Exploring Communication Load of Emergency Responders

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Abstract

The adhocratic emergency response organization has to allocate a relatively large portion of time and effort to communication in order to coordinate activities, and keep track of the current state of the emergency and the current assembly of the emergency response organization. Addressing the strain put on the emergency responder as a consequence of communication (the process of handling information) the current paper presents research applying and grounding a theoretical model that approximates the subjective load associated with handling messages (communication load) by the emergency responder. By placing the communication load of the emergency responders in a temporal perspective application of the model is able to reveal information about the cumulative subjective communication load at a given moment, providing valuable information to optimize information distribution during the response or add communication load indicators to emergency response evaluations. It furthermore is able to provide a testbed for various experiments regarding communication load. The communication load model showed the desired behaviour, providing a plausible indication of the load associated with handling messages during emergency response situations.

Keywords

Communication load, cognitive load, workload, workflow, simulation, emergency response

1. Introduction

For emergency response to effectively deal with the dynamics incorporated in an emergency situation, it has to be as flexible as the emergency itself, demanding innovation and creativity that is unique for that particular situation. During emergency response, a new mitigating organisation emerges consisting of multiple mono-disciplinary organisations, such as the fire department, the police department and the medical services that have to complement each other's activities, while working multidisciplinary in a temporarily bound high risk situation. Within this organisation, the sub-organisations are coordinating their activities through mutual adjustment via liaisons to most effectively use the decentralized expertise of the organisations involved in the emergency response. The adhocracy (Mintzberg, 1983), as such an organisation can be classified, is able to dynamically reorganize its own structure and workflow, and, by doing so is able to shift responsibilities and adapt to the changing environment (Van Aart, Wielinga, & Schreiber, 2004). The organisations' immediate purposes during the emergency thus shape the organisation structure.

The adhocracy is a widely used and empirically well suited structure to coordinate complex and ill-structured team performances, such as emergency response and provides the multidisciplinary organisation with the means to deal with the extraordinary (Mendonça, Harrald, & Jefferson, 2007). The downside of the adhocracy however, resides in the relatively large portion of time and effort spent on verbal communication in order to coordinate activities -workflow planning-, keep track of the current state of the emergency -situational awareness- (Mendonça, & Wallace, 2007, Sapateiro, & Antunes, 2009) and to keep track of the current state of the organisation -organisation awareness- (Oomes, 2004). As the emergency response organization scales up and becomes more complex, or the emergency itself changes (increasing the needed refresh rate of information), the resulting increased amount of verbal communication will lead to an increase of communication load for both the communication network and the emergency responders.

Given the dynamics of emergency response situations and the emergency response organization the communication network and the emergency responders have to allocate a changing amount of time and effort to verbal communication during an emergency response, while preventing overload. Overloading the communication network may lead to a breakdown of communication resulting in information deprivation and loss of situational awareness. The results of overloading the emergency responders on the other hand is more subtle, but will lead challenges related to hampered information sharing and decision making, biases in information acquisition, and fatigue due to increased workload. These factors furthermore influence the workflow of the emergency response, leading to sub-optimal performance (Netten, Bruinsma, van Someren, & de Hoog, 2006, Bruinsma, 2005, Bruinsma, 2010, ACIR, 2005, Van Someren, Netten, Evers, Cramer, de Hoog, & Bruinsma, 2005).

Quoting the Commissie onderzoek vuurwerkramp (2001), crisis management is first and foremost information management. Information determines which activities are started and the adaptation of the disaster response organisation and the organisation's flexibility (Corbacioglu & Kapucu, 2006, Hatum & Pettigrew, 2005). This is also emphasized in the conclusions of evaluations of major emergency response exercise in The Netherlands such as the Voyager exercise in 2007 (Capgemini, TNO, Berenschot, 2008) and incidents such as the riots at the "Veronica Sunset Grooves dance festival" in Hoek van Holland on August 22nd of 2009 (COT, 2009) and the crash of a Turkish Airlines passenger plane in Haarlemmermeer on February 25th of 2009 (De onderzoeksraad voor veiligheid, 2010). Information concerning elevated levels of verbal communication load can play an important role in identifying situations within emergency response in which communication overload may occur, providing a basis for adaptive information distribution support (i.e. Netten, et al., 2006, Berfield, Chrysanthis, & Labrinidis, 2004) within a net-centric approach (Bui, & Sankaran, 2001, Van Santen, 2009).

1.1 Communication load

In contrast to tracing the communication load posed by verbal communication on the communication network - which can be estimated by using (automated) indicators such as used bandwidth, the number of connections per communication channel and time occupied-, the tracing of verbal communication load of emergency responders (workload associated with handling messages) poses several challenges. The following sections will work towards a model estimating communication load of a single message for individual emergency responders in order to explore the communication load of these responders in emergency response situations.

Provided the strong link between communication load and workload (Manning, Mills, Fox, Pfeiderer, & Mogilka, 2002) one can state that in line with Kahneman's (1973) workload theory, verbal communication load refers to the subjective load experienced by the performer, caused by the universal load of the verbal communication. Personal characteristics and external task environmental characteristics furthermore moderate the relationship between the universal load of the verbal communication and communication load (Parasuraman & Hancock, 2001, Hilburn, & Jorna 2001. Communication load thus is subjective and situational. In order to trace communication load over time one has to define, operationalize and quantify the elements that make up communication load, the universal load of the message communicated (message load) and the factors that moderate the relationship between message load and communication load.

The following sections will discuss message load (1.1.1), external moderating factors (1.1.2), and person moderating factors (1.1.3) that are incorporated in the communication load model (1.2) that will be validated (2.1) en tested (2.2) resulting in a quantified model of communication load to explore communication load of emergency responders.

1.1.1 Message load

The first challenge to approximate communication load entails determining the universal load associated with handling a message, independent of the person who is handling it, or the conditions under which it is handled. Indicative for the message load is the amount of information that is included in the message; the number of information elements in a message (Bruinsma, 2010). Similar to the "act" that is used as the unit of analysis in the Bales group communication analysis (Bales, 1970), an information element contains a subject (topic of which is spoken) and a predicate (what is said about the topic) and is sufficiently complete in order for the receiver to interpret the information element and act on it. For example, the information element "the car is red" has a topic (the car), an attribute (colour) and an attribute value (red). The attribute value also can be "unknown", representing the communication of absence of knowledge (question) concerning topic and attribute combination. For topic extraction, communication thus is divided into utterances, that in turn consist of one or multiple information elements which incorporate a single topic, a single attribute and a single attribute value.

Unconstrained natural language, however, often is fragmentary and uses references to, for example, previous topics, the sender or the receiver. This makes it difficult to extract information elements by just using the information provided in the message. When an emergency responder, for example, communicates “I will do that” it is not clear who will be doing what; the topic and attribute remain unclear. However, when the information element is seen in its context as it was the dispatcher who communicated this in reaction to a request from the officer on duty to arrange communication with the head officer on duty, both the topic and the attribute can be filled in using the context in which they occur. Each added information element is likely to result in an increase of the message load, making it less easy to handle, independent of the person who is handling it, or the context in which it is handled.

For comparative reasons rather than using the absolute number of information elements in a message as an indicator for message load, message load can be represented on the same scale as the one that is used in the NASA-TLX (subjective workload assessment scale: Hart & Staveland, 1988). This makes comparison between the load associated with the activity of handling information and other work tasks (such as extinguishing a fire) possible. Based on this scale, the message load ranges from 0 to 20, where a message with a load of 0 refers to a message that is easy to handle and 20 refers to a message that is very hard to handle. The relation between message load and the number of information elements in the message is represented using the following formula:

$$\text{ML} = 13/10 \text{ x } e^{\left(\frac{InformationElements}{6}\right)}$$

For each positive whole number of information elements (*InformationElements*) the message load (ML) is calculated. The calculated message load ranges from 1.5 when the message contains one information element and is reaches its maximum value when the message load equals a 20 (the maximum TLX score). By dividing the number of information elements by 6, and multiplying the resulting value with 13/10 the exponential curve shown in Figure 1 emerges.

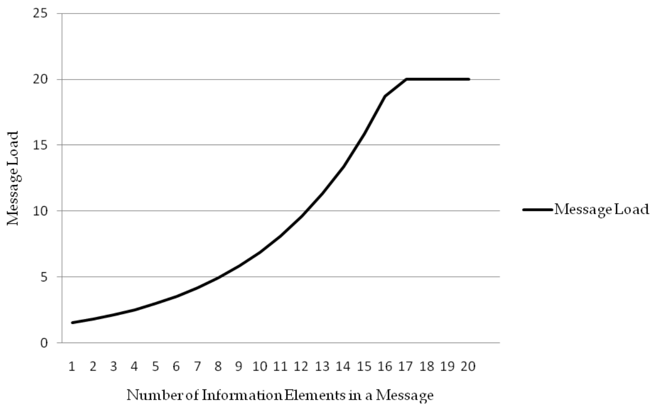


Figure 1: *Message load as a function of the number of information elements in a Message*

With every information element added to the message, the message load increases with an increasingly large amount, reflecting working memory capacity without chunking (Miller, 1956). Thus, the added message load of an extra information element is less for a message containing a small number of information elements when compared with the added message load of an extra information element for a message containing a larger number of information elements. When the message already is very complex (message load of 20), a newly added message does not lead to an increased message load since it is already at its maximum.

1.1.2 External moderating factors

When exploring the external moderating factors one can revert back to the strong link between communication load and workload mentioned earlier. A general moderator of the relationship between task load (universal load associated with task execution) and workload (subjective experience of task load) is provided by the NASA-

TLX. The NASA-TLX takes notice of an external, task environment related load source: time pressure. As Staal (2004) states “Time pressure limits the time available to perform a given task. This limit is a physical boundary that does not require any psychological explanation in understanding its direct effects on performance. However, this limitation often evokes a corresponding psychological reaction such as anxiety that has secondary or indirect effects on performance.” One of the psychological effects of time pressure is that it increases the workload given a task, since it compresses the distribution of the demands over time (Luczak, 1971). Workload is higher when performing the same task under high versus low time pressure conditions and moderates the relationship between task load and workload.

While time pressure is a general moderator of the relationship between message load and communication load, task specific moderators can also be distinguished that refer to the specific conditions in which a message is handled. Heat (Guidotti, 1992), noise (Becker, Warm, Dember, & Hancock, 1995) or vibrations (Newell & Mansfield, 2007) or task location, for example, increase the workload and hence the communication load for the person that is handling the message. However, while time pressure is a universal moderating factor, which applies to all messages in a timeframe, working conditions are task specific. This specificity is in contrast with the general aim of exploring the communication load during a whole emergency response, for all emergency responders. Furthermore, provided the high level of detail of the data needed to incorporate and validate these factors to determine communication load, and the scarcity and limitations of data available from emergency responses (Rodriguez, Quarantelli, & Dynes, 2006). Although these task specific moderators influence communication load they are left out as a moderating factor provided the focus of the research and the availability of empirical data. Therefore, within the communication load model time pressure is considered to be the ma main external moderating factor of the relationship between message load and communication load.

1.1.3 Person moderating factors

With regard to the person specific mediating factors for communication load, experience, or elements that can be directly related to experience (repetition, skill acquisition) are often seen as a major source of diversity for the subjective experience of task load (Hilburn & Jorna, 2001, Loft, Sanderson, Neal, & Mooij, 2007). Shiffrin & Schneider (1977) showed that experience with performance of a task results in automatic or subconscious processing of the task, and, in turn, results in a decrease of workload and time needed for task performance. Within the framework of human performance proposed by Rasmussen (1983), the relation between automaticity and communication is further addressed. Rasmussen (1983) argues that experience alters the perception of information. Given the same information, a person that executes a task at the highest level of automaticity (is engaged in skill based behaviour) is able to handle information more efficiently when compared with persons that execute the same task using rule or knowledge based behaviour. The experienced performer can better extract relevant information. Supporting this view, Lloyd and Somerville (2006) indicate that fire fighters develop a “fire sense” over the years that enables them to better extract relevant information during an emergency response.

When comparing inexperienced and experienced performers under time pressured conditions, interaction effects are reported. Experienced performers’ performance degrades less than the performance of less experienced performers under time pressure conditions. Reasons for these differences are sought in speed of pattern recognition (Calderwood, Klein, & Crandall, 1988) and differences in procedural knowledge of the performer (Spilker, 1994). Experience decreases the communication load. It enables the person that handles the message to cope with time pressure in a more efficient manner, decreasing the impact of the message on the processing capacity of the performer. Furthermore, due to effective coping responses that are learned from previous encounters to adequately deal with the impact of high workload and stressful situations (such as time pressure) creating a double edged sword.

In sum, experience is reported as a major source of diversity in communication load. Therefore, experience will be included in the communication load model as the person related moderator of the relationship between task load and workload. An increase of experience results in an increase of task automaticity, which results in a decrease of the communication load. The moderating relation of experience, in turn, is moderated by time pressure. Time pressure thus amplifies the communication load differences between experienced and less experienced performers and thus amplifies the damping effect of experience on the relationship between message load and communication load.

1.2 *Communication load model*

Based on the theoretical assumptions, the resulting communication load model (Figure 2) describes the process where the message load is the main predictor for communication load. Message load refers to a stable attribute of a message which defines the load of the message, independent of the person handling it and so refers to the load of the message using characteristics of the message itself.

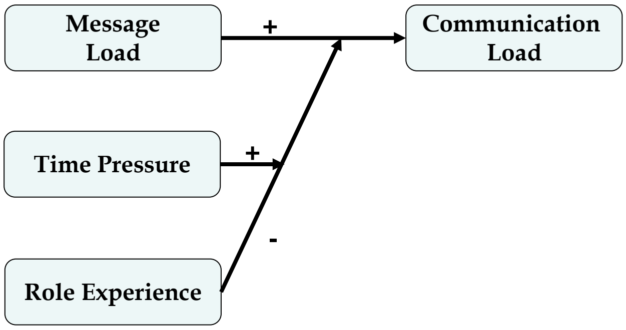


Figure 2: *Communication load model.*

The subjective experience of the message load is expressed by the communication load. Communication load refers to the actual impact of the message load on the sender or receiver's processing capacity. Indicative for the load associated with handling information is the load of the message that is handled by both the sender and the receiver: hence communication load can be represented by a single communication load model.

Given the same message, communication load associated with a message, however, can be different for the sender and the receiver. The relationship between message load and communication load is negatively moderated by the number of years of role experience of the emergency responder. Time pressure, furthermore, amplifies the damping effect of experience on the relationship between message load and communication load. An experienced emergency response experiences less communication load than a less experienced emergency responder.

The following sections describe the research methods and results of a validation study and an empirical test of the communication load model estimating communication load of individual emergency responders in order to explore the communication load of these responders in emergency response situations, identifying elevated levels of communication load of emergency responders.

2. Research methods

To validate and ground the communication load model presented in Figure 2 two empirical studies were conducted. The focus of these empirical studies was on validating the model and identifying deviant behaviour of the model when applied to communication data extracted from an emergency response exercise.

2.1 *Validation study*

To validate the assumptions in the communication load model presented in Figure 2 a questionnaire was administered to a group of experts in the field of emergency management. Experts possess the domain knowledge needed to ground the elements in the model and possess the knowledge needed for making the abstraction to "translate" theoretical concepts into practice.

2.1.1 *Material*

The questions regarding the validation of the communication load model were a subset of a larger questionnaire also touching the subjects of workload and recovery from tasks execution during emergency response. The communication subset addressed the relationship between experience and communication load, and the degree in which time pressure influences the experienced load related to the execution of tasks (of which handling messages is a specific one). The subset consisted of 4 questions. In most cases the questionnaire used a Likert scales to assess the (dis)agreement of the experts with a statement. The five point Likert scale ranged from “strongly disagree” to “strongly agree” with a neutral “Neither agree nor disagree” category.

The first question addressed if the respondents were of the opinion that the number of years of role experience would result in a lower communication load for experienced emergency responders compared with less experienced emergency responders when handling the same amount of information. In the questionnaire, this question was addressed with one item on which the experts had to indicate on a Likert scale to what extent they agreed or disagreed with the statement that that when a person possesses more experience in the role he/she has during emergency response, he or she experiences less communication load compared with less experienced emergency responders.

The second question addressed respondents were asked how the relationship between the number of years of role experience and communication load could be represented. In the questionnaire, this question was addressed by one item in which the experts were asked to indicate which of the nine graphs shown in Figure 3 to their judgment best represented the relationship between role experience on the horizontal axis and communication load on the vertical axes. The graphs shown in Figure 3 represent these plausible “simple” relationships that can exist between experience and communication load. What is the communication load of the same amount of information for emergency responder with varying levels of experience?

Graph (1) indicates that there is no relationship between experience and communication load. No differences exist between the communication load of experienced emergency responders versus less experienced emergency responders, given the same message load. Graph (2) indicates a negative linear relationship between experience and communication load. The communication load of the emergency responder when handling the same message decreases with a fixed amount with each extra year of experience gained by the emergency responder. Graph (6) is the mirror image of graph (2). The communication load of the emergency responder when handling the same message increases with a fixed amount with each extra year of experience gained by the emergency responder.

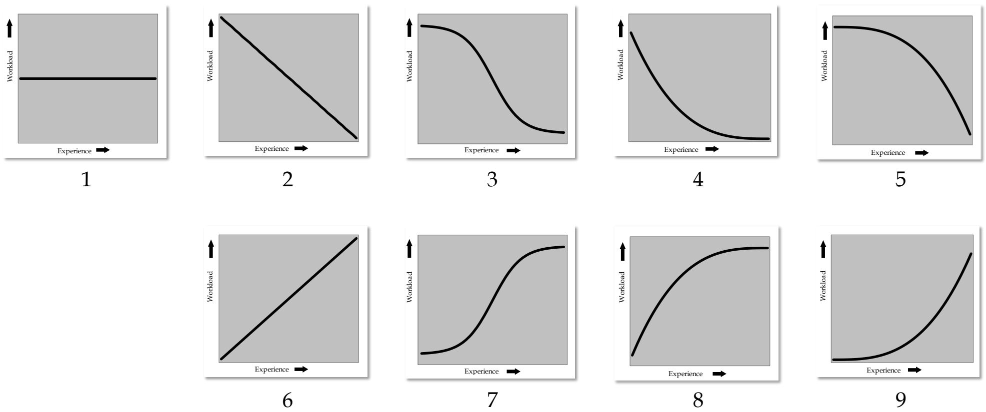


Figure 3: *Nine relationship graphs used in the expert questionnaire to indicate the relationship between role experience (horizontal axis) and communication load*

Graph (4) indicates a z-shaped relation between experience and the communication load of the emergency responder when handling the same message. During the early years of the career of the emergency responder the communication load when handling the same message gradually decreases. After some years, the communication load associated with handling that message decreases quickly and stabilizes in the last phase. An extra year of experience in this last phase thus leads to a relative small decrease of the communication load related to handling that message compared with the decrease in speed in the middle phase. Graph (7) is the mirror image of graph (4), an s-shaped relation between the number of years of experience in handling the same message and the communication load associated with handling that message. Communication load increases slightly in the first phase, increases fast during the second phase and stabilises in the third phase.

Graph type (8) is the mirror image of graph (4). It shows a quick increase of communication load related to the handling the of the same message in the first years that stabilises towards the end.

Graph (5) shows a slow decrease of communication load associated with handling the same message message in the first phase of a career. With every year of experience added, the communication load will decrease with larger steps. Graph (9) shows the mirrored graph of (5). At the start of the career the communication load associated with handling the same message increases slowly with each added year. However, with every year of experience added, the communication load will increase with larger steps.

The third question was a general question regarding the factors that may or may not contribute to the experienced load during emergency response situations. In this question respondents were asked to indicate to what degree is the experienced load during emergency response was determined by workload, communication load, time pressure, (in)ability to recover during tasks and multitasking? In the questionnaire, this question was addressed with four items (item 4, 5, 6, 7 in the questionnaire), covering the different levels of the emergency response organisation. In each item, the experts were asked to distribute 100% over the five pre-specified load contributing factors. In addition, they could specify two other factors that they thought determined the load on the emergency responder during an emergency response. The pre specified factors were:

- The mental and physical aspects of the tasks executed
- The quantity of information that is exchanged
- Time pressure
- The inability to recover from tasks
- Multitasking

Finally, an underlying assumption of the relationship between experience and communication load was addressed: does an increase of the number of years of role experience result in a better and quicker assessment of the relevance of information? In the questionnaire, this question was addressed with two items on which the experts had to indicate on the 5 point Likert scale to what extent they agreed or disagreed with the following statements. First: when a person possesses more experience in the role he/she has during emergency response, he or she is able to better assess the relevancy of information when compared with less experienced emergency responders, and secondly: when a person possesses more experience in the role he/she has during emergency response, he or she is able to quicker assess the relevancy of information when compared with less experienced emergency responders.

2.1.2 Procedure and Respondents

In total 90 experts were approached to fill out the questionnaire described above. The questionnaire was distributed via e-mail to emergency responders that were involved in the tactical, strategic, local government and regional governmental layers of the emergency that were active in the security region Twente the Netherlands. In addition, the questionnaire was distributed via e-mail to the members of the special interest group of the lectureship crisis management of the The Netherlands Institute for Physical Safety and the Police Academy. The special interest group also was provided with a paper and pencil version of the questionnaire during a meeting of the group. Table 1 shows the number of invited people and the response to the questionnaire for the subgroups.

Table 1: *Response to the expert questionnaire*

	Invites	Response
SIG crisis management	32	7 (22%)
SR Twente	58	19 (33%)
Total	90	26 (29%)

From the 90 experts that were invited to fill out the questionnaire, 26 (29%) responded (see Table 1). Given that participation was voluntary, no incentives were provided and none of the responders knew the researcher nor knew about the research, this is a satisfactory response rate when compared with response rates on undirected questionnaires in general. The respondents were affiliated with the traditional parties that are involved in emergency responses (fire department, police department and medical services) and with an organisation that provided education and did research in the field of emergency response and crisis management.

From the 40 roles that the 26 experts had in emergency response, the roles that were most prominent in the responder group were officer on duty (25%), chief officer (10%) and staff member of the regional operational team (7.5%). Thus most of the roles that are present in the emergency response organisation also are represented in the group that responded to the questionnaire.

The responders possessed a broad range of experience on the multiple levels of the emergency response organisation. The respondents had an average of 12,67 years (N=21, SD=9.86) of working experience on the operational level, with a minimum of 1 year and a maximum of 31 years of experience; an average of 11 years (N=21, SD=8.64) of working experience on the tactical level, with a minimum of 1 year and a maximum of 34 years of experience; an average of 10,88 years (N=16, SD=9.15) of working experience on the strategic level, with a minimum of 3 years and a maximum of 35 years of experience; and finally an average of 10.18 years (N=11, SD=9.62) of working experience on the governmental level of emergency response organisation, with a minimum of 1 year and a maximum of 31 years of experience. It should be noted that, since not all respondents had working experience on all levels of the emergency response organisation, the number of respondents that answered the questions (N) that relate to their experience on the levels is different. In this respect, 21 of the 26 respondents have experience on the operational level; also 21 of the 26 respondents have experience on the tactical level; 16 out of the 26 respondents reported to have working experience on the strategic level; and 11 out of 26 respondents reported to have working experience on the governmental level.

From all respondents, 81% had a direct working experience on the operational level, 81% had a direct working experience on the tactical level, 62% had a direct working experience on the strategic level; and 42% had a direct working experience on the governmental level. Since all respondents perform or had performed an active coordinating role in the emergency response organisation, all respondents were familiar with the activities performed at all levels of the emergency response organisation. Thus, all levels of the emergency response organisations are sufficiently represented by the respondents of the questionnaire.

Although the response to the questionnaire tends over represent the input of the fire department when compared with the other traditional parties, it should be noted that the questions about the workload and communication load model focus on the entire emergency response organisation and do not address the separate organisations. This makes it less likely that organisational bias played a role in the answers.

2.2 *Empirical test*

2.2.1 Procedure and Participants

The data acquisition activities performed to acquire detailed (complete) data concerning the communication concentrated around the officer on duty (OvD) level of the emergency response organisation. The OvD is a central node between the units in the field, receives multidisciplinary information from the other OvD's in the COPI (central team incident area) meeting and receives information from other coordinating layers via the head officer on duty (H-OvD).

Data acquisition entailed monitoring all information exchanged to and from the OvDs (fire department, police department and medical services) during a COPI exercise. This was achieved by monitoring the walkie-talkie channels that were used by the officers on duty and by equipping the officers on duty with microphones that recorded all face to face communication during a COPI exercise.

The mock emergency response that was monitored concerned an accident between a passenger train and a flatbed owned by the military carrying a Leopard II tank. The collision took place in the proximity of the central station of Almelo, the Netherlands. As a consequence of the collision, the passenger train derailed and partially fell into a not yet finished railway tunnel next to the temporary track the train was travelling on. The first two compartments were hanging in the construction pit. Complicating the accident was the fact that the train was overly crowded with people and that recently a sound wall alongside the track was placed over a length of 325 meters. The combination of the temporary (narrowed) track with the construction pit on one side and the sound wall on the other side, complicated the self help of the train passengers. Furthermore, given that at the same time of the accident the courthouse in the city of Almelo was the scene of a high profile terrorist court case, the emergency responders were suspicious of possible foul play or a possible terrorist act. This suspicion is fed when a fire fighter finds a suspicious backpack. The goal of this COPI exercise was to multidisciplinary deal with this situation and share discipline exclusive information of multidisciplinary importance.

The recordings from this COPI exercise were transcribed. The utterances were divided into information elements that were used to reveal the communication load in a temporal perspective. During the exercise, lasting 133 minutes, 1837 messages and 4709 information elements (35 information elements per minute) were identified.

3. Results and Implications

3.1 *Validation Study*

The beneficial effect of experience on information handling is supported by the respondents to the expert questionnaire. Using 5 point Likert scales, together 50% agreed and 42% strongly agreed with the statement that experience would lead to a better assessment of the relevance of information (M=4.31, SD=0.74, N=26); 50% agreed and 38% strongly agreed with the statement that experienced emergency responders are able to more quickly assess the relevancy of information compared with less experienced emergency responders (M=4.23, SD=0.76, N=26); and finally, the respondents indicated that more experienced emergency responders experience less communication load compared with a less experienced emergency responder, when provided with the same amount of information (M=3.73, SD=0.83, N=26). Two respondents did not agree with the statement that an increase in experience level would results in a decrease of the communication load. These two respondents were routed away from the questions regarding the representation of the decreasing communication load due to experience and so did not have to answer these questions .

To explore how the decrease of communication load due to experience (expressed in the number of years of role experience) can be represented, the experts that were of the opinion that an increase of experience decreased or did not influence the communication load (N=24), were asked to indicate which relationship type presented in figure 3 best describes this relationship.

From the 24 experts that made a choice between the relationship types, the majority (67%) indicated that graph 3 shown in Figure 3 best described the relationship between the number of years of role experience and the communication load. In addition, 13% chose graph 5, 8% chose graph 2, 8% chose graph 4, and 4% chose graph 1.

Based on these results, it can be concluded that, in line with Rasmussen (1983) and Lloyd & Somerville (2002), experienced emergency responders are likely to be able to better and quicker assess information relevancy and, furthermore, experience less load when handling the same amount of information compared with their less experienced colleagues. From these theoretical positions, the decrease of communication load due to an increase of experience is the consequence of the experienced performer’s ability to better and quicker assess information relevance. Hence, the communication load value implicitly incorporates these experience related competencies by making it a function of the number of years of role experience.

In addition to the fact that an increasing amount of experience decreases the communication load, the experts in the field of emergency response thus indicated that the beneficial effect of the number of years of role experience on the communication load can be represented by a z-shaped curve as is presented in Figure 5 (graph 3).

Quantifying the z-shaped curve resulted in implementing the following formula to describe the influence of role experience on communication via an experience factor (exfCL), moderating the relationship between message load and communication load for the influence of experience.

$$\text{exfCL} = 0.611\left(\frac{1}{1+e^{\frac{yre}{2}-4}}\right)+0.4 \quad (yre \geq 0)$$

For each positive whole number of years of role experience (yre), the experience factor is calculated. Figure 4 displays the resulting curve when entering role experiences ranging from 0 to 20 years. The corresponding experience factor ranges from 1 for emergency responders with zero years of role experience, to 0.40 for an emergency responder with twenty years of experience, following the z-shaped curve. An emergency responder with twenty years of role experience thus is loaded by only 40% of the message load.

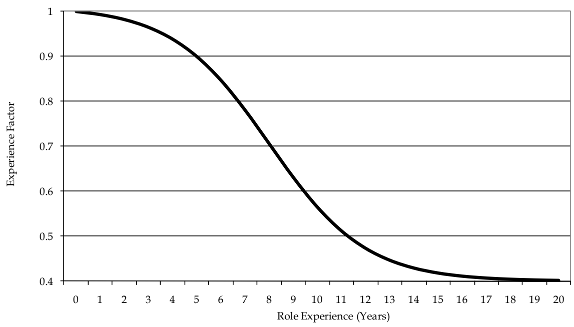


Figure 4: *Experience factor as a function of role experience in years.*

Not taking time pressure into account, communication load associated with handling messages can be represented by the following formula.

$$CLe = (ML \times exfCL)$$

Communication load corrected for the influence of experience (CLe) equals the message load associated with handling a message (ML) times the experience factor related to the number of years of role experience of the emergency responder handling the message, as shown in Figure 4.

Addressing the magnitude of the damping effect of time pressure, the experts in the field of emergency response were asked to indicate which proportion of workload is determined by time pressure during emergency response activities. The respondents indicate that time pressure accounts for 26% (N= 23, SD=11.6) of the total workload in emergency response situations. Furthermore, as Table 2 clearly shows, the proportion of workload determined by time pressure is similar for all organisational levels of the emergency response organisation.

Table 2: *Proportion of load determined by time pressure at the different organisational levels in the emergency response organisation (N =23).*

	Emergency Response Level				
	Operational	Tactical	Strategical	Governmental	Overall
Proportion of load determined by time pressure	25.65%	24.29%	26.84%	27.86%	25.96%

Thus, when time pressure is present, this should account for an average of 26% added communication load at all levels of the emergency response organisation. However, in line with Rasmussen's theory, more experienced task executers are less affected by the increase of workload due to time pressure than less experienced emergency responders.

The moderating influence of time pressure and the difference in added communication load of time pressure due to differences in years of role experience, is addressed by defining a time pressure factor (tpf) that amplifies the communication load corrected for years of role experience (CLe) by proportionally amplifying the CLe. More experienced emergency responders are less impacted by time pressure than less experienced responders. Communication load corrected for both time pressure and experience, therefore, can be represented by the following formula.

$$CLtpe = tpf \times CLe$$

Communication load corrected for time pressure and experience (CLtpe) equals the time pressure factor (tpf) times the communication load corrected for the number of years of role experience of the emergency responder handling the message.

Based on the theoretical model presented in Figure 2 we a able to calculate the load associated with handling a message, while correcting for experience and the presence of time pressure. The following section will describe the results from the empirical test, where the communication load model is applied to explore the communication load of emergency responders.

3.2 Empirical test

The current section will present the results an implications of the empirical test. To focus the results within this section only the results from the officer on duty will be used. Data from the other OvD's was also collected but is left out for illustrative reasons.

Turning to the OvD-B that will be used to explore the cumulative message load over time associated with the flow of information to and from the officer on duty from the fire department, using the formula presented above, the communication load, corrected for time pressure and experience, can be calculated. Table 3 shows the hypothetical cumulative communication loads (Sum), the average cumulative communication loads in the five minute intervals (M) and the standard deviations of the average cumulative communication loads in the five minute intervals (SD), while varying the presence of time pressure and the number of years of role experience (5 and 15 years) related to the information flow of the officer on duty.

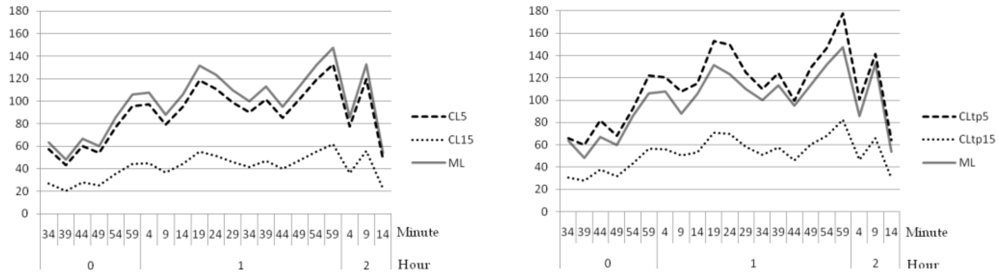
Table 3: *Hypothetical communication load for the officer on duty from the fire department in the COPI exercise with varying levels of role experience (5 and 15 years) under time pressured working conditions and under non time pressured working conditions.*

		Experience	
		5 Years	15 Years
Time Pressure	Present	Sum=2347,302	Sum=1090,516
		M=111,776	M=51,929
		SD=31.581	SD=14,672
	Not Present	Sum=1862,333	Sum=865,208
		M=88,683	M=41,200
		SD=25,289	SD=11,749

As is shown in Table 3, the *Sum*, *M* and *SD* decrease, due to an increase of experience and increase due the presence of time pressure. The differences in the *Sum*, *M* and *SD* between the two levels of experience are due to the ratio between the experience factors (exfCL) that are associated with the numbers of years experience. The hypothetical officer on duty with 15 years of role experience has an experience factor of 0,4179, while the other hypothetical officer on duty (with 5 years of role experience), has an experience factor of 0,8995, which is 2,15 times the experience factor of the more experienced officer on duty. Consequently, *Sum*(5 years)=2,15(*Sum*(15 years)); *M*(5 years)=2,15(*M*(15 years)); and *SD*(5 years)=2.15(*SD*(15 years)).

The differences in *Sum*, *M* and *SD* determined by the presence of time pressure are due to the time pressure factor (tpf). As indicated in the previous section, this is a random value between 1.144 and 1.376 that, when time pressure is present, is separately determined for each communication that is executed. In this example, due to the presence of time pressure, *Sum*(time pressure present)=1.26(*Sum*(time pressure not present)), *M*(time pressure present)=1.26(*M*(time pressure not present) and *SD*(time pressure present)=1.26(*SD*(time pressure not present)).

Figure 5 shows the message load (ML) and the average cumulative communication loads in a five minute interval over time in either time pressured working conditions (b) or non time pressured conditions (a). Since no time pressure is present in figure (a), the only factor influencing the relationship between message load and communication load is the experience factor. This factor is stable throughout an emergency response, therefore the average cumulative communication loads in a five minute intervals for the emergency responder with 5 (CL5) and 15 (CL15) years of experience "follow" the message load value.



(a) ML and CLtpe for 5 (CL5) and 15 (CL15) years of role experience without time pressure (tpf = 1).

(b) ML and CLtpe for 5 (CLtp5) and 15 (CLtp15) years of role experience with time pressure.

Figure 5: *Hypothetical communication load over time for the officer on duty from the fire department in the COPI exercise with vary levels of role experience (5 and 15 years) under time pressured working conditions (b) and under non time pressured working conditions (a).*

When messages have to be handled under time pressure, the random time pressure factor amplifies the experience factor. The semi random time pressure factor lets the communication load fluctuate between messages with a similar message load that are handled by emergency responders with the same level of experience, accounting for between and within emergency responder fluctuations. Furthermore, time pressure has a different absolute communication load increasing effect for experienced versus less experienced emergency responders; the absolute communication load increases more for less experienced responders handling information in time pressured conditions when compared with more experienced responders. This can be seen in the difference between the absolute increase of the height of the peaks corresponding with the CLtp5 and the CLtp15 lines in figure 5(b).

the communication load associated with handling a message is determined by the message load. Accounting for variations in communication load due to an increase of experience and the presence of time pressure, the relationship between message load and communication load is moderated by experience, whose effect, in turn, is damped by the presence of time pressure. Given the same message, more experienced emergency responders experience less communication load compared to less experience responders, and, when having to operate in time pressured conditions, experience a smaller absolute increase of the communication load.To conclude, the communication load model is able to provide information about elevated periods of communication load.

4. Conclusion and Discussion

In this paper a communication load model was presented validated and grounded by incorporating the experts' opinions in the development in the model and by testing the model's behaviour on real communication data based on the information handling activities of the officer on duty of the fire department during a COPI exercise. This provides an indication of the message load, communication load of the officer on duty over time. The communication load model showed the desired behaviour, providing a plausible indication of the load associated with handling messages during emergency response situations. As was illustrated with Figure 5, adding time pressure and experience resulted in fluctuations of the base message load that remain between plausible boundaries, accounting for both situational and personal fluctuations within and between emergency responders. The differences in communication load, due to experience and time pressure, are small enough to remain between plausible boundaries, and are large enough to be able to distinguish between the load associated with combinations of different levels of experience and time pressure.

The model also is able to differentiate between differences in communication load caused by situational differences for the sender and the receiver. For example, a message can be sent under low time pressure conditions, while the receiver is working under high time pressure conditions. In this case, the communication load for the receiver (given the same level of experience) is higher than the communication load for the sender of the message.

By placing the communication load of the emergency responders in a temporal perspective the communication load model is able to reveal information about the cumulative subjective communication load at a given moment, providing valuable information to optimize information distribution during the response (van Someren, et al., 2005) or add communication load indicators to emergency response evaluations (Bruinsma, 2010). It furthermore is able to provide a testbed for various experiments regarding communication load (Netten, et al., 2006).

Based on these results further empirical research however will be needed to strengthen the assumptions within formula underlying the calculation of the experience factor and the time pressure factor. Secondly, not addressed in this paper was the impact of heightened communication load on the workflow via hampered decision making during emergency response and the effect of chunking of information on communication load. Thirdly, further research is needed on how communication load is related to workload and their representation on the NASA-TLX scale. The application of the present model however provides a grounded and usable estimation of communication load of emergency responders in emergency response situations.

Acknowledgements

The author greatly appreciate the support from the Dutch Ministry of Economical Affairs (Agentschap.nl) under contract to the Human-Computer Studies Laboratory of the University of Amsterdam for financing this research as part of the TAID project (project number MMI04006). The content of this article does not necessarily reflect the position or the policy of the Government, and no official endorsement should be inferred.

References

ACIR (Adviescommissie Coördinatie ICT Rampenbestrijding) (2005). *De vrijblijvendheid voorbij: Op naar een effectieve multidisciplinaire informatievoorziening bij grootschalig gezamenlijk optreden in onze gedecentraliseerde eenheidsstaat.* Den Haag: Author.

Bales, R. F. (1970). *Personality and interpersonal behavior.* New York: Holt, Rinehart, and Winston.

Becker, A.B., Warm, J.S., Dember, W.N., & Hancock, P.A. (1995). Effects of jet engine noise and performance feedback on perceived workload in a monitoring task. *International Journal of Aviation Psychology* , Vol. 5, Issue 1, Pages 49-62.

Berfield, A., Chrysanthis, P. K., & Labrinidis, A. (2004). Automated service integration for crisis management. *Paper presented at the Databases in Virtual Organizations (DIVO 2004)*, Paris.

Bruinsma, G.W.J. (2005). *De rol van Communicatie, Informatie en Workflow in het hulpverleningproces tijdens (tunnel)rampen*. Technical Report. IOP-MMI, Universiteit Twente.

Bruinsma, G.W.J. (2010). *Adaptive workflow simulation of emergency response*. University of Twente: Enschede, The Netherlands.

Bui, T.X., & Sankaran, S.R. (2001). Design considerations for a virtual information center for humanitarian assistance / disaster relief using workflow modelling. *Decision support systems, 31*, 165-179.

Calderwood, B., Klein, G.A. & Crandall, B.W. (1988). Time pressure, skill, and move quality in chess. *American Journal of Psychology, 101*, 481-493.

Capgemini, TNO, Berenschot (2008). *Evaluatie oefening Voyager: Een systeemevaluatie van kritische processen bij crisisbeheersing*. Utrecht: Author.

Commissie onderzoek vuurwerkramp (2001). *De vuurwerkramp: eindrapport*. Enschede/Den Haag, The Netherlands: Author.

Corbacioglu, S., & Kapucu, N. (2006). Organisational learning and self adaptation in dynamic disaster environments. *Disasters*, *30*(2), 212-233.

COT (2009). *Strandrellen in Hoek van Holland dancefestival veronica sunset grooves, 22 augustus 2009*. Den Haag, The Netherlands: Author.

De onderzoeksraad voor de veiligheid (2010). *Hulpverlening na vliegtuigongeval Turkish airlines, Haarlemmermeer 25 februari 2009*. Den Haag, The Netherlands: Author.

Guidotti, T.L.(1992). Human factors in fire fighting: ergonomic-, cardiopulmonary-, and psychogenic stress-related issues. *International* Archives of *Occupational* and *Environmental Health* (1992), 64:1-12

Hart, S.G., & Staveland, L.E. (1988). Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In Hancock, P.A., & Meshkati, N. (eds) *Human Mental Workload*, pp. 239-250, Amsterdam: North Holland Press.

Hatum, A., & Pettigrew, A.M. (2005). Determinants of organizational flexibility: a study in an emerging economy. *British journal of management, 16*.

Hilburn, B., & Jorna, P. (2001). Workload and air traffic control. In: P.A. Hancock and P.A. Desmond, Editors, *Stress, Workload, and Fatigue. Human Factors in Transportation*, Lawrence Erlbaum Associates, Mahwah, NJ (2001), pp. 384–394.

Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, NJ: Prentice Hall.

Lloyd, A., & Somerville, M. (2006). Working information. *Journal of Workplace Learning*, 18(3), 186-198.

Loft, S., Sanderson, P., Neal, A. & Mooij, M. (2007). Modeling and predicting mental workload in en route air traffic control: critical review and broader implications. *Human Factors*. Jun 2007, Vol. 49, Issue 3, Pages 376-99.

Luczak, H. (1971). The Use of Simulators For Testing Individual Mental Working Capacity. *Ergonomics*, 1971, vol. 14, no. 5, 651-660.

Manning, C.A., Mills, S.H., Fox, C.M., Pfeiderer, E.M., & Mogilka, H.J. (2002). *Using air traffic control taskload measures and communication events to predict subjective workload*. (Report No. DOT/FAA/AM-02/4). Washington DC: Office of Aerospace Medicine Federal Aviation Administration.

Mendonça, D., & Wallace, W.A. (2007). A Cognitive Model of Improvisation in Emergency Management. *IEEE Systems, Man and Cybernetics: Part A*, *37*(4) 547 - 561.

Mendonça, D., Harrald, J., & Jefferson, T. (2007). Emergent Interoperability: Collaborative Adhocracies and Mix and Match Technologies in Emergency Management. *Communications of the ACM*, *50*(3) 45–49.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limitations on our capacity for processing information. *The psychological review*, *63*, 81-97.

Mintzberg, H. (1983). *Structure in fives: Designing effective organizations*. Englewood Cliffs, N.J.: Patience hall.

Netten, N., Bruinsma, G.W.J., van Someren, M., & de Hoog, R. (2006). *Task-Adaptive Information Distribution for Dynamic Collaborative Emergency Response*. Special issue on emergency management systems for international journal of intelligent control & systems, vol 1, no 11.

Newell, G.S., & Mansfield, N.J. (2007). *Influence of twisted posture and multi-axis vibration on seat-to-head transmissibility*. In Bust, P.B. (Ed.) Contemporary Ergonomics 2007: Proceedings of the International Conference on Contemporary Ergonomics. Notingham: Taylor and Francis Group.

Oomes, A.H.J. (2004). Organization awareness in crisis management: Dynamic organigrams for more effective disaster response. In Carle, B., & van de Walle, B. (Eds.), *Proceedings of ISCRAM2004* (pp 63-68). Brussels, Belgium.

Parasuraman, R., & Hancock, P.A. (2001). Adaptive control of mental workload, in P.A. Honcock and P.A. Desmond (Eds.), *Stress, workload, and fatique* (Mahwah, NJ: Erlbaum), 305-320.

Rasmussen, J. (1983). Skills, rules, and knowledge: Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-13(3), 257-266.

Rodríguez, H., Quarantelli, E.L., & Dynes, R.R. (Eds.) (2007). *Handbook of disaster research*. New York: Springer.

Sapateiro, C., & Antunes, P. (2009). An Emergency Response Model Toward Situational Awareness Improvement. In Lundgren, J., & Jul, S. (Eds.), Proceedings of the 6th international ISCRAM conference. Gothenburg, Sweden.

Shiffrin, R. M. & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual Learning, automatic attending, and a general theory. *Psychological Review*, 84, 127-190.

Spilker, B.C. (1995). The Effects of Time Pressure and Knowledge on Key Word Selection Behavior in Tax Research. *The Accounting Review*, 70, 1, 49-70.

Staal, M.A. (2004). *Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework.* NASA/TM-2004-212824. Ames Research Center, Moffett Field, California.

Van Aart, C.J., Wielinga, B., & Schreiber, G. (2004). Organizational building blocks for design of distributed intelligent system. *International Journal of Human-Computer Studies*, *61*, 567-599.

Van Santen, W., Jonker, C., & Wijngaards, N. (2009). Crisis decision making though a shared integrative negotiation mental model. In Lundgren, J., & Jul, S. (Eds.), Proceedings of the 6th international ISCRAM conference. Gothenburg, Sweden.

Van Someren, M., Netten, N., Evers, V., Cramer, H., de Hoog, R., & Bruinsma, G.W.J. (2005). *A Trainable Information Distribution System to Support Crisis Management*. Proceedings of Second International Conference on Information System for Crisis Response and Management (ISCRAM), Brussels, Belgium