Conditions for Normative Decision Making at the Fire Ground

PREPRINT * Short Communication

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Submitted: 15.12.2015

Abstract. We discuss the changes in an attitude to decision making at the fire ground. The changes are driven by the recent technological shift. The emerging new approaches in sensing and data processing (under common umbrella of Cyber-Physical Systems) allow for leveling off the gap, between humans and machines, in perception of the fire ground. Furthermore, results from descriptive decision theory question the rationality of human choices. This creates the need for searching and testing new approaches for decision making during emergency. We propose the framework that addresses this need. The primary feature of the framework are possibilities for incorporation of normative and prescriptive approaches to decision making. The framework also allows for comparison of the performance of decisions, between human and machine.

Keywords Fire Service · Decision Support · Decision Theory · Sensory Data

1 Introduction

In this Section we outline the main obstacles for machines to replace the incident commander.

The fire ground management attracts many researchers from different domains. This very complex decision making environment is often considered as the iron wall for many approaches from decision theory and artificial intelligence. The vaguely defined goals, high uncertainty, dynamically changed conditions, time and mental pressure as well as team and resources constrains,

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1 The nickname of Tigran Petrosian recognized as the hardest chess player to beat ever.
cause that most of the approaches to this field, fail to be successful. A well-trained human is still unrivaled decision-maker in this environment.

The reasons underlaying the superiority of humans are: (1) Exceptional perception – humans with their senses, and the ability of dynamically changing focus, information fusion, can still extract and infer more information than any set of sensors. (2) Incredible pattern recognition abilities – humans have the ability to find patterns and cues in a very noisy environment. (3) Dominant general knowledge about the world, allowing for deduction and implementation of solutions from other domains. (4) Bundle of heuristics for dealing with the complexity and ambiguity. Many machine’s algorithms, even accurate, fail to be used due to the huge computational requirements. The human is capable to dynamically structure and divide the problem and solve it efficiently. (5) Legal and ethical constrains. Humans may use solutions to some problems (i.e. triage) which are resolved by ethics and philosophy.

All these issues restrict the ability for support (or replacement) the incident commander by the machine. While rational choices can be made based on normative and prescriptive approaches, the application of these methods is limited by the complexity of the environment and human processing capabilities. This led to the excessive exploit of the naturalistic decision making at the fire ground.

However, the recent pervasive application of sensors, global integration of systems as well as new approaches for data processing extended the perception and processing abilities of the machines. Moreover, psychological works in the descriptive decision theory field, revealed many pitfalls in human decision making. All these results create possibilities and needs for searching other than naturalistic decision making solutions, eligible also to be executed on machines.

In this article we propose the framework for searching for new solutions for decision making at the fire ground. The framework incorporates last achievements in sensing as well as artificial intelligence. The data-flow within this framework allows for introduction and investigation of normative and prescriptive decision theory approaches. The framework defines a new promising direction of research, not feasible previously.

2 Ill-informed Machines

In this Section we argue that currently the machines are capable of enough perception to trigger further changes in decision making.

The machines’ low perception combined with inability to dynamically change focusing on the crucial things, is perceived as the most challenging issue in

\[ \text{2 compare i.e. FDS simulations} \]
\[ \text{3 see i.e. big data or deep learning} \]
\[ \text{4 The exhaustive list of cognitive biases can be found at: } \text{https://en.wikipedia.org/wiki/List_of_cognitive_biases} \]
overcoming the dominance of the humans at the fire ground. These limitations established the opinion that the most promising direction to improve performance of the management, is increasing the situational awareness of the incident commander [10,3,8]. There are several works which investigate this aspect [24,6,11,20]. There are also few projects which tried to implement these approaches [11,9,9].

ICRA [5] is one of such projects where the focus is set to increase the situational awareness of the incident commander. The general method to achieve the goal was building the excessive data/sensory layer combined with algorithms that convert the low-level data (i.e. temperature distribution in the room) into high-level concepts, easy to comprehend by humans (i.e. respiratory risk).

The ICRA data layer allows for gathering information related to the following issues: (1) Full information about the building, organized into Building Information Modelling [6] (BIM). (2) The physical parameters of the environment inside the building extracted from the building infrastructure in a form of: CO concentration, temperature, optical density of air (measured in UV, IR). (3) Parameters of the environment measured by deployed mobile robots in a form of: CO, CO₂, O₂, C₂H₄ concentration, temperature and visioning by IR and VIS cameras. (4) Indoor localization of the civilians by usage of their mobile phone tracking system [18]. (5) Firefighters indoor localization based on dead-reckoning system [24]. (6) Firefighters activity reporting system based on the body sensors network [23]. (7) Psychophysical conditions of the firefighters measured by wearable sensors in a form of: ECG, breathing rate, skin temperature and conductance [7]. (8) Parameters of the equipments used by firefighters, including their deployment time and disturbance factors (i.e. drop of pressure in fire hoses depending on how they were deployed). (9) Database of Incident Data Reporting System which allows among other for calculation of probability distribution for various events. (10) Domain ontologies and what-if database. The ontology structures the general knowledge about the domain and allows for simple deductive inference about the facts. What-if is a collection of experienced commander reflections about the outcomes of the given decision against the states of nature.

The full availability of this data needs some pre-processing and depends on proper robots deployment. However there is no limitation regarding the buildings instances.

Based on large collection of data, the fundamental questions arise: Is it humans that can best utilise this data and produce high-performance decisions? Shall we limit our activities to properly present this information to incident commander or should we try to suggest decisions?

5 http://www.icra-project.org/
6 https://en.wikipedia.org/wiki/Building_information_modeling
7 http://www.equivital.co.uk/about
3 Heuristics and Biases

In this Section we question that human is the best decision-maker at the fire ground.

The current training programs for incident commanders are mostly influenced by the naturalistic decision making (NDM) approach [15]. The central concept in NDM is expert intuition. The NDM researchers try to learn from expert professionals by identifying the cues and methods that experts use to make their judgments. It originates from the observation that chess grand masters have unusual ability to analyse complex positions and quickly judge a line of play [5].

The same performance was discovered in incident commanders required to make decisions under conditions of uncertainty and time pressure [17]. The recognition-primed decision (RPD) was proposed as an effective strategy for decision making at the fire ground [17]. The RPD and other NDM models offer a generally encouraging picture of expert performance in multiple domains [16].

The other approach – heuristic and biases (HB) – is in sharp contrast to NDM. HB favours a skeptical attitude toward expertise and expert judgments. The origins of this attitude can be traced to a Meehl’s monograph [22], extended later by Kahneman and Tversky [28]. They described the simplifying shortcuts of intuitive thinking and explained some 20 biases as manifestations of these heuristics.

In 2009 Kahneman and Klein – top researchers from the two opposite domains (NDM and HB) – did a joint analysis for settling an agreement in an intuitive expertise [12]. The researchers agree that intuitive judgments can arise from genuine skill. However, they can also arise from inappropriate application of the heuristic processes. An environment of high validity is a necessary condition for the development of skilled intuitions. The skilled intuitions are very hard to achieve, need tens of thousand hours with high-quality feedback. As a comparison, the top experienced commander from Warsaw city has 1256 hours of commanding in total, with mid-quality feedback as presented in [21]. Skilled intuitions are also very vulnerable to fragmented expertise i.e. development of the skills only for narrowed type of fires. Moreover, the Kahneman and Klein suggest that algorithms significantly outperform humans when validity of the environment is low, or in highly predictable environments.

It indicates that supremacy of human as a decision-maker is questionable and needs further investigations. While humans mostly outperform machines in the evaluation of the fire ground, this is only part of the commanding process. However, budgeting, i.e. proper calculation of resources, deployments methods and time, calculation of amount of needed water and many others are just as important. In these calculations machines are faster and more accurate.

* see for example FEMA courses [https://www.firstrespondertraining.gov/ntecatalog]
4 Normative Approach to Decision Making

In this Section we propose a framework that takes advantage of sensory data, models of phenomena, artificial intelligence and power of rational choices ensured by normative decision theory.

The data-gathering ability of ICRA presented in Section 2 allows for estimation of many subsequent parameters. Fire dynamics may be calculated by using the models such as [11,26,7]. Output from these models, BIM data, localization of the civilians and the evacuation models allow for estimation of the possible course of action or: states of nature in other notation. Moreover, the data from Incident Data Reporting System allows for evaluation of distributions of probabilities of these states.

The data from firefighters localization, activity reporting, and psychophysical conditions, allow for better judgement of the real human-resource availability. When combined with the parameters of the equipments it allows for calculating the sets of decision packages available to the incident commander.

Ontology and what-if analysis knowledge, enables the calculation of the outcomes for subsequent decision packages with respect to the states of nature.

The outlined concepts (states of nature, decision packages, outcomes and sparsely probabilities) are central for the normative and prescriptive decision theory. The concepts establish the Decision Matrix (DM). DM consists of: (a) rows related to the possible state of nature, (b) columns represent decision available for decision-maker, (c) outcomes – intersections of rows and columns – represent the results for combination of the decisions and the states of nature. The distributions, if available, allow for calculating the possibilities of occurrence of the states of nature.

Such a formalization allows for introduction of normative and prescriptive decision theories to the decision process. The normative approach allows for drawing a rational choice to the problem, eligible at the emergency. The general framework for supporting (or even eliminating) incident commander with normative approach is presented on Figure 1. The framework also enables the comparison of performance in decision making between the human and the machine.

The data layer represents the data resources which feed the framework. It could be at least the data outlined in the Section 2. The layer represents features or variables which are constant over time (ontologies, what-if etc.) and features that are measured by sensors.

The models layer contains models and algorithms for calculation of both physical and abstract variables. This layer employs the models for fire modelling, evacuation models, finite elements methods, classifiers for localization of the firefighters or any appropriate models from engineering, physics and thermodynamics. The elements of the models layer need an input, mostly derived from the data layer.

The conceptual layer consists mostly in models derived from artificial intelligence (classification, clustering, granular computing, adaptive judgements). The goal of the layer is to find the characteristic patterns in the output from
both models and data layer. The patterns are used for approximation of the concepts related to the states of nature, the possible decisions and the outcomes.

The Decision Matrix is a central point of the framework. It separates the process of information gathering from the decision making one. It can be used for applying the normative decision making as well as for presenting the gathered information to the incident commander.

The decisions layer is a set of methods, rules and criteria from normative and prescriptive domains, which allows for making the decision according the rational choice rule.

5 Conclusion

The emerged paradigms of Cyber-Physical Systems enable for gathering and processing large amount of data to the extent not seen before. This significantly increases the perception of the machines. The approaches face the obstacles that keep the status-quo (naturalistic decision making) of the decision making during emergency. On the other side, the results from the descriptive decision theory contradict the appraisal that human mostly makes rational choices. This enforced for searching new solutions based on the computer systems and rational choices. A normative decision theory is strongly rooted in the rational choice paradigm. It advises how people should really make decisions.
The paper proposes a framework for searching new solutions in the normative and proscriptive domains. It allows also for the comparison of human (naturalistic) decision making and the computer-aided one (normative). The foundation for this framework derives from the ICRA project. In the project the decision matrix was used to present the information to the incident commander [19]. This initially proves the foundation of the proposed idea and opens the possibilities for searching a better solution for decision making. The outcomes from these researches may even allow for the elimination of the human from decision making process.

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