Work of Incident Management Teams in the Laboratory - Measuring C2 Performance under Experimental Conditions

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ABSTRACT

Past incident events clearly demonstrate the relevance of effective command and control (C2) work. In particular, situation reconnaissance and visualization, as the foundation of decision-making processes, may potentially be optimized through new technological capabilities. To examine assumptions through automated position visualizations, an experimental study was designed to observe work of Incident Management Teams (IMTs) under laboratory-like conditions. For this purpose, a newly synthesized approach combining established situation awareness measurement methodologies was applied. Through three iterations of the experiment with different IMTs, initial measurement results were obtained and analyzed. When automated position visualizations was utilized, more accurate localization and a higher level of agreement within teams regarding location assessments were observed. In addition, an improved comprehension of the situation was identified. By correlation analyses with applied measurement methods of incident management performance, the reciprocal relationship between C2 performance and situation awareness can be examined, thereby allowing for an assessment of the effects of such information media.

Keywords

command and control, situational awareness, incident management team

INTRODUCTION

The quality of command and control (C2) is essential for the efficient management of emergency incidents. By controlling and directing operations, it forms the basis for further operational development. In the past, operations with limited incident management quality have already had far-reaching consequences for incident management. A recent example is the flood disaster in the Ahr Valley, Germany, in 2021. According to a member of the technical operations management team of the Ahrweiler district, "at 1:00 a.m. on July 15, 2021, [...] no one was certainly aware of the entire situation [translated]" (Landtag Rheinland-Pfalz, 2024). Massive damage in the region and 186 deaths, including two emergency personnel, clearly demonstrate the relevance of needs-based C2 work. Despite this relevance, the work of IMTs in hazard control is an area that has been little researched. In order to examine the processes and mechanisms, an investigation under laboratory-like conditions is necessary to identify obstacles and areas for optimization. This is why the project *Einfluss von digitalen Führungsmitteln auf Entscheidungsprozesse von Führungs- und Krisenstäben* [Influence of Digital Management Tools on Decision-Making Processes of Management and Crisis Teams] (EFFEKT) was carried out including the *Stabsarbeit der Zukunft Experiment* [Staff Work of the Future Experiment] (SDZ_E). The focus of the experiment was to investigate the influence of various C2 tools on C2 work in an IMT. The project was carried out at the German Aerospace Center in the Optical Technologies for Situational Awareness Lab (OPTSAL) in Berlin (Deutsches Zentrum für Luft- und Raumfahrt e. V.). The project aims to collect high-quality data, particularly in terms of objectivity, reliability, and validity. As a part of the scientific evaluation the Cologne University of Applied Science brought technical equipment and personnel, which is responsible for the planned measurements.

This paper contributes a measurement methodology for investigating the influence of automated location data on situational awareness in IMTs. It also presents the experimental design, which provides initial measurement results and enables the interpretation of the collected data. The objective is to evaluate, based on additional measurements, the correlations between the results of situational awareness and the performance of command and control activities.

RELEVANCE

Modern C2 tools have the potential to obtain and process information in new ways. Currently, however, there is a clear difference between the available technical potentialities and the technical possibilities implemented in the C2 structures of incident control (Kedia et al., 2022). These management tools offer a wide range of possibilities for influencing the quality of C2 work, for example, by reducing the cognitive load on IMTs. In particular, management tools for gathering information in the context of situation assessment enable more detailed feedback on the current situation. However, increased information density does not necessarily go hand in hand with improved management performance (Marusich et al., 2016). Information must always be processable, so the density of information must be adapted to human and technical capabilities. Otherwise, this information can lead to technical and human overload and thus fail to achieve optimization.

Automation can effectively support people in operating systems. However, the degree of automation must be adapted to the task at hand (Miller et al., 2014; Parasuraman et al., 2008). Otherwise, there is a risk of a so-called *out-of-the-loop process* occurring. By decoupling the operator from the active control loop, the operator assumes a passive control role. As a result, some processes take place less consciously, which can reduce situational awareness (Kaber & Endsley, 1997).

This gives rise to the objective of determining the influence of C2 tools. In this way, the nature and extent of possible influences can be analyzed. On this basis, an evaluation of C2 tools can be carried out. In addition, possible measures for meaningful integration into C2 work can be derived.

This led to the research question: ***Does the accessibility of current location data from emergency services have an impact on situational awareness in C2 work?***

The hypothesis assumes: ***Automated position visualizations improve individual situational awareness within the Incident Management Team***. This hypothesis is tested for the first time through a newly developed measurement methodology within an experimental study, to establish a foundation for further investigations.

C2 PERFORMANCE MEASUREMENT

C2 performance can be measured through different methods. For example, the *C3Fire microworld* (Granlund, 2002) can be employed to assess performance based on operational losses (in the explicit case, the total area burned in a wildfire scenario). Within this framework, lower losses are interpreted as indicators of superior performance (Johansson et al., 2010). The application of a standardized and simplified simulation environment enables the inclusion of large sample sizes in empirical investigations. This approach further enables systematic variation and comparison of C2 input information. In practical application, for example, differences in performance can be examined when using paper-based maps versus a GIS-based system providing real-time positional data and dynamic fire localization.

A collection of measurement indicators is described in the *Command and Control Measures of Effectiveness Handbook* (Bornman, 1993). Within this framework, subjective measurement indicators are positioned hierarchically above objective measurement indicators. Conceptual and perceptual ideas are captured by these subjective indicators; therefore, they are regarded as providing the overarching evaluative framework. The approach addresses multiple dimensions of C2 effectiveness, implying that comparisons must be conducted with respect to individual factors and in consideration of the initial conditions. Similar to this approach, The *Army Command and Control Evaluation System (ACCES)* (Halpin, 1996) also defines a range of measurement indicators that enable comparative assessments while taking the respective initial conditions into account.

According to Landsberg (2026), the performance of command-and-control (C2) work can be evaluated using a holistic approach. In this framework, multiple indicators are considered and placed into a mathematical relationship, thereby enabling an integrated assessment of overall C2 performance.

Initially, both partial and total damages within the target system are calculated. These damages can be modeled either through linear relationships (damage per unit of elapsed time) or by means of a propagation function describing the dynamic spread of damage over time. In addition, the damages are expressed as damage values according to their respective priority. For this purpose, a weighting factor is incorporated, which is selected on the basis of the asset or object to be protected.

Counteracting measures are evaluated according to the following five criteria: timeliness, degree of impact, level of understanding, proportionality/feasibility of resources deployed, and secondary effects. To this end, the measures are assessed within three categories, each of which is assigned a numerical value (0 - The measure does not correspond to the overall objective in any way/ 0,5 - The measure aligns with the overall objective /1 - The measure corresponds to the overall objective in a highly effective way). As a basis for the work of the IMT they are directly dependent on the quality and processing of the information. Therefore, an evaluation of these data is useful to assess the performance of the IMT and thus enable comparison. According to five criteria the evaluation is conducted: relevance, timeliness, information content, level of development, and validity. Here as well, three categories are defined, each assigned a numerical value of [0; 0.5; 1]. From this, the quality of the information can be calculated to compare the work under various conditions. In addition, the work required for information processing is evaluated. This assessment is carried out on the basis of the following indicators: competencies/skills, cognitive load/complexity/complicatedness, and coordination/communication. As part of C2 Performance, situational awareness will be considered in isolation and described especially.

SITUATIONAL AWARENESS

As a relevant human factor for critical decision-making situation awareness can be named. In the past this factor has been well researched for pilots and soldiers to improve the decision-making in warfare (Salmon et al., 2007). Because of the relevance of situational awareness in decision making, it has important potential for the performance of C2 work. In particular, perception as a component of situational awareness constitutes the basis for a wide range of C2 command and control processes (Ausschuss für Feuerwehrangelegenheiten, Katastrophenschutz und Zivile Verteidigung, 1999; U.S. The National Response Team; Zentrum Innere Führung, 2023). In the German system, for example, situation assessment forms the starting point of the command and control process and thus of analytical decision-making. Therefore, the visualization of the situation is an important component of IMT decision-making and has the potential to influence it.

Situation Awareness in Decision Making

The dynamic process of decision-making includes situational awareness as a relevant element. Situational awareness is described as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1990).

As shown in Figure 1, situational awareness describes the extent to which the current environment is perceived and processed. Decision-making is then based on this, as it provides the necessary information. The resulting actions in turn change the status of the environment, so that this becomes the new starting point for decision-making.

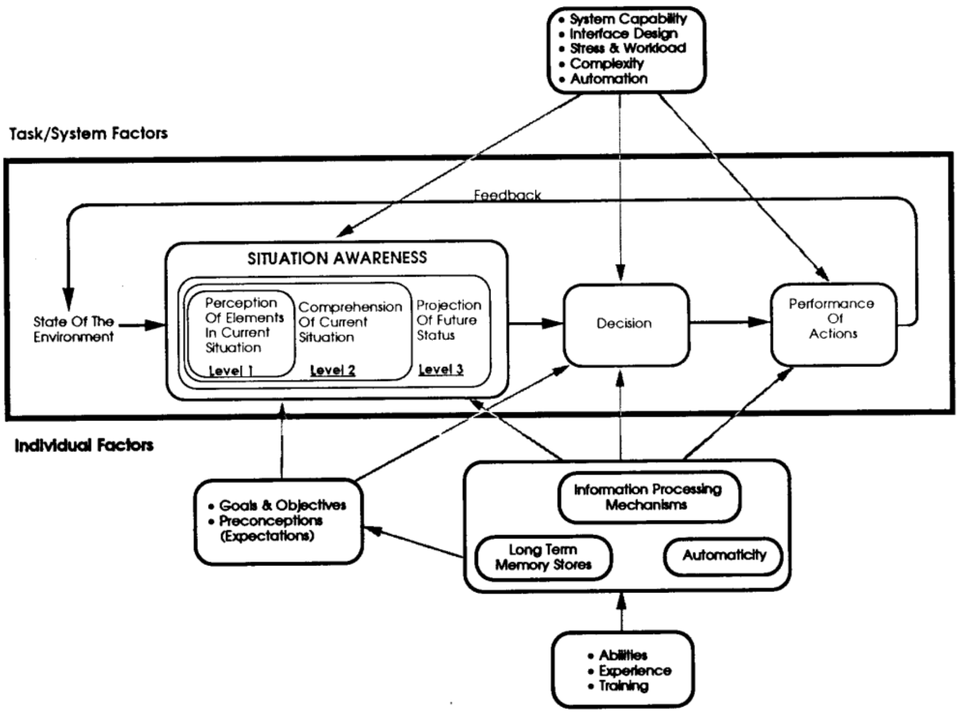

Figure 1 Model of situation awareness in dynamic decision making (Endsley, 1995)

Three-Level-Model

The three-level-model according to (Endsley, 1995) divides situational awareness into three successive levels: perception, comprehension, and projection. Table 1 shows the levels and their descriptions.

Table 1 Level of situational awareness according to Endsley (1995)

Level 1	Perception	Perception of the current situation through various information media such as sensory perceptions or measuring instruments.
Level 2	Comprehension	Comprehension of perceptions in the context of the general objective by assigning relevance and interpreting meanings.
Level 3	Projection	Short-term prediction of environmental behavior based on experience or logical conclusions.

Team Situational Awareness

According to Wellens (1993), team situational awareness can be defined as "the sharing of a common perspective between two or more individuals regarding current environmental events, their meaning and projected future". Especially, sharing important information is a key aspect of achieving a high degree of team situational awareness (Salas et al., 1995). It should be noted that not all information is relevant to every team member. The information must correspond to the goals and tasks within the team (Endsley & Jones, 2001). The generation of team situational awareness begins with an individual phase in which the modified information is cognitively processed. This is followed by team processes, which in turn can influence the individual situational awareness of the respective members (Liu et al., 2016). From this mutual influence, the corresponding degree of overlap in the understanding of the current situation emerges.

EXPERIMENTAL RESEARCH

In *SDZ_E*, the challenge is to make the work of an IMT comparable and observable. Various measures were implemented to achieve this.

Since the work of an IMT is a highly dynamic process, an exercise design is needed to ensure comparability. To this end, an exercise script was developed to standardize the simulated situation. For the scenario, a wildland fire was assumed that affects the structures of an adjacent city. Due to the spread of the fire, additional objects (e.g., people, built structures, infrastructure) are continuously affected, requiring the IMT to respond accordingly. The information to be fed in and the timing of its feed-in are precisely specified. Especially the density of information and the needed workload to process the information are designed to be comparable. This framework can then be used to orient the measurement times and information samples.

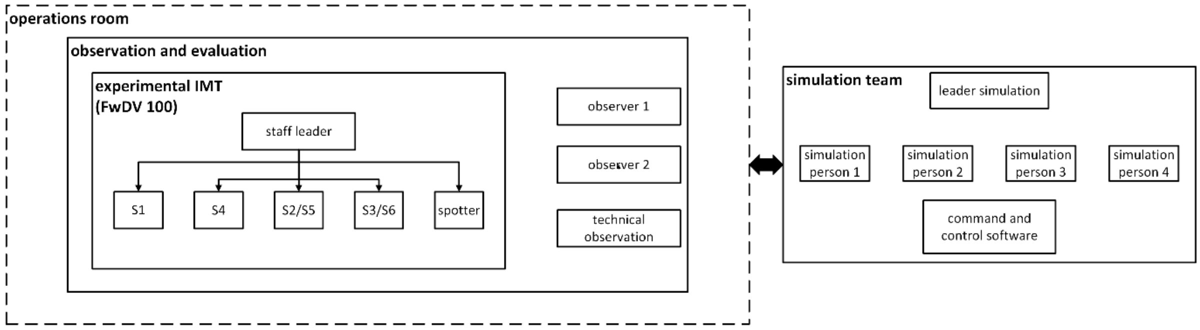

Figure 2 Structure of the experiment

To play out the scenario, the experimental IMT was opposed by a simulation team. The simulation team controlled the input of pre-defined information to ensure the scenario consistency. Command software was also used, which made it technically possible to input information at defined points in time within the framework of an exercise scenario.

The focus is on the experimental IMT, which operates and works in a unified operations room. The members of the IMT are the test subjects of the experiment. The structure of the IMT is based on the structure of an IMT according to the *Feuerwehrdienstvorschrift 100* (Ausschuss für Feuerwehrangelegenheiten, Katastrophenschutz und Zivile Verteidigung, 1999).

Tasks within the IMT are allocated like given in **Table 2**.

Table 2 Responsibilities of IMT members following FWDV 100 (translated from Hofinger & Heimann, 2022)

IMT member	Responsibilities
S 1 – personnel, internal service	• Alerting emergency services • Setting up staging areas • Maintaining force overviews • Managing internal IMT duties (IMT rooms, equipment, etc.)
S 2 – situation	• Obtaining and evaluating situation information • Presenting the situation (situation map, status display) • Informing the public and other agencies • Keeping the operations log
S 3 – operation	• Operational planning with assessment and decision-making • Determination of the command structure and the layout of the area (e.g., operational sector boundaries, staging areas) • Definition of operational priorities • Issuing of orders

IMT member	**Responsibilities**
S 4 – supply	• Provision of food for emergency personnel, fuel, extinguishing agents • Determination of the supply organization • Provision of rescue equipment for the self-protection of emergency personnel
S 5 – press and media relations	• Evaluation of the press and media situation • Preparation of press and media information • Support for press and media representatives • Preparation and implementation of press and media conferences
S 6 – information and communication systems	• Determination of the telecommunications organization • Development of a communications concept, including a telecommunications diagram • Transmission of commands, messages, and information

As shown in **Table 2**, individual IMT positions are combined and supervised by a single test subject. This measure is intended to ensure a sufficient workload for the test subjects, as past studies in this area have revealed deficiencies in this matter.

The room and the test subjects were observed within the operations room by people and technical means. The test subjects and the room were equipped with visual and audio recording technology so that their behavior could be observed in real time and retrospectively.

In order to investigate the influence of various digital management tools, the scenario was developed in four consecutive phases. The information provided varied between the phases.

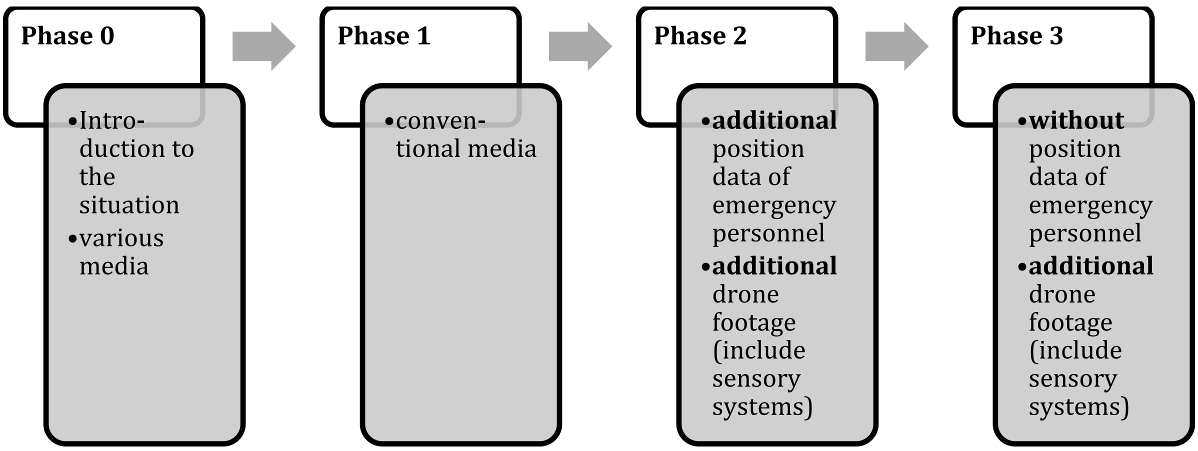

Figure 3 Phases of the scenario - Information provision

Comparable information samples in the phases were generated by so-called secondary scenarios. These secondary scenarios are identical in terms of their complexity, content, and significance within the overall operation. This means that only the underlying information varies according to the phase of the scenario. Measurements can therefore be compared directly with each other, and the corresponding information can be distinguished.

MEASUREMENT OF SITUATIONAL AWARENESS

A specialized approach for determining the influence of position data was used to assess situational awareness. The assessment was carried out in accordance with Endsley’s three-level model. The model was deliberately selected because its levels emphasize the products of the process rather than the process itself. This characteristic enables these products to serve as measurable constructs, thereby allowing for a systematic evaluation of process outcomes (Salmon et al., 2007; Smith & Hancock, 1995). By operationalizing the outputs of the process, the model provides a structured and empirically accessible basis for assessment.

In contrast, other established frameworks, such as the Perceptual Cycle Model (Smith & Hancock, 1995) or the Theory of Activity (Bedny & Meister, 1999) primarily describe the dynamic processes through which situation awareness is generated. These models conceptualize cognition as an interactive and reciprocal system.

While such approaches provide substantial explanatory power regarding the emergence and development of situation awareness, their process-oriented structure limits their suitability for direct measurement.

Initially, existing measurement methods were evaluated with regard to the specific application context. Using a systematic assessment framework, their suitability for C2 systems in operational deployments and training exercises was examined. Based on these findings, the individual methods were analyzed in terms of their quality indicators and the criticisms identified in the literature. This evaluation process revealed the necessity of developing an optimized approach grounded in established measurement methodologies while addressing their conceptual and practical limitations.

Based on the established approaches of Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995) and Situation Present Assessment Method (SPAM) (Durso et al., 1995), two distinct measurement modes were identified. The first involves freezing the scenario and removing all information sources. Then, participants are required to answer questions and complete tasks related to the current situation, structured according to the levels of situation awareness (SAGAT). The second mode entails solving situation-related questions and tasks (also aligned with the levels of situation awareness) while the scenario continues and with full access to all available information (SPAM).

The two measurement modes exhibit distinct characteristics. The SAGAT-based approach assesses the participant’s knowledge of the situation at a precisely defined point in time. Consequently, performance is dependent on short-term memory capacity, as the questions must be answered without access to external information sources (van de Merwe et al., 2012). Situation awareness is evaluated based on the proportion of correct responses. In contrast, the SPAM-based approach measures the extent to which the participant knows where to locate relevant information and how effectively it can be retrieved and utilized. In this context, the proportion of correct answers is of secondary importance compared to the response time required to solve the task, as temporal efficiency constitutes the primary performance indicator.

SPAM and SAGAT differ in their implementation in terms of whether participants are allowed to access information sources or whether these are concealed. The described measurement approach can be applied to both of these modes. Accordingly, by varying the modes, the effects on the recall of information (SAGAT) as well as the accessibility of information (SPAM) can be observed.

In addition, following the approach of Quantitative Analysis of Situation Awareness (QASA) (Edgar et al., 2018), a confidence rating was incorporated into the response procedure. This extension enables the assessment not only of the participants’ factual knowledge but also of their subjective confidence in the information on which their responses are based. Consequently, both the level of situation-related knowledge and the degree of trust in the available information can be systematically examined.

Since information and decisions vary in their relevance for effective C2 operations, an additional option consists of applying a weighting scheme to the partial results (Hauss & Eyferth, 2003). This allows individual items or task components to be differentiated according to their operational significance. By incorporating such weighting procedures, the comparability of overall evaluations across different scenarios can be enhanced.

Test Subjects and Measurement Times

Since the IMT members S2 – situation (combined with S5 – press and media relations) and S3 – operation (combined with S 6 – information and communication systems) have a particular interest in the position data, they were selected as test subjects. The measurement was first carried out for test subject S2 and then for S3. This procedure is based on the responsibilities of the IMT members, as function S2 is responsible for situation assessment and visualization, and function S3 works with the data provided by S2.

Because the goal of the experimental design was to simulate realistic work of an IMT, freeze probes (like SAGAT) were not carried out.

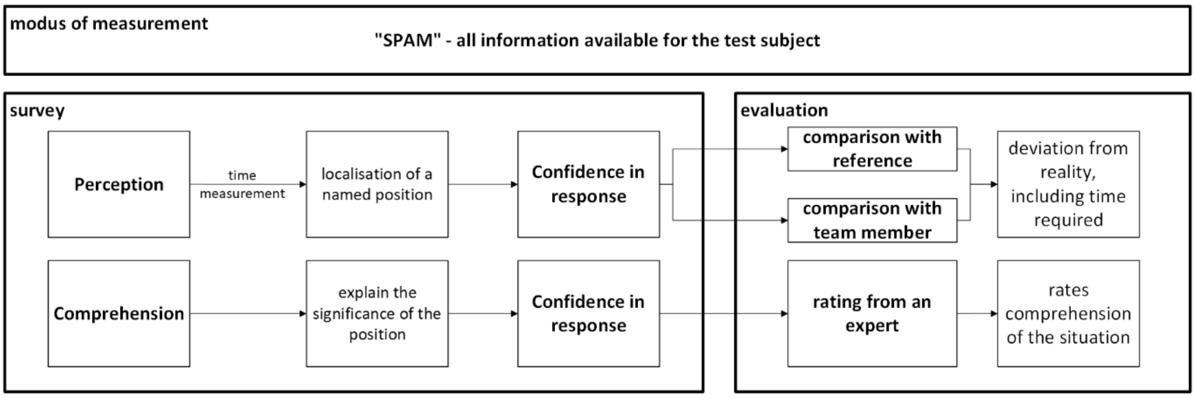

Figure 4 Schematic sequence of the measurement

Figure 4 shows the schematic sequence of the measurement that was applied. In the following, the named aspects are presented in detail.

Survey of Perceptions

The test subjects were given the task of determining a position. To do this, they were given a tablet on which they had to select a square from a three-by-three-meter grid. Precise position information was entered into the tablet a few minutes earlier based on the information provided. The response time was also measured.

Survey of Comprehension

Test subjects had to elucidate the meaning of the corresponding position in context of the whole C2-task. To this end, an open-ended questionnaire was used.

Survey of Confidence in Responses

In addition, the test subjects were asked how certain they were about their answers. They could choose between the options *sure, tends to sure, balanced, tends to uncertain* and *uncertain.*

Evaluation of Perception

Based on the responses of the test subjects, the straight-line distance between the reference location (recorded location data) was determined. Combined with the time measurement, this provides two measurement indicators for determining the quality of individual situational awareness. The straight-line distance between the responses of the test subjects was also determined, providing an indicator of the quality of team situational awareness for this area. This allows for the assessment of the extent to which the situational picture of the two participants (within an IMT) aligns.

Evaluation of Comprehension

The subjects' responses were evaluated by an expert familiar with the scenario who has extensive experience in C2 work, especially when working in an IMT. The expert had to rate the answers after the following system:

The test subject understands the significance of the location's position

- *completely*
- *fundamentally*
- *partially*
- *not at all*

The rating by an expert is particularly advantageous, especially when experimental designs with different scenarios have to be compared.

To enable quantitative evaluation, a numerical value is assigned to each rating level.

Table 3 Quantification of expert ratings

The test subject understands the significance of the location's position	**value**
completely	1
fundamentally	2
partially	3
not at all	4

Comparison Between Indicators

With the given indicators, various comparisons are possible. On the one hand, the values of the indicators between the different IMTs and the personnel can be compared. This enables the observation of the extent to which the results of the two participants within an IMT align, thereby allowing measures of team situational awareness to be derived. On the other hand, the correlation between the indicators can be evaluated. To give an example a negative linear correlation between the linear distance to the reference location and the confidence in response would indicate a good awareness about the own knowledge.

FIRST RESULTS

Initial measurement results for situational awareness were obtained. The experiment was conducted three times under identical conditions, each iteration involving a different IMT. Each IMT included two members holding the same positions (S2 and S3), for whom the measurements were conducted (3 x S2/S4; 3 x S3/S6). It has been observed that the test subjects localized positions more accurately when the positions of emergency personnel and vehicles were displayed automatically. As seen in **Table 4**, the results with automated data were predominantly improved. It can also be seen that the deviations have different characteristics, as the IMTs showed different dimensions of the deviations.

Table 4 location discrepancy secondary scenarios A

Difference of the location discrepancy [m]

ΔNL.A.b [automated location data] - ΔNL.A.a [conventional location data]

	S2/S4	**S3/S6**
IMT 1	438,1	**-4216,8**
IMT 2	**-164,5**	**-192,8**
IMT 3	**-462,9**	**-258,1**

In Figure 5, it is noticeable that the values show less variation in the automated representation. From this, it can be inferred that the representations lead to a unified understanding of the position in question. The data were plotted logarithmically because the values show significant deviations in relation to each other. The findings likewise indicate that automated data were reproduced with greater accuracy.

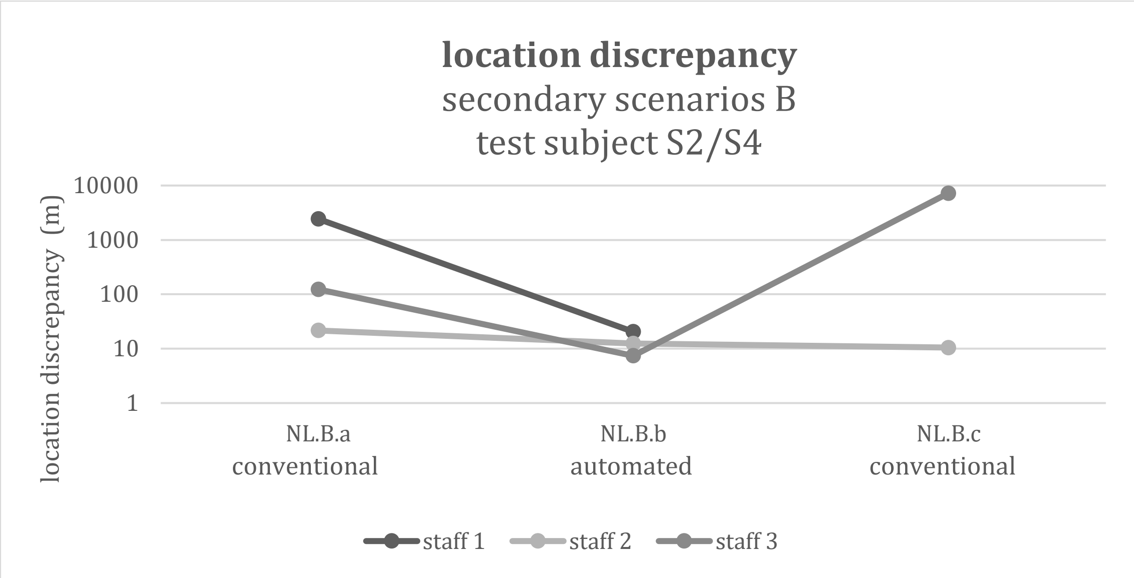

Figure 5 location discrepancy secondary scenarios B test subject S2/S4

This suggests that such automated situation displays have a positive influence on situational awareness. Strong correlations between the results of the *perception* level and the *understanding* level (r= - 0.64) also demonstrate the logical relevance of the accuracy and presentation of position data. However, no clear evidence of faster task completion was observed. In addition, a strong negative correlation was found between the degree of confidence and the time to response (r=- 0.53). This means that the test subjects were less certain of their answers when they took longer to respond.

DISCUSSION & FUTURE WORK

First results indicate that there are potential advantages of automated position visualizations as new C2 information sources which support the gaining of situational awareness. In particular, the reduction of workload and the minimization of human error in situation representation offer significant potential to support C2 activities. If a common understanding is promoted, the exchange of information within or between teams can occur more clearly. Automation mechanisms should therefore be designed in such a way that the human–machine system can exploit its full operational potential. As the measurement methodology is not capable of capturing situation awareness in its entirety, the resulting findings must be interpreted with these methodological limitations in mind. The research design established controlled conditions that, nevertheless, allowed for the dynamic processes characteristic of realistic work of IMTs. It must therefore be taken into account that this is a simulation, which is artificially generated. In particular, additional influencing factors that occur only in real-world scenarios may significantly affect situational awareness. For example, a real incident may increase the overall stress level, as errors can have real consequences. In the experiment, only a mode comparable to SPAM (all information can be accessed) was used. In an extended version of the experiment, a mode comparable to SAGAT (concealment of information) could also be implemented, allowing potential effects on short-term memory to be detected. Despite the limited sample size, valuable measurement results were generated, from which discernible trends could be derived. This, in turn, enabled the verification of the methodological design for subsequent and more extensive measurement endeavors within the domain of C2 research. Within the scope of the study, the approach proposed by Landsberg (2026) was likewise applied, and corresponding measurement data were collected. These data are currently undergoing analysis, enabling the evaluation of C2 performance in accordance with the defined operational phases and across the different participant groups.

A key component of the forthcoming work is to analyze the relationship between these results and measurements of C2 performance. Through a correlation analysis between the measurement data of C2 performance and situation awareness, various relationships can be identified. In particular, if the results of situation awareness correlate with the results of C2 performance, this may serve as a quality indicator for the applied methodology. High levels of situation awareness, as a component of the decision-making process, may potentially be reflected in overall performance outcomes. However, the absence of such a correlation does not constitute a refutation of the methodology, as additional influencing factors may affect the overall results of the C2 performance. Likewise, the influence of the individual components of situation awareness on the performance measurement indicators can be analyzed, thereby enabling an examination of their reciprocal relationship.

Further measurements are planned in order to increase the sample size and collect more data to validate the first tendencies.

CONCLUSION

The deployment of novel information media for situation reconnaissance and visualization in C2 work offers the potential to complement conventional procedures. Through automation, human error and cognitive workload may be reduced. However, potential out-of-the-loop processes may adversely affect situation awareness, thereby necessitating a systematic examination of these new capabilities.

By means of a tailored measurement methodology, differences in situation awareness associated with various information media were identified within the framework of an experimental study. In particular, the accuracy of assessments and the level of agreement within teams demonstrated improved results when automated position visualization of emergency service personnel and vehicle positions was used. Reference measurements were conducted in comparable sub-scenarios with regard to information content and implementation within the overall scenario. Ongoing analyses of overall C2 performance enable the examination of its reciprocal relationship with the results of situation awareness. Planned extensions of the study will enable further analyses through an increased sample size. The continued implementation of such research initiatives enables a more comprehensive understanding of the influence of information visualization on C2 work. On this basis, technical and organizational measures for effective implementation can be derived. The objective is to integrate existing capabilities as effectively as possible in order to achieve a sustainable optimization of C2 work.

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REFERENCES

Ausschuss für Feuerwehrangelegenheiten, Katastrophenschutz und Zivile Verteidigung. (1999). *Feuerwehrdienstvorschrift 100: Führung und Leitung im Einsatz - Führungssystem: FwDV 100.*

Bedny, G. & Meister, D. (1999). Theory of Activity and Situation Awareness. *International Journal of Cognitive Ergonomics*, *3*(1), 63–72.

Bornman, L. G., JR. (1993). *Command and Control measures of effectiveness handbook.*

Deutsches Zentrum für Luft- und Raumfahrt e. V. (Hrsg.). *SDZ_E*. https://optsal.de/projekte/sdz_e/

Durso, F., Truitt, T., Hackworth, C., Crutchfield, J., Ohrt, D., Nikolić, D., Moertl, P. & Manning, C. (1995). Expertise and chess: A pilot study comparing situation awareness methodologies.

Edgar, G. K., Di Catherwood, Baker, S., Sallis, G., Bertels, M., Edgar, H. E., Nikolla, D., Buckle, S., Goodwin, C. & Whelan, A. (2018). Quantitative Analysis of Situation Awareness (QASA): modelling and measuring situation awareness using signal detection theory. *Ergonomics*, *61*(6), 762–777. https://doi.org/10.1080/00140139.2017.1420238

Endsley, M. R. (1990). Predictive Utility of an Objective Measure of Situation Awareness. *Proceedings of the Human Factors Society Annual Meeting*, *34*(1), 41–45. https://doi.org/10.1177/154193129003400110

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors*, *37*(1), 32–64. https://doi.org/10.1518/001872095779049543

Endsley, M. R. & Jones, W. M. (2001). A model of inter and intra team situation awareness: Implications for design, training and measurement. New trends in cooperative activities: Understanding system dynamics in complex environments. *Human Factors & Ergonomics Society*, 46–67.

Granlund, R. (2002). *Monitoring distributed teamwork training*. Zugl.: Linköping, Univ., Diss., 2002. *Linköping studies in science and technology Dissertations: Bd. 746*. Univ.

Halpin, S. M. (1996). *The Army Command and Control Evaluation System (ACCES).* U.S. Army Research Institute for the Behavioral and Social Sciences.

Hauss, Y. & Eyferth, K. (2003). Securing future ATM-concepts' safety by measuring situation awareness in ATC. *Aerospace Science and Technology*, *7*(6), 417–427. https://doi.org/10.1016/S1270-9638(02)00011-1

Hofinger, G. & Heimann, R. (2022). *Handbuch Stabsarbeit*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-63035-8

Johansson, B. J. E., Trnka, J., Granlund, R. & Götmar, A. (2010). The Effect of a Geographical Information System on Performance and Communication of a Command and Control Organization. *International Journal of Human-Computer Interaction*, *26*(2-3), 228–246. https://doi.org/10.1080/10447310903498981

Kaber, D. B. & Endsley, M. R. (1997). Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety. *Process Safety Progress*, *16*(3), 126–131. https://doi.org/10.1002/prs.680160304

Kedia, T., Ratcliff, J., O'Connor, M., Oluic, S., Rose, M., Freeman, J. & Rainwater-Lovett, K. (2022). Technologies Enabling Situational Awareness During Disaster Response: A Systematic Review. *Disaster medicine and public health preparedness*, *16*(1), 341–359. https://doi.org/10.1017/dmp.2020.196

Landsberg, L. (2026). *Messung der Qualität von Führungssystemen der Gefahrenabwehr auf Grundlage semi-quantitativer Indikatoren* [Dissertation]. Albert-Ludwigs-Universität Freiburg. https://doi.org/10.6094/UNIFR/278233

Landtag Rheinland-Pfalz (Hrsg.). (2024, 2. August). *Bericht des Untersuchungsausschusses 18/1 „zur Flutkatastrophe in Rheinland-Pfalz, deren Folgen und zur rechtlichen und politischen Verantwortung der Landesregierung, ihrer nachgeordneten Behörden sowie aller sonstigen öffentlichen Stellen hierfür“*. gemäß Einsetzungsbeschluss vom 22. September 2021 (Plenarprotokoll 18/7, S. 90).

Liu, S., Liao, Z., Zhou, Y., Wang, X. & Tao, D. (2016). Analyzing and Modeling of Crew Team Situation Awareness. In S. Long & B. S. Dhillon (Hrsg.), *Lecture Notes in Electrical Engineering. Man-Machine-Environment System Engineering* (Bd. 406, S. 121–131). Springer Singapore.

Marusich, L. R., Bakdash, J. Z., Onal, E., Yu, M. S., Schaffer, J., O'Donovan, J., Höllerer, T., Buchler, N. & Gonzalez, C. (2016). Effects of Information Availability on Command-and-Control Decision Making: Performance, Trust, and Situation Awareness. *Human Factors*, *58*(2), 301–321. https://doi.org/10.1177/0018720815619515

Miller, D., Sun, A. & Ju, W. (2014). Situation awareness with different levels of automation. In *IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (S. 688–693). IEEE. https://doi.org/10.1109/SMC.2014.6973989

Parasuraman, R., Sheridan, T. B. & Wickens, C. D. (2008). Situation Awareness, Mental Workload, and Trust in Automation: Viable, Empirically Supported Cognitive Engineering Constructs. *Journal of Cognitive Engineering and Decision Making*, *2*(2), 140–160. https://doi.org/10.1518/155534308X284417

Salas, E., Prince, C., Baker, D. P. & Shrestha, L. (1995). Situation Awareness in Team Performance: Implications for Measurement and Training. *Human Factors*, *37*(1), 123–136.

Salmon, P. M., Stanton, N. A., Jenkins, D. P., Walker, G. H., Young, M. S. & Aujla, A. (2007). What Really Is Going on? Review, Critique and Extension of Situation Awareness Theory. In D. Harris (Hrsg.), *Lecture notes in computer science Lecture notes in artificial intelligence: Bd. 4562, Engineering psychology and cognitive ergonomics: 7th international conference, EPCE 2007* (S. 407–416). Springer. https://doi.org/10.1007/978-3-540-73331-7_45

Smith, K. & Hancock, P. A. (1995). Situation Awareness Is Adaptive, Externally Directed Consciousness. *Human Factors*, *37*(1), 137–148. https://doi.org/10.1518/001872095779049444

U.S. The National Response Team (Hrsg.). *Incident Command System/Unified Command (ICS/UC): Technical Assistance Document.*

van de Merwe, K., van Dijk, H. & Zon, R. (2012). Eye Movements as an Indicator of Situation Awareness in a Flight Simulator Experiment. *The International Journal of Aviation Psychology*, *22*(1), 78–95. https://doi.org/10.1080/10508414.2012.635129

Wellens, A. R. (1993). Group Situation Awareness and Distributed Decision Making: From Military to Civilian Applications. In N. J. Castellan (Hrsg.), *Individual and group decision making: Current issues* (S. 25). Psychology Press.

Zentrum Innere Führung (Hrsg.). (2023). *Handbuch innere Führung.*