Past and Future Challenges for Railway Research and the Role of a Systems Perspective

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Abstract. Operational train traffic is dependent on an efficient traffic plan monitored and executed by the traffic controllers, the proficient maneuvering of the trains by the train drivers, and on the interaction, communication, and coordination between these two work roles. The railway research community, and the branch of industry itself, has called for an integrated systems perspective for the whole train traffic system to achieve an efficient performance. As human-human and human-technology interactions are natural parts of the socio-technical system of train traffic, the aim of this paper is to provide illustrative examples for why a systems perspective is needed for the future of railway research. Furthermore, we present the theoretical framework of distributed cognition (DCog) as a necessary addition to the theoretical and methodological toolbox of the Human Factors and Ergonomics (HF&E) discipline. To realize efficient and coordinated processes involved in organizing and executing operational train traffic, the paper proposes that the DCog framework should be implemented in the train traffic domain as a viable approach forward.

Keywords: Train Traffic, Distributed Cognition, Safety-Critical Systems, Systems Perspective.

1 Introduction

It has long been called for a systems perspective in Human Factors & Ergonomics (HF&E) and one of the most prominent advocates for this view is the late scholar John Wilson [1-3]. He emphasized a systems perspective of HF&E where humans and their actions should be understood within their contexts and argued for the necessity to widen the unit of analysis to include the interactions between individuals, tools, and contexts. The need to complement HF&E with theoretical and methodological approaches from the field of cognitive science and especially theoretical perspectives that "puts brain, body and world together again" was stressed [4]. In this paper, we will show illustrative examples from rail human factors research and argue why a systems perspective is needed for efficient and coordinated processes involved in organizing and executing work in the domain of train traffic.

With its technology-intensive environment, the safety-critical decisions, and the extreme work conditions that often result in sudden shifts between high cognitive load and periods of very low cognitive load, train traffic involves complex, dynamic processes that pose many research challenges. Prior railway research has focused on either traffic control or train driving, however, in this paper, both these central roles will be in focus. While train traffic controllers are engaged in a remote control process of executing train paths, points, and signals; train drivers operate the trains and turn the timetable into reality. Based on this, we propose that the train traffic will not reach its full potential unless railway research considers these two roles as interdependent entities of the same socio-technical system. We argue that a systems perspective is needed to understand what work tasks are done, how they are done, and how these tasks need to be supported and mediated by technology now and in the future.

Much work activity is cognitive [5], and it is therefore essential to study cognitive and social activities of professional workers in train traffic. The theoretical framework of Distributed Cognition (DCog) has been put forward as prominent in order to study coordination mechanisms and information flow in complex socio-technical domains [5]. DCog views cognition as a socio-cultural process which is distributed in socio-technical environments [6-7], thus offering a shift from studying individual cognizers to studying individual cognizers as part of a whole, functional system.

We suggest that the past challenges in rail human factors can be addressed by the application of the systems perspective of DCog. With the use of examples from our own research group, we summarize the lessons learned with the purpose to pave the way for a discussion about the benefits of applying DCog for studying socio-technical systems in general, and the train traffic system in particular. Our aim is to shift the perspective in rail human factors research to focus on understanding the organization of the complex cognitive system, emphasizing how cognitive work is done, and highlighting the situated context of work. We argue that this approach will provide the theoretical filter to enable researchers to describe how cognitive resources within the socio-technical system of train traffic are used to accomplish an efficient traffic flow.

2 Examples from Railway Research

Rail human factors research is growing rapidly and although good research has been carried out over the years, this has been scattered around many separate themes and appears to focus on limited human factors issues rather than with the railway system as a whole [8]. To illustrate this complexity, we will in this chapter briefly introduce two examples of prior rail human factors research that, despite their differences in purpose and focus, ends up drawing similar conclusions.

One of the longest-running projects in the field of rail human factors, with specialization in the intersection of human-computer interaction and interaction design, is the Future Train Traffic Control project [9]. The project emphasized field studies and ethnographic analyses and observations, and interviews were conducted at three train traffic control centers in Sweden. By studying the everyday work tasks of the train traffic controllers' (sometimes also referred to as train dispatchers), it was revealed that the work was highly complex and cognitively demanding. Most of the identified cognitive ergonomics issues related to how well the traffic controllers were supported in their everyday work tasks. It was, for example, revealed that not all decision relevant information was available simultaneously but the traffic controllers needed to actively gather and integrate necessary information, which hindered their possibilities to achieve an updated understanding of the current traffic situation. This, in turn, centered much of the controllers' work around operational level activities and little time was left to monitor the traffic process from a strategic level. Furthermore, the goals for the control tasks were highly time related, but the information provided was usually not time specific, which added uncertainty regarding the present state of the traffic process. Also communication was highlighted as a central but challenging task since both the communication between traffic controllers and their communication with train drivers lacked proper support, which resulted in insufficient information for all involved actors [10]. These are all aspects that create uncertainty and may result in high cognitive load.

The project was considered a great success and the identification of these problems resulted in the development of a new work strategy for train traffic control which allowed the traffic controllers to continuously re-plan the traffic, instead of identifying and handling conflicts "last minute". This work strategy proposed a projection of the traffic situation and met the traffic controllers' need to plan ahead. A new decision support system was developed which enabled the traffic controllers to easier identify potential conflicts in the traffic plan and to re-plan traffic via the interface, upon which the system displayed all consequences of the suggested changes. This successfully provided the controllers with an overview of the traffic situation [11].

Although the improvements made were beneficial for the traffic controllers, it did not lead to any benefits for the train drivers. Hence, from a systems perspective, the new work strategy did not provide a proper solution.

In another project, the train drivers work situation, their use of information and how the available information affected driver behavior was investigated [12-13]. It was revealed that train drivers had too little information and that their main challenge was to obtain relevant information. In fact, Jansson et al. ([12] p. 40) concluded that "…the drivers sometimes found themselves driving in an informational vacuum". The drivers needed to use and integrate information from several information channels such as the trackside signals, the route book, and surroundings near the track, and they still considered much relevant information as absent. This hindered the train drivers' attempts to plan ahead and adopt a proactive driving behavior [12].

These illustrative examples aim to show how rail human factors research often has focused on either traffic control or train driving. Interestingly, the examples are from separate research projects but both derived at the same conclusion: the train traffic will not reach its full potential unless the separate work roles of train driving and traffic control are viewed as different parts of the same socio-technical system. The traffic controllers execute and, when necessary, re-plan the timetable but the train drivers are the ones who turn the timetable into reality. Both these examples highlight the relevance of widening the unit of analysis to include not only individual workers but the whole socio-technical system consisting of humans, multiple technical systems as well as other types of artefacts and tools. In order for the whole train traffic system to function efficiently, the two work roles of train traffic control and train driving, which are both central in operational train traffic, need to be considered simultaneously and it is essential to emphasize that what happens in one part of the socio-technical system is bound to affect the other parts. A chain is only as strong as its weakest link, and that is why a complete and holistic systems perspective in needed in future rail human factors research.

3 The Need for a Systems Perspective in Railway Research

The research examples described above are illustrations of the need for a systems perspective in rail human factors research. Similar discussions can be found in the HF&E literature from other domains and much of this has to do with the fact that work carried out within complex systems often by their nature are ill-defined and challenging to study [14]. This complexity makes it difficult to reproduce the work in a meaningful way in a laboratory setting [14] or even in a simulator [15]. When it comes to train traffic, the current need is to conduct field studies. Research in natural settings takes the social variables, the complexity of the dynamic environment, and the effects these have on behavior and performance into account [15]. Wilson and Norris [16] particularly emphasize that there is a need for field research with the aim to understand distributed groups working with multiple interfaces. These types of groups are easily found in the socio-technical system of train traffic, and even though the examples above were conducted as field research, they focused on the individual worker. Thus, they did not consider that the traffic controllers and the train drivers were part of the same distributed socio-technical system and dependent on each other in order to realize an efficient train traffic. By studying successful work [17], it is possible to understand the skills of the train traffic workers and how these skills and experiences can be integrated with new technical and organizational systems, which Wilson and Norris [16] stress as a major requirement for the future of train traffic. A related argument is put forward by Savioja, Liinasuo and Koskinen [18] when they emphasize that the common practice in safety-critical domains is to focus on performance-related issues. Because of the prevailing orientation towards HF&E, railway research runs the risk of not considering the modern understandings of human cognition and technology-mediated activity, as situated action [19], embodiment [20], and distributed cognition [6], in which humans are considered as meaning-making actors (not factors) in a socio-cultural and material context. Although HF&E research is dominant and well justified, it often puts forward the human as a *risk* factor. This approach may hinder the general development of research in safety-critical domains in which continuous development should be promoted as the work practice. Savioja, Liinasuo and Koskinen [18] argue that viewing the human as a risk factor is a conservative approach that might enable an implicit and slow degradation of the socio-technical systems towards "the drift into failure" (Dekker, 2011, in [18] p. 431). Thus, future research on train traffic should focus on viewing people as actors—not components or factors— within the socio-cultural and technical system. That means to recognize the influence of the context, work culture, and the situational circumstances on cognition and behavior [15] and to acknowledge that the interactions between individuals, tools and contexts are as critical to the performance of work as the technical factors [3].

Clearly, the need for a systems perspective has been highlighted both in the literature, and similarly, in our own research. In an interview study with dyads of one train driver and one traffic controller, it was revealed that the two work roles very much depended on interaction and coordination with each other in order for them to be able to fulfil their individual tasks. One of the traffic controllers expressed that "They [the train drivers] are our eyes out there. Without them, I would know nothing". This further supports the need for a systems perspective in railway research, in which these two roles, both central for operational train traffic, should be viewed as interdependent parts of the same socio-technical system. These issues will be further addressed in upcoming publications.

The complex work domain of train traffic presents many challenges for rail human factors research and we suggest that these can be met by the application of the systems perspective of the theoretical framework distributed cognition (DCog) [6]. Many models of HF&E research have highlighted interactions between people, products, and environments (e.g. [21]), but the main focus of these models are on redesigning user interfaces, equipment, or workspaces with the intention of improving the current work performance. However, it is relevant to instead study interactions with the focus of understanding the interactions themselves [2-3]. That would make it possible to grasp and clarify the more diffuse and complex socio-technical systems, which in fact is reality in many workplaces. It has also been pointed out that some of the most commonly used frameworks that present and define elements of complex socio-technical systems in HF&E (e.g. Cognitive Work Analysis [22] and Joint Cognitive Systems [23]), do not explicitly stress either the role and relevance of cognition, or the situated and cultural context of the socio-technical system [24].

Clearly, there are several theoretical approaches available for studying work in natural settings and with the socio-technical system as the unit of analysis. However, the theoretical framework of DCog, as originally presented by Hutchins [6], has been noted as one of the most pertinent when it comes to the study of work and interactions between human and technology [25-26]. An application of DCog will provide an understanding of how train traffic work is successfully performed "in the wild" and how the always-existing link between human and technology can be supported and improved. DCog as a theoretical framework is briefly presented in the next section.

4 The Theoretical Framework of Distributed Cognition

Distributed Cognition (DCog) may best be described as a framework for human cognition. It focuses on understanding the organization of complex cognitive systems and proposes that cognition should be studied "in the wild" as it naturally unfolds [6]. DCog discards the idea that human mind and environment can be separated and takes a distributed, socio-technical system as its primary unit of analysis [6-7]. The underlying principle is that human cognition is fundamentally distributed within the socio-cultural and technical environment. Accordingly, cognition is an emergent phenomenon resulting from the interactions between different entities in the brain, the body, and the social and material environment. A main concern is the way information is represented, transformed, and propagated in the performance of tasks in the cognitive system [6, 27]. Thus, cognition and knowledge are not viewed as confined within the individual brain but extended to the system level (see Fig. 1).

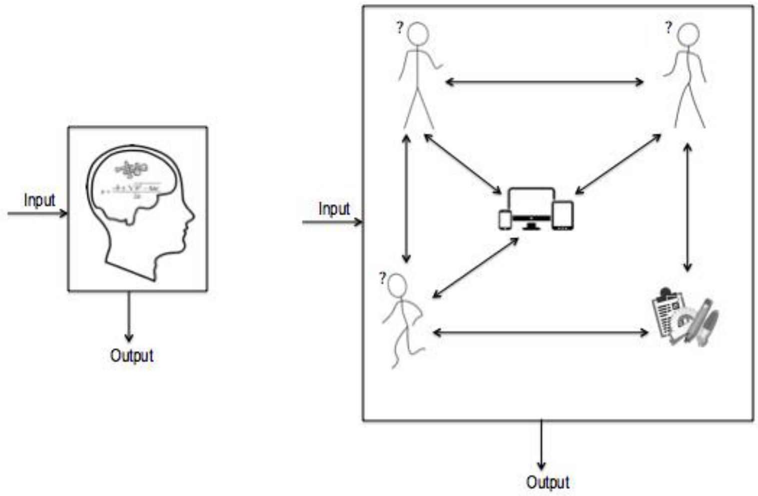

Fig. 1. The traditional cognitive science perspective (left), regards the unit of analysis as restricted to the individual's mind. From a DCog perspective (right), the unit of analysis is expanded to be distributed across people and artefacts, and cognitive processes are the result of the interactions between these entities of the distributed cognitive system (figure from [24]).

The system level view makes DCog especially fruitful for studies of whole socio-technical systems, and it differs from other cognitive approaches mostly by its commitment to two theoretical principles [27]. The first principle concerns the boundaries of the unit of analysis for cognition, which are defined by the functional relationship between the different entities of the cognitive system. The second principle concerns the range of processes considered to be of cognitive nature. From a DCog perspective, cognitive processes are seen as interaction between internal processes, manipulation of external objects, and propagation of representations across the system's entities [27]. When these principles are applied to the observation of human activity *in situ*, three kinds of distributed cognitive processes become observable: (1) across the members of a social group, (2) between internal (e.g. decision making) and external structures (e.g. material artefacts, social environment), and (3) distributed through time in such a way that the products of earlier events can transform the nature of later events ([27] p. 176).

Given that DCog treats the whole socio-technical system as the unit of analysis, it makes human work practice explicit and enables the portrayal of how humans handle tasks in action. With its focus on cognitive artefacts and the way in which information is propagated and transformed within the socio-technical system, a DCog analysis of the spatial, structural, social, and temporal distribution of information reveal properties about cognitive structures used to understand, access, and share information [4, 6]. DCog is not associated with a specific methodological procedure; however, to collect ethnographic data through naturalistic enquiry should be considered a foundation pillar of the framework. The data is then analyzed and interpreted in terms of work practices, routines, and procedures followed [26] with the purpose to seek to determine what certain tools and artefacts mean to the participants during an activity and to document how those meanings are created [27].

Since the inception of DCog in the mid-1990s, substantial work has been done with the DCog perspective as an analytical tool for studying interactions between humans and technology in complex socio-technical domains. DCog has, for example, been applied in ship navigation [6], aviation [7], air traffic control [28], human-computer interaction (e.g. [5, 27]), heart surgery [29], nuclear power plants [30] and manufacturing [24, 31]. However, DCog has to the best of our knowledge never been applied to the railway domain.

5 Role and Relevance of DCog in Railway Research

Over the years, much attention has been paid to the technology, and too little to the "human capital" of the humans that use the technology (e.g. [32]). The user has generally been considered as a factor in the human-technology interaction loop and, historically, more emphasis has been put on the technological aspects. The costs associated with neglecting cognitive and user perspectives have resulted in an emerging shift from considering users as passive elements in information-processing to human actors [33- 34]. By acknowledging that humans, technology, and artefacts together form a holistic socio-technical system, there is a vast potential to improve both the workers' cognitive and physical health and simultaneously increase efficiency in the workplace. With the application of DCog in the setting of train traffic, we can increase the understanding of the work practices as they are performed "in the wild" within this complex socio-technical domain. With its theoretical focus on the system level and the activities taking place within the distributed cognitive system, DCog can provide guidance in:

- Mapping out the information flow and the propagation of information over time and space in the distributed socio-cultural and technical system.
- Identifying various kinds of representation formats (graphical, numerical, written, and embodied) used in the information flow as well as recognizing the different shifts between these representation formats. This puts attention also to the tacit knowledge associated with being an experienced worker in the railway domain, which becomes visible through coordination of different kinds of internal and external representations in the information flow.
- Identifying workarounds and prevent breakdowns from a systems perspective. One part of being an experienced worker is to be able to find workarounds that allow for faster, more efficient work. This is often done through the use of smart coordination

mechanisms with the worker's individual goal to ease the work situation. With the identification of "best practices" and "lessons learned" developed by skilled workers in the distributed socio-technical system, the best of the culture within the railway can be preserved and this knowledge can be spread to others in the same domain and improve the training of new employees.

- Providing flexibility in the change of level of analysis. DCog enables the researcher to move between the general level of the socio-technical system to a detailed level where it is possible to specify concrete details of actual use of available artefacts.
- Providing implications for design and redesign of new and/or existing artefacts as well as for the organization of tasks in the socio-cultural and technical system. Observation and analysis of how work is performed "in the wild" can provide insights and requirements, which can then be properly implemented in the design of new products, tools, and cognitive artefacts.

In our opinion, DCog fits hand in glove with the request for a systems perspective in the train traffic domain. DCog enables the study of complex socio-technical systems and offers the desired characteristics by providing a holistic and emergent perspective of train traffic work. It widens the unit of analysis beyond the "individual skull" and focuses on cognitive processes and interactions between entities in the social and cultural context that also are distributed in space and time.

6 Concluding Remarks

This paper has attempted to both motivate and show concrete examples of how and why a systems perspective must be applied within rail human factors research. To broaden the perspective and include multiple work roles and their tasks as they are achieved in the distributed socio-cultural and technical system enables an understanding of how the work roles, separate in time and space, function as interdependent parts of the same socio-technical system.

Despite the large amount of research on human cognitive behavior, there still exists a knowledge gap about everyday human experiences and how people use "common sense" to successfully "muddle through life", in which technology is not disconnected from what we do but rather a fundamental part of human life [35]. Allowing the boundaries of what constitutes cognition to expand into the systems perspective offers a new toolset for identifying both potential problems as well as opportunities for improvement of human based work in the train traffic domain. Given the absence of relevant cognitive frameworks that provide a systems perspective in theory and practice for current HF&E applications, the inclusion of DCog should be a promising step in the direction of realizing efficient and coordinated processes involved in organizing and executing operational train traffic.

References

1. Marras, W. S., Hancock, P. A.: Putting mind and body back together: A human-systems approach to the integration of the physical and cognitive dimensions of task design and operations. Applied Ergonomics 45(1), pp. 55–60 (2014).
2. Wilson, J. R.: Fundamentals of ergonomics in theory and practice. Applied Ergonomics 31(6), pp. 557–567 (2000).
3. Wilson, J. R.: Fundamentals of systems ergonomics/human factors. Applied Ergonomics 45(1), pp. 5–13 (2014).
4. Clark, A.: Being There: Putting Brain, Body, and World Together Again. MIT Press, Cambridge, MA (1997).
5. Rogers, Y., Ellis, J.: Distributed cognition: an alternative framework for analysing and explaining collaborative working. Journal of information technology 9(2), 119–128 (1994).
6. Hutchins, E.: Cognition in the wild. MIT Press, Cambridge, Mass (1995).
7. Hutchins, E.: How a Cockpit Remembers Its Speeds. Cognitive Science 19(3), 265–288 (1995).
8. Wilson, J. R., Norris, B. J.: Rail human factors: Past, present and future. Applied Ergonomics 36(6), 649–660, (2005).
9. Future Train Traffic Control Homepage, http://www.it.uu.se/research/project/ftts, last accessed 2018/03/09
10. Sandblad, B., Andersson, A. W., Frej, I., Gideon, A.: The role of human-computer interaction in design of new train traffic control systems. In: Proceedings of World Congress on Railway Research, Vol. A, pp. 777-783. Florence, Italy (1997).
11. Kauppi, A., Wikström, J., Sandblad, B., Andersson, A.: Future train traffic control: control by re-planning. Cognition, Technology & Work 8(1) 50–56, (2006).
12. Jansson, A., Olsson, E., Kecklund, L.: Acting or reacting? A cognitive work analysis approach to the train driver task. In: Wilson, J. R., Norris, B., Clarke, T., Mills, A. (eds). Rail Human Factors: Supporting the Integrated Railway, pp. 40–49. Ashgate Publishing Limited, Aldershot, UK (2005).
13. Jansson, A., Olsson, E., Erlandsson, M.: Bridging the gap between analysis and design: Improving existing driver interfaces with tools from the framework of cognitive work analysis. Cognition, Technology & Work 8(1), 41–49, (2006).
14. Wilson, J. R., Jackson, S., Nichols, S.: Cognitive work investigation and design in practice: the influence of social context and social work artefacts. In: Hollnagel, E. (ed) Cognitive Task Design, pp. 83–98. Erlbaum, Mahwah NJ (2003).
15. Farrington-Darby, T., Wilson, J. R., Norris, B. J., Clarke, T.: A naturalistic study of railway controllers. Ergonomics 49(12–13), 1370–1394 (2006).
16. Wilson, J. R., Norris. B.: Special issue on rail human factors. Applied Ergonomics 36(6), 647–648 (2005).
17. Hollnagel, E.: The ETTO principle: efficiency-thoroughness trade-off: why things that go right sometimes go wrong. Ashgate Publishing, Ltd., Farnham, England (2009).
18. Savioja, P., Liinasuo, M., Koskinen, H.: User experience: does it matter in complex systems?. Cognition, Technology & Work 16(4), 429–449 (2014).
19. Suchman, L.A.: Plans and situated actions: The problem of human-machine communication. Cambridge University Press, Cambridge (1987).
20. Lindblom, J.: Embodied social cognition. Springer International Publishing, Berlin (2015).
21. Stanton, N.A., Salmon, P.M., Walker, G.H., Baber, C., Jenkins, D.P.: Human factors methods: A practical guide for engineering and design. Ashgate, Farnham UK (2005).

22. Vicente, K. J.: Cognitive work analysis: Toward safe, productive, and healthy computer-based work. Lawrence Erlbaum Associates, Inc., Mahwah, NJ (1999).
23. Woods, D. D., Hollnagel, E.: Joint cognitive systems: Patterns in cognitive systems engineering. CRC Press., Boca Raton FL (2006).
24. Lindblom, J., Thorvald, P.: Manufacturing in the wild - Viewing human based assembly through the lens of distributed cognition. Production & Manufacturing Research 5(1), 57–80 (2017).
25. Luff, P., Hindmarsh, J., HeathC.: Workplace studies- recovering work practice and informing system design. Cambridge University press, Cambridge (2000).
26. Rogers, Y.: HCI Theory: Classical, Modern, and Contemporary. Morgan & Claypool Publishers, San Rafael, California (2012).
27. Hollan, J. Hutchins, E., Kirsh, D.: Distributed cognition: toward a new foundation for human-computer interaction research. ACM Transactions on Computer-Human Interaction 7(2), 174–196 (2000).
28. Soraji, Y., Furuta, K., Kanno, T., Aoyama, H., Inoue, S.: Cognitive model of team cooperation in en-route air traffic control. Cognition, Technology & Work 14(2), 93–105 (2012).
29. Hazlehurst, B., McMullen, C. K., Gorman, P. N.: Distributed cognition in the heart room: how situation awareness arises from coordinated communications during cardiac surgery. Journal of biomedical informatics 40(5), 539–551 (2007).
30. Mumaw, R. J., Roth, E. M., Vicente, K. J., Burns, C.M.: There is more to monitoring a nuclear power plant than meets the eye. Human factors 42(1), 36–55 (2000).
31. Andreasson, R., Lindblom, J., Thorvald, P.: Interruptions in the wild: portraying the handling of interruptions in manufacturing from a distributed cognition lens. Cognition, Technology & Work 19(1), 85-108 (2017).
32. Norman, D. A.: Things that make us smart – defending the human attributes in the age of the machine. Addison-Wesley Publisher, Reading, England (1993).
33. Bannon, L. J.: From human factors to human actors: The role of psychology and human–computer interaction studies in system design. In: Greenbaum J., Kyng, M. (eds) Design at Work: Cooperative Design of Computer Systems, pp. 25–44. Lawrence Erlbaum Associates, Hillsdale (1991).
34. Bannon, L. J.: “20 years a-growing”: revisiting from human factors to human actors. In: Isomäki, H., Pekkola S. (eds) Reframing Humans in Information Systems Development, pp. 181–188. Springer, London (2011).
35. Flach, J. M., Voorhorst, F.: What Matters? Putting Common Sense to Work. Wright State University Libraries, Dayton, Ohio (2016).