to 28 (*M*=25, *SD*=1.6). They were chosen by opportunistic sampling at EEMCS. The walking path was approximately 600 meter.

All participants were able to reach the Northern border guided by only a compass needle. Overall they appeared positive about their experience and liked the idea of guidance by means of direction to destination. The needle of the compass kept moving during walk, showing an unstable North direction. To overcome this problem, the participants had to occasionally stop and hold the compass in their palm horizontally to read the needle direction. Some information such as time-to-destination, distance-to-destination, reference points, and landmarks were suggested by participants after the experiment.

4.1.2. THE SECOND STUDY: HIKING GPS

The second study was done with 6 participants between 24 to 30 years old (*M*=26 *SD*=2.1) on the Delft University of Technology campus. The experiment was conducted over two days, 3rd and 4th May 2007. The participants were asked to follow the arrow shown on a hiking GPS device from the EEMCS building to a destination behind the Aula of TU Delft. In the hiking GPS (Figure 4.2), it is possible to set a destination. The device then displays an arrow that points to that destination. In addition to the arrow, the time-to-destination and distance-to-destination were also shown. To reach their destination, the participants had to navigate around the Aula building since they were instructed not to go inside it. The distance they had to walk was approximately 500 meters.

All participants were able to easily navigate around the building obstacle and reach their destination. All participants found it easy to navigate using the arrow. One of the participants mentioned that a direction indication can be sufficient in itself for navigating short distances and the exact destination

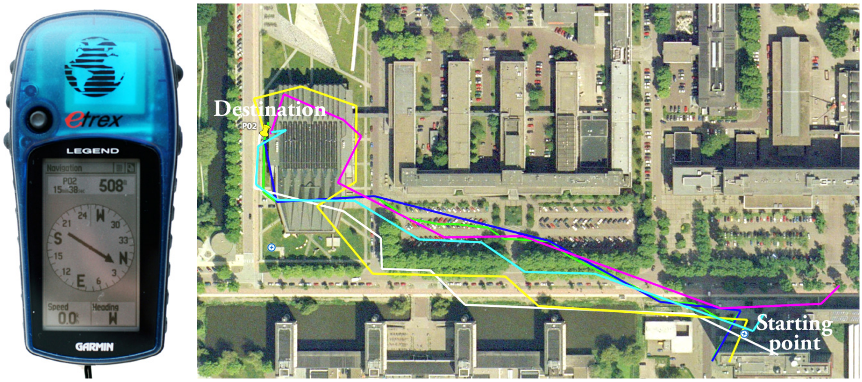


Figure 4.2. The GPS device and the participants' walking tracks.

point was not needed since you might see the destination (hospital, school, etc) from a distance. The majority of the participants (4 out of 6) preferred that the distance-to-destination information is shown on the navigation device, rather than the estimated time-to-destination. The argument in favour of the distance-to-destination measure were: (1) it demonstrated a certainty that when the participants took the correct route the distance visibly decreased (2) time was estimated and so prone to error calculation, and (3) the distance measurement was easier to comprehend than the time measure. The two participants who had favoured estimated time-to-destination argued that in a stressful situation people need to work within a time limit, so that time information is perceived to be more useful. The tracks of the participants can be seen in Figure 4.2

4.1.3. DISCUSSION

These two explorative studies show that navigation using the direction to destination has a potential to aid in navigating short distances. It was easy for the participants to use and effective, because they had all reached their destinations. Although these studies served as a successful proof of concept, it is acknowledged that during a real disaster the affected person may have to travel for longer distances. However, people tend to use intermediate destinations when navigating these long distances.

Some elementary navigation cues were suggested by the participants in the first study (time-to-destination, distance-to-destination, and landmarks), and only two of these cues (time-to-destination and distance-to-destination) were examined in the second study. Although the majority of the participants preferred the distance-to-destination, it was not yet possible to draw conclusions regarding which cue was more useful as a navigation aid.

As both small scale explorative studies indicated that navigation using a direction arrow with additional navigation cues could be effective in helping people navigate to a specific destination, an extensive study was needed to explore this idea further.

4.2. Third Study: A controlled field experiment

The goal of the controlled field experiment was to examine the minimum required amount of navigation guidance and the usefulness of multiple elementary navigation cues. The question therefore was whether an arrow showing the direction to destination is sufficient for guiding a user over short distances and what additional elementary navigation cues were still needed to assist the navigation process.

The experiment was conducted on the 22nd - 30th October 2007 in

Delfgauw, the Netherlands. The autumn days were relatively cold with an average temperature of 10° Celsius and the weather varied between 2 sunny days, 2 cloudy days, and one day with showers.

4.2.1. HYPOTHESIS

To answer the research question of the experiment, the main hypothesis of this chapter was broken up into three sub hypotheses.

H1. Direction arrow. The affected people are able to reach their destination by using only an arrow pointing to the destination

H2. Elementary navigation cues. Displaying elementary navigation cues, such as: distance-to-destination, time-to-destination, and landmark name, improve the navigation performance

H3. Confidence cues. Providing information about the system's state and limitation helps the user judge the reliability of the given navigation information.

4.2.2. MEASURES

Prior to the experiment, basic demographic data and information of experience with navigation devices was collected from each participant using questionnaires.

In order to examine the hypotheses, a set of measures were chosen. The first hypothesis involved navigating by using only the direction to destination information. To measure this, a simple checking mechanism to see whether a participant was able to reach the destination within a reasonable time limit was recorded.

The second hypothesis involved the importance of elementary navigation cues. This was tested by examining the effect of these different cues (dis-

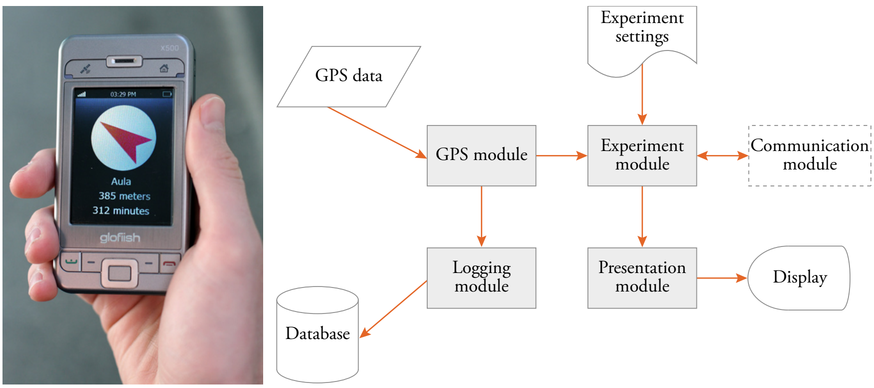


Figure 4.3. The prototype and its architecture.

tance-to-destination, time-to-destination, and landmark name) on the performance of the participants such as their speed, standard deviation of speed, distance travelled, and time completed. It was assumed that during navigating, a constant speed (without many fluctuations) meant that participants were more confident in navigating without frequent stopping or slowing down. A six items post-questionnaire on the perceived ease of use was conducted to evaluate each interface (clearness of the interface, ease of navigating, difficulties in finding the destination, confidence during the navigation process, trust in guidance and enough information provided for navigating) was used to evaluate each interface. The items were rated on a 7 cm continuous line with higher scores representing more support. A preference ranking was used to rate user's preference for each interface. Finally, a post-experiment interview was conducted to answer the third hypothesis and also get the experience and opinion of the participants.

4.2.3. EXPERIMENT DESIGN

THE experiment used a 2x2x2 within subject design. The three independent variables were the remaining distance-to-destination, the estimated time-to-

Figure 4.4. Some examples of landmarks used for this experiment, start from the left top clockwise: Kerk Centrum Delfgauw (Church center), Sporthal Emerald, Tuincafe, ReShare container

destination and the landmark name. So there were eight combinations of the interface (Figure 4.5). A Latin-square was used to counterbalance the order in which a participant used the interface.

4.2.4. PROTOTYPE

To accommodate the requirements of the experiment, such as the frequency of logged data and controlling different experiment conditions, a prototype was developed specifically for this purpose. The prototype was implemented on a smart phone with built-in GPS (Figure 4.3). This prototype could read the current location and display bearing directives to a destination point. The operating system on the smart phone was Windows Mobile 6. The developed software prototype of the system was implemented in C++. The implemented prototype and its architecture is shown in Figure 4.3.

The GPS module is responsible for communicating with the GPS receiver of the smart phone. The GPS position is recorded every second by the logging module. The heart of the system is the experiment module that controls the presentation of the interface to the user. Fixed settings, such as the GPS locations of the waypoints, which interface to show, landmark names etc., are stored in a text file with the experimental settings. Using this data and the most recent GPS position received from the GPS module, the experiment module can choose the correct interface and calculate the correct

Figure 4.5. User interfaces used in 8 conditions of experiment. The independent variables are: distance (2), time (2), and landmark (2)

values to show the user. Finally, the presentation module draw the interface on the display.

Five pieces of information can be displayed on the device. (1) The direction is presented by an arrow, (2) the landmark name is displayed using text, (3) the distance is shown in the number of meters, (4) the estimated time-to-destination is presented by minutes or seconds — under 1 minute the time scale changes to seconds, and (5) the GPS reliability indicators is conveyed by changing the colour of the arrow. All combinations of the user interface can be seen in Figure 4.5.

Direction. The arrow metaphor of a magnetic compass was chosen for its familiar form. This arrow always directs the user to the final destination by pointing to the final destination in a straight line. While following the arrow, the user might come across hindrances or dead-ends along the route. Consequently, the user needs to navigate around these obstacles while keeping track of the displayed orientation until he can continue in the correct direction.

Distance and Time Information. From the explorative studies, it was found that the estimated distance and time-to-destination might be useful cues for navigation. Even though earlier research of pedestrian navigation in urban environments showed that distance information was rarely used as a navigation cue (May, et. al, 2003), based on the two earlier explorative studies, it was expected that distance or time information would be helpful for such short distance navigation tasks.

Landmark names. From the first explorative study, using landmarks as a navigation cue was brought up. Additionally, for pedestrian navigation in urban environments it was recommended to use landmarks as cues due to their predominant role (May, et al., 2003 and Tarkiainen, 2001). Moreover, landmarks are commonly and intuitively used for giving directions in everyday life situations.

Confidence information. As the GPS chip can only give a limited amount of orientation information at low speed, an additional indicator was

Figure 4.6. The colour differences of the GPS confidence.

needed to represent the confidence level of the displayed orientation. This confidence level was calculated using the walking speed and the strength of the satellite reception. Based on that information, the indicator changed colour ranging from grey (no confidence) to dark red (full confidence) as seen in Figure 4.6. Other information displayed was a battery life meter, the current time, and the strength of the satellite reception.

4.2.5. THE AREA OF EXPERIMENT

The area chosen for the experiment was Delfgauw, the Netherlands. This place was considered appropriate since most of the participants were unfamiliar with its surroundings, thus simulating the novel environment of a disaster. The area of the experiment was approximately 5.5 square kilometres. The path is more or less in the shape of a round loop (Figure 4.7), with 8 destinations that were roughly the same distance apart (each path is around 300-400 meters). Each destination had a unique landmark identifying them (as seen in Figure 4.4). The challenge was to find these eight different landmark points which were separated with a similar amount of distance and had a name sign placed on it for successful identification.

4.2.6. PROCEDURE AND TASKS

Each session involved one participant who played the role of an affected person in a disaster area, using the mobile navigation device, and one experi-

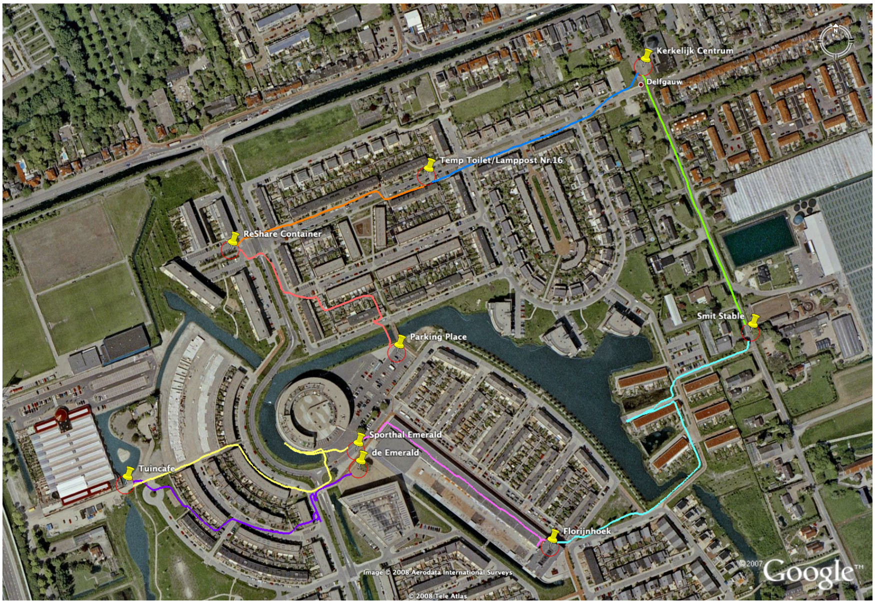


Figure 4.7. The complete path of the experiment

menter, who walked along with the affected person to observe, taking pictures, and noting down observations during the experiment.

On the day of the experiment session, the participant was requested to read the information sheet about the experiment and sign the consent form. The experiment location is a 10 minutes drive away. An explanation of the experiment goal, procedure, roles, tasks, and prototype was then given, followed by a practise session using the mobile navigation device.

The task was to reach 8 destinations by using the prototype (8 different interfaces). The participants were told to walk as fast as they could and were motivated by an additional prize for being the fastest among all participants (life being the ultimate prize in real life scenario). They were also told to walk around possible blockades (e.g. buildings, ponds) encountered and, as much as possible, avoid trespassing. Reaching some of the destinations required the participants to navigate around obstacles that blocked their direct path.

Each path took an estimated time of around five minutes to be walked. A questionnaire was given after the participant had reached a destination where the participant had to rate the interface. Each participant took between 60 to 90 minutes to complete the whole experiment.

4.2.7. PARTICIPANTS

In total, 16 participants took part in the experiment. There were 4 females and 12 males (*M* = 27, *SD* = 5.6, Range: 22 to 46). The participants were recruited by opportunistic sample in the Delft University of Technology campus area, as they were students and employees of this university. The participants had different nationalities (Czech, Chinese, Dutch, Indonesian, and Iraqi). A reward of approximately € 15 was given to participate in the 1.5 hour experiment. Moreover, to motivate the participants to go as fast as possible, another reward (an iPod Shuffle, € 74) was given to the fastest participant. Only half of the participants had prior experience with using a GPS system, mostly with vehicle based navigation systems.

4.2.8. RESULTS

4.2.8.1.Data preparation

Average walking speed.

The average walking speed was calculated for each participant and each path. As the speed is a function of distance travelled and time, the difference in distance among paths was thus eliminated.

The speed graphs per participant per path were plotted and examined. All plots exhibit a similar pattern to that shown in Figure 4.8. By looking at the graph it is possible to identify three clearly distinct phases: the starting phase, the wayfinding phase, and the ending phase.

The starting phase. After participant receives the device from the experimenter and gets instruction to start, he begin to walk. This phase ends when the participants started to walk with a relatively constant speed.

The wayfinding phase. The participant navigates and tries to find his way to the destination. This phase is usually characterized by a constant walking speed. This phase ends just before the participant reaches the destination.

The ending phase. The participant approaches the destination and then attempts to confirm that he has arrived at the destination.

The start of the wayfinding phase and the start of the ending phase has to be marked by looking at obvious starting and ending points in every speed plot for each path. After this, the speed, standard deviation of speed, distance, and time can be calculated. However, the average speed in the starting phase can not be analysed due to the prototype's limitation of accuracy at low speed. Therefore, the speed analysis focused on the wayfinding phase and the ending phase.

Distance travelled and time duration

Distance travelled and time duration. To remove potential distance difference between paths, the data was standardized by comparing

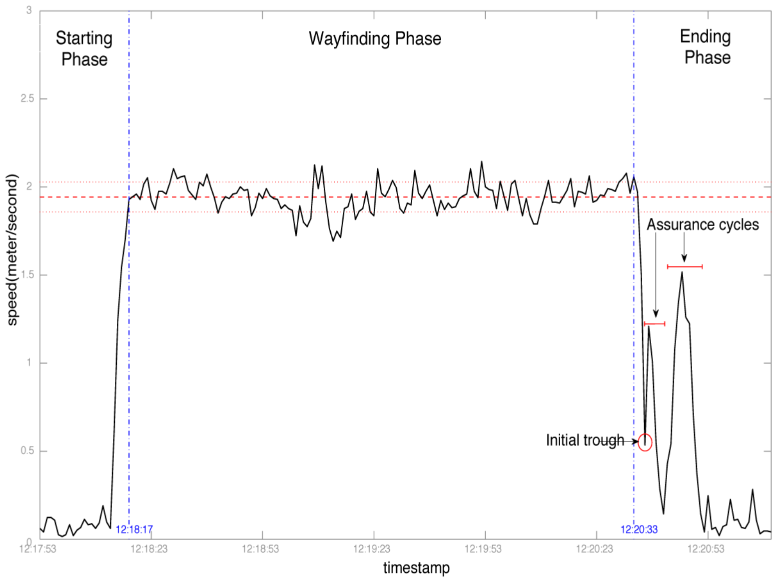


Figure 4.8. Typical speed graph with a clear phase classification: the starting, the wayfinding, and the ending phases.

it to the performance of the experimenter while completing the same path using this formula: *((travelled distance - optimum path length)/optimum path length*100)+100.*

The data for distance travelled and time duration was calculated as the sum of the wayfinding phase and the ending phase.

Ease of use questionnaires

Table 4.1 shows the reliability of the 6 ease of use questions for each interface. The results indicates a high level of internal consistency of the scales across all interfaces. Therefore, the six questions about the participants' experience in using the system can be averaged as one ease of use indicator.

Interface			Cronbach's alpha
Distance	Time	Landmark	
No	No	No	0.92
No	No	Yes	0.92
No	Yes	No	0.93
No	Yes	Yes	0.95
Yes	No	No	0.94
Yes	No	Yes	0.86
Yes	Yes	No	0.98
Yes	Yes	Yes	0.94

Table 4.1. The reliability of 6 self-rated questionnaires per interface

4.2.8.2.Statistical Analyses

The statistical analysis in this third study is divided into three parts. First, hypothesis H1 was examined by looking at the success rate of the participants going to their destination. Second, for hypothesis H2, elementary navigation cues were tested based on usability measurements of effectiveness, efficiency and satisfaction (time, distance, speed, preference questionnaires). Third, the hypothesis H3 was examined based on the answers of the participants during the post session interview.

Success rate of navigation task

In total, there were 16 participants evaluating 8 different interfaces, navigating to 8 different destination. This results in 128 geographical data sets. All participants were able to reach the destinations. Indicating a success rate of 100 percent.

However, it is important to mention that there was one participant who, when using only the direction arrow interface, almost gave up due to a failure, at least in part, of the limitation of the GPS device that was giving poor heading measurements at low speed. At one point, this participant stopped at a road crossing and the arrow showed a random direction, meanwhile the almost counter intuitive reaction from the participant to the random headings was to stand still in order to get a better reading from the direction arrow, mimicking the behaviour of someone using a magnetic compass. All participants were told in the beginning that if this situation occurred, they needed to simply keep walking. This participant did not remember the instructions and eventually the experimenter asked the participant to continue walking in any direction to get a better heading. Finally the participant was able to reach the destination. Ultimately, these results support hypothesis H1 that people are able to navigate to their destination by only using an arrow pointing to the destination.

Elementary navigation cues.

The effect of elementary navigation cues in supporting navigation was analysed using a repeated-measures Multivariate Analysis of Variance (MANOVA). The independent variables were the availability of the information of distance-to-destination, estimated time-to-destination, and landmark name. The dependent variables were average speed, average standard deviation of speed, standardize distance travelled, standardize completion time, and average score of ease of use questionnaires. The results across the three dimensions show that the distance-to-destination and time-to-destination had a main effect on the importance of elementary navigation cues with $F_{5, 11} = 12.12$, $p < 0.001$ and $F_{5, 11} = 4.97$, $p = 0.013$ respectively.

The univariate analysis of each measure revealed that the availability of the remaining distance-to-destination and estimated time-to-destination cues had a significant main effect on the ease of use questionnaire, as shown in Table 4.2 and Table 4.3. The participants perceived that when these navigation cues were visible in the interface it helped them during navigation (due to higher means in questionnaire rating average).

The average of the standard deviation of the speed when the estimated time information was shown was higher at 0.24 compared to 0.20 when it was not shown. This fluctuation of speed suggests that users were not walking at constant speed, which might be an indication of frequent stops or drops in speed. Therefore, it seems that displaying the estimated time-to-destination had a negative influence on the way users navigated (as there was no significant difference in speed for time-to-destination cue).

Measures	Distance: No		Distance: Yes		$F_{1,15}$	p
	M	*SD*	*M*	*SD*		
Average speed	1.80	0.24	1.81	0.23	0.044	0.836
Average SD of speed	0.23	0.15	0.21	0.12	0.848	0.372
Distance travelled	107.67	14.26	107.54	13.51	0.003	0.956
Time completion	99.47	16.63	98.77	15.49	0.12	0.734
Ease of use questionnaire	45.32	15.51	55.33	12.67	37.99	< 0.001

Table 4.2. The univariate analysis results of the distance-to-destination navigation cues, $n = 16$

Measures	Time: No		Time: Yes		$F_{1,15}$	p
	M	*SD*	*M*	*SD*		
Average speed	1.80	0.21	1.81	0.26	0.20	0.66
Average SD of speed	0.20	0.11	0.24	0.15	5.00	0.04
Distance travelled	107.14	12.91	108.08	14.87	0.11	0.74
Time completion	98.35	15.12	99.89	17.01	0.51	0.49
Ease of use questionnaire	48.33	13.80	52.32	14.38	9.71	0.01

Table 4.3. Univariate analysis results of the estimated time-to-destination cues, $n = 16$

From observations during the experiment, the availability of each elementary navigation cue (the direction arrow, the landmark name, the distance-to-destination, and the estimated time-to-destination) seems to have some distinct characteristics which the participants adapted to in order to support their navigation task.

Direction. A direction arrow could be used to indicate reaching a destination. Since it always points toward the destination, a sudden reversal of the arrow's heading can be an indication that the participants have passed the final destination. When this happened, it was observed that the first turning of the arrow generally put the participants in an alert state. They immediately slowed down and turned back. When they saw the same behaviour repeated (several times), they are convinced that they reached the correct destination. This activity is illustrated in Figure 4.9. Such behaviour could be easily noticed in the ending phase of the speed plot. It started with an initial trough (the first turning), followed by one or more relatively high amplitude "assurance cycles", which were formed depending on how many reversals were needed, as shown in Figure 4.8.

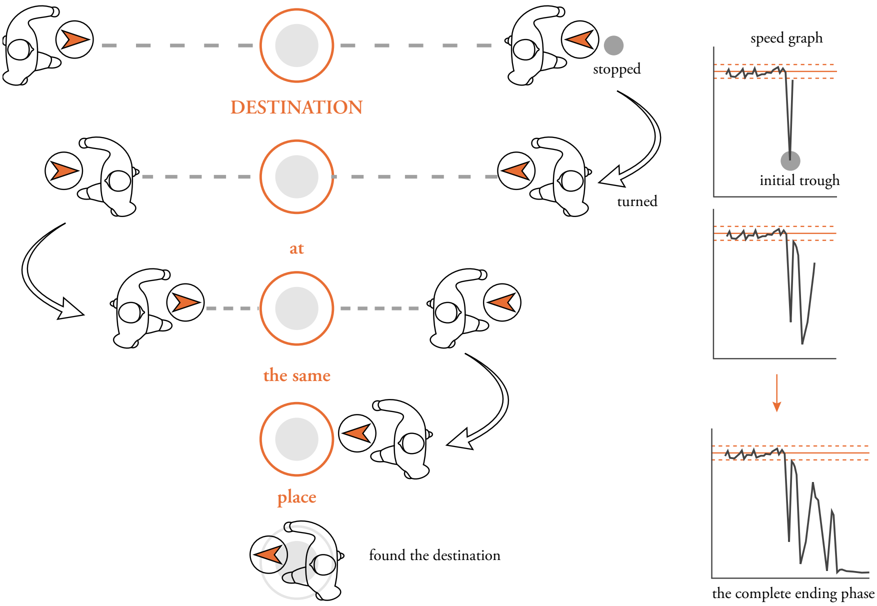


Figure 4.9. Finding the destination by using the direction arrow.

The remaining distance-to-destination gave an estimation of remaining distance (in meters). The decrement of the value was used by the participants that they are making progress toward their destination.

The estimated time-to-destination gave the estimated time to reach the destination in minutes (or second if it is below 1 minute).

Landmark. When the landmark name was given in the interface during the experiment, participants were noticed to constantly scan the environment while the direction arrow guided them. When the landmark was spotted from a distance, participants simply headed towards it without further reference to the interface.

Confidence Information. The colour change of the arrow represented the confidence level of the direction given by the system. Most participants mentioned that the difference was negligible. Even when it was noticed, participants mentioned that it lacked contrast and was too subtle to notice. The additional information such as battery level, satellite reception, and current time were also rarely checked. Thus there is no support to accept or reject hypothesis H3.

Preferences

Interface			Mean of rank
Distance	Time	Landmark	
No	No	No	8
No	No	Yes	6.19
No	Yes	No	6.19
No	Yes	Yes	4.06
Yes	No	No	4.31
Yes	No	Yes	1.94
Yes	Yes	No	3.38
Yes	Yes	Yes	1.94

Table 4.4. The mean of rank for each interface.

The result of Friedman's test applied on ranking preference by participants showed that there are some statistically significant differences in ranks between interfaces, $X^2 = 86.85$, $df = 7$, $p < 0.001$. The complete mean of rank for each interface can be seen in Table 4.4

The smaller the mean, the more preferred the interface by the participants. The interfaces that showed both landmark and distance information, including all three navigation cues, were the most preferred by participants ($M = 1.94$).

4.3. Discussion

The success rate of participants reaching the destination in the experiment was 100 percent. This strongly indicates that even the simplest interface was sufficient to guide the people to a specific destination. The one case mentioned earlier as part of the limitation of the GPS device in a low speed setting causing it to show a random heading. This technical limitation could have been solved by integrating an electronic compass into the prototype. Yet, despite it being sufficient for short distance navigation, the inconvenience of being guided into a dead-end was apparent.

The remaining distance-to-destination and the estimated time-to-destination cues were shown to be important elementary navigation cues in this study. The distance-to-destination cue was regarded to be providing important information. This might be due to the affordance it supports in both wayfinding and ending phases. It accommodates the user in two ways, the constant decrement of the distance value shows that the user is making progress towards the destination, and it shows the user how far he is from the destination. Despite being rated as easy to use by participants, the estimated time-to-destination cue was shown to have a negative influence on their performance during the wayfinding phase. In retrospect, with regard to this negative influence of time-to-destination, this cue might have been poorly implemented. Instead of calculating the estimated time based on the average speed, the calculation was based on the participant's current speed. As a result, the time kept fluctuating with the current speed, making the estimated time increase greatly when a participant stopped for a few seconds. Furthermore, the estimation algorithm did not take into account any unexpected obstacles ahead. Participants pointed out that the system should have a warning mechanism to indicate obstacles or dead-ends on their way towards the destination. Additionally, a progress bar was mentioned as the preferred alternative to the distance-to-destination that was shown in numbers.

The colour contrast of the direction arrow was not noticeable due to the similar tone of red that was used. This problem was made worse by the screen glare under the bright outdoor lighting. One possible solution is to have a larger hue difference between the used colour indicators, for example: green can represent a high confidence level, changing to red and then gray as the confidence level drops.

One limitation of this study is that the participants did not belong to the intended target group. However, they served as an adequate test group for this study. If well able civilians without real pressure can not be guided by this system, then people under stress would certainly not be able to be guided either. Additionally, a failure at this stage would have indicated that the design of the system would be unusable by the walking wounded in a real disaster situation.

4.4. Conclusion

The study in this chapter aims at investigating the possibility of navigating by only using a direction arrow and the usefulness of additional elementary navigation cues when a map is unavailable. Thus, testing the second main thesis hypothesis. Two exploratory studies that led to one controlled field experiment were conducted. Support to the hypothesis H1 was given as people were successfully guided toward their destination by a direction arrow alone, therefore it can be concluded that the direction arrow provides sufficient guidance for short distance navigation tasks. However, the user can be confused when no additional information is provided to give information about the destination. Additional information can increase the users' perceived system ease of use during navigation, especially the elementary cues such as distance-to-destination and time-to-destination. These two navigation cues are considered to be useful because they shows whether the user is making progress and how much longer the user needs to walk before reaching the destination. Thus hypothesis H2 was also supported. Even though additional elementary navigation cues were provided, navigation primarily based on the direction to destination has drawbacks. For example, there is always a risk of ending up in a dead end. It is also possible to be forced to circumnavigating a longer distance when faced with a blockade. Consequently, the distance-to-destination and time-to-destination calculation can be influenced, thus making this information misleading. However, despite these drawbacks, this study showed that when a map is not available, it is still possible to be guided by only direction to destination for short distance navigation. As for hypothesis H3, no supporting evidence was found since the displayed confidence information might have been poorly designed or implemented.

Chapter 5. The Collaborative Situation-Map Making

Some material presented in this chapter has been published in:

Collaborative Situational Mapping during Emergency Response (2009)
Lucy T. Gunawan, Augustinus H.J. Oomes, Mark A. Neerincx, Willem-Paul Brinkman, Hani Alers
Proceeding of European Conference on Cognitive Ergonomics 2009, pp. 6:1-6:7,
VTT Technical Research Centre of Finland VTT, Finland.

Effect of map sharing and confidence information in situation-map making* (2010)
Lucy T. Gunawan, Hani Alers, Willem-Paul Brinkman, and Mark A. Neerincx
Proceeding of European Conference on Cognitive Ergonomics 2010, pp. 41-48,
ACM New York, NY, USA
* This paper won the best long paper award

Distributed collaborative situation-map making for disaster response (2011)
Lucy T. Gunawan, Hani Alers, Willem-Paul Brinkman, and Mark A. Neerincx
Interacting with Computers, pp. 308--316, 23 (4), 2011, Elsevier.

In Chapter 4, it was shown that, although navigation system based on a direction arrow provides sufficient guidance for short distance navigation, a map is still necessary to eliminate the change of ending up in a dead end. Furthermore, having a situation map that shows the overview of a disaster situation can reveal areas which are dangerous, so that they can be avoided. Situation map is also a valuable tool for disaster response teams when deploying response efforts. However, it is complicated to rapidly generate a complete and comprehensive situation map of a disaster area, once the environment has been altered. The difficulties in creating the situation map are also exacerbated by the centralized organization of disaster response efforts and the limited availability of emergency services.

The aim of this study is to investigate the possibility of constructing a shared situation map using a collaborative distributed mechanism. Specifically, it aims to test the second main hypothesis of this thesis, as was formulated and discussed in the first and second chapters:

> *Using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map.*

This chapter makes use of the previous field observations described in Chapter 3, as the first study on this collaborative situation-map making. In the initial field observations, the challenges in the process of creating a disaster situation map during team exercises were observed. From these observations, it was found that the inefficiency of the situation-map making process resulted in an inaccurate and outdated situation map. These inefficiencies caused primarily by the setup of the map-making process: only one plotter was allowed to create and update the map, too many information chains before the information reaches the plotter, no map sharing across distributed teams, and the use of an improper communication modality to relay spatial information.

These observations shows that it may be useful to refine the way maps are currently created, by a single map plotter, and to make it a collaborative process where multiple actors at different locations can continuously check the accuracy of the map and make immediate corrections when required. Additionally, it may be useful to study the effectiveness of other communication modalities to improve the map-making process. To substantiate these findings two follow up experimental studies are conducted in this chapter: (1) the exploratory study of face-to-face collaborative map making and (2) the remote collaborative map making.

The first experimental study is a preliminary exploratory study to understand the process of collaborative situation-map making. Two participants see an accident from two different angles and are asked to draw the incident from their recollection and then collaborate to make one map. This study resulted in a list of potential benefits and pitfalls in the collaborative map-making process. For example, the participants frequently mention their confidence level about specific objects, suggesting that it may help to have this information explicitly part of the collaborative map-making process. Pitfalls were found when an unbalanced relationship in face-to-face collaboration led to a worse collaborative map.

To test the effectiveness of other forms of communication modalities as collaboration channels (an idea resulting from field observations) and to test the explicit use of confidence level with collaborative information, to overcome the unbalanced face-to-face relationship (a problem highlighted in the first experiment), a second controlled experiment was conducted. The second experiment evaluated the effect of additional collaboration channels and the confidence level information in remote collaborative situation-map making where two participants worked simultaneously to create a shared situation map. The results showed that more collaboration channels lead to a better situation maps, and that including confidence information for objects and events in the map may help in shortening one of the phases of the discussion process during map making. The results support the second main hypothesis in this thesis.

This chapter describes the two experimental studies in detail, their methodology, and the statistical analysis of the data. It ends with a discussion of the results and the conclusion reached.

5.1. Explorative study of face-to-face collaborative situation-map making

As briefly introduced above, the findings of field observations summarized in the discussion of Chapter 3, show that distributed collaborative map making helps to build-up a shared mental model faster, more complete and more accurate map. To investigate collaborative map-making further, an explorative experiment study was set up. The purpose of this study was to explore and to identify some basic characteristics and potential problems, which may arise during collaborative situation-map making.

5.1.1. PREPARATIONS

An accident scenario was created using a slideshow showing pictures of a disaster situation simulated, in a miniature world. The simulated incident setting was constructed using the Playmobil toyset.

5.1.1.1.Scenarios

In order for the participants to be able to make a collaborative map with overlapping information of the same incident, a scenario was constructed for the purpose of the study. The scenario tells a story about an accident unfolding on a t-junction with two victims and the rescue response (Figure 5.2). In the figure: A is the viewpoint of first participant, while B is the view point of the second participant.

> *(1) A child on a bike is talking on his mobile phone without paying attention to the traffic ahead. (2) At the same moment, across the street, a postman is riding his bike towards a yellow postbox (Figure 5.2, I).*

> *(3) A red racing car abruptly hurtles out of a repair garage while being worked on by mechanics. (4) The car runs over the child, and injures him badly. (5) After hitting the child, the car continues across the street, hitting both the postman and the postbox, and then it stops (Figure 5.2, II). (6) Shortly thereafter, the police arrives and closes down the area of the incident. (7) An ambulance with two paramedics arrives at the scene of the incident a while later. (8) One of the paramedics treats the child with the help of a bystander (Figure 5.2, III). (9) While the other paramedic provides first aid treatment to the postman with the help of another bystander. (10) The child is then transported by the ambulance to the nearest hospital. (11) The postman appears to have no serious injuries, and does not require further treatment. (12) Finally, the police cleares the incident area and opens the street again to traffic (Figure 5.2, IV).*

5.1.1.2.The miniature world for incident setting

After creating the scenario, a disaster settings in which the scenario took place was constructed. Making incident scenes in the real world setting is not practical due to time and budget considerations, therefore, it was decided to make a miniature world to simulate the incidents with Playmobil toy sets. These toys were chosen due to their simplicity and flexibility, which made them practical for the purpose of this experiment.

The scenes were constructed in such a way that they could be viewed from two different angles representing two different vantage points of the observers. Photos were taken from two specific locations, while the Playmobil model was adjusted as the accident storyline developed. The goal was to stimulate the exchange of information, requiring the participants to collaborate in order to figure out the complete scenario. An example of the scene from two different angles can be seen in a pair of photos below (Figure 5.1).

Figure 5.1. Scene of red racing car hitting the postman The left picture: 1st participant view, the right picture: 2nd participant view.

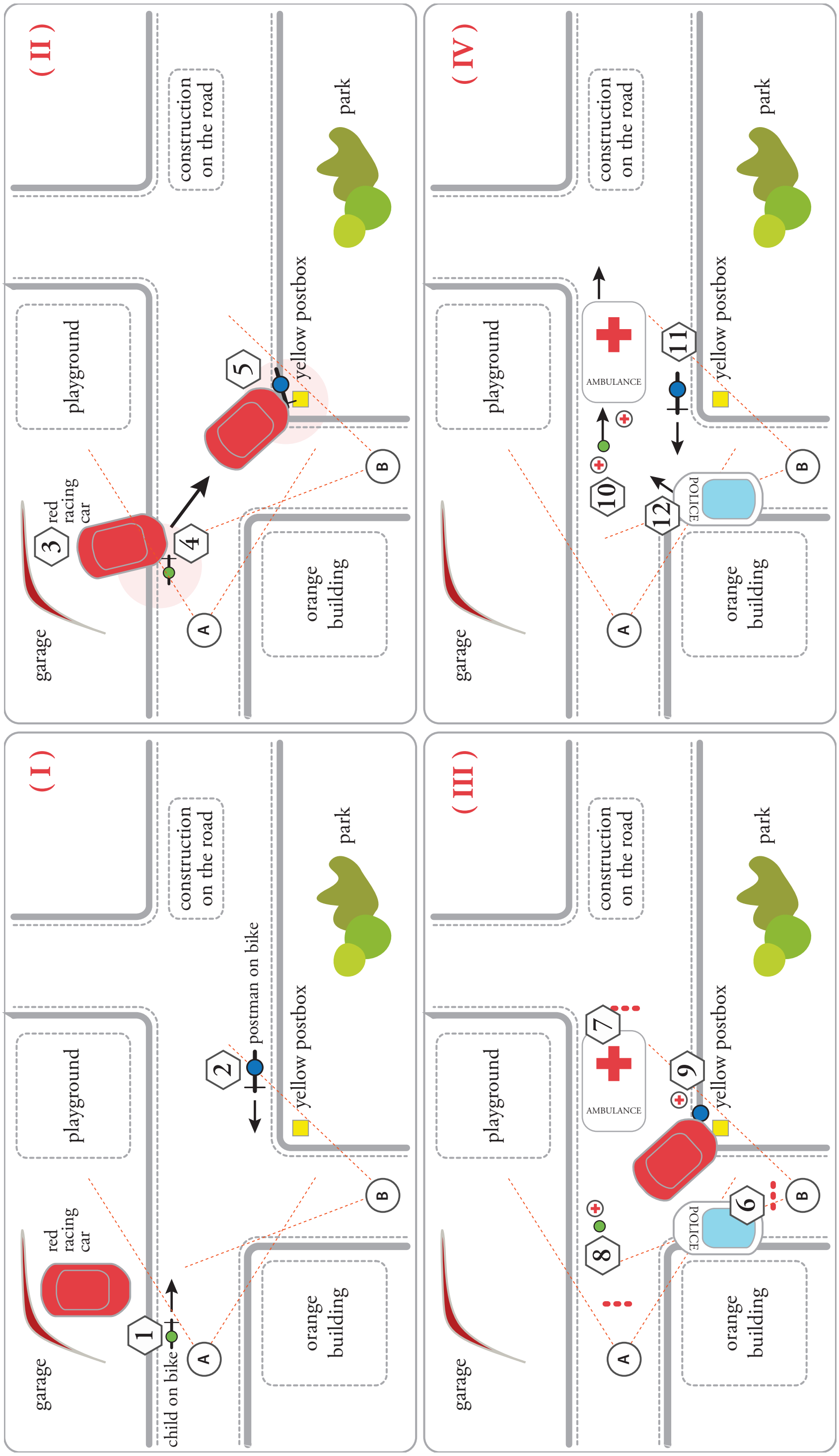


Figure 5.2. The incident scenario, (I) before the accident, (II) the accidents, (III) the response, and (IV) the completion.

This scene depicts the first accident, where the red racing car hits the child. Both participants are able to see the accident. The first participant has a clearer view of the initial accident: however, he can not see what happened after the red car runs over the child. Meanwhile, the second participant clearly see that the red car continues on to hit the postman.

5.1.2. PARTICIPANTS

Ten participants divided in five pairs took part in this experiment. There were 2 female and 8 male participants. The participant sample consisted of professors, PhD researchers, and master students from the Delft University of Technology.

5.1.3. PROCEDURE AND TASKS

The experiment was constructed to examine two participants, while they are collaboratively making a simple map together. Each experiment session was conducted with a pair of participants. Each experiment lasted between 30 to 40 minutes. First, the procedure of the experiment was explained to the participants. Then, the participants were shown a different series of 20 photos depicting the incident, with each photo displayed for 5 seconds. Each photo series contained pictures taken from a different vantage point, thus some events were occluded from one of the participants and vice versa. After watching the photo series, the participants were asked to make their own sketch map of the depicted situation on a piece of A4 paper. Afterwards, they were asked to compare and discuss the differences in the maps that they created individually and then make a new joint map together.

5.1.4. MEASURES

The main goal of this study was to explore the potential problems that can be encountered while constructing a collaborative situation map. The map produced from both participants and the joint map were compared to the real map and real location of key events in the scenario. From this comparison and the observation notes obtained during the experiment, specific problems in the collaboration were spotted and analyzed to identify their potential causes.

5.1.5. RESULTS

The results will be presented in two sections, the first section describes the phases of the collaboration observed, and the second section explores the specific collaboration issues in the experiment.

5.1.5.1.Collaboration phases

In the collaboration phase, the participants were instructed to compare their individual maps and based on their discussion, construct a new map out of their combined recollections. However, the choice of which steps the participants follow to achieve that goal was left entirely to them. Observing the collaboration phase among the five groups, emerged the same pattern of steps which were repeated in the whole experiment:

1. Each participant told their account of the scenario by using the individual maps created in order to determine overlaps and differences in their stories:
    a. The participants start by stating many landmarks and stationary objects such as: garages, playgrounds, building colours, construction roads, postboxes, cones, etc.
    b. Next is orientation step: the participants try to figure out their relative positions on the map.
    c. Afterwards, the participant start to exchange events in chronological order.
2. Resolving differences and unclear facts.
3. Adding complementary information which is only known by one of the participants
4. Reaching agreement on the complementary information
5. Drawing the information of their combined account on a new map. Both participants achieved drawing the details of their combined accounts in a new map by drawing at the same time or by allowing one to do the drawing while the other adds complementary information.

Map comparisons

Each key event in the incident scenario (5.1.1) was checked with the maps created by the participants, whether or not they presented these key events. The performance of the collaboration was measured by comparing the individual maps to the joint map as summarized in Table 5.1. A positive performance was achieved when the participant complemented each other's missing information, and thereby correcting wrong observations (depicted by the [•] boxes). A negative performance indicated when the joint map was worse or less complete than one of the individual maps (depicted by the [x] and the [!] boxes).

Two of the five pairs resulted in a positive performance, as shown in Table 1 (Pair 1 and Pair 4). They managed to piece together all the events of the incident scenario and drew them on their joint map. In both cases, certain collaborative elements which helped to improve their performance were observed. These elements include the participant's mechanism of constantly re-checking the story facts, their willingness to listen and learn from each other, the equality of their standing during the discussion process, and whether they had a prior history of collaboration.

#	PAIR 1			PAIR 2			PAIR 3			PAIR 4			PAIR 5		
	1	2	*	1	2	*	1	2	*	1	2	*	1	2	*
1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2	-	•	•	-	•	•	•	•	•	•	•	•	-	•	•
3	•	•	•	•	•	•	•	•	•	•	-	•	•	•	•
4	•	•	•	•	•	•	•	•	•	•	-	•	•	•	•
5	-	•	•	-	•	•	-	•	x	-	•	•	-	•	•
6	•	•	•	•	•	•	•	•	•	•	•	•	-	•	!
7	•	•	•	•	•	x	•	-	x	•	•	•	-	•	!
8	•	•	•	•	-	•	•	-	•	•	-	•	-	•	!
9	-	•	•	-	•	•	-	-	-	-	•	•	-	•	!
10	•	•	•	•	-	•	•	-	!	•	-	•	•	-	•
11	-	•	•	-	•	•	-	-	-	-	•	•	-	•	!
12	•	-	•	-	•	•	-	-	-	-	•	•	-	-	-
CL1	7	8		8	5		8	8		7	7		2	8	
CL2	9	9		7	7		8	8		9	9		4	9	

Table 5.1. Completeness of the individual and joint maps. The numbers are the scenario event numbers as described in 5.1.1.

Legends:
[-] are activities that were not drawn on any of the maps
[•] are activities that were drawn on an individual or joint map
[x] two types of activities: (1) wrongly drawn activities on the joint map even though they did not occur in the incident scenario, and (2) the activities that were known to one of the participants but became unclear or less certain as a result of the collaboration
[!] activities that took place in the scenario and were known by at least one of the participants, so they could have been on the joint map but were not
CL1: Self-rated confidence level before the collaboration by participants
CL2: Self-rated confidence level after the collaboration by participants

Below is a transcript of a conversation that took place during the experiment where the participants repeatedly re-check.

B: *"actually, I saw there was this car, but I thought it was going to run over the kid, but then afterwards I saw a picture of the postman also being run over …, with the letters on the ground"*

A:	*”okay, the postman was also hit?”*	A was being informed that the postman was hit by the car, and clarifying this fact
B:	*“yea, I think so, yea”*	
A:	*“oh, hmm ..., interesting”*	
	“what I remember there was this bike, from my point of view, cycling here”	
B:	*“he eh, was it a kid?”*	In this discussion, participant A and B were verifying that the first victim was a child on a bike.
A:	*“it was a kid”*	
B:	*“yea I saw the kid too here on the bike”*	
A:	*“so it was a kid then on the bike, sure”*	
B:	*“I think so”*	
A:	*“and then there’s a car coming from the playground and that’s run over the kid”*	
B:	*“well then the car runs over the both the kid and the postman”*	The conclusion of the discussion
A:	*“wow, that’s impressive”*	
B:	*“but the postman didn’t go to the ambulance”*	
A:	*“okay”*	

On the other hand, collaborative performance deteriorated in three out of five pairs (Pair 2, Pair 3, and Pair 5). From the observations, one can identify a number of different causes. For example, it seems that doubt about the observed events caused hesitation in the collaboration process. In order to overcome the uncertainties, participants sometimes resorted to adding extra information or omitting events they already had on their individual maps for the sake of reaching a consensus, as can be seen in the following example. The [x] box in Pair 2 of Table 5.1, represents a faulty conclusion that resulted from that pair’s discussion. They concluded that there were two ambulances instead of one. The pair was indecisive in their discussion and took a longer amount of time to draw their joint map compared to the others. They often expressed their hesitation by using words such as ‘maybe’ and ‘probably’ in their evaluation. Additionally, this caused a mistake in one of the individual maps, where the ambulance was drawn in a wrong position. As a result, they were trying to overcome the confusion by proposing extra events that did not belong to the scenario the extra ambulance was added to the joint map.

Four out of the five pairs were able to correctly identify their relative positions on the joint map. The process of understanding orientation and relative position was important and necessary to ensure an effortless collaboration. The one pair that failed to complete that step correctly (Pair 5), faced considerable confusion in the discussion process. This hindered their ability to identify certain events in the scenario. As a result, they failed to draw these known events on the map.

Some collaboration biases could have resulted from an unbalanced relationship between the participants, where a stronger personality or a more senior position allowed one participant to dominate the discussion process. These biases could have caused some known facts to be discarded from the weaker participant. The [x] boxes in Pair 3 of Table 5.1, represent the introduction of doubt over events which were believed for certain to be facts before the discussion. In this case, the second participant saw two accidents while the first participant, who seemed more dominant, only saw one of the accidents. In one such case, the second participant, who was correct in the beginning, was influenced by the first participant, became unsure about the two accidents and consequently left the uncertain facts out of the joint map. In the session of Pair 5, a senior researcher was paired with a young master student. The student is represented in Table 5.1 as participant 2. After viewing the photo series, the participant had almost all of the events of the complete incident scenario drawn on her individual map. Unfortunately, the senior researcher (participant 1) was uncertain of many facts. The discussion led to a worse joint map than the one originally drawn by the student. This was caused by the student's hesitation to speak up to the senior participant and being too polite towards authority when the senior was wrong. Therefore, many events in the student's account did not come out during the discussion and were not drawn on their joint map. These failures are represented by the [!] boxes in Table 5.1, Pair 5.

The post interview

After the experiment, the pairs were interviewed to gain insight into their experiences during the experiment. They were asked about their level of confidence of their map before and after the collaboration. Three out of the five pairs reported that their perceived confidence level increased. One pair stated the same level of confidence before and after the collaboration. Another pair stated that their confidence dropped.

Difficulties encountered by the participants during the experiment were asked. Usually the difficulty was in discovering, through discussion, that each participant saw the same accident from two different vantage points. The participants explained that stating this fact from the beginning of the experiment would have helped the discussion to go smoother. Another source of confusion was that the slideshow described a sequence of events while the participants were expecting multiple shots taken at one point of time after the accident occurred.

5.1.6. DISCUSSION

This study examined face-to-face collaboration and map making, highlighting potential benefits and pitfalls. A better joint map seems to be created when collaborators cooperate and help each other by rechecking the story, facts, and the certainty level of the events. On the other hand, joint maps can have a lower quality than the individually created maps when there is an unbalanced power or dominant relationship between the participants, e.g. if one actor is more dominant in the discussion, or if one of the actors has a more senior position. Additionally, during the discussion, while making a collaborative map, participants tend to repeatedly express their confidence about objects and events remembered from the scenario. However, there is a potential for occasional information-loss where collaborators, who may be quite confident about a particular event, give up their stance when their uncertainty for another collaborator dominates the discussion. This usually occurs when there is an unbalanced relationship between collaborators.

While examining the problem of dominance among participants in focus groups, earlier work (Carey, 1995) has concluded that such a problem can be bypassed by explicitly putting all relevant information on the table before starting the collaboration. Hence, the implementation of a collaborative map making system should have a mechanism that explicitly states the confidence levels of the presented information in order to overcome the dominance factor in the collaborative process. In regard to information sharing modalities, the system should have a combination of different modalities which can be used to continuously refine the generated map. One possible approach is to allow each user to construct an individual map as a first stage of the map making process. The system can then share the created map with other collaborators so that it allows them to compare the presented information and come up with a better shared map. An additional stage of collaboration can then introduce the modality of voice discussion (currently the only used channel of information by professional rescuers on the field) to allow collaborators to resolve ambiguities in the information on the shared map.

5.2. Remote collaborative situation-map making

The second experimental study is based on the field observation as described in Chapter 3, and the first experiment study (face to face collaborative situation-map making). The aim is to test the effectiveness of other forms of communication modalities as collaboration channels and the explicit use of confidence level in collaborative situation-map making.

5.2.1. HYPHOTESES

Three hypotheses were formulated:

H1. Additional stages of increased collaboration channels improve the quality of a shared situational map.

H2. Explicitly indicating confidence information of objects and events shown on a map improves the quality of a shared situational map.

H3. Explicitly indicating confidence information of objects and events shown on a map supports the communication process.

5.2.2. EXPERIMENTAL METHODOLOGY

With the three hypotheses defined, a detailed experiment was designed to examine their validity. In order to test the first hypothesis, the experiment involved different stages of collaboration adding different types of communication modalities. The tested additional stages in the experiment were: (1) no collaboration, i.e. individual map making, (2) updating maps after individual situational maps were exchanged, and (3) adding voice communication between collaborators to discuss and alter their maps. Testing the second and third hypotheses required two experimental conditions in which collaborators were able or unable to explicitly show their level of confidence on the map itself. The idea is that by making the confidence level information explicit, it will be possible to see whether this helped the participants during the map-making and discussion process by allowing them to focus on discussing objects that they found more important or they were less certain about.

5.2.3. PREPARATIONS

5.2.3.1.Scenarios

In order for participants to make a collaborative map with overlapping information on the same incident, two different scenarios were created. These two scenarios were an explosion in a gas station and a collapsed bridge, due to collision. The scenarios were verified for their plausibility by a fire-fighter commander. Each of the scenarios was divided into two parts: the unfolding accident and the rescue response. At the end, four sets of stories were created.

The explosion scenario starts with a man filling his truck at a gas station. The spillage of gasoline from the gas tank is ignited by a lit cigarette bud. The ignition causes the truck to explode, generating flames that engulf the truck, man, and gas station (as shown in Figure 5.3).

In addition, the explosion injures a boy playing near the gas station. While bystanders try to rescue the boy, flames spread to a neighbouring building trapping a girl in an upper level. When the fire truck arrives they focus their efforts on rescuing the boy and trapped girl. The man who was tanking his truck receives a lower priority since he already died from his injuries. Rescuing the trapped girl requires a fire truck with a turntable ladder since she is located in the 3rd story of the apartment building. Ultimately, the little boy is taken away in an ambulance, the girl is rescued, and the fire is put out.

In the collapsed bridge scenario a fire starts in a two-story house trapping a woman on the second floor. The chaos caused by the fire distracts the crew operating a freight boat cruising in a nearby water channel. As a result, the freight boat collides with a bridge sending a car with its driver into the water channel (Figure 5.4).

After navigating around a traffic jam caused by the collapsed bridge, fire fighters put out the flames in the burning house and rescue the trapped woman. Meanwhile the driver who fell into the water channel is lifted to safety with the help of a fire truck with a turntable ladder.

5.2.3.2. The miniature world for incident setting

As in the first study, the disaster setting was constructed in a similar way by using Playmobil toysets. In this case, four sets of photo slideshows for each scenario were created, giving eight slideshows in total. For each scenario, the first two slideshows presented the story of the unfolding accidents (from

Figure 5.3. A picture from the explosion scenario showing the flames consuming the truck, the victim, and the gas station.

two different angles) while the other two showed the rescue effort (again, from two different angles). Some of the images were later manipulated using Adobe Photoshop to add effects such as fire and smoke.

5.2.3.3. The magnetic board for map-making

To help the participants to rapidly create the situation map, and to ensure that the map can be consistently translated into quantitative data, this time, the participants were not asked to draw their recollection of the events. Instead, they were given sets of icons of the objects, actors, confidence levels, and a map of the environment. As shown in Figure 5.5, participants could use these icons to illustrate their recollections of the events on a top view map of the disaster area. Since the map was fixed on a magnetic board, it was also possible to edit the locations of icons after they were placed on the map. This also gave the participants the ability to quickly edit the map if they wanted to. The board was light and simple to handle making it easy to hold up right to face the camera, photograph the map, and share it with the other participant.

The confidence level information was represented by star icons that participants could place next to events, actors, and vehicles on the map. The confidence level information was presented with a red star for 'low confidence', yellow for 'medium confidence', and green for 'high confidence'.

Figure 5.4. One of the images of the collapsed bridge scenario, showing the freight boat colliding with the bridge causing it to collapse.

5.2.4. PARTICIPANTS

This study involved 32 participants that were grouped into pairs, thus totalling 16 pairs. The pairs were arranged in such a way that each team consisted of unacquainted partners, to simulate that they never worked together before as is characteristic during a disaster. There were 7 female and 25 male participants, between 22 and 42 years old (M = 28, SD = 4.26) with undergraduate to post-graduates level of education. The participants had a wide variety of different nationalities and were recruited from the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS) at the Delft University of Technology. They all had normal or corrected-to-normal eyesight. Only two participants had special training or experience as rescuers. The experiment took approximately two hours to complete. The participant received a gift as an incentive to take part in the experiment. The available gifts had a value of about €15.

5.2.5. DESIGN

A two-way repeated-measures design was used for this experiment. The within-subject factors were the stages of collaboration (no collaboration, shared map collaboration, and shared map with voice communication collaboration) and the availability of confidence level information (without confidence and with confidence). The order of the scenarios and the availability of the confidence level information were counterbalanced. It would however have been

Figure 5.5. A participant placing the icons on the magnetic board.

confusing to show the rescue slideshows before the accident slideshows, this aspect of the experiment was therefore not counterbalanced. Similarly, the stages of collaboration always followed the same sequence: individual maps with no collaboration, shared map collaboration, and then shared maps with voice communication collaboration.

5.2.6. PROCEDURE

Each experiment was conducted with a pair of participants. First, the procedure of the experiment was explained to the participants after which they were escorted to separate rooms. Each participant was given a consent form to be read and signed that explained how the results of the experiment will be used. Because coloured icons play an important role in this experiment, a colour blindness test was performed prior to the first sessions. The experiment consisted of four sessions (scenario A: accident, rescue; scenario B: accident, rescue). In each session, the participants went through the task of constructing a situation map in three different stages of collaboration (no collaboration, shared map collaboration, and shared map with voice communication collaboration) which are explained in further detail in the following

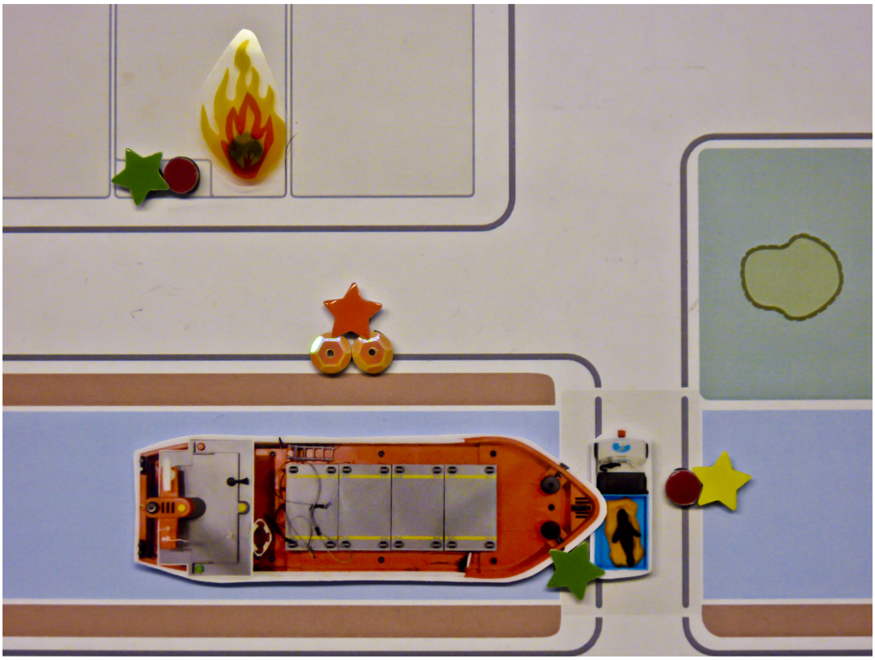


Figure 5.6. A participant's map with confidence level icons next to the objects in the map. This map shows, for example, that the participant was sure about the collision between the cargo boat and the small truck (green star), but has low confidence that there were two bystanders standing next to the water channel (red star).

Tasks section (Section 5.2.7. After finishing all four sessions, the participants filled in a final questionnaire giving their impressions of the experiment.

5.2.7. TASKS

In each session, a slideshow was shown to the participants depicting the events for one of the scenarios. Each slideshow consisted of 21 slides, and each slide was shown for 5 seconds. During a session, both participants are shown a slideshow of the same events but from a different point of view. After viewing the slideshow, the participants were guided through the three stages of collaboration.

In the no collaboration stage, participants were given a magnetic board with the top view map of the disaster area and were asked to reconstruct the events which they just saw from the slideshow, on the map. If 'with confidence level information' condition was true, the participants were also asked to add their confidence level for all events, actors, and vehicles involved in the scenario. Participants could place these confidence levels, represented by red, yellow, and green stars, next to the icons they placed on the maps, as shown in Figure 5.6.

In the shared map collaboration stage, a photo was then taken of each participant's magnetic board and exchanged to the other participant. The participants were given the chance to make adjustment to their map based on the new information if they felt necessary.

In the shared map with voice communication collaboration stage, the participants were again shown the map of the other participant and given the chance to have a voice discussion with the other participant for a maximum of 5 minutes. During and after the discussion, the participants could adjust their maps. A final photo of the maps were taken for evaluation purposes.

This procedure was followed three more times for the sessions involving the rescue slideshow of the same scenario and repeated for the accident and rescue slideshow of the other scenarios. In each of these sessions, the pair of participants went through the three above mentioned stages of collaboration. When starting to construct the map for the rescue session, the participants were given the choice to either modify the map they created for the accident slideshow or clear the map and start constructing a new one.

5.2.8. MEASURES

In order to examine the given hypotheses a set of measures was chosen. The first hypothesis involved the information sharing stages. To test this hypothesis, the quality of the map was measured after each stage of collaboration in order to see how it was affected. The quality of a maps was measured by comparing it to the ideal-map which contains all the events shown in the slideshows in the correct location.

The second hypothesis involved the effect of explicit confidence information on the quality of the map. To quantify this, the quality of the produced maps were used again to see how they were affected by the availability of confidence information. To analyse the effect of explicit confidence information on the communication process (the third hypothesis), all voice conversations were recorded. The voice recordings were examined for any effect on duration and behaviour in the discussion that was caused by the different conditions (with or without confidence information). Finally, the perceived usefulness of confidence information was collected by a post-questionnaire at the end of the experiment.

5.2.9. RESULTS

5.2.9.1. Data Preparations

For assessing map quality, an ideal-map was produced based on the ideal recreation of the events shown in the slideshows. The maps created by the pairs were evaluated by comparing them object-by-object to this ideal-map. Each object had two properties to be rated, namely detection (whether it was detected and placed on the map) and location (whether it was placed in the correct location). Each property received a score that could be either 0 (completely wrong), 0.5 (partially correct), or 1 (an exact match of the key-map). For example, an object on the map received a rating of 0 if the location did not correspond to the proximity of the object on the ideal-map, while a 0.5 rating was given when it was close to the correct location, indicating that the participant had an approximate idea regarding the location of the object.

Objects were then tagged into categories to facilitate further analysis of the data. For example, an analysis of the quality of the mapped vehicles can be made by looking at the score of all objects with the vehicle tag (police cars, fire trucks, cars involved in the accident, etc.). The score for this category was calculated by taking the average score from all vehicles. When calculating the general quality of the entire map, the average score was taken of all categories of the objects on the map (there were 15 categories and 68 objects). This average score was a value ranging from 0 to 1.

In preparing the voice discussion data, a coding scheme tailored to the recordings was developed. There were four sessions and 16 pairs of participants with a maximum of five minutes of discussion time. In total, 320 minutes (approximately five hours) of discussion recordings. While listening to these recordings, the important keywords were identified and were clustered to find the important phases and events in this specific discussion process. A phase is defined as a distinct period or stage in the discussion process that has a time duration. Only one phase can take place at the same time, meaning that one phase can only start once another phase has ended. In other words, phases are mutually exclusive. An event is a single occurrence of a process that can take place within a phase. Events have no time duration. Events that took place during the discussion were grouped into five different types of events.

The six different phases are identified: (1) communication, (2) meta-communication, (3) my story, (4) your story, (5) bargaining, and (6) conclusion. The phase definitions, some utterance examples, the average discussion time (seconds), and the standard deviation of each phase can be seen in Table 5.2.

	DEFINITION AND EXAMPLE OF UTTERANCES	DURATION(S)	
		M (%)	*SD*
1	Communication, a phase where the participants greet each other, give compliments, or say goodbye. *"Hello, how are you?", "Can you hear me?", "Time is up, goodbye"*	35 (3%)	36
2	Meta-communication, a phase where the pairs communicate on how they should communicate in this discussion, such as discussing their working procedure, suggesting procedures, and explaining what they are doing. *"So, how are we going to do this, shall we start by telling what each of us saw, or shall we discuss the differences between our map?", "I'm looking at your map at the moment, so what I did, I changed the camping car to your location."*	99 (10%)	58
3	My Story, a phase where a participant talks about his point of view of the story. *"I see that … ", "I have not seen that ..."*	670 (65%)	201
4	Your Story, a phase where a participant talks about (what they think is) the other participant's point of view. *"I've seen that you put it on your map"*	144 (14%)	69
5	Bargaining, a phase where the pairs discuss their findings, such as trying to convince the other participant and give suggestions of solutions. *"Can we remove that victim?", "Can you change the map then?", "We are now only focusing on the red car while there's more important things to discuss."*	26 (3%)	27
6	Conclusion, a phase when the participants conclude and summarized the agreements. *"Ok, I think this way we are totally in agreement"*	39 (4%)	33

Table 5.2. Six different phases in the discussion processes.

The five events are: (1) referencing the map, (2) certainty, (3) uncertainty, (4) agreement and (5) disagreements. The explanation of these events and some examples can be seen in Table 5.3. The table shows the median value instead of the mean value because the frequency of the events data was skewed, making the median a better measure of the central tendency of the data.

	EVENTS	FREQUENCY	
		MDN	*RANGE*
1	Referencing the map, an event that involves talking about the map itself. *"I saw it in your map that you put the fire truck", "Did you modify your map based on my map?", "Yes I modified it"*	0	0 - 6
2	Certainty, this event refers to moments where any of the participants are talking about how confident they are of certain events. *"I'm sure about the fire truck", "I'm really sure about it"*	5	1 - 21
3	Uncertainty, this event refers to moments where any of the participants are talking about how uncertain they are of events. *"I remember seeing it but don't know exactly where it is", "The thing is I can't be sure about that because I was standing in front of the building"*	13	5 - 21
4	Agreement, this event refers to the moments where the participants are in agreement. *"Okay, I will adjust my map then", "I put a victim on the map now, and we can agree about that one"*	0	0 - 4
5	Disagreement, this event refers to the moments where the participants are in disagreement. *"I don't completely agree about what you said"*	0	0 - 2

Table 5.3. Five events in the discussion process.

Using a custom built annotation program, a person not involved in the study was asked to annotate 320 minutes of discussion recordings with all the phases and events. To examine the reliability of the annotations, a second annotator rated a sample of 10 random recordings (out of 64 total). The average case by case inter-rater Pearson correlation was 0.98 for phases, and the Spearman correlation was 0.60 for events. Additionally, the average phase by phase inter-rater Pearson correlation was 0.78, and 0.46 for the average event by event inter-rater Spearman correlation. The duration of the discussion and frequency for each session and scenario was then calculated.

Durations were only calculated for phases and not the events. These were calculated by summing up the durations of all segments of the discussion spent in the specific phase. Furthermore, the duration data was logarithmically transformed, $log_{10}(x+1)$ to decrease the effect of outliers and extreme values. The frequency (of the phases and the events) refers to the number of times they were initiated during the discussion.

To find out whether the confidence information was related to the frequency of mentioning the objects, participants referred to during the discussions, the recordings in the sessions, which used 'confidence information', were further analysed. Depending on the combination of confidence information an object received from both participants, three different groups were defined: (1) both participants sure (green-green), (2) less sure (green-yellow, green-red, yellow-yellow, yellow-red, red-red), and (3) a confidence information was missing (green-missing, yellow-missing, red-missing, both missing). One missing value referred to a situation where one of the participants forgot to put the confidence information in their map. The average frequency, by which an object in a specific category was mentioned during the discussion, was calculated.

To meet the independent sampling assumption, all analyses were done on a pair level. Therefore, all data, such as the map quality, the duration of the discussion, and the post questionnaires were averaged for each pair.

5.2.9.2.Statistical Analyses

The statistical analysis in this study was divided into three parts. First, hypotheses H1 and H2 were tested by analysing the map quality. Second, the voice discussion was analysed to test hypothesis H3. Finally, hypothesis H3 was further tested by analysing the results of the post questionnaires focusing on the participants' experience.

Map quality

The quality of the map was analysed using a repeated-measures MANOVA. The independent variables were the availability of confidence level information and the stage of collaboration (no collaboration, shared-map collaboration, shared-map with voice communication collaboration), while the general map quality was the dependent variable. The results showed that the stage of collaboration had a main effect on the quality of the map with $F_{2, 14} = 57.13$, $p < 0.001$. This main effect was also found consistently in the analysis of the separate categories such as the victims, vehicles, etc., both on the accident map and the rescue map.

The effect of collaboration stages is illustrated in Figure 5.7, which shows that more collaboration improved the quality of the map. A post hoc comparison analysis using a Sidak correction $\alpha_{PC} = 0.025$ showed indirect collaboration by sharing a map was better than no collaboration at all (t_{15} = - 6.08, $p < 0.001$) and the collaboration of a shared-map together with voice communication was better than that with a shared map only (t_{15} = - 5.77, $p <$ 0.001). These results therefore supported hypothesis H1.

The analysis did not find a significant main effect for confidence level information availability $F_{2,15} = 0.02$, $p = 0.884$ nor an interaction effect between collaboration and the availability of confidence level information $F_{2,14} = 1.56$, $p = 0.244$. Therefore no support was found for hypothesis H2.

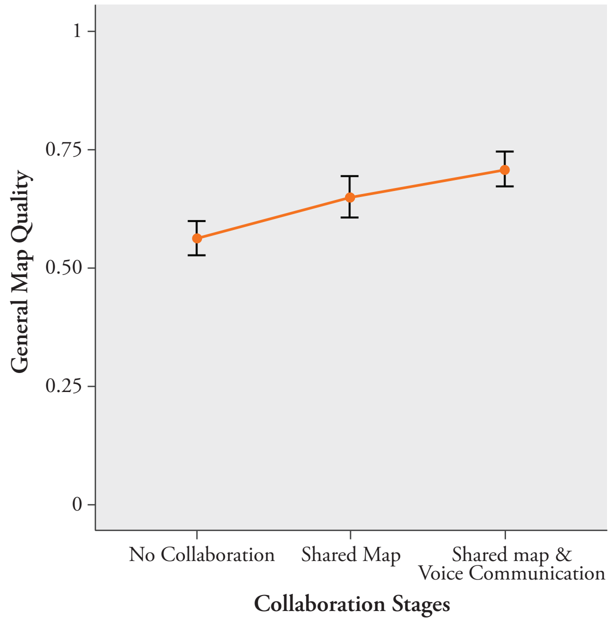


Figure 5.7. The mean map quality with 95% confidence intervals.

Voice Discussion

To study hypothesis H3 (the effect of confidence information on the communication process), the voice discussion data was analysed in two ways: (1) the total duration of each of the phases and (2) the frequency of the events.

To analyse the voice discussion duration, a repeated-measures MANOVA was used, with the type of phase (Communication, Meta-communication, My Story, Your Story, Bargaining, Conclusion) as an independent variable. The test showed a main significant effect $F_{5,10} = 139.27$, $p < 0.001$ for the type of phase. Looking at Figure 5.8, the duration of the My Story phase seemed to stand out from the rest of the discussion phases. Table 5.2 also shows that the My Story phase accounted for 65 % of the discussion time. Furthermore, the *t*-test comparisons (Table 5.4) among phases (Sidak correction α_{PC} = 0.003) showed that it was also significantly different from the other phases.

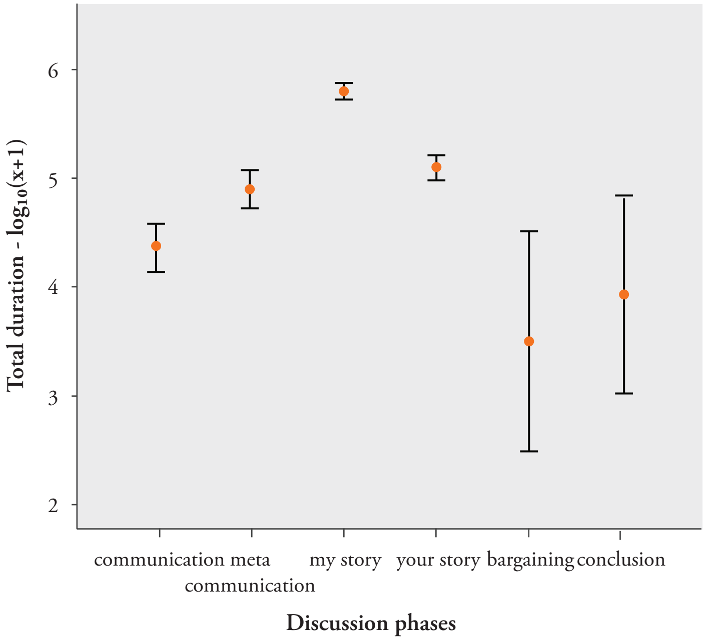


Figure 5.8. The total duration of discussion phases with 95% confidence intervals.

Phases comparison	*df*	*t*	*p*
Communication – Meta-communication	14	-3.79	0.002
Communication – My Story	14	-16.82	< 0.001
Communication – Your Story	14	-6.44	< 0.001
Communication – Bargaining	14	1.69	0.113
Communication – Conclusion	14	0.99	0.341
Meta-communication – My Story	14	-9.03	< 0.001
Meta-communication – Your Story	14	-1.93	0.074
Meta-communication – Bargaining	14	2.95	0.010
Meta-communication – Conclusion	14	2.15	0.049
My Story – Your Story	14	13.71	< 0.001
My Story – Bargaining	14	4.74	< 0.001
My Story – Conclusion	14	4.37	0.001
Your Story – Bargaining	14	3.29	0.005
Your Story – Conclusion	14	2.69	0.018
Bargaining – Conclusion	14	-1.40	0.184

Table 5.4. Phases duration comparison

Furthermore, a two-way repeated-measures MANOVA was conducted to analyze the effect of confidence level availability on the voice discussion duration. The session (accident and rescue sessions) and the availability of confidence level information were the independent variables. The two discussion phases (Bargaining, and Conclusion) were the dependent variables. The Bargaining and Conclusion phases were chosen since they were the phases during which the participants started to revise their maps. Although the test showed no significant effects (since the availability of confidence level information main result was $F_{2,13} = 2.94$, $p = 0.089$, with an interaction effect $F_{2,13} = 3.48$, $p = 0.062$), the result approached at significance level of $p = 0.05$. Furthermore, the univariate test for each of the phases revealed that only the availability of confidence level information had a significant main effect on the Conclusion phase of the discussion. The main effect found, $F_{1,14} = 5.31$, $p = 0.037$, showed that the duration of the Conclusion phase in the accident session became shorter when the confidence level information was available, supporting hypothesis H3. Additionally the analysis showed a significant two-way interaction effect between session and the availability of confidence information $F_{1,14} = 6.89$, $p = 0.02$, as shown in Figure 5.9. A detailed analysis of this interaction effect using a paired-sample *t*-test (Sidak correction $\alpha_{PC} = 0.0127$) showed that participants took less time in concluding when the confidence level information was available in the accident session ($t_{14} = 3.19$, $p = 0.007$), again supporting hypothesis H3. However, this effect was not found in the rescue session ($t_{14} = -0.77$, $p = 0.455$). Furthermore, without the confidence information, the time duration spent on concluding the discussion showed no significant time decrease between the accident and rescue sessions ($t_{14} = 1.86$, $p = 0.085$). There was also no significant increase in time (Sidak correction $\alpha_{PC} = 0.0127$) when the confidence level information was available ($t_{14} = -2.62$, $p = 0.02$).

Beside the effects on phases, the effect of confidence level information on the frequency of certainty and uncertainty events (Table 5.3) were further analyzed using a Wilcoxon signed-rank test (Sidak correction $\alpha_{PC} = 0.025$). Although the average of the event by event Spearman correlation was low (0.46), certainty and uncertainty events held a high interrater correlation of 0.87 and 0.79, respectively. The uncertainty event frequency showed a tendency toward a significant increase ($Z = -2.142$, $p = 0.03$), as a result of the availability of the confidence level information (*Mdn* = 8), compared to when the confidence level information was not available (*Mdn* = 4). In other words, when the confidence information was explicitly shown, the uncertainty was mentioned more often. This may be because participants were more aware of their uncertainties when it was represented on the map, which again supports hypothesis H3.

The next step was to move on from an analysis of having and not having confidence information, to an analysis of what happened when confidence information was presented. The frequency with which participants mentioned an object was analysed. The average frequency of mentioning an object in the discussion was compared using a paired sample *t*-test (Sidak correction α_{PC} = 0.025). The comparison between the frequencies of the group where both participants were sure about the object on the map (green-green) (*M* = 1, *SD* = 0.39) and when the participants were less sure about an object (green-yellow, green-red, yellow-yellow, yellow-red, red-red) (*M* = 3.87, *SD* = 3.69) showed a significantly higher value of frequency (which means that objects were mentioned more often) with t_{14} = -2.94, *p* = 0.011. Additionally, the comparison between total confidence (green-green) and when one participant missed the confidence level information (*M* = 2.93, *SD* = 1.74) also showed a significantly higher frequency of t_{14} = - 4.16, *p* = 0.001.

By exploring the voice discussions on a qualitative level, it was noticed that: (1) when the participants were both sure (green-green) about an object or an event, they briefly pointed it out and then used it as a reference; (2) when one was less sure than the other, or when one completely missed an object, they had a longer discussion; and (3) when they both were not sure (red-red), they simply ignored those events. In some cases, it occurred that missed objects were recalled from memory, but this occurred very rarely.

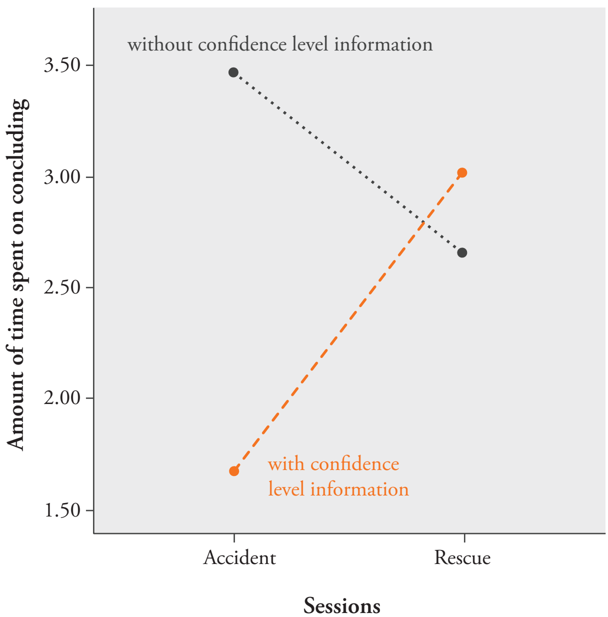


Figure 5.9. The effect of the availability of confidence level information on the duration of the conclusion discussion during the accident and rescue sessions.

Here is an example of a conversation where both participants were sure about the events (green-green):

A: I think we are quite sure about two things

B: the fire

A: the location of the accident

B: yeah

A: the car crash.

They later used these events as reference points to identify the timing of other events on the map:

B: did it happen after or before the fire start?

It therefore seems that the confidence level information sped up the Conclusion phase in the discussion process and made it more efficient by allowing the participants to focus on the things that they were less sure of.

Post Questionnaires

At the end of the experiment, participants were asked to rate the perceived usefulness of the confidence level information during the process of collaborative map-making on a 7-point rating scale. A one-sample *t*-test with test value = 4 (we assume here that 4 is the neutral ground between positive and negative attitude) showed a significant (t_{15} = 2.93, p = 0.01) deviation from this middle rating. Looking at the mean response of 4.97, this suggested that participants leaned toward a positive attitude with regard to this feature. From this, it seemed that participants on average were in favour of the confidence information. This again supports hypothesis H3.

5.2.10. DISCUSSION

Although it was found that the confidence level information affected the discussion process and the participants were in favour of this feature (hypothesis H3), the confidence level information was not shown to affect the quality of the map (hypothesis H2). This might be caused by confusion over how to use this confidence level information in the map-making process. In fact, it can be interpreted in two different ways, whether it was confidence about the type of the object, or the confidence level information about the location of the object. It is also possible that participants liked the confidence level information because it helped the discussion process run smoothly.

Additionally, the effect of the confidence level information was only found in a small part of the discussion process (Bargaining and Conclusion phases). Therefore, the confidence level might not have a major impact on the duration of the entire discussion process. Additionally, considering that the participants spent 65 percent of the discussion time talking about their point of view of the story (namely the My Story phase), improvements addressing this phase will arguably have most impact.

One possible limitation of the study was the lack of a practice session, which may have had a negative influence on the performance of the participants in the first session (e.g. because of unfamiliarity with Playmobil forms and colours). In retrospect, it seems evident that a practice session would have helped reduce this effect. On the other hand, by taking into consideration that each complete experiment took the pair of participants approximately two hours to complete, it would have been difficult to add extra components to the experimental setup.

This study showed that during collaborative map-making, an additional stage of collaboration can improve the quality of the map (hypothesis H1). It is useful to enable indirect collaboration by sharing maps made from different viewpoints since it improved the quality of the map. Next, this quality can be further improved by allowing the communication between the collaborators in addition to the shared map using voice communication. No support was found for the hypothesis that providing confidence information leads to an improved map (hypothesis H2). However, supporting the collaboration by providing confidence level information can shorten the conclusion phase of the discussion process (hypothesis H3). Additionally, during the discussion, uncertainties are more often expressed when the confidence level information is available. This shows that expressing confidence level information explicitly coupled with events and objects can help make the discussion more efficient. Finally, the confidence level information was also perceived as useful by the users. As the collaboration stages and the confidence level information can enhance the process of situation-map making, both methods can be implemented as a technological solution, especially with similar domain and usage.

5.3. Discussion of two studies

In regard to the novel use of toy sets, Playmobil, as quick prototyping tools for depicting disaster scenarios, served their purpose in the mentioned studies. It was possible to use the setup to easily simulate a modeled incident. On the other hand, since all Playmobil human pieces have a standard design with a smiling face, photos taken of the incident models may need further modification to convey more appropriate emotions. Surprisingly, consultations with a fire-fighter commandant revealed that Playmobil was also used to train fire-fighters during exercises, where the toys were used to model disaster situations that fire-fighter trainees used to understand the scenario and plan their actions. It is therefore recommended to use this kind of method to simulate large-scale real life situations for similar research in the future.

5.4. Conclusion

The study in this chapter investigated the possibility of constructing a shared situation map using a collaborative distributed mechanism. Specifically, to test the main hypothesis of this chapter namely, that using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area increases the accuracy and completeness of the disaster situation map. Two experiments were designed and conducted to test this hypothesis. The first study was an exploratory study to understand the process of collaborative situation-map making. The result showed that confidence levels were frequently mentioned during the collaboration. The second study was a more controlled study. The results showed that more collaboration channels lead to a better situation map and that including confidence information for objects and events in the map may help in shortening the "concluding phase" of the discussion process. Thus supporting the main hypothesis in this chapter.

As sharing the maps together with voice communication improves the quality of the produced map, the suggestion is made to open more communication channels (especially visually shared maps) during collaborative map-making to complement the voice communication channel. This is because relying completely on voice communication to relay spatial information has been reported in the literature to be inefficient and ineffective.

This chapter demonstrated that a distributed collaborative map-making mechanism can serve as a method to generate a situation map, thus in disaster situations it might lead to a better situation awareness.

Chapter 6. The Combined Solutions

Some material presented in this chapter has been published in:

TravelThrough: A Participatory-based Guidance System for Traveling through Disaster Areas
Lucy T. Gunawan, Siska Fitrianie, Zhenke Yang, Willem-Paul Brinkman, and Mark A. Neerincx
Proceeding of Computer Human Interaction, CHI 2012

In Chapter 4, a navigation solution for disaster response was presented. It showed that a simple navigation aid based on an arrow that directs the users to the final destination provides sufficient guidance for a short distance navigational task. However, by only conveying the direction toward a destination, there was a chance of ending up at a dead end. A map was, after all, deemed necessary as a navigation aid. Unfortunately, after a disaster with devastating damage, getting the latest up-to-date situation map is a complicated and difficult task to accomplish. Therefore, Chapter 5 investigated a solution for situation assessment by collaborative situation map making.

This chapter combines the above two solutions in a complete implementation of the envisioned system as described in Chapter 3. The aim is to test the third main hypothesis as formulated in the first chapter and discussed in the second chapter.

> *By collaboratively sharing spatial information between the affected population and professional actors on-and-off location: (a) the affected population will be guided in a safer manner and (b) a more accurate disaster situation map will be constructed, which in turn will better facilitate the relocation of the affected population, in comparison to the commonly used system.*

A controlled field experiment with several participants, simultaneously playing different roles, was conducted to compare a new evacuation protocol, proposed in this study, with the traditional centralized protocol. In the proposed protocol, civilians participate with smartphones as they lead themselves to safety, while at the same time serving as distributed active sensors that share observations of the disaster area. The results show that the proposed system is more effective, efficient, and preferred in guiding affected people safely to their destinations. It reduces the mental effort and workload of both the affected person and the operator while performing tasks. This is an important result considering the highly stressful conditions which are occurring during a disaster. Additionally, it also enhances the situation awareness of all the different actors involved and produces a more accurate disaster situation map, thus supporting the third main hypothesis.

This chapter describes in detail the design and the implementation of the system, the experimental methodology, and the statistical analysis of the results. It ends with discussions and conclusions.

6.1. System Design

In order to test the hypothesis and evaluate the proposed system, a state-of-the-art commonly used evacuation mechanism was used as a comparison base. In this study, two evacuation systems were designed and implemented tailored-made for this comparison purpose. The two designs that were compared in this study are:

1. The distributed participatory evacuation system (Distri-ES), is a new system proposed in this study
2. The centralized coordinated evacuation system (Centra-ES), represents the evacuation protocol commonly used worldwide, that is used as the baseline of this research.

A summary of the differences between the two systems is given in Table 6.1. The Centra-ES compilation is gathered from “The centralized disaster management system” section 2.1.1 in Chapter 2 and “Current situation” section 3.1 in Chapter 3.

	CENTRA-ES	DISTRI-ES
Protocol	Centralized Command and Control Model (Neal and Phillips, 1995; Dynes, 1983, 1994; Sobel & Lesson, 2006)	Distributed Participatory Model
Main Actor	Emergency services (local government) (Thristan, 1995; Waugh & Streib, 2006)	The affected population and the emergency services
Situation map	Separate maps (Gunawan, et al., 2009)	Shared map among actors
View of affected population	Helpless victims (Dynes, 1983, 1994; Thristan, 1995;)	Empowered citizens
Communication media	Audio communications (Kean & Hamilton, 2004; Landgren, 2007)	Visual + Audio communication
Navigation tools	Static visual media (paper maps), stand-alone GPS-based navigation system (Landgren, 2007)	Interactive visual media (interactive maps), integrated navigation system
Situation update	Radio broadcast to all (Landgren, 2007)	Targeted broadcast
Walked trails	-	GPS logs, walked route
Map maker	A plotter (Gunawan, et al., 2009)	Everyone participating
Main source of incident reports	The responders + civilians reports through emergency call number (Gates, 2007)	The responders + direct report of the affected population
Dependency on technology infrastructure	Less dependent on technology: radio and (mobile) phones (Schneider, 2005; Farnham, et al., 2006)	More dependent on technology: data connectivity, smart phone with GPS, camera

Table 6.1. The system differences between the Distri-ES and Centra-ES

The main actors in this research are the civilians (affected population) in the field and the operators in the information center. The main goals of the affected person are to (1) go to a safe location in a safe manner and (2) report incidents along the way. While the main goals of the operator are to (1) help the affected people go to a safer location by marking unsafe areas so that the

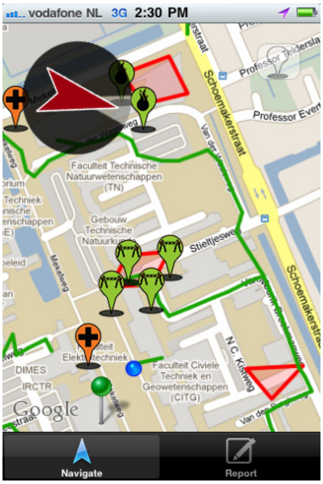


Figure 6.1. The Distri-ES Navigation Module with its interactive digital map, a direction arrow, situation updates, marked dangerous areas, and walked routes.

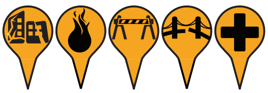


Figure 6.2. Incident report types: unstable building, fire, blocked road, broken bridge, and victim.

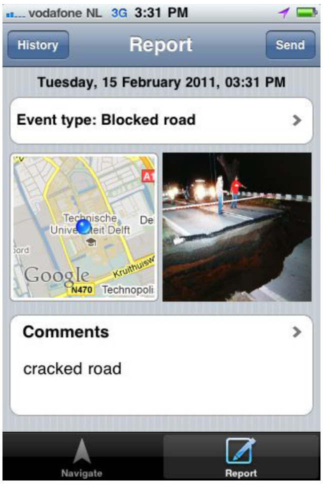


Figure 6.3. The Distri-ES Reporting Module with an incident report and a photo.

affected people can stay away from dangers and (2) understand the disaster situation, so that rescue efforts can be prioritised based on an informed decision.

6.1.1. DISTRI-ES

The Distri-ES consists of a server located in the information center and a client mobile application on a handheld device. The system supports a real-time two way context-sensitive data exchange by utilizing observational maps. Users are allowed to attach relevant information to a particular location of a disaster event to these maps. The client will automatically track the user's location using GPS. The system displays and tracks the user's approximate locations and shares this data with the information center. At the same time, each mobile device receives walked routes and incident reports which are symbolically displayed, and gathered from all other users. The information flow chart of Distri-ES can be seen in Figure 6.4.

6.1.1.1. Handheld Device

The Disti-ES mobile application consists of two modules: the Navigation Module (Figure 6.1) and the Reporting Module (Figure 6.3). The user can choose each interface by tapping on one of the options on the toolbar at the bottom of the display.

The navigation module is used to guide an affected person in a disaster to a safe destination point. It consists of an interactive digital map and an arrow that dynamically points towards the destination (Figure 6.1). The map interface shows the following information: (1) incident reports from all users in the vicinity shown by pin-like markers. The complete list of incident report types are shown in Figure 6.2. Orange indicates new reports, while green represents reports which have been acknowledged by the operator at the information center, (2) The user's position is represented by a blue blinking dot, (3) a designated nearest destination point is shown by a green pin, (4) danger areas are drawn in the shape of red shadowed polygons and (5) the trails of all users are displayed using green lines. The user can zoom the map in-and-out using the pinch-to-zoom gestures. Google maps was used as a digital map.

The arrow was chosen based on the results of the navigation experiment in Chapter 4 indicated that a simple arrows provide sufficient aid for short distance navigation.

The system collects and shares real-time trails and situation reports coming from all users, which may include the emergency-services responders. This way, it is expected that good routes will emerge since the most travelled route by the preceding individuals will have the greatest number of trails. Timely updates are vital, since they indicate dangerous areas that may lie on the route ahead. With up-to-date data, it is expected that all (mobile) users will be able to avoid such dangers and reach safety.

The reporting module is used to report dangerous areas encountered by the user. To use the reporting interface a user is required to select incident type and optionally the user can provide a photo of what was happening together with a brief incident description (Figure 6.3). The GPS location of the user at the time the message was sent is automatically attached to each message by the reporting module. After submitting a report the user receives a confirmation message.

6.1.1.2. The simulation module

To simulate high information load for the operator to cope with during disaster and also simulate the intense nature of a crisis situation, 15 virtual affected persons were added to the experiment. These simulated people were pre-programmed to imitate real people: move like real people and send

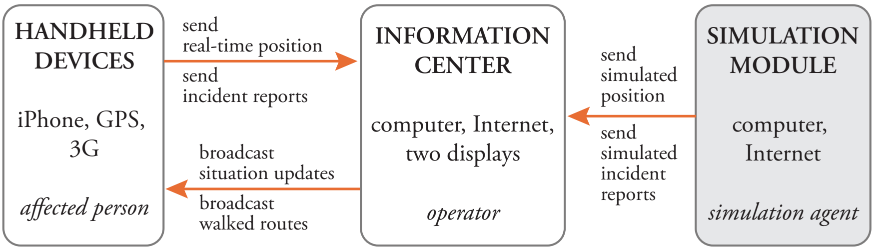


Figure 6.4. The information flow of the Distri-ES condition between the information center, handheld devices, and simulation module. The simulation module was not part of the system architecture, it was only used as a tool in this experiment.

reports like real people. They accounted for approximately 410 incidents dispersed around the city. The operator had no knowledge of the fact that only two real affected persons were taking part in the experiment. The virtual participants were run from a simulator in the server. As all virtual persons produced realistic data just like the real users would, their location was kept separated from the area where the real affected persons were walking, to keep them from interfering with the real participants. Because the operator is allowed to define dangerous areas on the map during the experiment, the simulated persons were programmed with the capability to detect dangerous areas on the way to their destination at runtime. Accordingly they avoid these dangerous areas and recalculate the alternative shortest route to the destination (if needed). They also did not make use of the walked route trails by other real or virtual effected people. A simulation module was developed specifically for the experiments purpose and is not a part of the system's architecture.

6.1.1.3. Information Center Application

Figure 6.5 shows the interface of the server at the information center. The interface has a toolbar on the top of the map interface consisting of the following features: (1) selecting objects on the map, (2) marking dangerous areas, (3) creating reports, and (4) running the server. When the server receives reports from mobile users, the interface automatically displays these as new reports on the map (in orange). Additionally, the interface displays

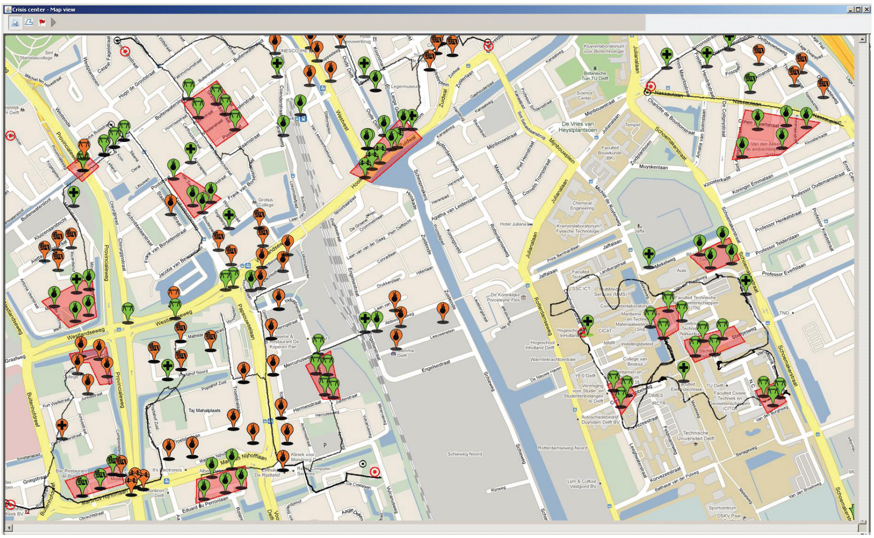


Figure 6.5. The interface of the information center for Distri-ES condition. Incident reports in green show acknowledged reports, red shaded polygons are the dangerous areas, and the black trail are the walked routes by both real and virtual affected people

the trails of all mobile users in real-time (both the real and the simulated participants).

At the information center, the operator may choose to acknowledge a report (after the acknowledgment the icon becomes green), link similar incidents deemed to be at the same danger zone, and alert users to prevent them from entering the zone by drawing a closed polygon, which is then automatically shaded in red, signalling a no entrance zone.

6.1.2. THE CENTRA-ES

The Centra-ES consists of a server located at the information center, an emergency call center application, a mobile phone, and a radio. The affected person navigates manually with a paper map and reports events to the emergency call center by using the mobile phone. In the emergency call center the report is further relayed to the information center. The information center operator has to place all the reports manually on the information center map and then broadcasts the reports to all affected people by radio. In comparison to the Distri-ES, an additional chain of information flow, the emergency call center was added. This meant that reporting and receiving situation updates could not be done in real-time. Additionally, there was no shared map among the actors involved, instead they had their own version of the situation map. The information flow of Centra-ES is shown in Figure 6.6.

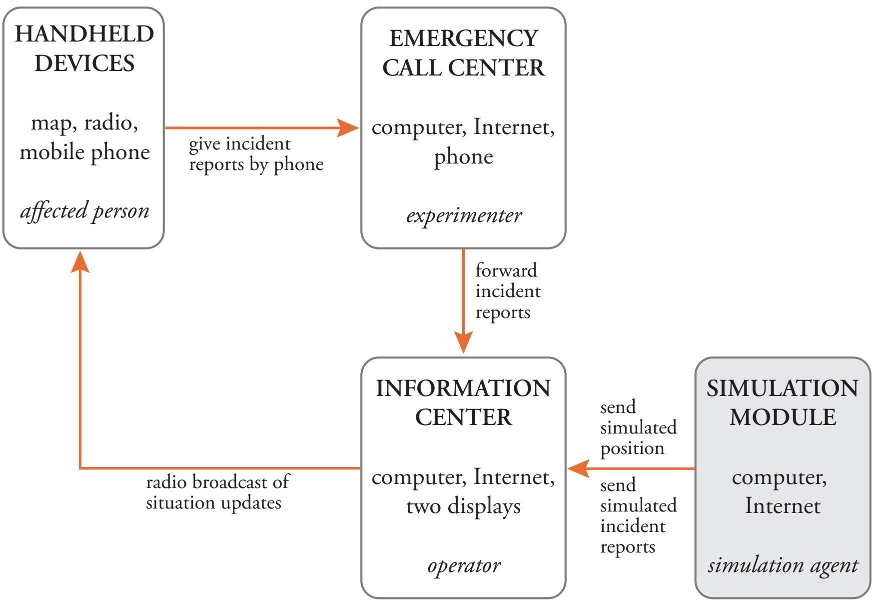


Figure 6.6. Information flow of the Centra-ES condition. The simulation module was not part of the system architecture, it was only used as a tool in this experiment.

6.1.2.1. Handheld devices

The affected person's navigation from the starting point to the destination was aided by an A4 colour paper map of the Delft University of Technology (TUD campus) area (Figure 6.7.a). The same image of Google map as shown in the Distri-ES condition was used on paper. The affected person was also equipped with a pen to be able to actively annotate the paper map when needed. Two mobile phones were used (Figure 6.7.b): one mobile phone was used to report incident reports and another mobile phone was equipped with headphones which were used as a radio for receiving situation updates from the operator. These updates could be drawn actively on the provided paper map by the affected person to help them understand the disaster situation around them. In addition, the experiment logging and tracking was done using an iPhone that the participants were not allowed to use or interact with during the experiment.

(a) (b)

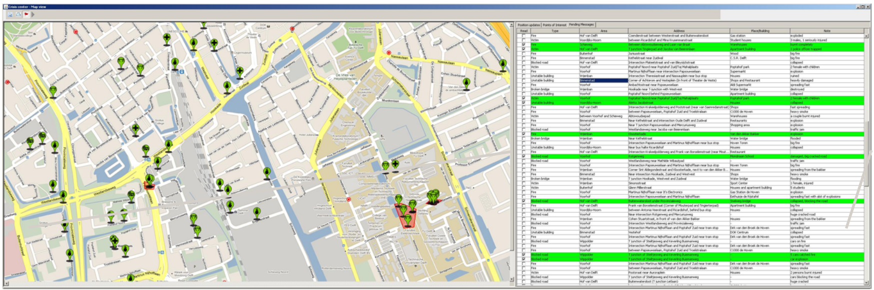
Figure 6.7. a. The paper map as a navigation tool in the Centro-ES condition with participant annotation. b. Mobile phones used as reporting tool and radio for the Centro-ES condition.

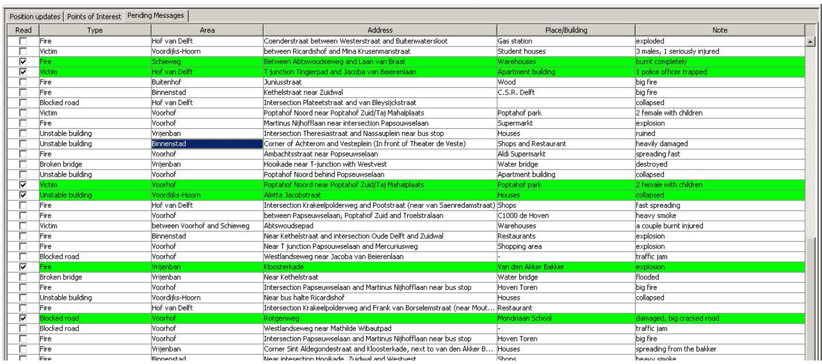
To report an incident, the affected person had to call the emergency call center by using the provided mobile phone and verbally describe his position and the incident to the operator of the emergency call center.

6.1.2.2. The Emergency Call Center Application

The emergency call center application was only used in the Centra-ES condition, to simulate a call center such as 911, where the affected persons can report incidents in the field. An experimenter functioned as the emergency call center operator. To avoid a bias, the operator was given a structured way in which to forward information relayed to him. This was done by standardizing the verbal information gathered from the affected person before relaying it to the operator in the information center, so that the noise factor of different observational reports from participants was eliminated. This was done by continuously asking additional information to the participant when the given information was incomplete. The experimenter then chose a corresponding report in the emergency call center interface and accordingly, sent this report to the information center. Thus, the experimenter always relayed the correct report to the operator.

6.1.2.3. The information center





Position updates | Points of Interest | Pending Messages

Read	Type	Area	Address	Place/Building	Note
☐	Fire	Hof van Delft	Coenderstraat between Westerstraat and Buitenwatersloot	Gas station	exploded
☐	Victim	Voordijks-Hoorn	between Ricardishof and Mina Krusenmanstraat	Student houses	3 males, 1 seriously injured
☑	Fire	Schieweg	Between Abtswoudseweg and Laan van Braat	Warehouses	burnt completely
☑	Victim	Hof van Delft	T junction Tingierpad and Jacoba van Beierenlaan	Apartment building	1 police officer trapped
☐	Fire	Buitenhof	Juniusstraat	Wood	big fire
☐	Fire	Binnenstad	Kethelstraat near Zuidwal	C.S.R. Delft	big fire
☐	Blocked road	Hof van Delft	Intersection Plateetstraat and van Bleysijckstraat		collapsed
☐	Victim	Voorhof	Poptahof Noord near Poptahof Zuid/Taj Mahalplaats	Poptahof park	2 female with children
☐	Fire	Voorhof	Martinus Nijhofflaan near intersection Papsouwselaan	Supermarkt	explosion
☐	Unstable building	Vrijenban	Intersection Theresiastraat and Nassauplein near bus stop	Houses	ruined
☐	Unstable building	Binnenstad	Corner of Achterom and Vesteplein (In front of Theater de Veste)	Shops and Restaurant	heavily damaged
☐	Fire	Voorhof	Ambachtsstraat near Popseuwselaan	Aldi Supermarkt	spreading fast
☐	Broken bridge	Vrijenban	Hooikade near T-junction with Westvest	Water bridge	destroyed
☐	Unstable building	Voorhof	Poptahof Noord behind Popseuwselaan	Apartment building	collapsed
☑	Victim	Voorhof	Poptahof Noord near Poptahof Zuid/Taj Mahalplaats	Poptahof park	2 female with children
☑	Unstable building	Voordijks-Hoorn	Aletta Jacobstraat	Houses	collapsed
☐	Fire	Hof van Delft	Intersection Krakeelpolderweg and Pootstraat (near van Saenredamstraat)	Shops	fast spreading
☐	Fire	Voorhof	between Papseuwselaan, Poptahof Zuid and Troelstralaan	C1000 de Hoven	heavy smoke
☐	Victim	between Voorhof and Schieweg	Abtswoudsepad	Warehouses	a couple burnt injured
☐	Fire	Binnenstad	Near Kethelstraat and intersection Oude Delft and Zuidwal	Restaurants	explosion
☐	Fire	Voorhof	Near T junction Papsouwselaan and Mercuriusweg	Shopping area	explosion
☐	Blocked road	Voorhof	Westlandseweg near Jacoba van Beierenlaan	-	traffic jam
☑	Fire	Vrijenban	Kloosterkade	Van den Akker Bakker	explosion
☐	Broken bridge	Vrijenban	Near Kethelstraat	Water bridge	flooded
☐	Fire	Voorhof	Intersection Papseuwselaan and Martinus Nijhofflaan near bus stop	Hoven Toren	big fire
☐	Unstable building	Voordijks-Hoorn	Near bus halte Ricardishof	Houses	collapsed
☐	Fire	Hof van Delft	Intersection Krakeelpolderweg and Frank van Borselemstraat (near Mout…	Restaurant	
☑	Blocked road	Voorhof	Rotgenweg	Mondriaan School	damaged, big cracked road
☐	Blocked road	Voorhof	Westlandseweg near Mathilde Wibautpad	-	traffic jam
☐	Fire	Voorhof	Intersection Papseuwselaan and Martinus Nijhofflaan near bus stop	Hoven Toren	big fire
☐	Fire	Vrijenban	Corner Sint Aldegondestraat and Kloosterkade, next to van den Akker B…	Houses	spreading from the bakker
☐	Fire	Binnenstad	Near intesection Hooikade, Zuidwal and Westvest	Shops	heavy smoke

Figure 6.8. The information center of the Centro-ES condition (top) with a magnified report table (bottom).

The incoming reports, both from the real affected person (that were relayed by the emergency call center operator), and from the simulated participants were displayed in a table. Despite the additional step in the communication chain in the process (from the user to information center through the emergency call center), the reports from both the real and the virtual affected person did not have visible differences when the reports were displayed on the operator interface. Unlike the Distri-ES condition, these reports were not automatically linked to their location on the map. The operator, as a map plotter, had to place these reports manually, based on the available address description.

The displayed reports in the table contained the following information: (a) the type of incident, (b) building name (if available), (c) the address, (d) the district name, and (e) an optional comment from the reporter. The table was displayed on the right side of the interface, next to the situation map (Figure 6.8). The reports were displayed in a first-in first-out order. The operator could adjust the size of the table, but no sorting options were available.

The operator had a mechanism to mark which report was placed on the map, and also broadcast this newly added information in batches by radio. Additionally, there were no visible walked routes, of both the real affected people and the virtual ones, displayed in this information center.

6.1.2.4.Simulation Module

The same simulation module as in the Distri-ES condition was used, to simulate the virtual affected people.

6.2. Experimental Methodology

As mentioned earlier, the goal of this study was to evaluate two different kinds of evacuation system models: the Distri-ES and the Centra-ES. To evaluate these two models, a disaster event was simulated in the city are of Delft, the Netherlands. The experiment was conducted at the TUD campus area. Three participants were needed for each experiment session, with one participant acting as an operator of the information center and two participants acting as the members of the affected population walking around the campus area. The two affected persons were needed to understand the effect of sharing information. Therefore in this study, they had two different time frames assigned with a five minutes difference between the two. The first (antecedent) affected individual navigated through the disaster area to a designated destination and reported incidents for the first time. After a five minute delay, the second (subsequent) affected individual started evacuating from the starting point as the first individual and reaching to the same designated destination. Ideally, the subsequently individual may benefit from reports created previously by the antecedently affected individual. As the experiment was performed simultaneously for both the operator and the affected persons in two different locations, two experimenters were needed to control the experiment.

6.2.1. THE DESIGN OF THE EXPERIMENT

For the operator, a one way within-subject design was used, the independent variable was the type of systems: the Distri-ES and the Centra-ES.

For the affected person, a two-way 2x2 within-subject design was used, the independent variables were the system (the Distri-ES and the Centra-ES) and the order of the participation (the antecedent affected individual and the subsequent affected individual). For the two system conditions, participants used two different sets of predefined starting and destination points, in which the order was counterbalanced to eliminate any learning effect or route difference.

For the overall system, a one way within-subject design was used, where the independent variable was the systems compared: the Distri-ES and the Centra-ES.

In all conditions, the role of each participant (the operator or the affected person) remained the same, so the operator was always the operator, antecedent affected individual was always the first participant and the subsequent affected was always the second participant.

6.2.2. HYPOTHESES

This chapter hypothesis was broken up into five sub hypotheses.

H1. Usability. The distributed participatory evacuation system (Distri-ES) is more usable than the centralized coordinated evacuation system (Centra-ES) for the affected person in the field and the operator.

H2. Subsequent effect. Compared to the leading affected individuals in the field, the subsequent affected individuals have a higher additional usability benefit from the distributed participatory evacuation system (Distri-ES) than from the centralized coordinated evacuation system (Centra-ES).

H3. Overall performance. The overall performance of the distributed participatory evacuation system (Distri-ES) is higher than the centralized coordinated evacuation system (Centra-ES).

H4. Situation awareness (SA). The SA of the affected person and the operator of the distributed participatory evacuation system (Distri-ES) is higher than the SA of the affected person and the operator of the centralized coordinated evacuation system (Centra-ES).

H5. Perceived Usefulness. The perceived usefulness of the distributed participatory evacuation system (Distri-ES) is higher than the perceived usefulness of the centralized coordinated evacuation system (Centra-ES) for the affected person and the operator.

6.2.3. SCENARIO

A disaster scenario was developed, in which Delft was devastated by an enormous 7.3 magnitude earthquake on the Richter scale. This scenario was chosen due to the characteristics of an earthquake to create multiple dangerous locations spread over a wide disaster area.

For the affected persons, the area of TUD campus was chosen for conducting the experiment for the practicality of experiment logistics. Specifically, the boundary of the area was between the Schoemakerstraat, Rotterdamseweg, Landbergstraat, and Balthasar van der Polweg. The area is roughly rectangular has an area of approximately 0.45 square kilometres making up most of the Wippolder district. Most of the areas were pedestrian area, bike paths, and parking area, with Mekelpark in the center.

There were two sets of predefined starting and destination points that were selected for two sessions to evaluate the two systems. The selection was based on the consideration that possible routes from both sets were comparably similar in length.

For the operator, the area of the experiment was extended to a larger area that covered 7 additional districts in Delft, with a size of approximately 5.4 square kilometres. The experiment area covered 8 districts, but only one was used as the real experiment area and the other 7 districts were simulated with virtual affected people. The division of districts can be seen in Figure 6.9.

Some predefined dangerous areas were positioned in such a way so as to cause the participant to make a detour around the dangerous area. The pre-

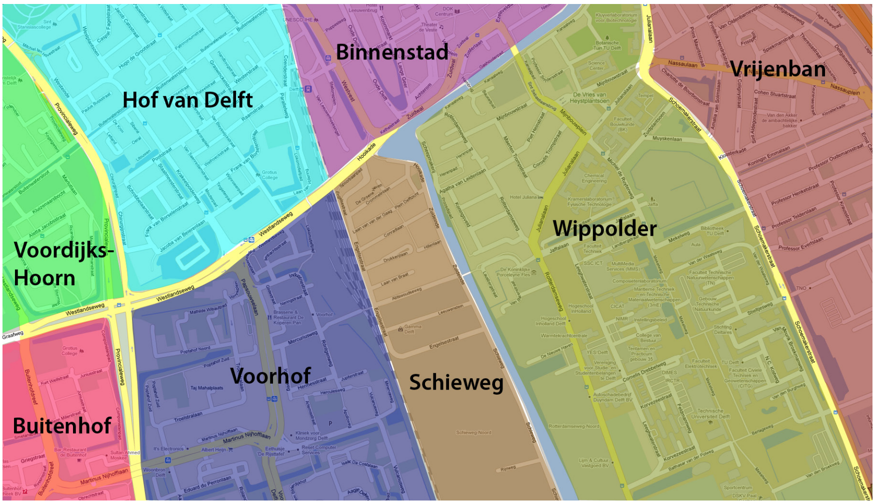


Figure 6.9. The eight districts used in the experiment (adjusted from real map locations for the purposes of the experiment). The real participants walked in the Wippolder district.

defined dangerous areas types were: fire, broken bridge, blocked road, and unstable building. There were 8 predefined dangerous areas in the Wippolder district and 24 predefined dangerous areas in the 7 other districts. In addition to the predefined dangerous areas, predefined victim locations that the affected people can report about were also defined, there were 4 victims in the Wippolder districts, and 12 victims spread across the other districts.

In order to simulate disaster incidents resulting in dangerous areas around the city while the experiment was running and the affected people were walking, some prominent landmarks were used as triggers. Accompanied by a booklet with details about incidents in the vicinity of the landmark triggers, the affected person participants were asked, when they spotted a specific landmark (± 25 m from the landmark), to (1) open the instruction corresponding to the landmark (a unique number), (2) try to understand the situation, and (3) report the corresponding predefined incident to the information center using the provided information in the booklet. This booklet has two main parts: (1) a matrix of 12 landmarks spread around the experiment area with unique numbers (Figure 6.10) and (2) corresponding instructions

Figure 6.10. The matrix of 12 landmarks

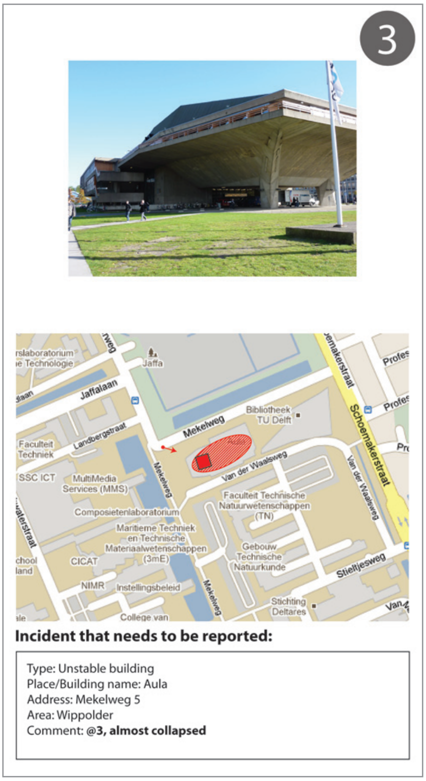


Figure 6.11. Example of corresponding instruction

associated to the numbers obtained from the matrix (Figure 6.11).

This method was chosen due to its paper prototyping practicality. Additionally, it also resembles the situation after a disaster, where even a person who knows the area well has to take detours as a result of blockades ahead that could only be known when this person was in the vicinity of the incident. As there were two sets of predefined starting and destination points, there were also two booklets for each set. Moreover, the booklet contained a map of the area with a predefined starting and destination point for the specific set, as well as all the questionnaires the participants had to fill during the experiment's session.

6.2.4. MEASURES

Basic demographic data and information on familiarity of the Delft area, navigation skill, and prior experience to using any navigational devices were collected. The usability was measured in order to test hypotheses H1, H2, and H3. Furthermore, SA was measured to test hypothesis H4, and finally the perceived usefulness was used to test hypothesis H5.

6.2.4.1. Usability

The broad definition of ISO standars usability (ISO/IEC, 1998) was adopted as the usability model in this study. It consists of three distinct dimensions: effectiveness, efficiency, and satisfaction.

Effectiveness was defined as the accuracy and completeness with which users achieved specified goals. In this study, for the operator, the quality of the produced situation map was used as the primary indicator of effectiveness. This was done by measuring the completeness and accuracy of the dangerous areas defined. While for the affected person, the danger exposure was the main indicator of the effectiveness by measure of frequency and duration of the affected person in the dangerous areas.

Efficiency was measured by relating the level of effectiveness achieved to the resources used. For the operator, mental effort and workload were chosen as the primary indicators of efficiency. For the affected person, time duration, distance, mental effort, and workload were used as the measure of efficiency.

Satisfaction was defined as the users' comfort level and positive attitudes towards the use of the system. Users' satisfaction was measured using an attitude rating scale. In this study, preference was used as the primary indicator of satisfaction for both the operator and the affected persons.

Additionally, the usability of the system's interactive components was measured both at the information center and the handheld device to check whether each component had at least a reasonable usability level for its given task. Since the Centra-ES handheld device did not have any interaction components, the interaction components were only measured for the Distri-ES mobile application.

The operator's UI usability

The effectiveness of the operator was measured on two dimensions: the completeness and accuracy of the defined dangerous areas and the completeness and accuracy of the incident reports registered into the system.

The completeness and accuracy of dangerous areas were measured by assessing the dangerous areas drawn on the map by the operator against the total of 32 predefined dangerous areas. The completeness was defined as the percentage of dangerous areas drawn by the operator compared to the predefined dangerous areas. The higher the percentage, the more areas were drawn by the operator. Completeness was a simple measure that did not take the correctness of these drawings into account, therefore an accuracy measure was required. For measuring the accuracy of the defined dangerous area, the Detection Theory (Macmillan & Creelman, 2005) was chosen for its ability to measure the operator's accuracy in drawing dangerous areas, as well as understand their errors. The measure of performance in this theory is called the sensitivity measure. High sensitivity refers to a good ability to match the predefined dangerous area, likewise low sensitivity refers to a poor ability to match the predefined dangerous area. Additionally, response bias was measured using the likelihood ratio, which measures the operator's tendency toward defining a dangerous area or not to define a dangerous area. This measure is independent of sensitivity.

The completeness and the accuracy of the incident reports entered into the system by the operator were measured by assessing the processed incident reports with reference to the total incoming reports. The higher the percentage, the higher the completeness score. The accuracy was measured by assessing the number of reports that were inside a predefined dangerous area and had the same type of danger, divided by the total number of reports in that area. This was repeated for each dangerous area. For accuracy, only reports that were lying inside dangerous areas were used. The higher the number, the higher the accuracy of the operator using a specific system.

The efficiency of the operator was measured by using mental effort and workload measurements. These were measured twice by using subjective workload assessments.

The Rating Scale Mental Effort (RSME) is a subjective workload measuring tool used to assess mental effort in uni-scale ratings (Zijlstra, 1993). On the RSME, the amount of effort invested into the task has to be indicated, and not the more abstract aspect of mental workload. The RSME score scale ranges from 0 to 150, with lower scores indicating lesser mental effort.

NASA Task Load Index (NASA-TLX) is a subjective workload assessment tool originally developed by NASA to assess workload while working with various human-machine systems (Hart and Staveland, 1988). A two-pass process (ratings and weight comparison) measures several subscales (Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration). Higher scores indicate greater workload. In this study, the paper and pencil format was chosen for its practicality in outdoor conditions.

The operator's satisfaction was measured with subjective preference. Each condition measured the preferences of the operator in using the system in three subscales: the preference for gathering and registering event or incident reports, the preference for broadcasting situation update to the affected population, and the preference in general. The higher the score, the more preferred. A forced choice preference was measured by making the participants choose one of the two systems: the Centra-ES or the Distri-ES.

The general interaction components of the system were measured using a Component-Based Usability Questionnaire (CBUQ). This is a testing approach that empirically tests the usability of system interaction components (Brinkman, 2009). It was used to measure the general rating of the information center interaction components for each system (Centra-ES and Distri-ES).

The affected person's UI usability

The effectiveness of the affected person was measured by the frequency and duration in entering dangerous areas. The more frequent participants entered a dangerous area and the more time they spent there, the worse their effectiveness would be. Likewise, less frequent entrance into dangerous areas and shorter exposure time represented better system effectiveness.

The efficiency of the affected person in the disaster was calculated with four measures: (1) the completion time, (2) distance travelled, (3) mental effort according to RSME, and (4) workload according to NASA-TLX. Completion time was measured the time the participant starts to navigate from the starting point until he reaches the destination. So it includes total time of navigating, reporting, and comprehending the situation. Distance was measured by using the total distance of each participant's route from the starting point to the destination point.

The satisfaction was measured using two preferences questionnaires: (1) system preference and (2) a forced choice between systems. The system preference measures the preference for each condition using a 7-point Likert scale questions. The scale measured the preferences of the system in four subscales:

the preference for getting situation updates from the operator, the preference for reporting incident reports, the preference for navigating, and the preference in general. The higher the score, the more preferred a system was. The forced choice preference was measured by a direct choice made by the participants in favour of one of the two systems.

The system interactive components for the mobile application of the field device used by the affected person were measured by CBUQ. For this, only Distri-ES were measured by a general measure and two interaction components: the report view control and the navigation view control.

The effectiveness of the overall system

The overall system effectiveness was measured by the frequency in entering dangerous areas and time spent in them of all affected people (real and simulated participants). The lower frequency of entering dangerous areas and the shorter exposure time in the danger zones by the affected people, the better the overall system effectiveness is.

6.2.4.2.Situation Awareness

SA is the perception of 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 (Endsley, 1995). For this experiment and for both the affected person and the operator, SA was measured using two methods:

1. a freeze probe approach by using the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 2000)
2. a post trial subjective rating approach by using the Three Dimensions of Situational Awareness Rating Technique (3D-SART) (Taylor, 1989)

The SAGAT involves the direct administration of SA queries (perceptions of the situation at that time) during a 'freeze' of the task. The SAGAT queries in this study include pinpointing locations, indicating dangerous areas, and prioritising rescue. During the SAGAT administration, the participants were asked to draw details of the disaster to the best of their memory without help from the system. These drawings were compared to the predefined disaster situation to get a SAGAT score. The higher the score of the situation map, the higher the SA of the participants is. While a lower score for the priority rescue means that the priority set by the operator is closer to the ideal rescue priority.

The 3D-SART is a three dimensional self-rating technique that was used to elicit subjective assessments of participant SA. The participants were asked to rate SA in three dimensions using a 7-point Likert scale: (1) the demand of attentional resources (*D*), (2) the supply of attentional resources (*S*), and (3) the understanding of the situation (*U*). The demand of attentional resources referred to the question of how much effort the participants had to devote to keeping track of the situation. The supply of attentional resources referred to how well they could keep track of the situation. The understanding of the situation referred to how well the participants understood the situation. The overall SA score was calculated using: $SA = U - (D - S)$. A higher overall score means a better SA.

In addition to these two measures, in order to prioritise the rescue allocation, the operator was asked to rank the potentially problematic districts with 1 as the first priority and 8 as the last priority, by taking into consideration the number of dangers and victims in each district.

6.2.4.3.Perceived Usefulness (PU)

Perceived usefulness is one of the theoretical constructs of the Technology Acceptance Model (TAM) by Davis (1989). It is defined as “the degree to which a person believes that using a particular system will enhance his or her job performance”. Since users are usually driven to adopt an application primarily because of the functions it performs for them, this questionnaire is chosen to understand the acceptability of the Distri-ES compared to the Centra-ES.

6.2.5. PROCEDURE

Each experiment session involved three participants: two affected persons who walk in the field and one operator sitting in an information center. The experiment used an opportunistic sample, where participants were recruited from the TUD campus area. The participant roles were assigned by their own preference and practical reason such as the operator should be able to pronounce the Dutch street names, since one of their tasks was to broadcast the dangerous areas in the Centra-ES condition. When a participant agreed on participating, an information sheet about the experiment was sent by email, together with the consent form. They also received comic strips explaining how the Centra-ES and Distri-ES worked.

On the day of the experiment, the participants, depending on their roles, were guided to two separate rooms to receive separate briefings. The intention was to keep the operator unaware of the fact that there were only two affected people in the experiment. Since the operator was given additional simulated affected people with a greater disaster area coverage around Delft.

There were two experimenters for each experiment session. One experimenter sat in the same room with the operator, to brief and guide the operator, and also to function as the emergency call center operator (for the Centra-ES condition). The second experimenter, briefed and assisted the two affected people participants in the field. In total, for each experiment session, there were 3 participants, 2 experimenters, and 15 simulated participants. The summary of the experiment timeline is shown in Figure 6.12.

6.2.5.1. The operator

Each experiment session began with signing a consent form, this was followed by filling in a pre-experiment-session questionnaire. A brief summary of the experiment goal, the procedure, the scenario used, and the tasks was described. For each condition (Centra-ES and Distri-ES), a brief explanation of the system being evaluated was given, followed by a practise session. The operator's goal was to help the affected people on the field so that they can reach safety and have a good overview of the disaster situation. This was done by registering incident reports coming from the field, marking the dangerous areas so that people could avoid them, and broadcasting these dangerous areas to warn the affected people in the field. On the 8th minute of each condition, the experiment session was paused for 5 minutes to administer a SA query (SAGAT) and an effort questionnaire (RSME). This pause froze the experiment session for the operator and both affected persons. The participants were contacted by the experimenter 5 minutes later informing them that they were allowed to resume the experiment. At the end of the session, the post-condition questionnaires on preferences, workload - NASA-TLX, and perceived usefulness were measured. After finishing both conditions, the participant was asked to fill in post-experiment-session questionnaires (preferences and CBUQ).

6.2.5.2. The affected person

Each experiment session began with signing a consent form, this was followed by filling in a pre-experiment-session questionnaire. A brief summary of the experiment goal, the procedure, the scenario used, the tasks and the use of the booklet for triggering dangerous areas were described and given to the participants. Participants were given example booklet to practise with three landmark photos shown on the screen. Then the twelve landmarks used (in the matrix of Figure 6.10) were reviewed and the participants were asked to pinpoint this landmark on a 3D bird's-eye view map of the test area. This was done to ensure that they were familiar with the landmarks and knew where they were located. Participants were given all the devices which needed to be carried, were given a safety jacket to be worn for safety purposes, and then went out to practise.

This setup was followed by starting the actual experiment itself. For each of the evaluated systems (Centra-ES and Distri-ES), while walking towards the starting point and practise landmark, an explanation about the system and the tools used was given. This was followed by more practise sessions to familiarize with the use of each system's functions: navigating, reporting, and getting situation update. After the participants gained confidence and were comfortable with using the system, they were guided to the starting point.

The antecedent affected individual would start first with the difference of 5 minutes to the second participant. After finishing a condition, the participants were asked to fill in post-condition questionnaires (preferences, perceived usefulness, and workload - NASA-TLX).

After finishing both conditions, the participants were guided back to the experiment base, and were asked to fill in post-experiment-session questionnaires (preferences and CBUQ). The whole experiment session was designed to take approximately three hours. The approximate timeline of the experiment is shown in Figure 6.12.

6.2.6. TASKS

The task of the operator was to assist the affected people in the field in reaching predefined destination safely. The operator could help them by (1) receiving and acknowledging incident reports, (2) recognizing patterns and sizes of dangerous areas around similar reports, (3) marking dangerous areas, and (4) broadcasting the latest situations. The incoming incident reports were sent by the real participants as well as the virtual affected people.

In the Centra-ES condition, the operator had to manually locate and create incident reports, and additionally broadcast the situation updates by radio in batches.

In the Distri-ES condition, the operator was asked to acknowledge every individual incoming report displayed directly on the map (based on the GPS position of the message). The operator did not have to broadcast the new situation updates because this was done automatically.

The task of an affected person was to navigate from a predefined location to a designated destination using field devices (different devices were provided for each evaluated condition) as safe and as fast as possible. In the process, the participants behaved as victims in a disaster area who were searching for a safe shelter. On their way through the disaster area, they were asked to report relevant incidents they might have found along the way, and to try to avoid dangerous areas.

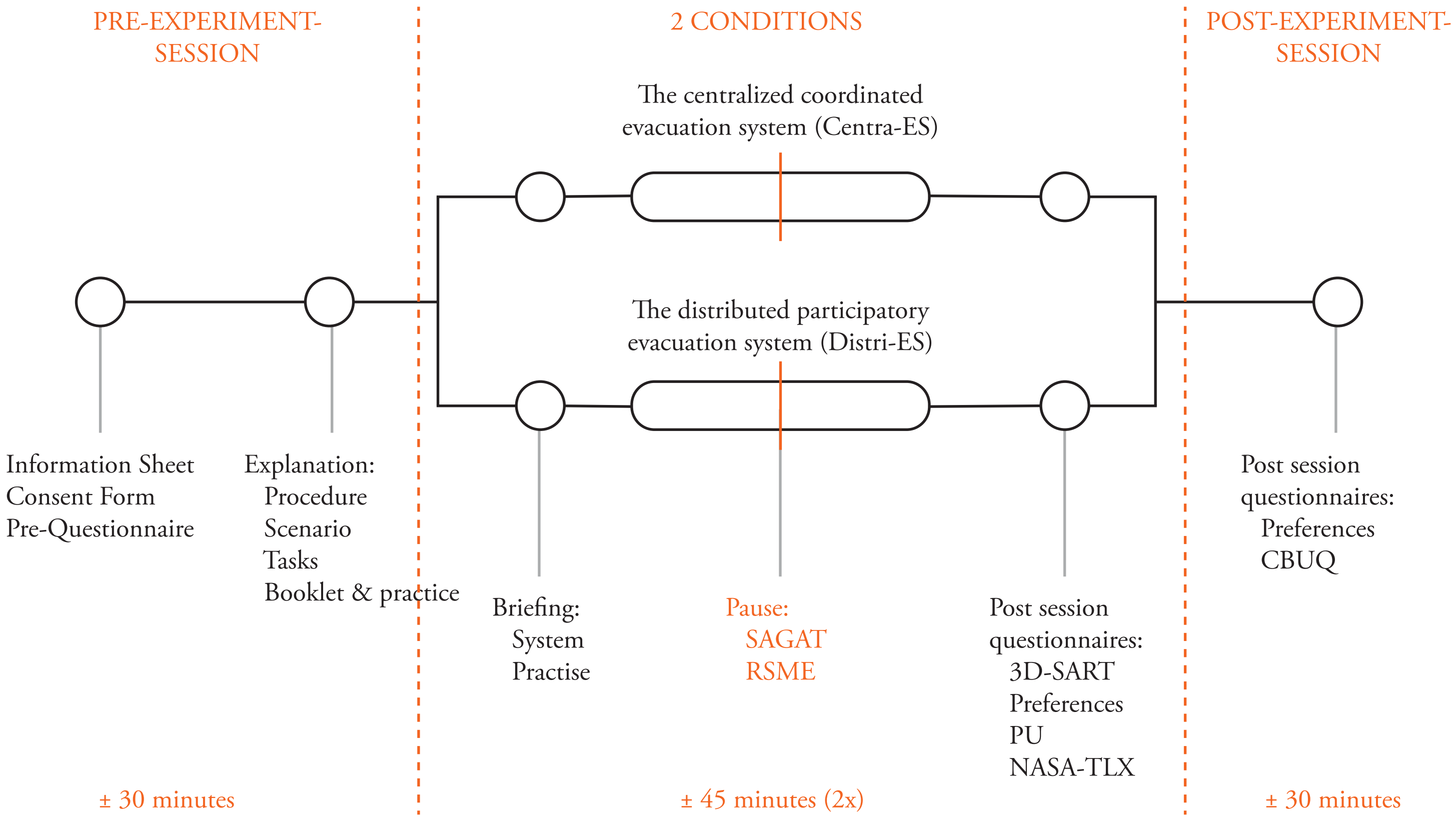


Figure 6.12. Procedure and timeline of an experiment session. Each participant had to evaluate both two conditions in which the order was counterbalanced.

6.3. *Participants*

This study involved 72 participants in groups of three, making a total of 24 groups. The three participants were split into two roles, two participants played the affected persons and one participant was an information center operator. There were 15 female and 57 male participants, between 18–57 years old (*M* = 29, *SD* = 8) with secondary school, undergraduate and post-graduate levels of education. A more detailed participant composition for each role can be seen in Table 6.2. The participants had a wide variety of different nationalities, and were recruited from different faculties at the TUD. The participant received a token gift (in value about €15) as an incentive to take part in the experiment which took approximately 3 hours to complete.

	Operator	Affected person	Total
Age			
Range	21 - 64	18 - 43	18 - 64
Mean	32	27	29
SD	11	4.5	8
Gender			
Male	18	39	57
Female	6	9	15
Total	24	48	72

Table 6.2. Participant composition by age (in years) and gender.

Information about the participants demographics were collected prior to the experiment session. 81% of the affected persons indicated to have experience using a navigation device and their average living/working/studying time at the experiment location (TUD campus) was 3.3 years (*SD* = 3.4). The results of the affected person self rating 7-point Likert scale questions are shown in Table 6.3. where higher numbers indicated a positive answer.

Rating	*M*	*SD*
Familiarity with TUD campus area	4.7	1.3
Orienting ability	5.0	1.5
Navigation ability	5.0	1.2

Table 6.3. Self-rating on a 7-point Likert scale pre-questionnaire for the affected person

The operator average of studying/living/working at the experiment location (TUD campus) was 7.9 (*SD* = 9.8) years. Using the same Likert scale, the result of the operator's self-rating are shown in Table 6.4.

Rating	*M*	*SD*
Abilty to read maps	5.9	0.6
Familiarity with Delft city area	3.5	1.3
Familiarity with TUD area	4.8	1.5

Table 6.4. Self-rating on 7-point Likert scale pre-questionnaire for the operator

6.4. *Environment factors*

The experiment was conducted over six weeks, between 7th March - 12the April 2011. The months of March and April 2011 were extremely dry months. March 2011 was ranked the 4th driest month in the Netherlands over the last 100 years since 1911 (KNMI, 2011a). While April 2011 was ranked 2nd as the month with the most stable weather over the last three centuries since 1701 (KNMI, 2011b). Only two times the experiment sessions were done in the rain and one day with hard wind. From all the experiment sessions, only one session needed to be rescheduled. All other experiments where done under similar weather conditions.

6.5. *Data Preparation*

6.5.1. OPERATOR'S ACCURACY

Using detection theory, sensitivity and response bias measures were calculated. To calculate sensitivity, the first step was to classified the dangerous areas drawn by the operator into four categories based on how they matched the predefined (dangerous and non-dangerous) areas. These four categories are : hit, miss, false alarm, and correct rejection, as seen in Table 6.5.

	Operator's Response	
	Defined dangerous area	Not defined dangerous area
Predefined Dangerous Area	HIT Operator defined an area to be dangerous correctly matching the predefined dangerous area	MISS Operator did not define an area to be dangerous where it is actually a dangerous area
Predefined non-dangerous area	FALSE ALARM Operator defined an area to be dangerous where it is actually not a dangerous area	CORRECT REJECTION Operator defined an area not to be dangerous correctly matching the predefined non-dangerous area

Table 6.5. Area classifications model used in the detection theory

Next the hit rate and the false alarm rate were calculated. The hit rate (H) is the proportion of dangerous areas that were correctly drawn by the operator, and the false-alarm rate (F) is the proportion of incorrectly assessed dangerous areas by the operator:

$H = P$ (“defined dangerous area”|Predefined dangerous area)

$F = P$ (“defined dangerous area”|Predefined non-dangerous area)

The sensitivity measure d' (dee-prime) is defined in terms of z, the inverse of the normal distribution, by using the function: $d' = z(H) - z(F)$. A typical value of d' is from 0 to 2 (Macmillan & Creelman, 2005), with a higher d' being better, referring to a good ability of the operator to match the predefined dangerous areas.

Response-bias measures how conservative or liberal the operator is in defining dangerous areas. The response-bias was measured as a Likelihood Ratio (β) with formula $\beta = e^{cd'}$. Where e is Euler’s number, c is the criterion location $c = ½ [z(H) + z(F)]$ and d' is the sensitivity. The larger the β, the more conservative the operator is in defining dangerous areas. In this context, conservative behaviour means missing some hits in an effort to keep the number of false alarms to a minimum, while liberal means accepting a higher false alarm rate in exchange for defining the highest percentage of hits.

6.5.2. SITUATION AWARENESS MAP

The maps produced from the SA query when the experiment session was paused (for both the operator and the affected person), were evaluated against the predefined disaster situation map by using transparent sheet overlays. Each observation drawn; such as dangerous areas, victims, starting and destination points, and participant’s locations; were manually scored based on the correctness of its location. The correctness of the location were scored following the rule of *core area*, *outer border area*, and *a penalty grid*. A *core area* is defined as the exact location of each predefined dangerous area with additional tolerance border of 20 m. An *outer border* marked a 40 m distance outside the core area. If the dangerous area drawn by the participant lies inside the *core area*, a score of 1 was given. If it lies in the *outer border area*, a score of 0.5 was given. In the case that it is crossing the border of two areas, the average score was used. Finally, a score of 0 was given for observations drawn outside the *outer border*, and a penalty was imposed. The penalty score was calculated based on a grid system (20 m width) depending on the distance from the *outer border* (for indicated locations) or the size of the area covered (for defined areas) multiplied by a penalty score of -0.25 for each overlapping grid square. The overall score of the SA map was obtained by summing up the scores of all drawn observations.

6.5.3. RESCUE PRIORITY RATING

The ideal rescue priority was determined by weighing the number of victims in each district to the amount of dangerous area in the district. The priority score was calculated by $\Sigma\ (pr_o\text{-}pr_i)^2$ where pr_o is the operator rescue priority and pr_i is the ideal rescue priority. The lower the value of the priority score, the closer it was to the ideal rescue priority, thus the better the operator's performance in setting the rescue priority.

6.6. *Statistical Analysis*

Throughout this study, Multivariate Analysis of Variance (MANOVA) was used to analyse the data:

- The operator and the overall system data analysis was conducted by using a one way within-subject MANOVA. The independent variable was the system (the Centra-ES and the Distri-ES), while the dependent variables were the measure dimensions.
- The affected person data analysis was done by using a two-way 2x2 within-subject MANOVA. The independent variables were the systems compared (the Distri-ES and the Centra-ES) and the order of participation (the antecedent affected individual and the subsequent affected individual). The dependent variables were the measure dimensions.

For all the tests scoring significant multivariate results, the univariate test were performed and reported.

6.7. *Results*

The statistical analysis in this study was presented in three parts. First, hypotheses H1, H2, and H3 were tested by analysing the usability. Second, the situation awareness was analysed to test hypothesis H4. Finally, hypothesis H5 was analysed using perceived usefulness data.

6.7.1. USABILITY

6.7.1.1. The operator

The effectiveness of the operator was analysed by using a one way within-subject MANOVA with dependent variables being the completeness and accuracy of both dangerous areas drawn and the incident report processed by the operator. The results revealed that the system had a main effect for systems on the effectiveness of the operator $F_{4,\ 20} = 80.39$, $p < 0.001$. Further, the univariate comparison analysis showed that Distri-ES gave a superior support to the operator compared to Centra-ES by helping the operator to consistently achieve a higher level of completeness and accuracy both for the drawn dangerous areas and the reports processed by the operator (Table 6.6).

Measures	Centra-ES		Distri-ES		F	p
	M	SD	M	SD		
Dangerous areas defined						
Completeness	0.22	0.15	0.77	0.28	106.00	< 0.001
d' - Sensitivity	0.55	0.62	1.78	0.47	52.00	< 0.001
Incident report registered						
Completeness	0.20	0.16	0.65	0.16	299.61	< 0.001
Accuracy	0.94	0.05	0.97	0.03	10.09	0.004

Table 6.6. The univariate analysis results of the operator's effectiveness, $n = 24$, $dfs = (1, 23)$

Using the Distri-ES, the operator had 77% completeness of defined dangerous areas compared to 22% completeness with the Centra-ES. The same result was achieved for the accuracy of the dangerous area drawn, in which the Distri-ES had a higher sensitivity ($M = 1.78$) than the Centra-ES ($M = 0.55$), meaning that by using the Distri-ES the operator had a higher accuracy in defining dangerous areas than by using the Centra-ES. Thus Distri-ES seems to support the operator better in defining more complete and accurate dangerous areas.

The response bias obtained was analysed by using a paired-sample *t*-test to understand the tendency differences of defining dangerous areas by operators. The results showed no significant difference of bias $t_{23} = 1.01$ $p = 0.32$, thus no indication that a different system pushed the operators towards a specific bias in defining dangerous areas. i.e. systematicly overestimating or underestimating.

By using the Distri-ES, the operator managed to register (or acknowledge) 65% of the observation reports ($M = 129.38$, $SD = 32.33$) with 97% accuracy into the system compared to 20% completeness with the Centra-ES ($M = 37.38$, $SD = 19.1$) with 94% accuracy. This means that the operator using Distri-ES had more reports registered with a better accuracy than the Centra-ES.

In summary, the above findings show that the Distri-ES performed more effectively in comparison to the Centra-ES. The operator produced a more complete and accurate map of the disaster situation as measured in two dimensions: the defined disaster areas and the observation reports registered in the system. Therefore, based on these findings, hypothesis H1 is supported.

THE EFFICIENCY OF THE OPERATOR was analysed using a repeated-measures MANOVA with workload as the dependent variable, measured by the RSME and NASA-TLX questionnaires. The test revealed that the system had a main effect on the efficiency of the operator with $F_{2, 22} = 21.84$, $p < 0.001$. The univariate analysis (Table 6.7) showed that Distri-ES imposed less workload with RSME ($M = 7.69$ cm) compared to the Centra-ES ($M = 10.54$ cm). From the NASA-TLX measure, the Distri-ES also indicated a lower workload ($M = 58.39$) compared to the Centra-ES ($M = 75.99$). This result supports hypothesis H1 as well.

Measures	Centra-ES		Distri-ES		*F*	*p*
	M	*SD*	*M*	*SD*		
RSME	10.54	2.50	7.69	2.17	43.32	< 0.001
NASA-TLX	75.99	17.55	58.39	15.89	16.43	< 0.001

Table 6.7. The univariate analysis results of the operator's efficiency, $n = 24$, $dfs = (1, 23)$

THE SATISFACTION OF THE OPERATOR was analysed using a one way repeated-measures MANOVA with the dependent variable being the preference of the operator indicated using a 7-point Likert scale (where a higher the score indicates a more preferred system). The test revealed that the system had a main effect on the satisfaction of the operator $F_{3, 21} = 33.54$, $p < 0.001$. The univariate analysis showed that Distri-ES received a higher preference ratings than Centra-ES for the three measured component: the gathering and registering of the incident report, the broadcasting of the situation update and general preference. (Table 6.8). This again supports hypothesis H1.

Measures	Centra-ES		Distri-ES		*F*	*p*
	M	*SD*	*M*	*SD*		
Gathering and registering incident reports	2.33	1.20	5.25	1.03	98.17	< 0.001
Broadcasting situation update preference	2.92	1.25	5.46	1.22	43.51	< 0.001
General preference	2.50	1.06	5.12	1.12	87.19	< 0.001

Table 6.8. The univariate analysis results of the operator's preferences, $n = 24$, $dfs = (1, 23)$

FOR THE FORCE CHOICE PREFERENCES, a one sample binomial test was used to analyse the preference of choosing either Centra-ES or Distri-ES with hypothesized test value of 0.5. The results indicated that there was a statistically significant difference, $p < 0.001$. In other words, the proportion of preference in choosing Distri-ES in this sample significantly differ from the hypothesized value of 50%. The absolute majority chose Distri-ES (*n* = 23) compared to Centra-ES (*n* = 1). This supports hypothesis H1. The one operator who chose Centra-ES mentioned that although Distri-ES helped more in gaining an overview of the situation compared to the Centra-ES, using Centra-ES made it possible for the operator to understand more details about the incidents.

The CBUQ general ratings of the two systems were first compared to each other, using a paired-sample *t*-test. The result showed that Distri-ES ratings (M = 5.17, SD = 1.25) was significantly higher than those of theCentra-ES (M = 3.52, SD = 1.29), with t_{23} = -5.01, p < 0.001. Furthermore, an analysis of each rating to a norm value of 5.29 (Brinkman, 2009) showed that the Centra-ES general rating of interaction components was comparable to the norm set of difficult to use components, t_{23} = -6.71, p < 0.001. It was not found significant for the Distri-ES, with t_{23} = -0.48, p = 0.63, making it inconclusive whether the interaction components in Distri-ES was comparable to the norm set of difficult or easy to use components.

6.7.1.2. The affected person

For the effectiveness, the frequency and duration of an affected person in dangerous areas were analysed using a Wilcoxon Signed-ranks test. The test indicated that the subsequent affected individual (2nd participant) using the Distri-ES received help from the antecedent affected individual (1st participant) resulted in less frequent entering the dangerous areas (Table 6.9). This result was also consistent with the results of the time spent in the dangerous areas (Table 6.10). This table also shows a reduction in completion time for the subsequent individual using the Distri-ES. The time reduction was significantly greater for the Distri-ES. Thus from this result, hypothesis H2 is supported.

	Sum		*Sum*	*Z*	*p*
Centra-ES: P1	13	Centra-ES: P2	13	- 0.32	0.974
Distri-ES: P1	15	Distri-ES: P2	6	-1.97	0.049
Centra-ES: P1	13	Distri-ES: P1	15	-0.25	0.800
Centra-ES P2	13	Distri-ES: P2	6	-1.50	0.134
Centra-ES: P1-P2	0	Distri-ES: P1-P2	9	-1.40	0.163

Table 6.9. The frequency of entering dangerous area comparisons of each system and participant order. P1 is the antecedent affected individual and P2 is the subsequent affected individual

	Sum		*Sum*	*Z*	*p*
Centra-ES: P1	318	Centra-ES: P2	688	- 0.97	0.331
Distri-ES: P1	702	Distri-ES: P2	99	-2.61	0.009
Centra-ES: P1	318	Distri-ES: P1	702	-1.79	0.074
Centra-ES P2	688	Distri-ES: P2	99	-1.92	0.056
Centra-ES: P1-P2	-370	Distri-ES: P1-P2	603	-3.82	< 0.001

Table 6.10. The time duration (in seconds) spent in dangerous area comparisons of each system and participant order.

The efficiency of the affected person in the field was analysed using a two way 2x2 within-subject MANOVA with dependent variables completion time, distance covered, mental effort and workload. The test revealed a multivariate main effect for system ($F_{4, 16} = 5.76$, $p = 0.005$), order ($F_{4, 16} = 6.31$, $p = 0.003$), and main significant interaction effect ($F_{4, 16} = 4.71$, $p = 0.011$). The univariate analysis showed that Distri-ES led to a lower mental effort and workload as measured by RSME and NASA-TLX compared to Centra-ES (Table 6.11).

Measures	Centra-ES		Distri-ES		*n*	*dfs*	*F*	*p*
	M	*SD*	*M*	*SD*				
Time completion	24.50	6.30	26.98	5.45	20	1, 19	2.94	0.103
Distance	1486.20	766.97	1725.51	666.67	24	1, 23	1.72	0.203
RSME	4.81	2.58	3.71	2.28	24	1, 23	6.75	0.016
NASA-TLX	46.90	20.95	34.93	14.50	24	1, 23	18.70	< 0.001

Table 6.11. The univariate analysis of system comparison across measures of affected person's efficiency. Completion time is in minutes while distance is in meters.

However, there were no significant differences in the completion time and distance travelled. A further separate analysis of completion time by using paired sampled *t*-tests revealed that although the subsequent individual in the Distri-ES was significantly helped by the antecedent individual ($t_{19} = 6.61$, $p < 0.001$), the antecedent affected individual of the Distri-ES was significantly slower compared to the antecedent affected individual of the Centra-ES ($t_{19} = -2.59$, $p = 0.018$). Furthermore, there was no difference in completion time between the subsequent individuals in using the two systems ($t_{19} = 0.51$, $p = 0613$) and no difference between the antecedent and subsequent individual using Centra-ES ($t_{19} = 0.64$, $p = 0.527$). This finding suggested that the Distri-ES might have a negative effect on the antecedent individuals by making them slower, thus taking a longer time to reach their destination.

This might be caused by the time spent on learning to use the new system.

The order of the participant affected the completion time and distance travelled (Table 6.12). However, this difference was not found in the workload analysis. It seems that there was no difference in workload between the antecedent affected individual and the subsequent affected individual.

Measures	1st		2nd		*n*	*dfs*	*F*	*p*
	M	*SD*	*M*	*SD*				
Time completion	27.85	7.14	23.63	4.61	20	1, 19	17.45	0.001
Distance	1798.06	821.90	1413.64	611.74	24	1, 23	8.19	0.009
RSME	4.36	2.62	4.17	2.24	24	1, 23	0.12	0.738
NASA-TLX	38.05	19.09	43.78	16.36	24	1, 23	2.55	0.124

Table 6.12. The univariate analysis of order comparison across measures of affected person's efficiency. Completion time is in minutes while distance is in meters.

From the univariate analysis of the interaction effect (Table 6.13), it could be seen that the subsequent affected individual using the Distri-ES benefited from the antecedent affected individual, as a result their completion time shortened considerably. Thus hypotheses H1 and H2 are supported by this finding.

Due to the timing problem in administering the SA query, the first four groups of participants were not included in the analysis of the overall multivariate measures. Since these problem only influenced the completion time, the univariate analysis included all 24 pairs of the other measures.

Measures	Centra-ES		Distri-ES		*n*	*dfs*	*F*	*p*
	P1	*P2*	*P1*	*P2*				
Time completion	25.05 (8.15)	23.95 (4.44)	30.65 (6.12)	23.30 (4.78)	20	1, 19	9.24	0.007
Distance	1468.33 (681.36)	1504.06 (852.57)	2127.79 (962.44)	1323.22 (370.90)	24	1, 23	8.80	0.007
RSME	4.85 (2.64)	4.77 (2.52)	3.87 (2.60)	3.58 (1.96)	24	1, 23	0.10	0.750
NASA-TLX	43.75 (22.54)	50.06 (19.35)	32.35 (15.64)	37.51 (13.36)	24	1, 23	0.05	0.832

Table 6.13. The univariate analysis of the interaction effect of affected person's efficiency. Completion time is in minutes while distance is in meters. All values are averages with the standard deviation between brackets.

Additionally, a correlation in the completion time between the antecedent and the subsequent affected individual was found when they were using

Distri-ES, $r_{20} = 0.61$, $p = 0.004$. While for the Centra-ES, there was no correlation between the two affected persons, $r_{20} = 0.38$, $p = 0.095$. This suggests that the performance of the subsequent affected individual in Distri-ES was influenced by the antecedent individual, making the completion time of the subsequent affected individual shorter. Thus hypothesis H2 is supported.

The satisfaction of the affected people was analysed using a two way 2x2 within-subject MANOVA with the dependent variables being the updating preferences, reporting preferences, navigation preferences, and general preferences. Each preference was scored using a 7-point Likert scale, where a higher a score means a more preferable system. The test revealed that a multivariate main effect for system was found, $F_{4, 20} = 18.72$, $p < 0.001$. The univariate analysis showed that Distri-ES was consistently more preferred than Centra-ES across all the component measures, as can be seen in Table 6.14.

Measures	Centra-ES		Distri-ES		*F*	*p*
	M	*SD*	*M*	*SD*		
Geting situation update	4.08	1.48	5.85	1.02	42.23	< 0.001
Reporting	3.73	1.81	5.92	1.23	38.33	< 0.001
Navigating	5.02	1.41	6.00	1.02	16.17	0.001
General preference	4.21	1.31	5.94	0.87	73.39	< 0.001

Table 6.14. The univariate analysis results of the affected person's preferences, $n = 24$, $dfs = (1, 23)$

The CBUQ of the Distri-ES field device and all its components were analysed using a one-sample *t*-test to a norm value of 5.29 (Brinkman, 2009). The results showed that all the components in the Distri-ES field device were comparable to distribution of easy to use components of the norm set (Table 6.15).

	M	*SD*	*t*	*df*	*p*
Reporting Event Control	6.10	0.37	10.54	23	< 0.001
Navigation Control	6.01	0.66	5.37	23	< 0.001
General	6.19	0.45	9.95	23	< 0.001

Table 6.15. Results of one-sample *t*-tests with test value 5.29

6.7.1.3. The effectiveness of the overall system

The frequency of entering dangerous areas both for the real and virtual affected person as an overall system measure was analysed using a Wilcoxon Signed-ranks test. The dependent variable was the frequency of entering dangerous areas. The test of frequency indicated that the Distri-ES (*Sum* = 223) helped all affected people go less frequently into the dangerous areas compared to the Centra-ES (*Sum* = 248) with $z = -2.24$, $p = 0.025$. This supports hypothesis H3.

The duration in the dangerous areas was analysed using a paired-sample *t*-test. No significant difference between the two systems was found $t_{18} = -0.98$, $p = 0.341$).

6.7.2. SITUATION AWARENESS

6.7.2.1. The operator

The situation map score resulting from the SAGAT query of the operator, was analysed using a paired sample *t*-test. Distri-ES ($M = 5.54$, $SD = 5.36$) showed a significantly higher rating, ($t_{23} = -2.49$, $p = 0.02$) in operator's SA compared to Centra-ES rating ($M = 3.14$, $SD = 2.06$). Thus the participants, using Distri-ES achieved a better SA compare to the one achieved by using Centra-ES, supporting hypothesis H4.

The ranking of resource allocation from the SAGAT query was analysed using a Wilcoxon Signed-ranks test. The test indicated that priority ranking set by the operator using the Distri-ES had lower deviation (*Mdn* = 29), thus was closer to the ideal ranking than that using Centra-ES (*Mdn* = 32), $z = -2.13$, $p = 0.033$), supporting hypothesis H4.

The operator's SA by 3D-SART was compared using a paired sample *t*-test. Distri-ES ($M = 4.67$, $SD = 3.70$) showed a significant higher overall SA score, $t_{23} = -5.38$, $p < 0.001$, compared to Centra-ES ($M = -0.42$, $SD = 3.26$). Thus the participants indicated having achieved a better SA by using Distri-ES than using Centra-ES, supporting hypothesis H4.

Thus from these three measurements (situation map, the priority rescue, and SART self ratings), the operator seems to have received more help in understanding the SA using the Distri-ES, thus supporting hypothesis H4.

6.7.2.2. The affected person

The SAGAT was administered on the 8th minute after the starting time of the antecedent affected individuals. This means that it was administered on the 3rd minute of the subsequent affected individual, since the delays between the first and the second participant was 5 minutes. Because of this, comparing the SA of the antecedent and subsequent affected individuals did not provide meaningful information, since the subsequent affected individual consistently achieved a lower score. Therefore, the comparison was performed between the antecedent affected individual using Centra-ES and the antecedent affected individual using Distri-ES, and the subsequent affected individual using Centra-ES and the subsequent affected individual using Distri-ES. To analyse this, a paired-sample *t*-test was used. The result suggested that there was no significant difference in SA between the antecedent affected individual either using Centra-ES or Distri-ES, $t_{23} = -0.34$, $p = 0.734$). This result can be understandable, since in both cases they were the first on the field without any supporting information. For the subsequent affected individual, the test showed significant effects, $t_{23} = -2.10$, $p = 0.047$). This finding suggested that the subsequent affected individual using Distri-ES received more help by receiving more information given by the antecedent affected individual, and was therefore more aware of the situation ($M = 3.39$, $SD = 1.32$) than using Centra-ES ($M = 2.57$, $SD = 1.83$), thus hypothesis H2 is supported

The SA using 3D-SART for the affected person was analysed using a 2x2 within-subject ANOVA with the SA overall score as the dependent variable. The results showed that the system had a main effect on the SA with $F_{1, 23} = 9.72$, $p = 0.005$. Distri-ES ($M = 7.88$, $SD = 2.90$) received a higher SA rating than the rating for Centra-ES ($M = 6.02$, $SD = 2.81$), thus H4 is supported.

6.7.3. PERCEIVED USEFULNESS

The user's perceived usefulness was an average rating on six questionnaire items, which were rated on a 7-point Likert scale. A system which scored high on perceived usefulness, was one that the user perceived to be helpful in enhancing their job performance.

6.7.3.1. The operator

The operators' perceived usefulness for the two systems were compared using a paired sample *t*-test. Distri-ES ($M = 5.59$, $SD = 1.17$) show a significant higher rating for perceived usefulness, $t_{23} = -7.25$, $p < 0.001$, than the Centra-ES ($M = 2.68$, $SD = 1.26$). Thus the participants, rated Distri-ES more positively regarding its perceived usefulness. Thereby, H5 is supported.

6.7.3.2. The affected person

The affected persons' perceived usefulness was analysed using a 2x2 within-subject ANOVA with the perceived usefulness being the dependent variable. The results show that the system had a main effect on the perceived usefulness with $F_{1, 23} = 62.91$, $p < 0.001$), showing that Distri-ES ($M = 6.01$, $SD = 0.70$) received a higher perceived usefulness rating than the Centra-ES ($M = 4.32$, $SD = 1.35$). Thus hypothesis H5 is supported.

6.8. Discussion

RESULT HIGHLIGHTS	H*
Usability	
Overall system usability	
The Distri-ES was more effective in helping the operator and the affected person by reducing the number of times affected people entered dangerous areas (*Sum* = 223) compared to the Centra-ES (*Sum* = 248).	H3
Operator's usability	
Distri-ES was more effective by having: a higher completeness of dangerous areas drawn (*M* = 77% compared to *M* = 22%), a higher accuracy in defining dangerous areas (sensitivity of *M* = 1.78 compared to *M* = 0.55), a higher completeness of registering the incident reports (*M* = 65% compared to *M* = 20%), and a higher accuracy of the incident reports registered in the system (*M* = 97% compared to *M* = 94%)	H1
Distri-ES was more efficient for the operator requiring less mental effort. T measured on RSME (*M* = 7.69 compared to *M* = 10.54) and less workload measured on NASA-TLX (*M* = 58.39 compared to *M* = 75.99)	H1
Distri-ES was consistently preferred in: gathering and registering incident reports (*M* = 5.25 compared to *M* = 2.33), broadcasting situation updates (*M* = 5.46 compare to *M* = 2.92), general preference rating (*M* = 5.12 compared to *M* = 2.5), and given a choice, the majority of participants chose Distri-ES (*n* = 23) compared to Centra-ES (*n* = 1)	H1
The affected person's usability	
Distri-ES was more effective: the subsequent affected individual using Distri-ES was less often in entered the dangerous area information (frequency-P1 = 11 compared to frequency-P2 = 6) and spent less time in the dangerous area. This means that the subsequent affected individual was helped by the information provided by the antecedent affected individual. Additionally, the decrease in time completion duration between antecedent and subsequent affected individual was more for the Distri-ES.	H2
Distri-ES was more efficient by creating less mental effort as measured on RSME (*M* = 37.13 compared to *M* = 48.13 on a scale of 150) and less workload as measured on NASA-TLX (*M* = 34.93 compare to *M* = 46.90)	H1
The second participant using Distri-ES was better aided compared to the Centra-ES as shown by a correlation between the antecedent and the subsequent affected individual in the Distri-ES that was not found in Centra-ES	H2

H*: Supported Hypothesis

RESULT HIGHLIGHTS	H*
Distri-ES received higher preference in getting situation update (*M* = 5.85 compare to *M* = 4.08), higher preference in reporting (*M* = 5.92 compare to *M* = 3.73), higher preference in navigation (*M* = 6.00 compare to *M* = 5.02), and higher general preference (*M* = 5.94 compare to *M* = 4.21)	H1
SITUATION AWARENESS	
Operator's Situation Awareness	
From the SAGAT freeze probe query, participants using Distri-ES scored a higher rating of SA from the produced situation map (*M* = 5.54 compare to *M* = 3.14) and scored better in prioritising the rescue districts by having a smaller difference compared to the ideal prioritise rescue (*Mdn* = 29 compared to *Mdn* = 32)	H4
From the SART post trial, Distri-ES had a higher SA score measured on 3D-SART (*M* = 4.67 compared to *M* = -0.42)	H4
The affected person's situation awareness	
From the SAGAT freeze probe query of the situation map, the second participant (subsequent affected individual) was helped by the first participant (antecedent affected individual) to achieve a better SA when using Distri-ES.	H4
The SART post trial showed that Distri-ES had higher SA score measured on 3D-SART (*M* = 7.88 compared to *M* = 6.02)	H4
PERCEIVED USEFULNESS	
Operator's perceived usefulness	
Distri-ES had a higher rating on perceived usefulness (*M* = 5.59 compared to *M* = 2.68)	H5
The affected person perceived usefulness	
Distri-ES had a higher perceived usefulness rating (*M* = 6.01 compare to *M* = 4.32)	H5

H*: Supported Hypothesis

One of the most important measures of success for the system was whether it would guide the affected persons safely by keeping them away from dangers. The way Distri-ES achieved this can be explained by: the availability of a shared map, a faster rate of situation updates, and a more usable system. Using the Distri-ES, there were no additional information chains going through the emergency call center. In addition, no bottlenecks resulting from high workload were placed on the operator's shoulders as they are in the centralized model. Instead, the effort was distributed across all resources. However, using the Distri-ES did not mean that no participants entered dangerous areas, the participants were going less through dangerous areas.

The use of the Distri-ES as a navigation aid did not seem to have a large negative effect on the time needed to walk the same distance compared to the current centralized system. The workload of the operator using the Distri-ES was less than that of the Centra-ES. There is a number of possible explanations for that. First, the Distri-ES system was simply a better solution. Second, the result of Centra-ES's information center CBUQ being comparable to the norm set of difficult to interact, interactive components. This, may have influenced the operator's workload. Third, in the Centra-ES, the operator had to register the reports manually, understand the situation, and broadcast the incidents, while in the Distri-ES, the operator only needed to acknowledge and understand the situation. Comments made by the participants pointed out that the manual action of placing each incident report in the map when using the Centra-ES resulted in a detailed understanding of a few incidents, while they had a superior overview capability when using the Distri-ES. In addition to this, in the real-life situation, the information center operator for the centralized system may consist of a number of people sharing the workload instead of only one person (e.g. plotters, broadcasters), which may explain the higher mental effort and workload of the operator in the Centra-ES condition.

The arrow metaphor of directing the participant to the destination was not well utilised by the affected people. Participants mentioned that they thought that the arrow pointed to the destination on the map, while it was actually pointing to the direction of the destination from where the participants were. Participants also noted that they may have paid less attention to the arrow just because they were familiar with the experiment area. It is, therefore, possible that they will rely more on the arrow for guidance if the area is unfamiliar to them.

In the Centra-ES condition, the emergency call center was an additional step in the information communication chain from the reporter to the operator. The experimenter, acted as the emergency call center operator, always relaying the correct observation report to the operator in order to avoid any noise that may have resulted from the verbal reporting mechanism. In a real-world condition this information relay is a weak link in the communication process, as it was observed earlier in Chapter 3 when spatial information was relayed verbally. Furthermore, as the theory of rumour transmission (Buckner, 1965) suggests, an additional link in the information chain may further distort the original message.

Limitations. Like most empirical research, this study still suffers from some limitations. First, the experiment was done in a controlled setting which is not as realistic as a real disaster. As a result, important factors that play a role in real disasters could not be investigated. These factors include the different emotions and social issues people exhibit during a disaster. Also, how people deal with multitasking and task interruptions in these situations. Secondly, all participants of this study were highly-educated people, which only reflects one segment of the population. Thirdly, the operators of the information center were not professionally trained. This may have hindered their ability to process reports, to understand the situations and to broadcast information to the affected people, which in turn also influenced how the affected people performed their tasks. Fourthly, the complexity and extended duration of the experiment may have exhausted the participants and thereby influenced their performance.

Reflection. Despite the length and the complexity of the experiment, the affected person participants seemed to enjoy doing the experiment outdoors, as noted by one participant: "It is like a treasure hunt game, you were given a map, a compass, and clues, now you need to find the treasure".

Future works. Regarding the usability for the affected person in the field, when using Distri-ES, the subsequent affected individual was greatly helped by the antecedent affected individual both in effectiveness and efficiency. As this study only examined a situation with two affected persons, it may be interesting to see the effect of the system on a larger group of subsequent participants. It is arguable, from these preliminary results, that the Distri-ES will perform even better, and that the maximum potential is yet to be discovered. Further study can use this research work as its foundation.

Since the analysis was done mostly separately for the affected person and the operator, a further advanced analysis is needed. For example, correlation between the performance of the operator and the performance of the affected people, or an analysis to identify the most important contributor to the success of Distri-ES in guiding the affected person more safely.

In addition, an extension to this study can also examine models that combine elements from both Distri-ES and Centra-ES and classify situations where one of them is more suitable. As it is wise with any technological solutions, it is important to form multiple layers of services as a form of redundancy that may protect the whole system from collapsing.

Additionally, the source of disaster situation data may also be extended by other institutions participating in disaster response management. Different stakeholders and emergency service actors such as first responders, authorities, or environmental institutions, can enrich the knowledge of the disaster situation.

6.9. Conclusion

This chapter deals with the designs, the implementation and the evaluation of the complete implemented systems as proposed in Chapter 3. The two independent component solutions, which were individually evaluated, were integrated. These two components are: (1) the mobile navigation in disaster situations in Chapter 4, and (2) the collaborative situation map making in Chapter 5.

In order to compare the proposed system, Distributed Participatory Evacuation System (DISTRI-ES) with a state-of-the-art evacuation system, a second system, Centralized Coordinated Evacuation System (CENTRA-ES) was designed and implemented. The Centra-ES system is based on the evacuation protocol that is commonly used by disaster management worldwide. Both systems were designed to be easily comparable. An extensive controlled experiment was performed to evaluate these two systems. The experiment involved multiple devices (field handheld device and information center server), applications (mobile client, server, and simulation), participants (3 participants for each experiment session), roles (the affected person and the operator), and locations (in the field and in the information center).

The experimental results showed that the distributed participatory mechanism has a number of major benefits compared to the centralized system. The Distri-ES scored better in all the usability measures, provided better situation awareness, and was perceived to be more useful. Specifically, using the Distri-ES system, operators were able to offer safer guidance to affected people, which translated into a significant lower frequency of entering dangerous areas. The information shared by the antecedent affected person in the Distri-ES helped the subsequent affected person in avoiding dangerous areas (lower frequency and duration of entering dangerous areas). The operator was also more effective in defining dangerous areas and registering the observation reports. This was shown by a higher level of completeness and accuracy compared to the Centra-ES. Furthermore, the results also show that the Distri-ES system significantly reduces the mental effort and workload for both the affected people and the operator. This is an important result, considering that the application will be used in highly stressful conditions. Moreover, Distri-ES was preferred by participants. The Distri-ES also successfully helped the operator and the affected person achieve a higher situational awareness. Not only did this result in a safer way of navigating in the field, it also allowed the operator to be better at prioritizing the rescue effort. Finally, the Distri-ES was perceived to be more usable for both navigation and information sharing in a disaster event.

It can therefore be concluded that the third main hypothesis (outlined in the introduction) was supported. The proposed system, a distributed participatory mechanism, was superior in guiding the affected people safely, helping them achieve better situational awareness, and lowering their workload in comparison to the traditional evacuation system. This confirming result shows that a distributed participatory mechanism may be suitable for use in the evacuation process during disaster response, replacing or complementing the current commonly used centralized evacuation system.

Chapter 7. Conclusion

This thesis investigated how to effectively utilize the potential capacity of affected people with prevalent mobile technology in crisis situation. A distributed system was proposed in which the affected people could lead themselves to safety while at the same time serving as field sensors that share information about the disaster situation. The study was specifically designed to answer the main research question as follows:

> *Can affected populations be effectively and efficiently guided to safety in a disaster area through a participatory mechanism by collaboratively sharing spatial information among professional and nonprofessional actors during the disaster response?*

In order to establish background support for this research, it is important to first understand that the affected population is often not a group of helpless victims. Instead,

> *the affected population are often capable humans beings, who are able to a large extent, to take care of themselves and help others during time of collective stress.*

After this background assumption is defined, three hypotheses were formulated to answer the main research question in a manageable way.

1. *In a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues.*

2. *Using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map.*

3. *By collaboratively sharing spatial information between the affected population and professional actors on-and-off location: (a) the affected population will be guided in a safer manner and (b) a more accurate disaster situation map will be constructed, which in turn will better facilitate the relocation of the affected population, in comparison to the commonly used system.*

The conclusions in this thesis are structured by an examination of the arguments for these three hypotheses. The examination is based on the substantiation gathered in several studies (literature studies, contextual inquiries, and the empirical studies). Thus, each hypothesis stands on a full study cycle. Together, the support for these three hypothesis make up the support for the main hypothesis.

The first examination will start with an initial background claim about the capabilities of the affected population.

The affected population as capable human being

Through the literature study, it was argued that the affected persons in a disaster are not helpless victims. Instead, they are capable human beings who form an enormous potential resource for helping disaster responses. This stepping stone claim was supported both from the field of disaster sociology and the experience of the past humanitarian operations. The affected people tended to act logically and rationally with calm behaviours (McEntire, 2006). Disaster victims are more immune to disaster shocks, more innovative in resolving their problems and more resilient in the wake of severe challenges that they are given credit for (Quarantelli & Dynes, 1972). Panic flight is rare (Tierney, 2006). Generally, those affected by disaster are most likely to be proactive, rather than wait for emergency personnel to arrive at the scene, they take care of themselves and others (Wenger et al., 1986, Quarantelli, 1999, Tierney et al., 2001, McEntire, 2006) and exhibit a great deal of pro-social behavior (Lomnitz, 1999). These supports from literature were covered extensively in Chapter 2, Section 2.1.

The support from literature confirms the finding from the contextual inquiry with the urban search and rescue team of the Netherlands. It was clear that, during their USAR mission in Pakistan, the affected people were helpful for the USAR operation. The affected people were reported to be valuable in providing information about local environment and other possible victims nearby (In Chapter 3, Section 3.1.3.2).

Therefore, as the affected people usually accounts for 94% of the population (Guha-Sapir, 2011), consists of capable human beings, distributed over the disaster area, and witnessing the disaster themselves, they are a massive potential resource to collect first hand information about the disaster.

The First Hypothesis: Navigation Guidance

Major events (e.g. earthquakes, tornadoes, explosions and fires) can significantly change an area, rendering earlier geographical data obsolete (van der Walle et.al., 2010) and can make damaged infrastructure hazardous to the affected population. In order to minimize public exposure to such dangerous conditions that often prevail in disaster areas, the affected people in the neighbourhood need to be guided to a safer area. In this case, the affected population must use any means available to cope with the situation and to support their movement. A navigation system that provides sufficient and flexible guidance given the changed environment in the disaster area is useful. Therefore, the first hypothesis tackles this issue, and states that, *in a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues.*

Support for this hypothesis was first gathered from the literature to reassure that (navigation) technology solutions can be used by the affected people. Becker (Becker et al., 2008) reported that not everyone is equally affected by a disaster, and not all disasters are equally devastating in psychological terms. Recent disasters showed that people use whatever means of available technology to fulfil their needs, especially for information seeking (Boyle et al., 2004). They are also able to creatively utilize familiar technology, or quickly adopt new unfamiliar ones for their purpose (Shklovski et al., 2010). As mobile technology becomes prevalent (with nearly 80% mobile phone penetration worldwide) and more advanced (GPS, camera, and mobile ad-hoc network) (ITU, 2011), people with mobile phones can form a network infrastructure that can serve as an information gateway. Mobile technology has been repeatedly useful for information exchange in a disaster area, as it was extensively used during the disaster response in the UK flood in 2007 (Johnson, 2009) and Hurricane Katrina in 2005 (Rao et al., 2007). Although the use of mobile navigation in disasters has not been widely put into practise, from the available literature, it was discovered that mobile handheld navigation devices have been successfully implemented for guiding adults with cognitive impairments (Chang et. al., 2010, Liu et al., 2006, Fickas et al., 2008) and elderly people (Goodman et al., 2004, Kawamura et al. 2008). Considering the diminished capacity of cognitively impaired people and the elderly might be comparable (or worse) to the decreased cognitive abilities of stressed affected population during a disaster, it is argued that development of a similar navigation system could be useful in guiding the affected population through a disaster.

The second support for this hypothesis was established through empirical studies, investigating the possibility of navigating by using a simple direction arrow and the usefulness of additional elementary navigation cues when a map is unavailable. Two exploratory studies and one controlled field experiment were conducted. Support for the hypothesis was demonstrated as participants were successfully guided toward their destination by a direction arrow alone. They were able to circumnavigate obstacles on the way and were resilient when finding a dead-end. This field study also showed that elementary navigation cues such as distance-to-destination and time-to-destination can increase the perceived system's ease of use during navigation. These two navigation cues were considered useful because they showed if users were making progress and how much longer a person needed to walk before reaching the destination. There are, however, two drawbacks to the navigation-by-direction method: the guided people can end up in a dead end and there is the possibility of circumnavigating a longer distance when a person faces a blockade. Despite these drawbacks, this study showed that when a map is not available, it is possible to be guided by only using the direction to destination.

The Second Hypothesis: Collaborative Mapping

In order to make navigation technology work more efficiently for disaster response, an up-to-date representation of the post impact situation is required, especially in the case when the environment is altered and the situation is dynamically changing. The traditional centralized mechanism of gathering this kind of information might not be efficient due to the sole use of verbal communication in relaying spatial information of disaster situations (Chan et. al., 2004), limited emergency resources that collect this kind of information (Schneider, 2005), and the hierarchical reporting structure in command-and-control organizations of disaster management (Drabek, 1985, Kean & Hamilton, 2004, Ramaswamy et al., 2006, U. S. House of Representatives, 2006b). Therefore, a distributed approach that utilizes the affected population for collecting situation data in the field, and the use of an additional modality beside verbal communication, is deemed more effective and efficient. The mechanism to do so in a distributed manner is outlined in the second hypothesis. It states that *using (audio) visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map.*

Support for this hypothesis was established by the literature study. Problems of relaying spatial information of disaster situations by the sole use of verbal communication has often been reported as the cause of inaccurate exchange of location information (Udtke 2008, Herald Canada, 2008). This was also observed during the contextual inquiry in the disaster exercise in the Safety Region of Rotterdam-Rijnmond. It confirmed the inefficiency and inaccuracy of the verbal modality to transmit location information (Chapter 3, Section 3.1.2). Therefore, Schoning et al. (2009) pointed out that adding graphical and map data could lead to a more efficient coordination of emergency resources than with textual data alone.

From the contextual inquiry of making situation-maps (Chapter 3, Section 3.1.2), it was found that the inefficiency of the situation-map making process can result in an inaccurate and outdated situation map. The inefficiency seems to partly stem from the hierarchical organization setup of the map-making process, such as: not sharing a map across the distributed team and too many links in the information chains before information can be drawn on the situation map. Considering the dynamic nature of disaster situations, Buckner (1965) and Bryant et al. (2005) argued that with a distributed network structure of information sources using the contribution and verification of many people, a more complete and more accurate information would emerge. This, makes the affected people, who are highly distributed spatially over the disaster area and witnessing the disaster first hand, the ideal reporters of what is going on in the field (Palen & Liu, 2007). When enough people are participating in this process, the overview of a disaster situation will emerge in a shorter time compared to a limited number of emergency workers surveying the disaster area (Utani et al., 2011). For example, some successful collaborations in massive situation map making have been reported during the Haiti Earthquake of 2010 (ITO-World, 2010), the Great East Japan Earthquake, and Tsunami of 2011 (METI, 2012).

Direct support for this second hypothesis, was established by conducting two experiments. The studies investigated the possibility of constructing a shared situation map using a collaborative distributed mechanism. The first study was an exploratory study to understand the process of collaborative situation-map making. The results showed that the confidence level was frequently mentioned during the collaboration. The second study was done in a more controlled setting specifically to answer the second hypothesis. The results showed that more collaboration channels lead to a better situation map, and that including confidence information for objects and events in the map may help shorten the discussion process. Sharing the maps together with voice communication improved the quality of the produced map. The suggestion is made to open more communication channels (especially visually shared maps) during collaborative map-making to complement the voice communication channel. This is because relying completely on voice communication to relay spatial information has been shown to be inefficient and ineffective.

Thus, findings from these empirical studies support the second thesis hypothesis. These findings also demonstrate that a distributed collaborative map-making mechanism can be a good method to generate situation maps, which may, in a disaster situations, lead to a better situation awareness.

The Third Hypothesis: Collaborative Map-Based Navigation

Good coordination and collaboration is needed for an effective response (Gao et al., 2011), both between the emergency services and the affected people, and among themselves. Both parties have access to two different kinds of information that may complement each other: (1) the affected people has the knowledge of what is going on in the field, while (2) the emergency services have knowledge of the disaster response such as: population data, emergency facilities, shelter locations, and vulnerable infrastructures. This leads to the third hypothesis, *by collaboratively sharing spatial information between the affected population and professional actors on-and-off location: (a) the affected population will be guided in a safer manner and (b) a more accurate disaster situation map will be constructed, which in turn will better facilitate the relocation of the affected population, in comparison to the commonly used system..*

Support for this hypothesis was first provided through literature study by looking at successful crowdsourcing systems through popular and social media and cross-sector collaborations. Citizen journalism has changed the use of the Internet and mobile phones in recent disasters to collaborate through crowdsourcing.

During the Indian Ocean Tsunami 2004, the Hurricane Katrina 2005 and the Haiti earthquake 2010 disasters, people used social networks, Wikipedia, twitter, blogs, photo and video sharing, and websites to report the situations and offer of shelter, jobs, and emotional support (Laituri & Kodrich, 2008, Palen et al., 2009, Vieweg et al., 2010, Gao et al, 2011). SMSs have been used extensively during the China SARS epidemic in 2003 to inform others about the physical locations of apparent SARS victim (Law & Peng, 2004). Camera phones with MMSs were used for capturing structural damage in the underground surroundings after the London underground bombings (Palen & Liu, 2007). Two examples of crowdsourcing systems that have been deployed in several countries are Ushahidi (2008) and Sahana (Samaraweera & Corera, 2007, Sahana, 2009). These systems can collaborate data from various resources and can be used for reporting news and managing the coordination of relief efforts.

Although crowdsourcing applications can provide relatively accurate and timely information, Gao et al. (2011) and U.S. House of Representatives (2006a) showed that the lack of collaboration and coordination between emergency services, the affected population, and other response sectors may cause an imbalance in effort and logistics. Moreover, if emergency services are not ready for collaboration and incorporating a citizen's report in their structural organization, they will further overburden themselves (Gates, 2007; Marlar, 2007). Therefore, cross-sector collaboration between emergency services and the affected population is necessary (Bryson et al.,2006). By including citizen participation in the early stages of the incident, citizens can report incidents or volunteer to be contacted for help if an incident takes place in their vicinity, in real time (Meijer, 2010, van der Vijver et al., 2009). The concept of cross-sector collaboration has been applied in dealing with difficult challenges in current society, such as natural disasters and emergency management (Simo & Bies, 2007; Maon et al., 2009).

The third hypothesis confines the envisioned system described in Chapter 3, and integrated two component solutions (mobile navigation and collaborative situation map making) that were encapsulated by the two previous hypotheses.

In order to compare the proposed system, Distributed Participatory Evacuation System (DISTRI-ES) with a state-of-the-art evacuation system, a second system, Centralized Coordinated Evacuation System (CENTRA-ES) was designed and implemented. The Centra-ES system is based on the evacuation protocol that is commonly used by disaster management worldwide. Both systems were designed to be easily comparable. An extensive controlled experiment was performed to evaluate these two systems. The experiment involved multiple devices (field handheld device and information center server), applications (mobile client, server, and simulation), participants (3 participants for each experiment session), roles (the affected person and the operator), and locations (in the field and in the information center).

The experimental results showed that the distributed participatory mechanism has a number of major benefits compared to the centralized system. The Distri-ES scored better in all the usability measures, provided better situation awareness, and was perceived to be more useful. Specifically, using the Distri-ES system, operators were able to offer safer guidance to affected people, which translated into a significant lower frequency of entering dangerous areas. The information shared by the antecedent affected person in the Distri-ES helped the subsequent affected person in avoiding dangerous areas (lower frequency and duration of entering dangerous areas). The operator was also more effective in defining dangerous areas and registering the observation reports. This was shown by a higher level of completeness and accuracy compared to the Centra-ES. Furthermore, the results also show that the Distri-ES system significantly reduces the mental effort and workload for both the affected people and the operator. This is an important result, considering that the application will be used in highly stressful conditions. Moreover, Distri-ES was preferred by participants. The Distri-ES also successfully helped the operator and the affected person achieve a higher situational awareness. Not only did this result in a safer way of navigating in the field, it also allowed the operator to be better at prioritising the rescue effort. Finally, the Distri-ES was perceived to be more usable for both navigation and information sharing in a disaster event.

It can therefore be concluded that the third main hypothesis (outlined in the introduction) was supported. The proposed system, a distributed participatory mechanism, was superior in guiding the affected people safely, helping them achieve better situational awareness, and lowering their workload in comparison to the traditional evacuation system. This confirming result shows that a distributed participatory mechanism may be suitable for use in the evacuation process during disaster response, replacing or complementing the current commonly used centralized evacuation system.

7.1. Limitations

Like most research, these studies suffer from some limitations. First, although the experiments were performed in a controlled setting, they were not as realistic as a real disaster, since it is difficult to perform an experiment in a real life disaster scenario. The same is true for contextual inquiries, some of them were done in training exercises. As a result, important factors that play a role in real disasters could not be investigated. These factors include the different emotions and social issues people exhibit during a disaster and how people deal with multitasking and task interruptions in these situations. Nevertheless, an extensive literature study and contextual inquiries based on previous experience were conducted to gather as much relevant information as possible from other researchers and practitioners.

Secondly, almost all participants of these studies were highly-educated people, which means that the results are only reflects on one segment of the population. However, as the system is expected to be used in groups, for example a family or group of coworkers, it is more likely that there will be someone in the group who is able to operate the system. Finally, no professionals were involved in the experiment who might have specific domain relevant routines when operating these systems.

7.2. *Contributions*

7.2.1. SCIENTIFIC CONTRIBUTIONS

This research aims to utilize the untapped potential of the affected population in the disaster area using advances in mobile communication technology. It is based on literature from the field of disaster sociology and humanitarian operation experiences, showing how humans behave in times of crisis. Since the affected population, as a resource, have rarely received attention from disaster management researchers, many disaster response solutions usually focus on supporting emergency services. This study contributes an early attempt to utilize technology to support citizens with their movement in a disaster area. The model of information sharing suggested in this study, based on a distributed, open contribution, shared with all system, and incorporating two way information exchange may be beneficial, not only for the affected population in the disaster area, but also for emergency services. The approach suggested can form the foundation of the next generation of disaster response systems as it harvests the potential of the effected population by sharing some tasks with them. This may reduce the workload of the disaster responders and improve the effectiveness of the disaster response process.

This study also establish that a minimal navigation cue, an arrow that points towards the destination, might be sufficient to guide people to the destination in short distance navigation tasks. Additional elementary navigation cues such as distance or time-to-destination, gives reassurance to the users, making it easier to follow guidance. The contribution of different communication channels to collaborative map-making is investigated and better understood. Additional communication channels help lead to a better situation map and visually shared maps complement voice communication. Explicitly showing confidence information for objects and events in the map further aids in the discussion process. Finally, it was shown that a participatory distributed open information sharing mechanism, helped the affected population to avoid dangerous areas, to achieve a higher situation awareness, and lower the workload in comparison to the evacuation system mechanisms used today.

The findings in this study complement the concept of observability (Heath and Luff, 1992, Woods and Hollnagel, 2006) among collaborative users in a distributed setting. Displaying observability in joint activity coordination leads to an increase in performance and a decrease in the workload and in the need for frequent communication (de Greef, 2012). Visually sharing the situation map, broadcasting situation updates, presenting confidence information, and displaying the walked route of other users, might have provided the users with observability-display, leading to a higher level of shared situation awareness (Endsley, et al., 2003). Hence, this study, contributes to further the insight in displaying observability and improving shared situation awareness.

7.2.2. PRACTICAL CONTRIBUTIONS

The proposed system implemented in the Distri-ES prototype makes a greater practical contribution for future designers of similar systems by providing the blue print for developing and designing such systems. Important elements include: (1) the mobile device for affected population which incorporated the destination arrow, location/waypoints on a map, tracking information of the other affected people, and a reporting interface and (2) the information center for operator which incorporated system elements such as: maps, tracks, destinations, report icons, and danger zone information.

The Playmobil toysets served the purpose of this study well, as quick prototyping tools for depicting disaster scenarios. Their potential can also be extended for use in training purposes or for simulating large-scale real life situations for similar future research.

With the enabling technology proposed in this study, the end users (the affected people), may contribute to the disaster response effort. Instead of waiting to be rescued, they are now able to pro-actively engage in the disaster response process.

7.2.3. ADVICE FOR THE POLICY MAKERS AND DISASTER RESPONSE RESEARCHERS

The advice given to policy makers in the disaster response domain is to look at the affected population from a new perspective and to see that they are capable human beings. People have a tendency to be resilient in times of crisis, and they will always try to get out from problems in creative ways. Let them be part of the process instead of just seeing them as group of people who can only hinder the disaster response process or who need to be taken care of. It is the nature of human beings to have empathy for those who suffer during and after a disaster. However, instead of imposing solutions that the outsiders assume they know best, solutions should stem from the actual requirements of those facing the situation and based on how humans behave in a disaster. By acknowledging this, the affected population can be utilized to increase the effectiveness of the overall disaster response process.

Information verification, such as checking the reliability of all civilian reports, can slow down the situation awareness process. Therefore, an open distributed model is proposed. When information is shared openly and not only in one direction but looped back to the source, it can be cross-verified by the general public. This way, all people can check whether the data is correct, thereby sharing this task across multiple actors. As many emergency institutions usually do not share their data publicly, there should be an effort to make nonsensitive and non private data easily accessible as much as possible. If credibility is a concern, cross verification and the weighted credibility mechanisms can be implemented. This problem is analogous to the reliability issues that faced Wikipedia when it first started (Tapscott and Williams, 2008) and it might therefore be solved in a similar manner to achieve an equal level of success.

Furthermore, disaster exercises should not only aim to train the rescuers and practice the procedure involved in disaster response, but also try to examine the potential of new support technologies. This way, new technological solutions developed for disaster response can be effectively tested.

7.3. Future work

The data collected from the field can be extended beyond the media described in this study (text, GPS coordinates and pictures, map) to include other media such as voice, video, 3D geo-representations, and physiological data to name a few. This will also allow for additional intelligent systems (e.g. analysing user behaviour and measuring stress levels) to be added. Furthermore, the data gathered can be processed, analysed, and clustered with existing GIS data, making them more meaningful for disaster managers. Another important future work for this study might be the incorporation of credibility weighing to the information, so that the reliability of the data gathered can be ensured (e.g. a single police report versus 200 reports from the affected population). Additionally, the future work may include the possibility of correcting the information and visibility of the changes.

Most research on information gathering in the field, focus on unilateral information flow. The concept explored in this study, feeds information back to the providers in the field. This opens up the possibility for other benefits such as the possibility of rechecking the information and cross verification. This closed loop mechanism requires further research to see how it can be best approached and implemented. Additionally, in this study, only confidence information was investigated. Further study may include the concept of trust, reliance, and reliability of situation reports.

The collaboration tackled in this thesis is collaboration within the disaster area itself. An extended collaboration with volunteers helping remotely from all over the world may also be beneficial, such as the Haiti collaborative mapping (ITO-World, 2010). Dividing the tasks that can be outsourced and distributed (microtasking) to volunteers outside the disaster area, for example, connecting route networks on a map, formed by the walking trails of the affected people, may further help the load of the operator that works in the information center.

As the prototypes were developed specifically for experiment purposes, a real implementation should adopt the common standards that are widely used for information sharing in both disaster management and geographic information, such as Emergency Data Exchange Language, EDXL (Raymond et al.,2006) and GeoRSS (Reed, 2006). This ensures interoperability among many agencies in the disaster management domain. Additionally, future development of the prototype should integrate some of the widely used systems available, such as Facebook, Twitter, Google maps, etc. Although people caught in disaster are able to creatively utilize and adapt any technologies available (Shklovski et al., 2010), a system that is specifically designed to work when a disaster strikes is unlikely to be used optimally, as people may not remember to use it or need to learn to use it again. Finally, the prototypes can be further developed to construct a fully endorsed distributed system, for example by incorporating ad-hoc networks into the system.

Although testing in the real life situation can be difficult, an attempt should be made to test the solutions proposed in this study in a more realistic way: for example, having exercises with multiple stakeholders, professional and nonprofessional actors.

As this study focused on the disaster response phase of disaster management, it can be broadened to encompass different phases in the disaster management process, such as in the mitigation phase or the recovery phase. Beyond the disaster response domain, there are also possible applications where a similar protocol of sharing knowledge and observations over a distributed area can be applied. For example, a collaborative traffic information system, amber alert system, and certain games (e.g. a treasure hunt).

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This thesis was based on earlier findings in the literature study of how humans behave in times of crisis, and aims to utilize advances in personal mobile devices. The approach suggested, a participatory distributed mechanism, can form the foundation of next generation disaster response systems. This system harvests the potential capabilities of the effected population as distributed active sensors for assessing disaster situations. This study showed that this mechanism might reduce the workload of the disaster responders and may thereby improve the effectiveness of the disaster response process.

Appendix A: Prototype Architecture

This chapter presents the architecture of the applications that were developed to perform the experiment described in Chapter 6. The experiment made use of four applications: (1) a *Mobile Application* for an iPhone, (2) an *Information Center Application*, (3) a *Simulation Application*, and (4) an *Emergency Call Center Application*. The communication between the applications uses XML-RPC protocol via the Internet and 3G networks.

A.1. Mobile Application

The *Mobile Application* client was developed for an iPhone 3GS on iOS 3.2. The application uses the built in GPS and magnetometer of the iPhone to retrieve location information. Figure A.1 shows the Model–View–Controller (MVC) architecture of the *Mobile Application*.

The *Crisis Model* keeps track of the data necessary to give the user an overview of the disaster situation, this includes: (1) the current position and heading of the user, (2) the destination given by the server, (3) a list of road sections other affected people have previously walked, (4) a list of danger areas, and (5) a list of all reported events in the neighbourhood.

The *Connection Controller* provides functionality to send messages and receive responses from the *Information Center*. For this communication, a connected to the Internet via the 3G network is required

The *Location Controller* communicates with the iPhone's *Core Location* to retrieve the user's current position and heading. This information is sent to the *Crisis Model* and the *Connection Controller*.

The *Report Controller* checks if a new report is valid and stores the user's report history. The *Map View* displays a maps (Google maps) with visual aids overlaid on it to help the user navigate to the destination.

The *Report View* displays Graphical User Interface (GUI) controls to assists the user with creating reports.

There are two types of messages passed between the *Mobile Application* and the *Information Center*: (1) Position reports containing current position and heading. This is sent every time the *Location Controller* receives a new position from the *Core Location*; and (2) Event reports containing reports created by the user in the *Report View*.

The following sequence of actions are performed when there is an update of the position of the user: (1) the *Location Controller* gets a new position from *Core Location*, (2) the *Location Controller* updates the *Crisis Model* with the new information, (3) the *Map View* updates the position and heading on the map and *Report View* updates the position on the mini map displayed in its view, (4) the *Connection Controller* sends the position to the *Information Center* via XMLRPC, (5) the *Connection Controller* receives the response from the *Information Center*, (6) the *Connection Controller* updates the *Crisis Model* with the new information, and finally (7) the *Map View* and the *Report View* updates their map based on the information in the updated *Crisis Model*.

The following sequence of actions are performed to report an event: (1) the user fills out the *Report View* GUI to construct a report, (2) the user

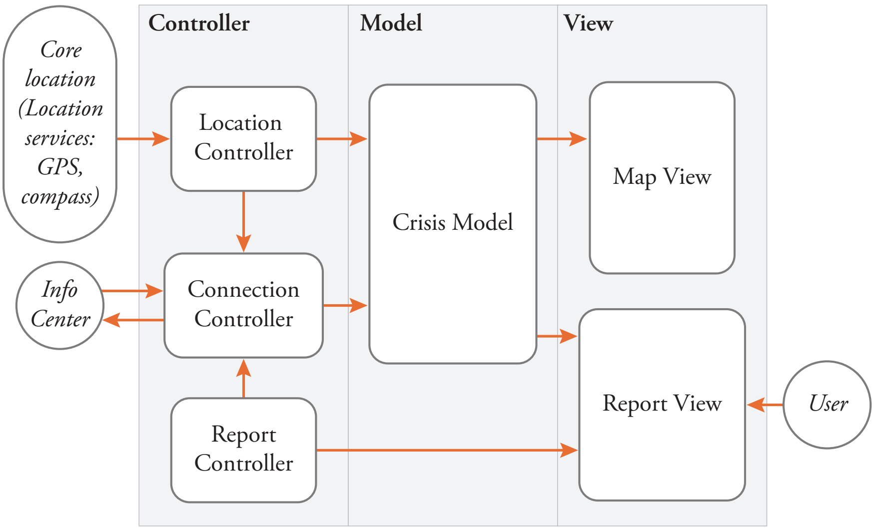

Figure A.1. The Model–View–Controller (MVC) architecture of the mobile application presses the send button (3) the *Connection Controller* sends the report to the *Information Center* via XMLRPC, (4) the *Connection Controller* receives a response from the *Information Center*, (5) the *Connection Controller* updates *Crisis Model* with the new information, and finally (6) the *Map View* and the *Report View* update their map based on the information in the updated *Crisis Model*

A.2. Information Center Application

During the experiment, the *Information Center* application was run on a PC (Dell Precision T3400 Workstation, Intel CPU Core2Duo 3.00 GHz, 2 GB RAM) with Microsoft XP and dual screen 24 inch displays.

The *Information Center* application is developed in Java, and uses a map of Delft (Google map) showing the area with the following latitude/longitude boundary coordinates: top-left: 52.008952, 4.342861 to bottom-right: 51.995292, 4.381785. All user interactions during the experiment as such reports, positions of both the real and virtual affective persons, relayed reports from the *Emergency Call Center*, and actions of the operator on the user interface are unobtrusively logged by the *Information Center* application .The MVC architecture of the *Information Center* can be seen in Figure A.2.

The *Views* display the disaster situation to the operator depending on the experiment condition, a different view is presented to the operator (*Alpha View* for the CENTRA-ES condition and *Bravo View* for the DISTRI-ES condition). *Views* are composed of several layers: (1) top layer shows the

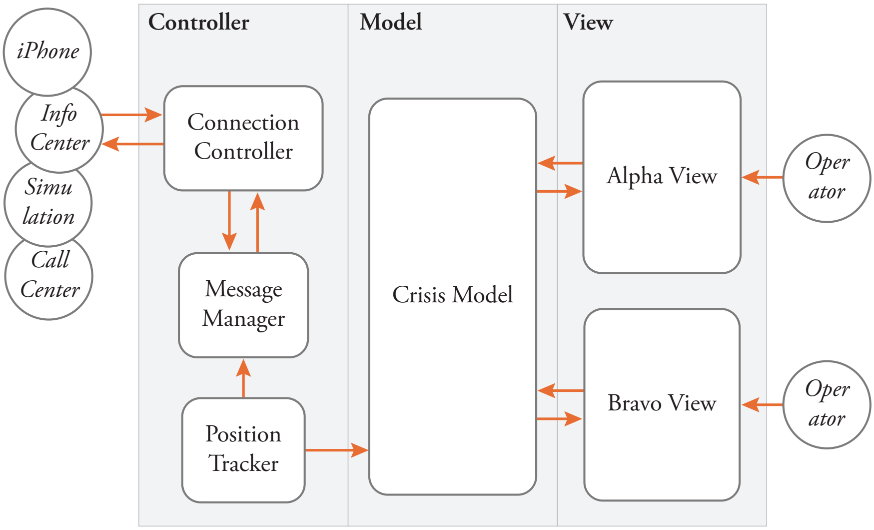

Figure A.2. The Model–View–Controller (MVC) architecture of the information center (server) reports, (2) middle layer shows the tracks, and (3) the bottom layer is the map of Delft. The top and the middle layer can be turned on or off to accommodate different experiment conditions.

The *Crisis Model* contains all relevant data of the disaster situation (e.g. danger areas, event reports, confirmed reports, safe road sections, GPS positions and headings of affected people). This data is regularly updated by:

- The *Mobile Application* run by affected people participants (position updates and event reports),
- The *Emergency Call Center Application* (event reports),
- The *Simulation Application* (position updates and event reports),
- The operator (danger areas, report acknowledgment, destinations),
- The *Position Tracker* (save road sections).

The *Connection Controller* provides functions to receive messages and send responses to and from actors (the *Mobile Application*, the *Simulation Application*, the *Emergency Call Center Application*).

The *Message Manager* is responsible for interpreting the received messages (it must check who the sender is and what message type is, etc.). There are two types of messages: (1) Position updates where message body contains a user-id, timestamp, GPS coordinate, and heading; and (2) Event report that contains event type, photo, and event note. The *Message Manager* updates the *Crisis Model* and relays the position update message to the *Position Tracker*.

The *Position Tracker* runs the following procedures: (1) update the *Crisis Model* with the new position (of the actor), (2) create new tracks for new actors, (3) check if an actor has reached his destination, (4) find save road sections, and (5) update the *Crisis Model* with new save road sections.

On receiving the first position update of a client (*Mobile Application* or *Simulation Application*), the client is registered at the *Information Center*. The *Information Center* calculates the best destination for the client and responds with relevant information in its neighbourhood and along the intended route (i.e. reports, danger areas and walked routes). On subsequent position updates, the *Information Center* keeps track of the client's progress and responds with updated information if necessary (new or deleted destination, new or deleted reports, new or deleted danger areas and new or deleted explored routes). A similar communication protocol is used for handling reports.

A.3. The Simulation Application

The goal of the *Simulation Application* is to emulate the behaviour of an affected person walking in the disaster area. Fifteen virtual affected people were used in the experiment. The *Simulation Application* is also implemented in Java and runs on the same machine as the *Information Center* server. Figure A.3 shows the architecture of the *Simulation Application*.

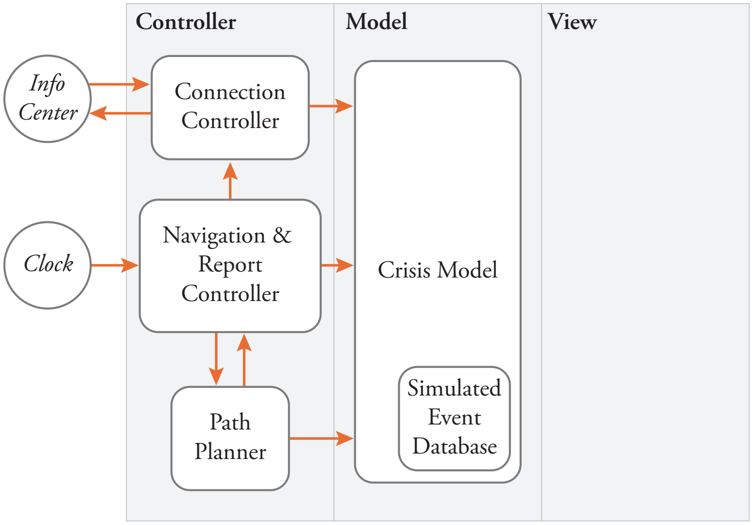

Figure A.3. The Model–View–Controller (MVC) architecture of the simulation module

The *Crisis Model* contains all data of the crisis that is relevant to the *Simulation Application*. This includes the current position (updated by *Navigation* and *Report Controller*), destination, danger areas (updated by the *Connection Controller* via the *Information Center*), and a predefined list of simulated events (loaded at startup). The *Connection Controller* provides functions to send messages to and receive responses from the *Information Center*.

The *Clock* sends a trigger at every time interval. By varying the value of the time interval, the walking speed of the simulated affected person can be adjusted.

The *Path Planner* plans a path from the current position to the desired destination while avoiding the danger areas (it gets the locations of the danger areas from the *Crisis Model*). The *Navigation* and *Report Controller* has three functions: (1) Calculate the next position (by querying the *Path Planner*), (2) Report the next position, and (3) check whether there are events that need to be reported and report them.

A.4. The Emergency Call Center Application

THE *Emergency Call Center* is implemented in Java. It run on a MacBook Pro with Mac OS X 10.6.7 and connected to the *Information Center* through the local network. It passes an event message reported by a participant to the *Information Center* in a standardized way. The experimenter selects a suitable event from the event report list, and presses the send button.

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Curriculum Vitae

Lucy Trianawaty Gunawan was born on March 14, 1978, in Purworejo, Indonesia.

She attended Purworejo State High School I, and graduated first in her class in 1996. Upon her graduation from high school, she was awarded a full scholarship to study at the Bina Nusantara University in Jakarta. She graduated with honors in 2000 with a bachelor's degree in Computer Science.

Afterwards, she was awarded with another full scholarship to pursue a master's degree in the Netherlands. In 2003, she earned her Master of Science degree in Technical Informatics *Cum Laude* at the Delft University of Technology.

She later attended Design School at the Technical University Eindhoven as a research trainee, where she received her Professional Doctorate in Engineering in User-System Interaction in 2005.

Lucy embarked on a career in the field of computer technology in 1996. Lucy was hired by Bina Nusantara University and move up through several positions as programmer, application analyst & designer, and finally a developer coordinator, managing the development and implementation of various information systems for the university's daily operations.

Before joining the PhD research, she was involved at Philips Applied Technology and Océ Technologies in the Netherlands in developing new innovative technologies from scratch by employing User-Centered Design methodologies.

As a visually oriented person, she enjoys finding beauty in everyday things. Her passion for creating and capturing beautiful objects led her to a side profession as a designer and photographer. Besides globetrotting, swimming, and playing guitar, she also enjoys learning new crafts as a creative outlet.

In July 2006, Lucy started her PhD research project at Man-Machine Interaction group in the Faculty of Electrical Engineering, Mathematics and Computer Science at Delft University of Technology in the Netherlands.

Propositions

1. In a disaster area without an updated map, the affected population can be guided towards a destination by using mobile navigation technology which points in the direction of the destination and provides elementary navigational cues. (Chapter 4 of this thesis)
2. Using (audio)visual communication channels to collaboratively share spatial information among people in the disaster area, increases the accuracy and completeness of the disaster situation map. (Chapter 5 of this thesis)
3. Collaborative map-making can result in a joint map that is worse than the underlying individual maps. A method of explicitly showing the individual contributions with confidence information enhances the collaborative map-making process. (Chapter 5 of this thesis)
4. A system that supports collaborative sharing of spatial information between the affected population and professional actors on-and-off location, will result in a more accurate disaster situation map and safer navigation of the affected population to safer area, in contrast to the commonly used system. (Chapter 6 of this thesis)
5. Bystanders and victims are often capable humans beings who are able, to a large extent, to take care of themselves and help others during disaster responses. (WHO, 1989, Quarantelli, 1999, Tierney et al., 2001)
6. Most people never experience natural disasters. Their understanding of how humans behave in a disaster situation is derived from popular media, such as TV and print media, that show a bias towards entertainment and sensationalism (as opposed to good journalism that provides facts and accounts). Consequently, a human's resilience is often underestimated and hardly anticipated. (Mitchell et al., 2000 and McEntire, 2006)
7. Toys are not really as innocent as they look. Building on Charles Eames' statement that toys and games are a prelude to serious ideas, the research domain of disaster management shows that toys, like Playmobil, can actually be utilized for "serious" professional training and evaluation purposes.
8. The fact that so many travellers forget to checkout when using the Dutch public transport chip card (OV-chipkaart) reveals a design failure in supporting human negligence, whereby the traveller forgets to perform an additional action after the main goal has been reached (in this case the main goal is going from A to B). As long as the environment cannot incorporate the additional action in the main goal, hints like "Do not forget to check-out!", will only partially prevent such errors.
9. The Internet, despite containing a wealth of information and various methods to connect the global population, is slowly eroding human communication and interpersonal skills.
10. Mobile phones may bring us closer to the people further away from us, but they can also pull us away from the people nearest to us.

These propositions are regarded as opposable and defendable, and have been approved as such by the supervisors prof. dr. M.A. Neerincx and dr. ir. W.P. Brinkman.

Stellingen

1. De mensen die zich bevinden in een gebied dat door een ramp is getroffen waarvoor geen bijgewerkte situatiekaart aanwezig is, kunnen naar de bestemming geleid worden door gebruik te maken van mobiele navigatie technologie die de richting van de bestemming aangeeft en eventueel elementaire navigatie aanwijzingen verschaft. (Hoofdstuk 4)
2. De nauwkeurigheid en volledigheid van de rampsituatiekaart wordt vergroot door gebruik te maken van (audio) visuele communicatiekanalen om ruimtelijke informatie uit te wisselen tussen mensen in het rampgebied. (Hoofdstuk 5)
3. Een gezamenlijke situatiekaart kan een slechtere weergave van de werkelijkheid geven dan de losse, individuele situatiekaarten. De kwaliteit van de gezamenlijke situatiekaart verbetert wanneer de individuele bijdragen worden vastgelegd met daarbij een zekerheidsindicatie. (Hoofdstuk 5)
4. In vergelijking met de traditionele systemen, zal een systeem waarop ruimtelijke informatie gedeeld kan worden tussen de getroffen bevolking en de professionele hulpdiensten (op locatie en daarbuiten) resulteren in een meer accurate rampsituatiekaart en een veiligere evacuatie van de getroffen bevolking. (Hoofdstuk 6)
5. Toeschouwers en slachtoffers zijn vaak capabele personen die in grote mate in staat zijn om voor zichzelf te zorgen en om anderen te helpen tijdens een ramp. (WHO, 1989, Quarantelli, 1999, Tierney et al., 2001)
6. De meeste mensen maken een natuurramp nooit mee. Hun idee hoe mensen zich gedragen gedurende een ramp is afkomstig van populaire media zoals televisie en gedrukte pers die gekleurd zijn door amusement en sensatie (in tegenstelling tot serieuze journalistiek die feiten en omstandigheden benoemt). Hierdoor wordt de menselijke veerkracht onderschat en nauwelijks in acht genomen. (Mitchell et al.., 2000 en McEntire, 2006)
7. Speelgoed is niet zo onschuldig als het lijkt. Voortbordurend op de gedachte van Charles Eames dat speelgoed en games een voorportaal zijn van serieuze ideeën, toont het onderzoeksdomein van rampenbeheersing dat speelgoed zoals Playmobil gebruikt kan worden voor serieuze professionele trainingen en evaluatiedoeleinden.
8. Het feit dat reizigers vaak vergeten om uit te checken met hun OV-chipkaart toont dat het systeem zo ontworpen is dat een typische menselijke nalatigheid optreedt, waarbij hij of zij vergeet om een additionele handeling uit te voeren na het bereiken van het hoofddoel. (In dit geval is het hoofddoel reizen van A naar B). Waarschuwingen als " Vergeet niet om uit te checken" zullen slechts gedeeltelijk helpen zolang de omgeving niet in staat is om deze additionele handeling (uitchecken) in de hoofddoel te verweven.
9. Ondanks het feit dat het internet een weelde aan informatie bevat en diverse methoden biedt om de wereldbevolking met elkaar te verbinden, verzwakt het de menselijke communicatie en interpersoonlijke vaardigheden.
10. Door mobiele telefonie kunnen mensen die ver weg zijn dichterbij gebracht worden, terwijl mensen die dicht bij zijn verder weg uit elkaar getrokken worden.

Deze stellingen worden opponeerbaar en verdedigbaar geacht en zijn als zodanig goedgekeurd door de promotoren: prof. dr. M.A. Neerincx and dr. ir. W.P. Brinkman.


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