Unified command? Preliminary findings from a situation awareness experiment

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ABSTRACT

This study investigates high-pressure decision-making in fire response operations, with a particular focus on the cognitive abilities of incident commanders. It builds upon the naturalistic decision-making approach, emphasizing the pivotal role of situational awareness in decision-making. While existing studies predominantly concentrate on individual decision-makers, this study shifts attention to the collaborative dynamics within incident command teams. Through computer-based experiments, it explores the impact of interdependence between fireground commanders on situational awareness, challenging the presumed benefits of teamwork. Counterintuitive results question the conventional wisdom regarding the advantages of having a second pair of eyes. The experiment's findings indicate that commanders operating alone achieve the highest situational awareness scores, suggesting that organizing periodic moments of consultation works better than operating in pairs during response operations. This study provides insights into the intricate interplay of interdependence and situational awareness during high-pressured decision-making.

Keywords

Situational awareness, decision-making, command & control, experiments, fire department.

INTRODUCTION

Try to imagine a fire engine rushing to the incident scene, blue light flashes, sirens, and rapid commands uttered by the crew commander to his team. While squeezing through heavy traffic, crews put on their gear, getting ready to battle a raging fire. Probably one of the key concerns on the mind of the engine commander and his crew is getting a bearing of what they will run into. A sense of awareness and vigilance. Not only will this aid in the rapid rescue of victims, it is also imperative to safeguard the lives of the crew. When the fire crew arrives on-scene and rushes onto the fire ground, they will need to carry out a rapid risk assessment and take critical decisions that will likely determine the difference between life and death.

Such tense situations of high-pressured decision-making have attracted the attention of academics. The classic work of Klein et al. (1986; 2010) on rapid decision-making on the fireground marked the beginning of a fruitful line of research. The study departed from the classic idea of rational, stepwise decision-making and instead stressed the key role of experience by which decision-makers interpret regularities in the environment. Traditional decision models did not take into account the critical role of experience to assess operational settings, as they often relied on students participating in decision-making experiments. Instead, Klein et al. (1986) forwarded a naturalistic approach, in which decision-making is closely connected to the environment, in which previous experiences and expertise plays a major role in guiding the decision-making. It was found that experts are able to read regularities in the environment on which they develop heuristics or rules of thumb, which function as cognitive shortcuts that enable rapid decision-making based on recognition (Klein et al., 2010).

As the naturalistic decision-making school gained footing, many studies on incident command teams followed suit, focusing on the cognitive abilities of the commander (Boehm, 2018), such as situational awareness (Endsley, 1995), sensemaking (Barton et al., 2015; Barton & Sutcliffe, 2009), intuition and mental simulation (Klein et al., 2010). Other studies documented the sequential order of decision processes (Cohen-Hatton et al., 2015; Groenendaal & Helsloot, 2016). This resulted in a renewed understanding of the decision-making process, in which a different sequence of decision phases is identified, which departs from the logical stepwise order seen in normative models (Cohen-Hatton et al., 2015). In these models phases like situation assessment, plan formation, and plan execution are identified as important phases in the decision process (Cohen-Hatton et al., 2015). Initial results support the idea that in high-(time) pressured situations decision-making is primary guided by expertise as decision-makers skip plan formulation. It is also found that goal-directed training can aid decision-makers to switch to more deliberate refection in action (Cohen-Hatton et al., 2015). Taking the time to question perspectives and renewing one's situational awareness remains a key challenge in time pressured environments.

If one thing stands out from this line of research is that most studies focus on the cognitive abilities of the individual decision-maker. Given the attractiveness of the role of the commander in this setting, this is understandable, but also is a limitation that warrants our attention. There are important empirical and theoretical limitations to this focus. A key concern is that the individual decision-maker is often biased and is prone to make intuitive errors (Kahnemann & Klein, 2009). Moreover, a range of studies point to the importance of *shared* and *distributed* sensemaking (Barton, et al., 2015; Wolbers, 2022), *collective mind* (Weick & Roberts, 1993), and *dynamic delegation* (Klein et al., 2006). Indeed, in many operations a commander is not alone, but part of a hierarchy with multiple lines of command. As incidents turn more complex, multiple commanders work in parallel and interact with each other. Therefore, it is time to take distributed command into account more elaborately.

This study explores the impact of collaboration between commanders on situational awareness. Does it help to organize backup for a commander that is operating in a dynamic and chaotic scene? The question is posed: *what is the influence of different types of interdependence between fireground commanders on situational awareness in a fire response operation?* In order to answer this question, the concepts of situational awareness and interdependence are discussed and later operationalized in the methodology. The design and execution of the computer-based experiments offers an innovative way to study the role of teamwork in command and control studies. This study offers counter-intuitive results that question the benefits of teamwork for reaching a high level of situational awareness.

FROM SITUATIONAL AWARENESS TO SYNCHRONIZED DECISION-MAKING

Command & control is a key process in incident response operations that determines what actions response organizations need to take. There are multiple studies that map what incident commanders do when they take command (Njå & Rake, 2009). These studies show that incident commanders usually focus on problem solving and are operating within narrow time horizons. Njå & Rake (2009) note that command strategies were often reactive and interestingly, that very few commanders turn to giving commands. Most of the incident commanders were found to give very few commands (Groenendaal & Helsloot, 2016). Instead, commanders are busy with developing situational awareness in order to monitor the work of others and intervene only when absolutely necessary.

Studies into incident command tend to use a naturalistic decision-making approach (NDM). NDM centers its focus on the proficient decision maker, who operates within bounded rationality. The NDM framework comprises two primary components: situation assessment and mental simulation, both of which are context-specific and rooted in experience. The RPD model, as proposed by Klein et al. (1986), draws upon research spanning diverse domains, including (wildland) fireground command, military battle planning, critical care nursing, ship and flight deck operations, and chess tournaments (Njå & Rake, 2009). In essence, the RPD model depicts decision-making as a sequential process, where proficient decision makers assess the situation and choose an action based on their expertise. The model involves continuous monitoring of deployed actions, and incorporates feedback loops to account for the effects of actions taken. Additionally, mental simulations in the RPD model facilitate feed-forward loops, enabling a proactive approach to decision making.

In contrast to the naturalistic decision-making (NDM) approach, the heuristics and biases (HB) approach points out that humans are often inconsistency and reach different conclusions based on similar information (Tversky & Kahneman, 1974). Tversky & Kahnemann (1974) argued that human judgment is often flawed due to unconscious bias. The naturalistic and HB are often pivoted against each other in terms of influence of expertise. When integrating the insights from both approaches, Kahnemann & Klein (2009) conclude that the quality of intuitive judgment relies on the predictability of the environment and the individual's opportunity to learn the regularities of that environment. Both agreed that situational awareness formed the ground on which decisions were made (Kahnemann & Klein, 2009).

Assessing the environment thus plays an important role in decision-making processes, which points to a key role for situational awareness. This is corroborated by studies that investigate the sequential order of decision-making process, who point out that the step of situation assessment is leading in decision processes (Cohen-Hatton et al., 2015). According to Endsley (1995: 36), *'situation awareness is 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'.* This definition identifies three levels of situational awareness: (1) perception of elements in the environment, (2) comprehension of the meaning of those elements, (3) and the projection of a future state.

Whereas most often situational awareness is frequently measured on the individual level, a range of studies has explored team-level dynamics (Artman & Garbis, 1998). These studies point out that teams play a key role the quality and direction of decision-making (Salas et al., 2017). For instance, Stanton et al. (2017) discuss the role of distributed awareness in dynamic systems and explain that each actor holds their own situational awareness, which may be very different from others. While large disparities may emerge between actors, they note that it is not always necessary to share a similar level of situation awareness, as commanders may have different roles or focus. In that sense, team situational awareness may be understood as a dynamic, fluctuating process, binding agents together on a moment-by-moment basis (Treurniet & Wolbers, 2021). Similarly, Salas et al. (1995) argue that team situational awareness is comprised of a cyclic process that oscillates between individual and team level awareness. On a slightly different note, Shu & Furuta (2005) point out that the required awareness depends on the intensity of a collaboration, and introduce the concept of mutual awareness. Mutual awareness describes the situation where two actors interact intensively for the completion of a task. Therefore, in order to understand the required level of situation awareness, it is necessary to look into the intensity of different forms of collaboration.

In order to find out whether different forms of collaboration impact the level of situational awareness, the concept of '*interdependence'* is helpful. This concept from organization theory lays the foundation for what type of coordination and sensemaking can be achieved in organizing processes (Weick, 1993; Wolbers & Boersma, 2013; Wolbers et al., 2018). Thompson (1967) identifies three forms of interdependence: *pooled*, *sequential* and *reciprocal*. Pooled interdependence refers to arrangements were a task is split among actors that work independently with no flow of work between them, requiring little contact. Sequential interdependence occurs when actors rely on one-directional pathways that contain predictable workflows, which are often codified into plans. The idea of a conveyer belt in a factory comes to mind, to describe a situation where one step is required in order to a colleague to take a next step. Finally, reciprocal interdependence describes the situation where actors work back and forth and mutually adjust their actions.

These three types of interdependence are crucial in the setting of crisis management, as they describe how the composition of, and interaction between command teams may influence distributed sensemaking (Schakel & Wolbers, 2021; Wolbers, 2022). How mutual interdependencies influence cognition is described by Weick et al. (2005), who notes how each type of interdependence is tied to a specific type of cognition. Pooled interdependence is associated with automatic cognition through stereotypes, as actors are not in the position to communicate directly, but have a share sense of how a task should be completed. Discussions on collective mind also describe such a type of meta-cognition (Weick & Roberts, 1993). Sequential interdependence is often tied to heuristic cognition associated with memorized if–then rules, which builds upon the sequential order between work processes. We can recognize this type of recognition in the naturalistic decision-making school, discussing heuristics as a way to codify the expertise of decision-makers in dynamic situations. Reciprocal interdependence involves a more controlled type of cognition based on doubt, inquiry, and argumentation, which emerges from the continuous interaction between decision-makers. Indeed, reciprocal interdependence is time intensive, but also important as actors are able to question and doubt dominant frame that develop in a response operation (Barton et al., 2015). By engaging in this type of controlled cognition actors are able challenge existing frames and able to prevent a collapse of sensemaking (Weick, 1993). These studies show the key role that the different types of interdependence may play in influencing the cognitive abilities of incident commanders.

METHODS

In this study, we measured the impact of different types of interdependence (pooled, sequential and reciprocal) on the level of situational awareness of fire ground commanders. We have created a 1,5h scenario in a virtual reality environment of a complex fire in a storage facility that commanders were asked to watch. The commanders cannot walk around in the computer simulated environment themselves, but have to watch 5 extracted video fragments in which the incident response simulation unfolded, in order to show each commander exactly the same information. The commanders are asked to answer 15 probe questions after each video in order to measure their level of situational awareness. In order to determine the effect of the type of interdependence, we have randomly assigned the commanders into three corresponding groups. We designed these manipulations according to the concepts of pooled, sequential, and reciprocal interdependence (Thomson, 1967). The control group engaged in pooled interdependence, which meant that subjects viewed the videos completely independent (alone). In the manipulation of sequential interdependence, subjects were asked to work together, but were only able to update each other after watching a video, just before answering the questions. In the manipulation representing reciprocal interdependence, the subjects were allowed to engage in full, continuous consultation while watching the videos. In this way, we were able to simulate the three different types of interdependence in the experiment.

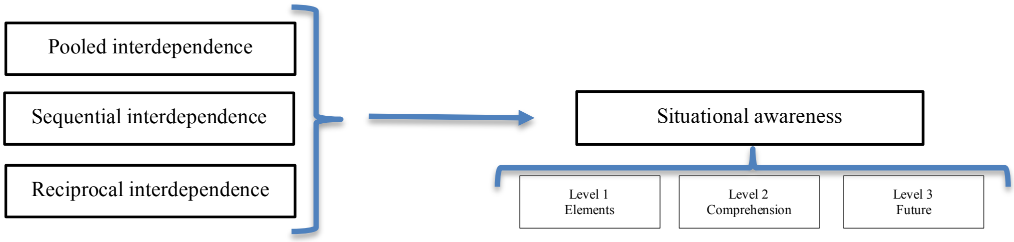


Figure 1. Conceptual design of the experiment

We measured situational awareness according to the QATA methodology, as described in Edgar et al. (2018). In this method, probes are presented to the subjects in the form of visual cues, situation reports, or radio messages. Subjects are presented with relevant and irrelevant probes during the videos, and depending on the manipulation group they are in, are able to discuss their assessment with another commander. The QATA methodology uses a confirm or deny format, as subjects can select that questions are true or false. To measure situational awareness, we formulated 75 probe questions. Each video contained 15 questions, 5 corresponding with each level of situational awareness: level 1) perception of elements, level 2) comprehension of the coherence between the elements, and level 3) future projection. We used the same set of probes and questions throughout the entire incident across all subjects. Subject were asked to state whether a probe was true or false, and how confident they were about each answer on a 5-point Likert scale. Examples of the probe questions are: *'there are people in front of the print shop that make access to the launderette difficult'* [level 1]; '*since the color of the smoke has changed, the situation in the Laundromat is deteriorating'* [level 2], '*heat affected IBCs behind the building pose a risk for a rapidly developing fire'* [level 3].

Participants

112 fire commanders volunteered for this study and provided informed consent for their participation. They were drawn from a representative sample covering all 25 safety regions in the Netherlands. The sample included 103 males and 9 females. The average age was 45 years. The participants were randomly assigned in three groups on the basis of whether they were to engage in pooled, sequential or reciprocal interdependence during the experiment. The participants were not informed there were three different groups. Each participant was briefed on the procedure and gave informed consent for their participation.

We determined the minimal number of participants in advance, by conducting a G-power effect size calculation. To find a large effect size, we required 21 participants in each group, with 3 groups manipulations, this means 63 participants. To find a medium effect size, we required 52 participants in each group, with 3 group manipulations, so 156 participants. We concluded that we needed a sample of at least 52 participants up to 156 participants to measure a medium effect size. In total, 112 commanders participated in the experiment, with 44 in pooled, 34 in the sequential group, and 34 in the reciprocal group. Previous operational experience was assessed in a questionnaire leading up to the experiment that identified how long participants had served in the role of on-scene commander. The mean overall command experience was 9.33 years.

Equipment

The experiment was designed by making use of the software XVR Simulation. The XVR Platform provides all fire departments in the Netherlands with computed-based scenario training. Trainees are immersed in a controllable situation, which is repeatable and measurable. Similar research with support of simulations exists, such as C3 fire (Johansson et al., 2003) and FireChief (Omodei & Wearing, 1995). XVR is step forward in this sense, as it provides the subject with an immersive realistic 3D view of the incident scenario. This paper builds on successful experiences with XVR software in the Firemind and FireFront research projects (Thoelen et al., 2020; Polikarpus et al., 2022). The scenario was designed from scratch, for which we made use of fire department experts, and scenario trainers in a safety region in the Netherlands. We consulted with these experts to make sure to develop a scenario that is realistic for fire-fighters, which contain cues that they would also encounter in a real-live situation, such as the of the spread and intensity of the fire, color of the smoke, fire hoses, fire engines, and other emergency services. We created a 5 separate videos from the 1st person perspective of our avatar walking through the incident, as the scenario unfolded.

The subjects watched the videos on the Labvanced platform, which we used to build online experiments. The platform was used to build, record and share online experiments directly in the browser. It also enabled multi-user studies, in which two subjects perform a task together and the system waits for them to complete the task together before moving forward. In this way, we made sure participants watched the same videos and answered the questions at the same time. We asked the participants to conduct the experiment on their home desktop, in order to provide a calm environment. The subjects in the sequential and reciprocal interdependence groups stayed in contact with each other through a video call on Microsoft Teams in a separate desktop window, which enabled them to interact with each other throughout the scenario. This channel was recorded and continuously monitored by two research assistants to check for disturbances or technological problems. Before the experiment was launched, two research assistants checked in with respondents to check the setup, ensure a quiet environment, and explain the logic of the experiment based on a predefined procedure with fixed talking points. As a result of this monitoring, the data of one participant was deleted due to technical problems with the microphone.

It is important to recognize a few limitations of this setup as the commanders cannot 'seek' information as they normally would do during an incident as they watch pre-recorded videos, are not inside an operational setting itself, and do not continuously see their real-life counterparts. This was accounted for in the setup by showing prerecorded conversations with virtual role players, and information that reached commanders through visual cues, pager notifications, and radio messages. The advantage of this setup is that we were able to create exactly the same operational environment for all participants, the downside is that participants could not adjust it.

Nature of the scenario

The scenario depicts a complex fire in an industrial warehouse building with several compartments, housing a laundry, garage, car repair shop, and a printshop. The fire starts in the garage, but soon spreads to the laundry and car repair shop. As the fire and smoke grow in intensity, a hidden XTC-lab in the back of the laundry catches fire and explodes. A fire fighter is reported missing and part of the building collapses. In this way, the scenario starts relatively simple, but as the videos progress increases in terms of complexity. Cues are offered to the subjects that hint to an XTC lab inside one of the compartments, before and after the collapse, such as reports of interference with electrical wiring, blue barrels, and chemical equipment. There are multiple fire department processes that needs to be arranged simultaneously (asking for additional engines to provide water, scaling up the operation, and deciding on the entry tactics). In that way, we simulate a growing cognitive load for the commanders.

The first video covers the initial reconnaissance walk as the commanders arrive for the first time. It shows an industrial complex on fire, with smoke pillowing from multiple windows. The second video shows the initial attack by fire crews, in which there is an escalation of the fire/smoke propulsion, which leads up to the question whether or not to ventilate. The third video shows the situation directly after the explosion, in which the north side of the building has collapsed and possible persons missing. Here we also introduce the XTC barrels for the first time. The fourth video shows the XTC lab in detail and the fire escalating in other parts of the premises, so that the subjects have to choose between focusing on the XTC lab, or focusing on the fire that is developing in other parts of the building. At the end of the fifth video, the fire fighter that is reported missing is found and the fire is contained by the crews on site.

Picture 1. First view on the fire

Picture 2. Crews going into the laundry for reconnaissance

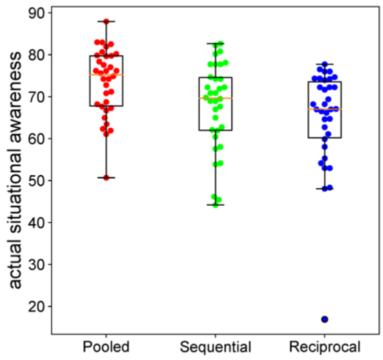
Picture 3. First cue of the toxic waste from the XTC lab

Picture 4. Situation after the explosion and collapse

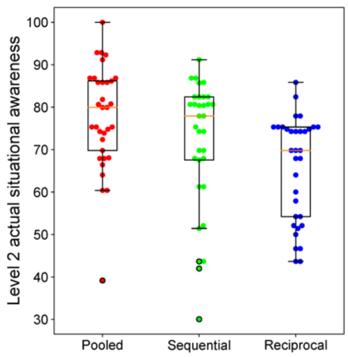
Picture 1 - 4. Screenshots from the videos shown to participants during the simulation

RESULTS

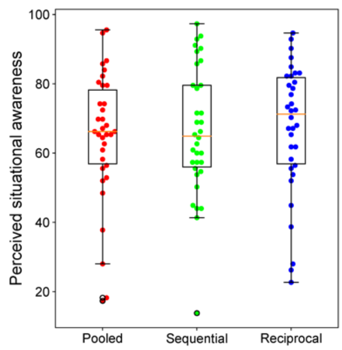
The first results of the experiment indicate significant differences between the pooled, sequential and reciprocal interdependence, both at the combined situational awareness (across levels), and in particular at the second SA level (comprehension). A score ranges from 0 - 100 and means that the subject has a good overview of that percentage of the cues. That means that a score of 100% is not realistic, as subjects are not expected to remember all cues, but discriminate important and less important cues. The score does give an impression of the scope of situational awareness, not so much whether crucial signals are missed or not. All groups appear to be relatively capable of building up an adequate level of situational awareness.



Picture 5. Actual Situational Awareness (ASA)



Picture 6. Level 2 ASA



Picture 7. Perceived Situational Awareness

The analysis offers two important statistically significant results on the measure of overall actual situational awareness (ASA) and level 2 situational awareness (L2ASA). A Kruksal Wallis non-parametric test was conducted to test whether the medians of the different groups are equal. The Kruksal Wallis was found to be most fitting to the dataset, as it does not assume a normal distribution, in contrast to a regular one-way ANOVA. In a Kruksal Wallis test the is data reorganized based on a ranking.

For overall situational awareness (ASA), the Kruksal Wallis test showed that individual exploration of the scene significantly affects the level of situational awareness, compared to actors that engage in continuous collaboration: $H(2) = 20.92$, $p = .004$. Commanders exploring the scene alone based on pooled interdependence (*Mdn* = 73.26), or engaging in a form of sequential interdependence (*Mdn* = 69.64), scored significantly higher than commanders engaging in reciprocal interdependence (*Mdn* = 67.03).

For level 2 situational awareness (L2ASA) that focuses on the comprehension of the meaning of elements in a scenario (i.e. overview of the situation), results show that engaging in individual exploration significantly affects the level of situational awareness: $H(2) = 22.29$, $p = .002$. Here, commanders engaging in a form of sequential interdependence (*Mdn* = 76.63), score higher than in exploring the scene individually in pooled interdependence (*Mdn* = 75.33), and scored a significantly higher than commanders engaging in reciprocal interdependence (*Mdn* = 69.81).

These results indicate that the subjects in the pooled interdependence group had a higher situational awareness score than the subjects engaging in periodic or continuous consultation. In comparison, the subjects engaging in continuous consultation (reciprocal interdependence) have the lowest scores on average. In the right figure, the perceived situational awareness (PSA) is indicated, of which the scores are not significant and are dispersed across the plot. This could suggest that subjects may find it difficult to make a valid assessment of their own situational awareness.

CONCLUSION

The results of this experiment indicate that when commanders engage in continuous conversation during a response operation, it limits their situational awareness. Commanders that take in cues on their own, score significantly higher than commanders working in teams. This is an important result that shows that having two pair of eyes does not always result in a better situational awareness.

It is important to note that this study concentrates on situational awareness, whereas this is not the only aspect at stake during a response operation. The required decisions, interaction with other crews and emergency services, may very well warrant the help of other commanders. It is unlikely that a commander will be in the position to develop situational awareness all by him/herself during the entire incident. These results of this study also provide valuable lessons for shared incident command. If a second commander is called towards the scene, he or she has the most positive contribution if he/she takes in the situation before coming into contact with the other commander. During a response operation, it works better to organize periodic moments of consultation, compared to operating in pairs. That makes it important to make process agreements in command teams on how commanders will collaborate, when to separate, and when meet up again. Although commanders are of course not able to spot all cues, engaging in continuous joint exploration is also not the solution. A good assignment for a second commander could be to focus on noticing abnormal signals that he or she feels have not been picked up by the other commander(s). By distributing tasks in this way, the mental load during high-intensity decision-making can be reduced. This makes the assignment of the second commander twofold: 1) mapping the situation independently of other commanders; 2) find out what the perception of the other commander is, in order to complement and challenge existing beliefs. As such, these findings have important implications for the development of the command tactics and situational awareness in situations of high-pressured decision-making.

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