Challenges of the adoption of AI in High Risk High consequence time compressed decision-making environments, postion paper

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Abstract. Every day incident commanders at emergency scenes need to make decisions in high risk, high consequence, time compressed environments. The decision-making is supported by neurological processes that have an evolutionary background, these processes are fed with the incident commander's understanding of his environment at the emergency scene. With the emergence of a wide variety of public and private data-sets there has been a push to use these data-sets to assist this decision-making process, the method of providing this data to the incident commanders however is not well adapted to the neurological method of decision-making at emergency scenes. Now through the rise of smart-cities, smart-buildings and emergency service specific smart technology the amount of data that can be used to augment the incident scene is increasing even more. AI is often called upon to solve this data overload problem for incident commanders, however no suitable way has yet been proposed to help better integrate digital information in the neurological decision-making process. This paper is intended to summarize the current state of research in the neuroscience of decision-making and the challenges that current data driven approaches have within the emergency response domain, and propose research directions for AI in emergency response.

Keywords. High Risk Decision Making, Emergency Services, Smart buildings/smart technology, Neuroscience, Data driven approaches, Emergency response

1. Introduction

The authors of this paper have been in the emergency service for more than 25 years, and in this period have witnessed the rise of digital information and the related tooling in the field. This rise of technology has been accompanied by extravagant marketing terms about the advantage of the technologies provided. And whilst the provisioning of digital intervention plans made the information more current and easier to maintain in comparison to the paper versions that were present in the organization, a point has been reached where the systems are used to provide more and more information. This however does not integrate well in the neurological process that comes with decision-making in high risk, high consequence time compressed environments.

The neurological process of decision-making in high risk, high consequence time compressed environments relies heavily on the building of Situational Awareness (SA) and the recognition of the environment to be able to predict what will happen and what cause of action to take. The building of SA is largely taking place by using senses to perceive the environment. This is not a conscious process where every sense is deliberately engaged to provide input on the situation at hand, it is a largely automated process with its own pitfalls. Incorporating digital operational information in its current

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form requires a conscious process to align the information from the digital tools with the images obtained from the human senses, this requires significant brain capacity, which could lead to the loss of SA.

The challenges of using the information do not take into account the problems with the information itself, issues with quality, volatility and trust play a crucial role when it comes to using data in the challenging environment of incidents. Providing information as is, without context or any operational perspective, requires a lot of mental horsepower for an incident commander to assess the value of the information.

With the arrival of AI there has been renewed interest in digital information assistants for incident commanders, however these assistant until now do not take into account the neurological process of decision-making

This position paper is intended to gather and reference the current state of research that is relevant to the problem and as a result identify the gaps that can be associated with the integration of AI assistant into high risk high consequence decision-making.

2. High Risk High Consequence Decision-making

The Recognition-Primed Decision-making (RPD) model was discovered in research focused on the decision-making of U.S. fire ground commanders. In 1986. This groundbreaking research led to the creation of the RPD model, providing an explanation for how commanders were able to make "split-second decisions using a rapid and unconscious situation assessment and recognition from an array of stored templates" (Sadler-Smith and Shefy, 2004, p.83). The study revealed that fire ground commanders used the RPD process to make more than 80% of their toughest incident command decisions, usually in less than one minute (Klein, 1998; 2003).

Klein (2003) described the RPD process as one that began with the identification of cues from the environment that helped fire ground commanders recognize patterns–a task not unlike what a person might do in the early process of assembling a jigsaw puzzle when two or three similar pieces were assembled based on a pattern recognition (e.g., colors, shapes and textures). Klein et al., (1986) then discovered that commanders plugged the patterns they formed into mental models that were developed from their collective experiences. Applied again metaphorically to the jigsaw example, the assembler's collective life experiences helps to form mental models of what logically fits together (e.g., a boat will be in water, clouds will be near the top of the puzzle while land or water will be near the bottom, etc.). In the final step of the RPD model, Klein et al., (1986) discovered that commanders used mental models to run mental simulations, making assumptions (based on experience) about how events would play out into the future. Klein (2003) noted this step helped the commanders develop potential courses of action. Again, applied to the jigsaw example, an assembler who ran a mental simulation could mentally project what the final picture might look like based on the application of a mental simulation. Of course, in the jigsaw example, the assembler has one advantage over a fire ground commander–he or she can look at the picture on the box and know the certain outcome of his or her decisions, in advance.

Intuition also plays an important role in fire ground decision-making. Klein (2002) described intuition as: "the way we translate our experiences into judgments and decisions. It's our ability to make decisions using patterns to recognize what's going on in a situation and to recognize the typical action script with which to react. Once experienced intuitive decision makers see the pattern, any decision they have to make will usually be obvious." (p. 13)

Sadler-Smith and Shefy (2004) noted that intuitive decision-making processes involve feelings that the decision maker cannot easily articulate. This observation was supported by Klein (1998) as he interviewed fire ground commanders and observed their struggles with describing how they knew their decisions were correct. One commander proclaimed he could not remember ever making a decision on the fire ground. When asked how he knew what to do, he could not explain it.

3. The role of Situational Awareness in decision-making

The ability to form and maintain good SA is regarded as critical in NDM environments (Klein, 1993; Lipshitz, 1993; National Research Council Staff, 1998). The value of SA has also been identified in firefighter safety. Jones (2007) asserted, "If there ever was a concept that captures part of what we need to understand in firefighter safety, it is situational awareness" (p. 6). In March 2004, a Firefighter Life Safety Summit was convened in Tampa, Florida to discuss the need for changing fire service safety practices. The fire service leaders assembled for the summit developed 16 life safety initiatives. In a review of those initiatives, Jones (2007) noted that SA played a "part of at least the first five initiatives and could also be a part of No. 8 as well" (p. 6).

Jones (2007) concluded that the presence or lack of SA by commanders, sector officers, safety officers, team leaders and firefighters can have "significant safety implications" (p. 6).

In high stress fire ground settings, human error, such as the "failure to recognize incident-specific cues" (Murgallis, 2001, p. 11), can significantly impact situational awareness (SA) and decision-making. SA has been frequently cited as a critical component to effective decision-making under stress (Aksen, 1994; Buckman III, 2001; Calderwood et al., 1990; Danielsson and Ohlsson, 1997; Gasaway, 2007; Graham, 2006; Jarboe, 2006; Klein et al., 1986, 1988; Lubnau II, 2006; Okray, 1998; Rielage, 2001; Routley, 2005; Rubin, 2001c; Salka, 2004; Varone, 2000a, 2000b, 2001).

Commanders use size-ups to form SA, monitor fire ground progress and to anticipate/prevent situations that could lead to firefighter injuries and death (Brunacini, 1985; Rubin, 2001b). Achieving and maintaining the proper level of SA, however, is not easy. As Lubnau II (2006) noted:

In fire ground operations, maintaining situational awareness is at best a challenge. Multiple hazards, intense time pressures, the 'fog of war,' life-or-death decisions, and the need to use multiple resources to effectively accomplish a difficult and varied task provide barriers to knowing what is exactly going on at any one time. (p. 139)

Okray (1998) described SA on the fire ground as the "ability to maintain awareness of surroundings, the current location, events, the environment, crew members, assessments of psychosocial conditions, affecting the operation, and more" (p. 12). While Okray discussed SA on the fire ground, Brunacini (1985) argued that effective SA actually begins in advance of the commander's arrival, noting

The initial evaluation begins at the time the alarm is received. Dispatch can provide useful information, including the type of call, occupancy, general areas, and the units responding. While en route, the FGC can observe weather conditions, note the time of day and receive additional information such as reports of persons trapped. The IC considers all this information, beginning the situation evaluation before arriving at the scene. As the FGC approaches the scene, he can add any visual signs to his database along with an initial impression of fire conditions. (p. 39)

4. Current integration of data sources in High Risk decision-making

The most commonly used way to supply an incident commander en route to an incident with information is a tablet or a laptop computer. The big majority of these tablets or laptops are more or less digital information portals, no matter how the information is displayed, it's a portal to information, information about the current incident and the resources deployed, and information about the location where the incident takes place. One could argue that the systems act as a digital 'informant' (the person who you meet on scene and can supply you with information) the incident commander is free in his choice to use the information, but needs to actively engage with the system to get to any depth. The so to say offline method to support the whole process of dealing with incidents incident commanders have several mental checklists for various types of incidents, e.g. for a reported Fire; Building, Smoke, Flow path, Temperature and Flames, we collect our cues and clues in this order, with Hazmat, distance to incident, weather conditions, obtain substance identification etc. For every type of incident there is a different checklist, if you look at information systems, the layout they use most often is roughly the same, they do not adhere to the checklists that an incident commander uses. It must be noted that (small) steps are being made here. More and more the tablet is also used to provide current information about the ongoing dispatch, which type of vehicles are on scene or alarmed, and what is the escalation level of the incident. Provisioning this clear, unambiguous and relevant information is an example of using the technology to convey relevant information to enhance the SA of the commander on scene.

As seen in the paragraph about the RPD, based on what we perceive at a fire scene, we scan our memory to match similar experiences. This match will then help to predict the potential outcome of our actions and allows us to assess if the proposed action is a good thing to do. The key to success of this method is SA, we really need to understand what all the cues and clues are to construct the correct mental image for matching. If we miss information in the process, then the outcome is probably not what we expect.

Since most tablets and laptops are only information portals they won't help if you don't know that you are missing something, you'll not be looking for it, you think your mental image is complete and correct. The surprise is due to the unknown, unknowns.

There is new and ongoing work by parties that use ML algorithms and AI to chew on the information and try to present an important subset or digest from all the information available. However, they still do not tap into the standard processes of how decisions are made, nor do they acknowledge that this decision-making and situational awareness development is highly personal. Every incident commander has a unique set of experiences and training which will give him choices from his long term memory during the high risk, high consequence decision-making. The available solutions are one size fits all approaches.

So far this paragraph has focussed on on-scene command and control. Also, off-scene command and control of an incident has similar challenges. And while the organization is sometimes anticipating the enormous amount of information by adding an information manager to the respective team, similar problems remain. Extracting the relevant information for the incident at hand in itself from all the available information is complicated and can result in an information bias; over-valuing the information that is available and undervaluing the information that is missing. Also, here an understanding of the incident at hand and RPD are crucial to a successful SA.

5. Data Quality issues and challenges

Apart from the previously described issues with the delivery method, the data that is delivered has its own issues.

Data that is typically used by the fire service, e.g., building data, is not collected and maintained with a fire department use case in mind. There are numerous process in communities which gather data that could have value for the fire service, but are not collected specifically for the fire service. This could mean that some properties of this data seem highly relevant for the fire department, but have a low relevance for the organization who maintains is. A good example is in the Dutch 'Building and Address Registry, BAG' it contains a field 'purpose of use', it has a limited set of options like 'store', 'industry', 'living','office' and others, the value in this field however is more related to the original planned purpose of use than the actual purpose of use at any given time. It is in general not maintained with high accuracy, since it is not the intention of the data set.

And this is only one part of the highly acclaimed Dutch data infrastructure. Looking at the overall data infrastructure, there are more shortcomings that make processing and using this information on the fly on emergency scenes not as straightforward as it might look. [DISGEO1]

Various attempts have been made to use these data sources to create risks profiles [linked data risk profiles] by combining the public datasets with fire department internal data.

Then use advanced technologies to help with actual predictions, and while at first this sounds like a good idea, there are some serious caveats in this approach.

All the advanced technologies you hear about, Machine Learning, Deep Learning, Predictive Analytics and AI are more or less very complex statistical routines, although their promise is much bigger, the current state of play is brute force statistics. To get proper statistics you need a lot of training data, and for the complex statistics you need even more training data. It's like learning to walk, you'll need a lot of crawling and falling before you make your first uncertain steps.

The use of fire department data as training data for algorithms has 2 significant issues, the quality of historical data is problematic at best [NFIRS], and the data describes incidents, events with a low occurrence, so not providing a significant body.

Algorithms

Even when enough data is collected, most of the technologies which talk about learning are rolled forward statistics, which work very well on assessing what a potential future mean will be. “How quick will the population of my city grow”, a statistical mean. The outliers “how many battery operated heat pumps will catch fire in my city in 5 years”, is much harder, if not impossible.

This is for multiple reasons

- The amount of variables needed to make this claim are almost endless.
- Even though it looks like a precise question, the exact answer is an outlier since it will be statistical insignificant (a black swan)
- Outlier detection (fat tails) is not what statistics are good at, they are good at generalizing data sets.

The big issue here is that the very existence of the fire service is to basically battle these outliers.

A similar problem can be found in the ‘Finding Errors in Perception Data With Learned Observation Assertions’ article, where it is shown that the huge amount of data that is used to help AI make decisions about traffic in autonomous vehicles is still dramatically flawed.

6. Data Quality in Emergency response

The fire service is an industry flooded by implicit terminology, there is a lack of a taxonomy for the fire service and from jurisdiction to jurisdiction terms change dramatically in meaning and expectation. Even within fire departments, you'll see that certain areas of the city might have their own folksonomy.

If due to the lack of a formal terminology full misunderstanding around concepts can be created by verbal communications, how will intelligent systems help us? Without a taxonomy, these systems are like a person listening to a foreign and unknown language and hope they'll get the tiniest glimpse of it. If this problem is translated to complex datasets like NFIRS, where there is a huge misunderstanding about what its contents indicate, it is hard to claim that datasets like this will assist in creating better SA.

Since the fire service is responding to the outliers, the conditions of the properties they are faced with during the incident is very different from the static data that is recorded. No organization maintains information about buildings on fire, even an administration would be at the top of its game, with high quality drawings, relentless inspections in the field and a willing population to support that financially, as soon as an incident occurs the information is outdated or irrelevant. In other words, the context of the information is wrong.

Information versus Knowledge, systems around today are about sharing information, house at address X has 4 stories, it is not so much about knowledge. Knowledge is better transferred in the form of a narrative, anecdotes stick because of the surrounding narrative.

When dealing with information from various sources, the following characteristics and questions are relevant:

- Quality, What are the quality measures?
- Volatility, how often is it updated? (and how quick does the underlying reality change)
- Trust, can we trust the party supplying the data?

This is a problem that is not unique to the fire service, even research has this issue and tries to address this with FAIR data principles.

Under the pressure of time it is impossible to investigate these characteristics, yet no systems available for first responders provides clues about these properties for the data they use, sometimes even more problematic, they do not show that the data comes from different sources. This leaves an incident commander in the dark and assuming it is all good, because there was no indication it wasn't.

This is in high contrast to the situation where an informant is on scene, questions can be asked to clarify the information provided, or rephrase the questions is needed. An emotional component of the information provided can generate important cues and clues, which are very hard to obtain from a pure digital system.

Due to the lack of these emotional layers digital systems are very good at telling us lies, the 'fake news' around resent elections through social media is a prime example, ‘It was on my screen, so it must be true’.

It is very hard to question truthfulness, context and usability in the time pressured environment.

If we take into account that developing proper SA is a very personal task, systems which are not personalized by definition cannot truly assist in developing proper SA.

Proper SA can only be supported by showing information tailored to you as an incident commander with a certain background, skill set, qualification, and experience, in the context of the incident you are currently operating.

7. Conclusion

RDP + SA do not work together well with the data quality issues and current integration.

Short version:

- RPD, looks at mental options first,
    - If agents are not personalized, they will not be triggered in the right way
- SA requires processing the environment, including information at tablet/laptop where information overflow might hinder this process, or create confusion

- o besides relevant information about the actual state of the response organization, the tablet complicates the processing of the environment by providing too much and sometimes irrelevant information
- Information quality is problematic at best, so feeding bad quality of information into an incident commander can be disastrous.
  - o On scene the quality of the information often cannot be judged too positive, and relevant information that is not present has the risk of being undervalued

8. Future Research direction

To address the combined issues, there is work to be done:

• How can we transform all the information to be relevant to the context and supply knowledge needed to improve the development of SA

• How can smart systems be integrated in the neurological decision-making model of high-risk, high-consequence environments.

• How can smart systems help with information overload, by providing the right information at the right moment

• How can smart systems understand the true context of an incident commander in relation to his skill set, training and experiences.

• What tooling can be used to measure the performance of smart systems, would immersive VR work for that?

• How can outlier detection help in signaling the unknown unknowns in contrast to predicting where an incident is heading.

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