Understanding Crises: Investigating Organizational Safety Culture by Combining Organizational Ethnography and Agent Modeling

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ABSTRACT

This paper presents a novel, advanced research approach to investigate organizational safety culture as a complex phenomenon, combining agent modeling and organizational ethnography. Safety culture is an emergent property of organizations that largely influences the resilience of organizational responses in crisis situations. However, theory describing the precise ways in which safety culture influences resilience is lacking. Thus the first step is to understand how safety culture gradually emerges from interactions between formal and informal organizational processes. The paper explains the proposed research methodology illustrated by a case of an aircraft maintenance organization. A preliminary analysis is performed from which a conceptual model is derived, and the subsequent simulation and automated analytical techniques that will be used to validate the model and gain new insights are explained.

Keywords

Safety culture, organizational ethnography, multi-agent systems, complexity science, aircraft maintenance

INTRODUCTION

When a crisis hits, organizations are faced with a complex, rapidly unfolding and harmful chain of events. The combination of complexity and time pressure creates a paradoxical set of requirements that organizations have to manage well if they are to respond in a resilient manner and limit the negative consequences of the crisis (Bigley and Roberts, 2002). Organizational actors have to adhere to standard procedures and rigid command structures, but also improvise and make decisions based on local expertise and experience where necessary.

Researchers found that organization cultural characteristics enabled organizations to manage the paradox (Weick, Sutcliffe and Obstfeld, 1999). These characteristics, such as employee commitment to safety goals, became known as *safety culture* (Choudry, Fang and Mohamed, 2007). However, precise relations between safety culture and resilient performance of organizations are still unclear (Roelen and Klompstra, 2012). A precondition for establishing how safety culture influences resilience is therefore to understand how, from which interacting formal and informal processes, safety cultural characteristics emerge in organizational practice.

In this paper we present a novel, advanced research approach to investigate organizational safety culture as a complex phenomenon, emphasizing its gradual emergence in years of mostly normal operations. The approach takes the systemic view on safety modeling and analysis (Hollnagel, 2009), according to which crises, accidents and incidents develop from complex interaction between diverse organizational processes. The proposed approach combines organizational ethnography and agent-based modeling to gain better insights into the mechanisms behind the emergence of safety culture.

The methodology is illustrated by a case study from the aircraft maintenance domain. In this domain daily practices are usually hidden from view in crisis investigations. Only the emergent errors or failures are found when an incident or accident occurs. Thus, investigating aircraft maintenance safety culture has the dual benefit of understanding the emergence of safety cultural characteristics over longer periods of time, and of uncovering hidden, 'latent failures' (Reason, 1990) of air traffic systems.

The paper is organized as follows. First the methodological premises and the research project format are outlined. Then, the research process is described and illustrated in the context of the case study. We end with conclusions and future work.

INVESTIGATING SAFETY CULTURE THROUGH AGENT MODELING AND ETHNOGRAPHY

The challenge for a research methodology gaining a more fundamental insight in safety culture is to derive a consistent ontology and research process. There is limited consensus about what safety culture is supposed to represent and how it can be measured (Choudry et al., 2007). The research project we propose therefore combines relevant specialized knowledge of the social and exact sciences. The solution this methodology offers is to measure safety cultural indicators not directly, but as emergent properties of complex systems.

Organizational anthropology offers useful expertise because it is specialized in studying organizational culture through ethnography, a loosely structured research process in which qualitative data are gathered in natural work settings. The expertise of computer scientists is used on the other hand to contribute in mathematical sense to the quantitative modeling challenges of structures and processes of complex organizations from which safety culture emerges. A previous example of this is Stroeve, Sharpanskykh and Kirwan (2011) who developed a formal modeling approach to analyze the safety culture of Air Traffic Management service providers.

The research ontology makes informed choices about the nature of organizational culture, complex systems, and safety. The ontological premise is that safety culture is socially constructed (Berger and Luckmann, 1966). Values emerge in repetitive processes of daily interactions between members of a culture, the norms that they jointly create, and the material changes they make to their life worlds. Values like safety evolve in ways that are hard to predict through complex interactions along context-specific paths.

From a modeling point of view, the organizational multi-agent systems paradigm (Dignum, 2009) suits the ontological premise of social construction of safety culture. Agents are autonomous entities able to interact with each other and the environment, and to make decisions independently. Both humans and technical systems can be represented by agents. In our study a formal multi-agent model of an aircraft maintenance organization is being developed. In this model safety cultural phenomena emerge from a large number of local dynamic properties and distributed interactions of agents representing organizational actors.

Below we describe a research process that unites ethnography and modeling, and illustrate it by a study on safety culture from the aircraft maintenance domain. The process comprises three main phases: first, the research team gathers easily available knowledge to build a conceptual model. Second, the conceptual model is constructed and more detailed data are gathered to arrive at a detailed simulation model. Subsequent simulations allow for an in-depth analysis of emergent safety cultural phenomena.

Research Orientation

The research process starts by identifying a domain, its boundaries, and formulating a research question. In our project, a broad literature review on safety culture revealed relatively little is known about manifestations of safety culture in aircraft maintenance organizations, while maintenance is critical to flight safety.

To identify specific research questions we analyzed various safety culture literature and secondary data on the operation of aircraft maintenance organizations. The commitment to safety of maintenance technicians and teams emerged as an essential aspect of safety culture. Thus, the main research question of our study is *how does the commitment to safety of maintenance technicians emerge and develop under social and organizational influences?* We assume that the commitment to safety of a technician can be estimated by the amount of risk the technician is willing to take when performing maintenance operations. Furthermore, the social (or shared) commitment to safety of maintenance teams is considered to be a complex property emerging from the behavior of and interaction between the team members.

As a relevant and recent source of data for our study we used the case study on aircraft maintenance safety culture by Atak and Kingma (2010). The first author of this paper performed auto-ethnography for the duration of four years, allowing a unique insider's view of safety culture.

After the domain and the research question have been identified, the next methodological step is to determine relevant actors, factors and processes that underpin the basic outline of a conceptual model. Three types of actors were identified in our study: Aircraft Maintenance Technician (AMT), Maintenance Management (MM) and Safety Department (SD). The behavior of ATMs is the main focus of modeling in our study. MM and SD exert pressures on that behavior, which are driven by conflicting goals and different interests, values and norms.

Through informal interviews we determined specific factors and processes at individual, social and organizational levels. The AMT's decision making about maintenance procedures is the central process at the individual level. Individual factors that influence decision making comprise the AMT's knowledge of procedures and of the safety consequences of different actions regarding the procedures, individual characteristics (e.g., risk aversion), goals and values. Social factors include informal power relations in maintenance teams and different forms of social interaction by which knowledge in teams is spread. Organizational factors comprise the availability of resources (e.g., procedures and tools), safety-related trainings, and the distribution of formal and informal power in the organization (particularly the priority given to production versus safety goals). Based on this preliminary analysis, a conceptual model was designed.

Conceptual and Detailed Agent-Based Modeling

Conceptual modeling is done by establishing and refining relations between the factors and processes identified in the orientation phase. A conceptual model is specified using the multi-agent systems paradigm. A specification of a multi-agent system comprises a description of internal and behavioral properties of individual agents and of properties of interaction between the agents. Furthermore, the institutional context and the environment of the multi-agent system need to be specified.

To obtain a detailed formal model of a multi-agent system in the context of a specific case study, the factors, processes and relations of the initial conceptual model need to be refined and initialized using more specific data. Such data may be gathered using ethnographical techniques like semi-structured interviews, observations, and document analysis.

We continue to illustrate this research process with the conceptual model from our study. It describes the emergence of commitment to safety of technicians, reflected in their execution of maintenance procedures.

The agent types were specified in accordance with the actor types identified in the orientation phase. Only AMT agents have an elaborated internal structure, describing the decision making about the execution of procedures. In maintenance practice there is usually just one specific procedure for a task. However, the AMT may decide to use different tools or skip some actions of the procedure. All those modified procedures represent different decision options.

A decision option is characterized by three prominent aspects (c.f. Rasmussen, 1997): *risk*, *efficiency*, and *effort*. Risk represents a combination of the probability and severity of an undesirable event resulting from the execution of an option (e.g., malfunctioning of some system of an aircraft). Pettersen (2008) discovered in his field study at an aircraft maintenance organization that technicians developed their own categories of errors related to maintenance operations and made qualified judgments about the corresponding risks. Using these findings and by performing interviews with maintenance personnel, we shall identify classes of risk (e.g., low, average, high) for particular decision options. Efficiency covers the cost of an option in terms of both money and time. In our ethnographical study efficiency will be evaluated by estimating the execution time of the decision options. Finally, effort represents the amount of personal effort that has to be invested in the execution of an option. The subjective perception of the amount of effort (e.g., high, average, low) required for the decision options will be determined by interviews with technicians. For a more intuitive understanding, the aspects of an option are associated with the axes in three-dimensional space, so that the decision making can be visualized as a choice of a point in this space (Figure 1).

Every AMT agent has its own beliefs about the coordinates of every option based on its training, personal experience, and individual characteristics. Furthermore, every AMT agent assigns a weight to every aspect of an option, based on the agent's needs, goals, and values. Both the coordinates and weights of the aspects of the options for specific maintenance operations (such as daily check) will be determined by semi-structured interviews with maintenance technicians in our future research.

To compare the options, an AMT agent has to assign a single value to every option, called *fitness*. The fitness of an option is calculated as a weighted average of the option's aspect values. After all options have been evaluated, the one with the highest fitness is the preferred option of the agent (Figure 1, left).

Our preliminary analysis of empirical data showed that in reality maintenance technicians do not always choose the options they most prefer. This is largely because their decisions are influenced by diverse, often conflicting demands existing in real organizations. For example, consider a conflict situation, in which management demands more efficiency, safety department demands less risk and the influence of other technicians steers the decision to less effort.

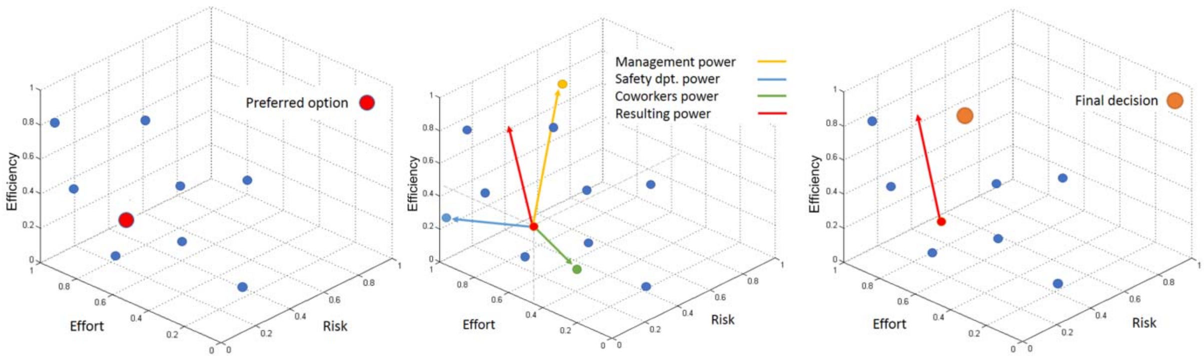

Figure 1. The decision making steps: the initial option choice (left); a displacement of the initially preferred option upon the influence of management, safety department, and own team (center); the final option choice (right)

These influences are modeled as power forces from MM, SD and other AMT agents, which steer the agent's preferred option in the directions of the desired options of these influencing agents (Figure 1, center). The power forces were refined using the bases of power model from Raven (1992). To estimate the direction and magnitude of these forces in different phases of development of the maintenance organization from our study, we used data from Atak and Kingma (2010) and conducted an interview with the first author. For example, in the survival phase, both management and the maintenance team had strong conflicting influences on the technicians, whereas the influence of the safety department was less prominent.

The effect of the power forces on the preferred option is estimated by a weighted superposition. The higher the distance between the AMT agent's and the influencing agent's preferred options, the lower the weight of the power force of the influencing agent in the superposition. The option with the smallest Euclidian distance to the point resulting from the application of the power forces is the final decision of the agent (Figure 1, right).

After every execution of an option, its values of all aspects are reevaluated based on feedback received from the environment. Note that the feedback for risk values may be given after a long period of time. This is because a quality of a maintenance action may be proven only after a certain flying period of the aircraft. The feedback is specified by a probabilistic model of the environment using the statistics on safety occurrences accumulated by maintenance organizations. The other two aspects of an option can be evaluated immediately after the execution.

Automated Analysis of Emergent Safety Cultural Phenomena

A detailed formal model of a multi-agent system can be simulated using dedicated automated tools (e.g., Matlab, Leadsto (Bosse, Jonker, van der Mei and Treur, 2007), Jade framework). Social construction of safety cultural phenomena (global properties of the model) develops gradually in the course of simulation based on the local properties of the model. The global safety cultural properties can be established by analyzing simulation traces (i.e., temporally ordered sequences of events). For such an analysis automated tools can be used, such as TTL Checker (Bosse et al., 2007) and Matlab. For specifying properties to be checked by TTL Checker a hybrid order-sorted predicate language called TTL (Bosse et al., 2007) is used, which allows expressing dynamic (temporal) relations over states of the model using arithmetic operations and logical expressions. For example, in the context of our study a property can be formulated that in every simulation trace γ the amount of risk taken by every technician agent a (i.e., the commitment to safety) decreases over time:

$$\forall\gamma{:}\mathrm{TRACE}\ \forall a{:}\mathrm{TECH\_AGENT}\ \forall t, t'{:}\mathrm{TIME}\ \forall v, v'{:}\mathrm{VALUE}\ \mathrm{state}(\gamma, t) \models \mathrm{risk}(a, v)\ \&\ \mathrm{state}(\gamma, t') \models \mathrm{risk}(a, v')\ \&\ t' > t \ \Rightarrow\ v' < v$$

Here the notation $\mathrm{state}(\gamma, t) \models p$ means that state property p holds at time point t in simulation trace γ. For more details please refer to Bosse et al. (2007).

Another set of emergent properties that is planned to be checked on simulation traces of our model describes characteristic manifestations of the safety cultural perspectives from Atak and Kingma (2010). These perspectives correspond to different organizational development phases: *fragmentation* highlights ambiguity and conflicting meanings; *integration* emphasizes shared understandings; *differentiation* focuses on the lack of consensus between sub-cultures. Individual and shared meanings (beliefs of agents) are considered in our study in relation to the maintenance operations in the social boundaries of maintenance teams.

Besides verifying emerging safety cultural properties from Atak and Kingma (2010), the developed model could be validated by interviews with experts. In such interviews an expert is provided specific safety scenario's and cultural properties identified in these scenario's by simulation. The degree of validity of the model is established based on the expert judgment about the realism of the obtained safety cultural properties.

CONCLUSION

In the paper a novel research methodology is described, by which safety culture of complex, dynamic organizations (e.g., incident management organizations) can be investigated. The methodology combines agent-based modeling and organizational ethnography, and is based on a social constructivist premise. The methodology allows identifying emergent values by automated modeling and analysis of local processes and interactions, in which the participants of the culture are involved. The results of this analysis will allow for theory development and advice to organizations and safety regulators struggling with the questions related to making societies more resilient. This could lead to more subtle and effective controls for managerial culture interventions. The results could also serve as impetus for societal debate on what we *cannot* expect from organizations with regard to limiting negative consequences of crises.

The methodology was illustrated by a case from the aircraft maintenance domain. A preliminary analysis was performed, by which several important factors and processes related to attitudes to and responsibilities for safety at different aggregation levels were identified. These factors and processes were further related and refined in a multi-agent model. In the future research the developed model will be completely instantiated using the data from Atak and Kingma (2010) and additional semi-structured interviews with maintenance technicians. After that the emergent safety cultural properties discussed in the paper will be analyzed by simulation.

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REFERENCES

1. Atak, A. and Kingma, S. (2010) Safety culture in an aircraft maintenance organisation: A view from the inside, *Safety Science*, 49, 268-278.
2. Berger, P.L. and Luckmann, T. (1966) *The social construction of reality*, Anchor Books, Garden City, NY.
3. Bigley, G. A. and Roberts, K.H. (2001) The Incident Command System: High-reliability Organizing for Complex and Volatile Task Environments, *The Academy of Management Journal* 44, 6, 1281-1299.
4. Bosse, T., Jonker, C.M., Meij, L. van der, and Treur, J. (2007) A Language and Environment for Analysis of Dynamics by Simulation. International Journal of Artificial Intelligence Tools, 16, 435-464.
5. Choudhry, R. M., Fang, D., & Mohamed, S. (2007) The nature of safety culture: A survey of the state-of-the-art. *Safety Science*, 45, 10, 993-1012.
6. Dignum, V. (ed.) (2009) *Handbook of Research on Multi-Agent Systems: Semantics and Dynamics of Organizational Models*. IGI Global.
7. Hollnagel, E. (2009) *The ETTO principle. Efficiency-Thoroughness Trade-Off. Why things that go right sometimes go wrong*, Ashgate Publishing Limited, Farnham, UK.
8. Pettersen, K. (2008) *The social production of safety – Theorising the human role in Aircraft Line Maintenance*, PhD Thesis.
9. Reason, J. T. (1990) *Human Error,* Cambridge University Press, Cambridge.
10. Rasmussen, J. (1997) Risk management in a dynamic society: a modelling problem, *Safety science,* 27, 2,183-213.
11. Raven, B.H. (1992) The Bases of Power: Origins and Recent Developments, *Journal of Social Issues*, 12, 49, 4:227 - 251.
12. Roelen, A.L.C. & Klompstra, M.B. (2012) The challenge in defining aviation safety performance indicators, *Proceedings of PSAM & ESREL.*
13. Stroeve, S., Sharpanskykh, A., Kirwan, B. (2011). Agent-based organizational modelling for analysis of safety culture at an air navigation service provider, *Reliability Engineering & System Safety*, 96, 515-533.
14. Weick, K. E. , Sutcliffe, K.M., and Obstfeld, D. (1999) Organizing for High Reliability: Processes of Collective Mindfulness, in Sutton, R.S. and Staw, B.M. (eds), *Research in Organizational Behavior*, Volume 1 (pp. 81–123), Jai Press, Stanford.