A Theoretical Framework for Shared Situational Awareness in Sociotechnical Systems

Shalini Kurapati[1], Gwendolyn Kolfschoten[1], Alexander Verbraeck[1] Hendrik Drachsler[2], Marcus Specht[2], and Frances Brazier[1]

[1] Delft University of Technology, Delft 2600 GA , The Netherlands
[2] Open Universiteit, Heerlen 6419 AT, The Netherlands

Abstract. Sociotechnical systems are large technical systems comprising many stakeholders (e.g.: Supply chains, Transportation networks, Energy distribution systems etc.). Decision making in such systems is complex, as the stakeholders are inter-dependent and the large size of the systems leads to insufficient Shared Situational Awareness (SSA), which is important for participatory decision making. The aim of this paper is to develop a framework to understand the goals and requirements for designing processes to create SSA in such systems. The framework is based on the Capability Maturity Model (CMM) and systems thinking perspective. The framework is initially validated by experts and will be further validated with experiments with stakeholders in several workshop settings.

Keywords: Shared Situational Awareness, Sociotechnical Systems, Decision making

1 Introduction

1.1 Sociotechnical systems and relevance of SSA

Sociotechnical systems involve both complex physical-technical systems and networks of interdependent stakeholders. These systems consist of technology that drives the system, and stakeholders that design, maintain, operationalize, and implement that system [4]. However, during a problem situation, as the number of stakeholders increases, the conflicts of interests become greater, making decision making complex and challenging. Eventually, it may become impossible for any one actor to understand the situation in its entirety [4], which can be defined as lack of a 'common operational picture' or lack of shared situational awareness. For example, according to research conducted by IBM among various supply chain network managers, more than 70% expressed concern about lack of visibility, transparency and awareness in the network due to organizational silos, lack of information sharing, coordination issues, local optimization against global view etc. [13]. The aim of this paper is to design a theoretical framework to gain insight into the objectives and requirements for SSA in sociotechnical systems. Thereby, understand the processes towards better participatory decision

making in such systems. The relevance and importance of SSA for such systems is introduced in Section 1, followed by a brief theoretical background of SSA. Subsequently, the research gap in the study of SSA is highlighted. After which, a theoretical SSA framework is presented along with the research methodology. This paper concludes with the presentation of the future work, in lieu of the nature of this paper which is Work-In-Progress.

2 Shared Situational Awareness background

Shared Situational Awareness is described as "shared awareness/understanding of a particular situation" or "common operational picture" or common relevant picture distributed rapidly about a problem situation [18]. The concept of situational awareness (SA) was developed after the World War II to improve the judgment and decision making abilities of fighter pilots. Individual situational awareness is defined 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" [10]. The success of the applications of SA led to its adoption by other areas such as energy distribution, nuclear power plant operational maintenance, process control, maritime, tele-operations etc and is a key topic in human factors literature [23]. As today's organizations are largely comprised of teams, the research focus in the human factors community is shifting from individual SA to SSA. However, there is no one-for-all definition and theory that explains SSA.

2.1 The theoretical gap: SSA in sociotechnical systems

Existing individual, team and shared SA models, whilst each containing useful elements, may prove impractical when applied to the description and assessment of SA in non-hierarchical environments [23]. The research on SSA so far has not dealt enough with the multi-stakeholder networks or organizations. Most of the current application domains of shared SA have a structural hierarchy of decision-making and their operations are conducted in a command and control environment. But there has not been much focus on shared situational awareness in multi-stakeholder networks such as global supply chain networks, intermodal transportation networks etc. These are sociotechnical systems where the stakeholders though are autonomous, are inter-dependent and have to be participative in nature. Therefore, the following sections describe the design of a framework that aims at closing the identified research gap in the study of SSA in sociotechnical systems.

3 Research Methodology

The SSA framework for sociotechnical systems is designed based on deductive theory construction using an iterative design process [2]. Firstly, a comprehensive inventory of literature was gathered to study the topic of interest- SSA in

sociotechnical systems. In the second step, the knowledge gaps in the topic were analyzed. Based on the identified gaps, a framework was derived with a novel perspective on SSA, using the systems thinking perspective. The framework was presented to 2 professors at TU Delft and 2 professors at OU, Heerlen for expert opinion. With the feedback received and further literature survey, it was improved in the second iteration. Further improvements will be based on feedback from expert sessions, as well as testing with user groups. The following chapter describes the SSA framework in detail.

4 The SSA theoretical framework for socio-technical systems

Sociotechnical systems are frequently affected by wicked problems [22]. Solving wicked problems requires the joint decision making of all the stakeholders.The joint decision making in the system requires an 'overview' of the problem, effects of each others' actions, and planning for the future. In other words, there needs to be SSA among the stakeholders. As the sociotecnical systems become large and complex, the actors lose an overview about the problem as well as the actions and decision of others to handle it jointly [5]. Therefore, it is crucial to understand the concept of SSA in sociotechnical systems where the actors are autonomous yet interrelated and wield varying degrees of power. When a problem occurs in the present sociotechnical systems, ad-hoc decisions are being made by actors without mutual consultation and shared awareness about each others plans, leading to conflicts, opportunistic behavior and under-utilization in the system. To address these issues, a framework for SSA was created, analogous to a framework in literature named as Capability Maturity Model (CMM) [12], which has 5 evolutionary process steps towards system organization and capability utilization. The aim of CMM is to control, measure and improve processes in large organizations and systems where the base situation is chaotic. Therefore, the CMM framework was chosen as an inspiration to design the process levels for SSA framework

The five CMM steps are as follows

"1. *Initial* - until the process is under statistical control, no orderly progress in process improvement is possible. 2.*Repeatable* - a stable process with a repeatable level of statistical control is achieved by initiating rigorous project management of commitments, cost, schedule, and change. 3.*Defined* - definition of the process is necessary to assure consistent implementation and to provide a basis for better understanding of the process. 4.*Managed* - following the defined process, it is possible to initiate process measurements. 5.*Optimized* - with a measured process, the foundation is in place for continuing improvement and optimization of the process "[12].

Against the 5 levels of CMMs, only 3 levels have been chosen for SSA framework as level 1 and 2 of the CMM are merged into level 1 of the SSA framework,as the initial level has no interesting properties from an SSA perspective. The level 4 and 5 are merged as the objectives of SSA framework are closer to collabo-

ration and participation rather than optimization. Therefore the three maturity levels of the SSA framework are as follows.

1 *Perception*: The ability to perceive oneś (individual, group or system) surroundings, circumstances and function in the system
2 *Prescription*: The ability to modify existing plans , if a problem affects the system, to remain as close as possible to the existing plans
3 *Participation*: The ability to participate in joint corrective actions, and adapt while a problem occurs in the system

As described in theoretical gap, SSA has not been studied in sociotechnical systems. The existing theories and models of SSA have not yet dealt with localized problems in the system that have a wide impact across the entire system. Therefore, a system thinking viewpoint has been adopted to define the SSA framework in addition to the individual and group levels, which have already been introduced in literature. The core aspects of systems thinking is gaining a bigger picture and making decisions while taking the perspectives of other stakeholders in the system into consideration [7]. Systems thinking approach is very useful to understand SSA in sociotechnical systems, as it offers approaches to understand the interrelationships, different objectives, and power relations among the stakeholders in a system [20].

The framework is intended to describe the purpose of SSA in sociotechnical systems. SSA is goal oriented and the requirements for reaching the gals at individual and group levels have been discussed in a command and control environment [11]. Following a similar pattern, this paper introduces goals, and the requirements for sociotechnical systems that have multiple stakeholders at individual, group and system levels along the three SSA maturity levels. The framework also focuses on learning, whether associated with individuals, groups or organizations, comprise of a set of processes that improve performance [17]. As our main objective is to study SSA in sociotechnical systems towards improving participatory decision making, learning and reflection are essential constituents of the processes towards such an improvement. The following chapters describe them in detail.

4.1 Objectives

The objectives for the various system decomposition levels of the framework at the all three SSA maturity levels are defined with support from literature in Figure 1.

4.2 Requirements

Requirements are the necessary conditions to achieve objectives stated in the above subsection. Each of the requirements for individual, team/group and system level for the three maturity levels of SSA are described in Figure 2.

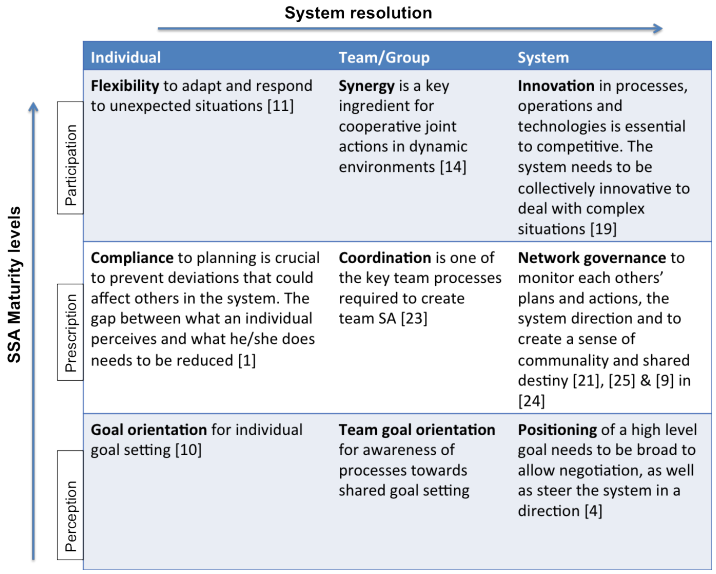

Fig. 1. Objectives of SSA for sociotechnical systems

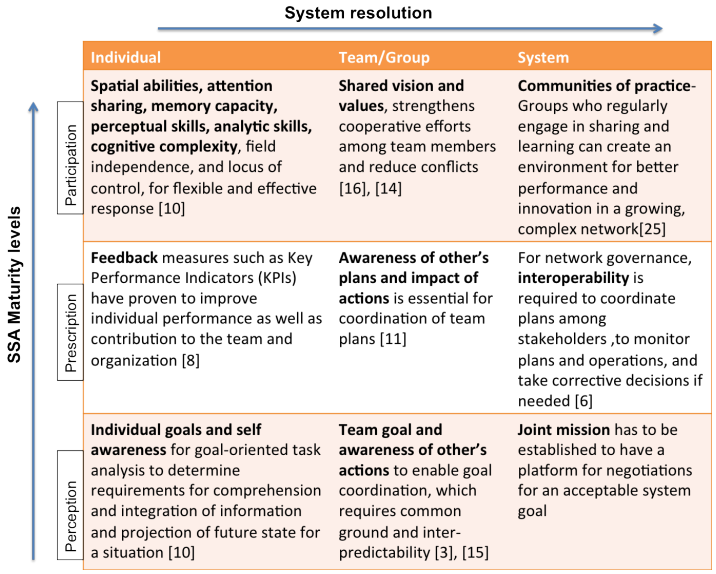

Fig. 2. Requirements for SSA in sociotechnical systems

5 Conclusion and future work

SSA has rarely been studied in multi-stakeholder systems. A framework has been designed to define the processes, requirements and examples of methodologies to

be employed to understand SSA in these networks, towards reducing the theoretical gaps found in SSA literature. The model has been primarily validated by expert opinion, and the ARTEL workshop will be a platform for further feedback. As for the future work, experiments will be designed with the stakeholders of multi-stakeholder networks based on the SSA framework, to gain an insight about the impact of SSA in theory and practice. The experiments are scheduled to be serious games, which will be validated for design, content and rigor with both scientific and professional experts in game design. The effectiveness of the experiments will be discussed in extensive workshop sessions after the game play with the participants in the form of group interviews and feedback sessions. With the gathered results from the experiments, the framework will be improvised in several iterations and is intended to be a basis of a measurement tool for assessment of SSA in sociotechnical systems, as well to aid in the design of serious games for SSA training in these systems. The final objective of the research is to deduce SSA theory in sociotechnical systems describing the cognitive processes of stakeholders, factors influencing SSA, to create an insight into how SSA comes to be in sociotechnical systems.

6 Acknowledgement

The research presented in the paper is conducted under the SALOMO project (Situational Awareness for LOgistic Multimodal Operations) in container supply chains and networks sponsored by the Dutch Institute of Advanced Logistics (DINALOG). We also acknowledge the input from Christian Glahn (International Relations and Security Network, ETH, Zurich, formerly associated with OU, Heerlen) for the SSA framework.

References

1. Alfredson, J.: Differences in Situational Awareness and How to Manage them in Development of Complex Systems. Ph.D. thesis, Linköping University (2007)
2. Babbie, E.: The Basics of Social Research. Thomson Higher Education, Belmont, 4 edn. (2008)
3. Bolstad, C.A., Endsley, M.R.: Shared displays and team performance. pp. 1–6. No. 2, Human Performance, Situation Awareness and Automation Conference, Savannah, GA (2000)
4. de Bruijn, H., ten Heuvelhof, E.: Management in networks: On multi-actor decision making. Routledge, Oxford, 1 edn. (2008)
5. de Bruijn, Hans, H., Herder, P.M.: System and Actor Perspectives on Sociotechnical Systems. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans 39(5), 981–992 (2009)
6. CEN: Disaster and emergency management - Shared situation awareness. Tech. rep., European Committee for Standardization, Brussels (2009)
7. Chapman, J.: System Failure: Why Governments Must Learn to Think Differently. Demos, London, 2 edn. (2004)

8. Chen, Y., Harper, F.M., Konstan, J., Sherry, X.L.: Social Comparisons and Contributions to Online Communities : A Field Experiment on MovieLens. American Economic Review 100(4), 1358–1398 (2010)
9. Dryzek, J.: Networks and Democratic Ideals: Equality, Freedom, and Communication. In: Theories of Democratic Network Governance, pp. 262–73. Palgrave Macmillan, Basingstoke (2007)
10. Endsley, M.R.: Toward a Theory of Situation Awareness in Dynamic Systems. Human Factors: The Journal of the Human Factors and Ergonomics Society 37(1), 32–64 (1995)
11. Endsley, M.R., Jones, W.M.: Situation Awareness Information Dominance & Information Warfare. Tech. Rep. February, DTIC Document (1997)
12. Humphrey, W.S.: Characterizing the Software Process: A Maturity Framework. Tech. rep., Software Engineering Institute, CMU, Pittsburgh (1987)
13. IBM: The smarter supply chain of the future. Tech. rep., IBM (2010)
14. Juga, J.: Organizing for network synergy in logistics A case study. International Journal of Physical Distribution & Logistics Management (2010)
15. Klein, G., Woods, D.D., Feltovich, P.J.: Common Ground and Coordination in Joint Activity. Organizational Simulation pp. 1–42 (2004)
16. Locke, E.A., Latham, G.P.: New Directions in Goal-Setting Theory. Current directions in psychological science 15(5), 265–268 (2006)
17. Nevis, E.C., Ghoreishi, S., Gould, J.M.: Understanding Organizations as Learning Systems. Sloan Management Review 36(2), 73–85 (1995)
18. Nofi, A.: Defining and Measuring Shared Situational Awareness. Tech. Rep. 10, Center for Naval Analyses, Arlington (2000)
19. Nonaka, I., von Krogh, G.: Tacit Knowledge and Knowledge Conversion: Controversy and Advancement in Organizational Knowledge Creation Theory. Organization Science 20(3), 635–652 (2009)
20. Reynolds, M., Holwell, S., Beer, S.: Systems Approaches to Managing Change: A Practical Guide. In: Reynolds, M., Holwell, S. (eds.) Systems Approaches to Managing Change: A Practical Guide, pp. 1–23. Springer, London (2010)
21. Rhodes, R.: Understanding Governance: Policy Networks, Governance, Reflexivity and Accountability. Open University Press, Buckingham (1997)
22. Rittel, H., Webber, M.: Dilemmas in a general theory of planning. Policy sciences 4(1969), 155–169 (1973)
23. Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D.P., Mcmaster, R., Young, M.S.: What really is going on ? Review of situation awareness models for individuals and teams. Theoretical Issues in Ergonomics Science pp. 37–41 (2008)
24. Sorensen, E.: Governance Networks as a Tool for Democratizing Inter-Governmental Policy Making (2010)
25. Storck, J., Lesser, E.L.: Communities of practice and organizational performance. IBM Systems Journal 40(4), 831–841 (2001)
26. Young, I.: Inclusion and Democracy. Oxford University Press, Oxford (2000)