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IFAC-PapersOnLine 49-19 (2016) 212–215

Representing distributed cognition in socio-technical systems

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Abstract: Distributed cognition is characterised by multiple 'agents' (both human and technological) working together in pursuit of common goals for which high levels of communication and coordination are required. The dynamic nature of transportation means the cognitive functions change moment-by-moment, in light of changes in the task, environment and interactions. It is argued in this paper that the EAST method is able to represent the complexity of distributed cognition using a network of networks approach. This systems paradigm provides the necessary foundations and methods to explore the non-linearity experienced in complex, highly automated, socio-technical systems, such as those found in ground, maritime and aviation transportation.

Keywords: Distributed cognition, supervision, networks, automation, transportation.

1. INTRODUCTION

Stanton et al (2005) proposed Event Analysis of Systemic Team-work (EAST) as an integration of methods for analysing complex sociotechnical systems. Since its conception, EAST has been applied in many domains, including naval warfare (Stanton et al, 2006), aviation (Stewart et al, 2008), air traffic control (Walker et al, 2010a), emergency services (Houghton et al, 2006), energy distribution (Salmon et al, 2008), and railway maintenance (Walker et al, 2006). The approach is gaining momentum as well as showing its domain independence. The analysis has demonstrated how distributed cognition (Hutchins, 1995) for complex systems could be represented by networks, with the distinct advantage that networks enable both qualitative and quantitative investigations. It has been argued that the multifaceted nature of the different networks (i.e., social, task and information networks) have revealed the aggregated behaviours that emerge in complex sociotechnical systems (Stanton et al, 2008). Task networks describe the relationships between tasks, their sequence and interdependences. Social networks analyse the organisation of the system (i.e. communications structure) and the communications taking place between the actors and agents working in the team. Finally, information networks describe the information that the different actors and agents use and communicate during task performance (i.e. distributed situation awareness). These representations have been proposed as an alternative to the reductionistic approaches often used to understand systems, which presented systems in their constituent parts but fail to capture the system as a whole. Walker et al (2010a) suggested that the insights gained by network modelling were superior to the traditional ethnographic narrative which has previously been used to describe distributed cognition because they present graphical models of systems. Griffin et al (2010) went further to show how the EAST method offers insight into system failure. Again, the cited advantage of the approach was the non-reductionist, non-taxonomic, method for analysing non-normative behaviour of systems. Whilst EAST does not employ taxonomies in the analysis, the resultant network structures may be classified into archetypes. The systemic approach allows system interactions to be understood in their entirety (Plant and Stanton, 2012). EAST is underpinned by the notion that complex collaborative systems can be meaningfully understood through a network of networks approach (see Figure 1). Each of these network approaches have been presented independently in other papers. Farrington-Darby et al's (2006) presentation of task diagrams in a study of railway controllers was an example of a task network. Furniss and Blandford's (2006) presentation of communication channels in emergency medical dispatch teams was an example of a social network. Sanderson et al's (1989) analysis of verbal protocols for a process control task was an example of an information network. What EAST does is bring these three networks together into the same analysis framework.

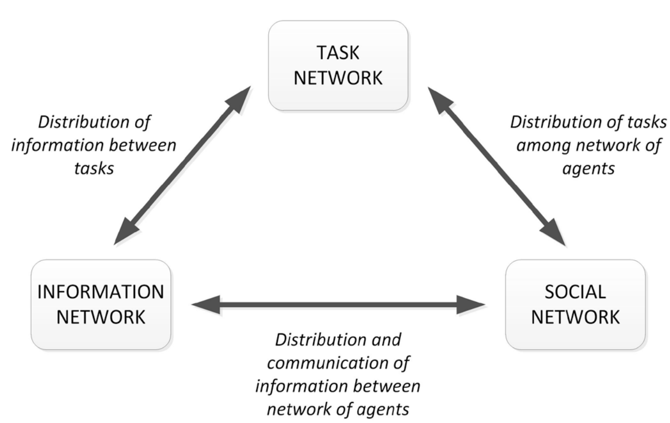

Figure 1: Network of networks approach used by EAST.

The EAST framework lends itself to in-depth evaluations of complex system performance, examination of specific

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.526

constructs within complex socio-technical systems (e.g. situation awareness, decision making, teamwork), and also system, training, procedure, and technology design. Whilst not providing direct recommendations, the analyses produced are often highly useful in identifying specific issues limiting performance or highlighting areas where system redesign could be beneficial

2. SOCIAL NETWORK ANALYSIS

Social Network Analysis (SNA) offers a means of analysing the network as a whole as well as the behaviour of individual nodes and their interactions. As such, SNA is potentially a very powerful tool for Systems Ergonomics. Whilst it has traditionally been applied to the analysis of social networks (as implied by the name of the method: Driskell and Mullen, 2005; Houghton et al, 2006), there is no reason why it cannot be applied to other networks, such as task and information networks. This is a new application for the method, but a potentially useful one. The method can also be applied to the design of anticipated networks, so that more effective task, social and information networks can be designed into new a system which is another new avenue of research for Systems Ergonomics that would enable network resilience to be explored in a practical manner. The first step in a SNA involves defining the network that is to be analysed. Once the overall network type is specified, the tasks, agents or information should be specified. Once the type of network under analysis has been defined, the scenario(s) within which they will be analysed should be defined. Once the network and scenario(s) under analysis are defined clearly, the data collection phase can begin. There are a number of metrics associated with the analysis of social networks, depending upon the type of evaluation that is being performed. The size of the network determines the number of possible relations, and the number of possible relations grows exponentially with the size of the network. This defines the network's complexity. The first step in the analysis is to calculate the statistics for each of the nodes in the network, of which a range can be produced to represent the metrics of distance (i.e., eccentricity), sociometrics (i.e., emission/reception and sociometric status) and centrality (i.e., centrality, closeness, farness and betweeness). The second step is to calculate statistics for the whole network (i.e., density, cohesion and diameter). The final step is to combine the networks for a qualitative assessment. In this analysis the networks can be considered in terms of their resemblance to basic archetypes such as the chain, circle, star, Y and all-connected as well as more advanced archetypes such as the mesh, bus, or a hybrid structure. Each of the archetypes has particular characteristics which may be more or less suited to any given scenario or circumstance.

3. DISTRIBUTED SITUATION AWARENESS

Distributed Situation Awareness (DSA) is presented as an alternative way of thinking about SA in systems. As Hutchins (1995) advocated, the unit of analysis is not the individual person (as presented with the three-level model), but the entire system under investigation. This notion has since gained credence within human factors with Hollnagel (2003) even suggesting that, due to the complexity of modern day socio-technical systems, the study of information processing in the mind of individuals has lost relevance. In the original paper specifying the DSA theory and approach, Stanton et al. (2006) indicate how the system can be viewed as a whole, by consideration of the information held by the artefacts and people and the way in which they interact. The dynamic nature of Situation Awareness (SA) phenomena means they change moment by moment, in light of changes in the task, environment and interactions (both social and technological). These changes need to be tracked in real time if the phenomena are to be understood (Patrick et al. 2006). DSA is considered to be activated knowledge for a specific task within a system at a specific time by specific agents. By agent, it is intended to mean either a human or non-human actor in a system. Thus, one could imagine a network of information elements, linked by salience, being activated by a task and belonging to an agent. To understand how this might work, one has to imagine a network where nodes are activated and deactivated as time passes in response to changes in the task, environment and interactions (both social and technological). Viewing the system as a whole, it does not matter if humans or technology own this information, just that the right information is activated and passed to the right agent at the right time. It does not matter if the individual human agents do not know everything, provided that the system has the information.

3. SYSTEM RESILIENCE

Resilience Engineering has emerging as a new paradigm in safety management, where "success" is based on the ability of organisations, groups and individuals to anticipate the changing shape of risk before failures and harm occur (Hollnagel et al. 2006). Resilient systems are able to withstand minor perturbations and are agile enough to adapt to major disturbances. Proactive resilient processes are the hallmark of such systems, which are in a state of continuous flux in anticipation of threat. Truly resilient systems are able to handle disruptions beyond those anticipated in the original design. These concepts have much in common with the Socio-Technical Systems (STS) approach to systems, and viewing systems though network models offers one approach to testing resilience. Systems may be thought of multimodal interconnecting social (actor and artefact), task (goals and operations), action (procedures and rules), informational (data and knowledge) and cognitive (perceiving, remembering, recognising, deciding) networks. The structure and adaptability of these networks are likely to be indicators of the systems resilience, which can be subjected to non-destructive testing to identify weaknesses and strengths. Past work has adapted the EAST method to analyse incidents of fratricide (Rafferty et al, 2012) although this has largely been conducted as retrospective and concurrent analyses. Similarly, 'broken links' approach (i.e., failure to communicate information from one agent to another in a system) has only been investigated by EAST analysts when looking retrospectively at accidents to identify underlying causes. Griffin et al (2010) demonstrated the 'broken link' between the Engine Vibration Indicator and the pilots in the cockpit was a causal factor in their failure to shut down the correct engine in the Kegworth accident. If this information