Ethnographic Analysis of the Dispatchers' Workplace in a Rail-Based Transport Control Center

Ullrich Martin, Carlo v. Molo
Institute of Railway and Transportation Engineering
University of Stuttgart
Pfaffenwaldring 7
70569 Stuttgart
ullrich.martin@iev.uni-stuttgart.de, *carlo.molo@iev.uni-stuttgart.de*

Niels Henze, Lars Lischke, Sven Mayer
Institute for Visualization and Interactive Systems
University of Stuttgart
Universitätsstraße 38
70569 Stuttgart
niels.henze@vis.uni-stuttgart.de, lars.lischke@vis.uni-stuttgart.de, *sven.mayer@vis.uni-stuttgart.de*

Monika Rieger, Benjamin Steinhilber, Florestan Wagenblast
Institute of Occupational and Social Medicine and Health Services Research
University of Tübingen
Wilhelmstraße 27
72074 Tübingen
monika.rieger@med.uni-tuebingen.de, *benjamin.steinhilber@med.uni-tuebingen.de*,
florestan.wagenblast@med.uni-tuebingen.de

Abstract:

In traffic control centers a large number of complex processes are monitored by few dispatchers. Dispatchers are assisted by computer-aided systems that are able to support dispatchers' operations/decisions by filtering task-relevant from task-irrelevant aspects. With the increased use of computer-aided systems, the area controlled by a dispatcher increases and so does the risk of non-normal operations which require additional dispatcher action. In case of these non-normal operations, monotonous surveillance work can quickly change to a complex operation requiring sustained attention, cognitive effort, and responsible decisions since they might impact efficiency and quality of railway traffic as well as even safety. The level of dispatchers' attention and alertness is crucial for adequate decisions in non-normal operations. A computer-aided system that supports these abilities, for example by measures of attention control could be a key element for optimizing the work in traffic control centers regarding fewer mistakes and less mental demands to the dispatcher. In this paper we identify potential improvements in traffic control centers for promoting dispatchers' attention and alertness that can be included in a computer-aided system. Therefore, in a first step, we conducted a ethnographic analysis of rail-based transport control centers to gain knowledge about work conditions, work processes and its impact on the dispatcher. In a second step we identify a scenario classification to distinguish actions. This classification gives a structure for a detailed description of potential improvements to promote dispatchers' attention and alertness. As a first stage, our classification revealed eleven scenarios for in which the dispatcher has no safety responsibility. We clustered these eleven scenarios in three high level groups, namely: *peak hour*, *special service time* and *during off-peak hour and night-owl service time*. Further, we highlight potential options how to utilize the latest technology to enable an efficient operation in control rooms in the future.

Introduction

Nowadays the control and monitoring of many complex processes in production and operation is possible with few operators thanks to computer-aided systems. These computer-aided systems are becoming increasingly complex due to the ever more precise monitoring of production and operating processes. Furthermore, through these systems, it is possible to present more and more information to the user, which is not only more detailed but also derived from non-spatially linked information. On the one hand, these systems become increasingly complex and demanding in operation, while on the other hand, they support operators in more and more tasks of the regular operation, while monitoring can be carried out by a few persons. Through performing control tasks by computer-aided systems and the consequent expansion of the monitoring districts, the number of exceptional cases that cannot be automated and standardized increases. In addition, in case of deviations from normal operation, the tasks of operators change extremely quickly from predominantly monotonous monitoring activities to partly safety-relevant tasks with an immediate decision-making function. Especially in situations deviating from normal operation, the amount of incoming and required information increases to a barely comprehensible level. In control centers such control and monitoring systems consist of one or more workstations with numerous input and output devices. In today's control centers, the main output device is a number of monitors. To optimally display the information and to be able to enter it, each operator has a number of input devices. However, even in situations in which normal operation is deviated from normal, operators must be able to maintain an overview of the situation at all times and make time-critical decisions while maintaining operational quality and safety.

To facilitate the operating procedures and to ensure fast and precise actions and decisions, especially for time-critical situations deviating from normal operation, it is necessary to have the support of specific operating concepts and user interfaces. The objective is to design the actions of the dispatchers by reworking and modernizing the human-machine interface considering optimal physical and mental requirements. Therefore, we seek to use the fundamental understandings for human-computer interaction. Here, Shneiderman and Plaisant stated that the development of new operating forms and user interfaces is based on the four-pillar model of successful user interface development [28]. Therefore, in the first step, an ethnographic analysis[1] in consideration of environmental factors is carried out to determine the users' requirements for user interfaces. After deriving model approaches and their methodological algorithms, software tools are designed to develop new operating forms and user interfaces. Finally, the new developments are systematically reviewed in a test environment and assessed by experts and users.

Work environment of traffic control centers

To control and to monitor the operation of a certain network size, e.g., several train stations, a central higher-level control center is necessary. As a result, railway infrastructure companies have control centers that often house not only the dispatchers' workplaces carrying out train monitoring tasks but also workstations of train operators performing safety-related tasks. These control centers have evolved and changed considerably in recent years. A few years ago, jobs that could hardly be customized were standard, whereas in modern control rooms workstations are designed according to the latest ergonomic findings and can be flexibly configured for standing or sitting operation. However, old and modern control panels resemble each other in the form of operation and workplace design. The dispatcher sits or stands in the middle of many monitors of common standard size, and uses a mouse and keyboard to provide input or a telephone and radio for communication.

Ethnographic Analysis

We carried out an ethnographic analysis to obtain a comprehensive picture of the current state of control rooms [32]. For this purpose, a control room of a local transport company in south Germany was analyzed, in which both about 200 light rail vehicles and about 250 buses are monitored and coordinated. We found that despite extensive renovations of the equipment and technology in recent years, the operating concept was hardly changed compared to less modern control panels. Innovations have emerged, especially regarding the arrangement and ergonomics of the workstations. In addition, the operation was revised so that the control of all systems required is possible through a mouse and a keyboard. Hence, the dispatcher no longer needs to switch between multiple mouse devices and keyboards. Due to the enlarged digital display area at the workplace, the mouse pointer must be moved over greater distances. Regularly, the dispatcher moved and clutched the mouse until the cursor was at the desired positions. To counteract this the system is already equipped with a mechanism to move the mouse directly to a dedicated screen. However, the dispatcher is often unaware about the reappearance location of his mouse pointer. Nevertheless, because of the variety of different applications, the dispatchers would wish to expand the digital display area but this requires a deeper integration of the systems used. When logging in, a dispatcher must enter multiple user IDs and passwords for access and personal activation of the systems. Other important sight related activities of the dispatchers are the documentation of actions and operations. On the one hand, these are automatically logged by systems; on the other hand, certain actions are documented manually on paper. An additional activity that falls within the area of responsibility of the dispatcher is the communication with other dispatchers on the neighboring workstations as well as with external agencies and drivers operating a vehicle. Often, only the actual state is passed on by word of mouth. An automatic, digital data transmission of the actual state does not exist. For these exemplary activities, the dispatcher would be relieved by automation.

[1] An ethnographic analysis is a participatory observation that tries to gain knowledge about actions, behaviors, or effects of the behavior of individuals or a group of people.

Normal operation vs. disturbance, mental underload vs. overload

In addition to the general operating actions, the ethnographic analysis reveals a discrepancy between understaffing and overstraining the dispatchers in various operating situations. Especially outside rush hours, a relatively monotonous operation can be observed, in which usually the dispatcher hardly ever intervenes. However, such a scenario can change within seconds quickly in the event of a disruption, so that there can be a rapid change from underload to excessive demand. Even a disruption in the rush hour increases the demands on the dispatchers so much that it can lead to an increased number of wrong actions. In addition, the increased use of computerized systems for the operation and the consequent larger number of surveillance districts significantly increases the likelihood of a fault occurring, along with the particular risk of the overlapping of multiple independent disturbances at different locations within the surveillance district.

Interim conclusion working environment

As we analyzed a recently modernized control room, we found that upgrading the hardware to support the dispatchers' needs and wishes is only the first step towards reducing the mental overload in today's control rooms. Therefore, we conclude that there is a need for further research. New technical concepts, both hardware, and software have to be adapted to support the dispatchers better to avoid excessive requests in situations of increased demands. This would aim at ensuring an efficient operation and achieving a customer-oriented quality of operation. In addition, there seems to be potential for user interface optimization. New technologies can contribute to a need-based design of user interfaces which considers both physical and mental requirements to improve work processes.

Scenarios

To select suitable approaches and methods for the analysis of mental load a classification of the work in control rooms is needed. Based on our ethnographic analysis [8] we derive a set of situation- and activity-related scenarios (see Figure 1). Scenarios are first derived from being able to systematically limit different operating situations and operating conditions, which are in turn used for further analyzes. In principle, two scenarios need to be distinguished in the control or monitoring of rail traffic. These are namely actions with and without safety responsibility.

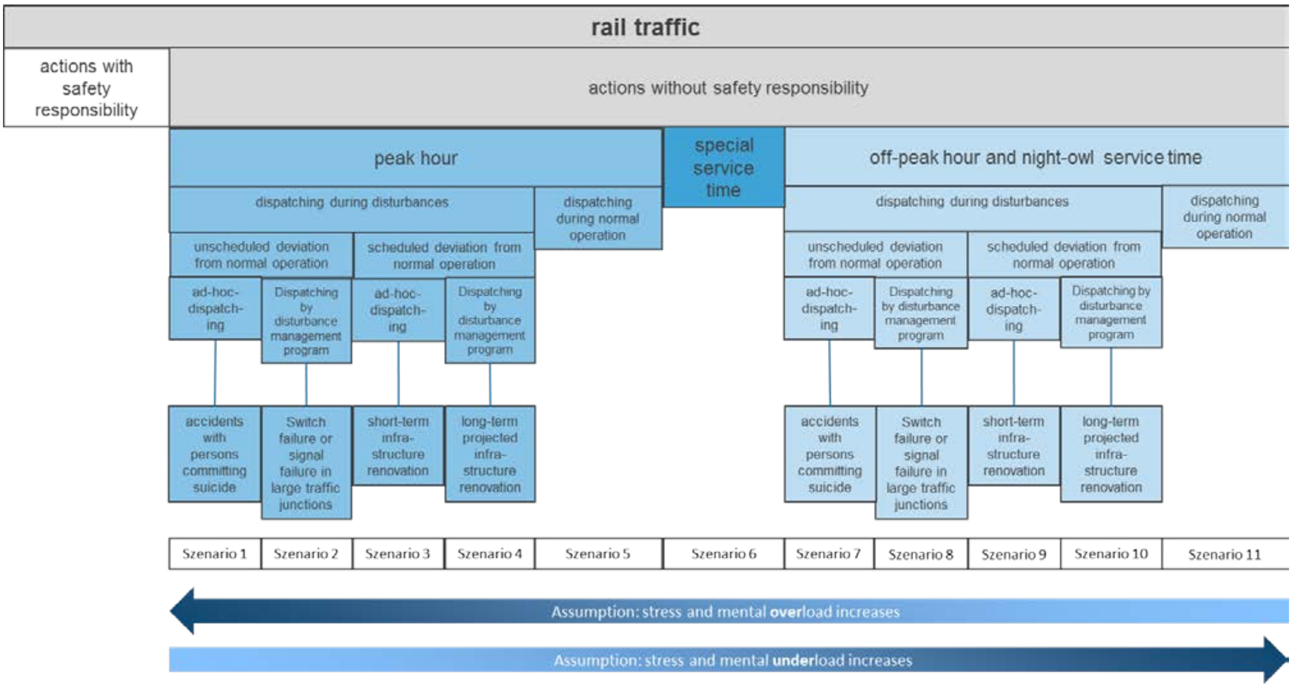

Figure 1: The scenario classification based on our ethnographic analysis.

Rail traffic scenario – with safety responsibility

Train operators assume the safety responsibility, e.g., when they command the engine driver to pass a stop signal. Basically, in regular operation, these safety-relevant actions are technically supported in highly frequented areas of the network. The technical protection can be overridden by the train operator through substitute actions. This happened, for example, in the spring of 2016 when two trains crashed near the town of Bad Aibling in Bavaria, Germany. For this purpose, the train operator is personally legally liable. In low traffic networks, some or even the entire support and monitoring of safety-relevant actions provided by technological solutions is dispensed with, so that operational safety only depends on human action.

Rail traffic scenario – without safety responsibility
The most of activities of the dispatchers in the rail-based transport control centers, as well as the operational controlling and dispatching activities of the train operators, are characterized by actions without safety responsibility. Dispatching and train monitoring look after a failure-free and efficient operation with high quality. A wrong or deferred typical action of a dispatcher may, e.g., cause a fast-moving train to "catch up" to a slower moving train, which means that the faster-moving train must slow down or stop at the block signal. The fast-moving train is delayed, but the safety of the operation is not compromised in that case. In the following we will highlight the actions with no safety relevance or implications as a first stage.

Situational consideration normal operation and disturbance scenarios
In a more general situation-related consideration, a classification into two basic scenarios "dispatching during normal operations" and "dispatching during disturbances" seems sensitive. During normal operation, dispatching is limited to the monitoring of the recent and expected operating situation in compliance with the scheduled operation. Nevertheless, it is necessary to make decisions depending on the route and the situation, e.g., if a train operator reports that a freight train needs to enter from a branch line on a mainline the operator must obtain permission for this trip from the dispatcher. In contrast, the scenario "dispatching during disturbances" describes a situation, which deviates significantly from the timetable due to operational, technical or external influences.

Subdivision by type of deviation from normal operation
In the scenario "disturbance", the predictability of the situation can be taken into account by a further subdivision into "scheduled deviation from normal operation" and "unscheduled deviation from normal operation". A scheduled deviation from normal operation is a middle- or long-term planned action, e.g., infrastructure maintenance or the movement of exceptional transports [2], whereas a short-term deviation from the timetable is referred to as an unscheduled deviation from normal operation. The cause can be, for example, a disturbance caused by the vehicle or the infrastructure, or an accident. For both deviations, dispatchers have to make ad-hoc decisions. For larger nodes and sections of particular importance, there are usually predefined generalized disturbance management programs since many trains and dispatchers could be affected. A fast ad-hoc decision would be delayed by the need for coordination of the involved dispatchers.

Subdivision by method of dispatching
The activity-related influencing factors are subdivided into "ad-hoc dispatching" and "dispatching by disturbance management program". This applies not only to the scenario "scheduled deviation from normal operation" but also to the scenario "unscheduled deviation from normal operation". An existing disturbance management program could prove to be very stress-relieving in such an exceptional situation but requires that its activation and handling have workload-reducing and time-efficient effects. Here, the scenarios "Dispatching under a normal operation" during the off-peak hours and night-owl service time, as well as "dispatching through a disturbance management program", "unscheduled deviation from normal operation" and "ad-hoc dispatching" are of equal interest. The discrepancy between monotonous activities (stress due to mental underload) and highly complex activities (stress due to mental overload) is particularly evident in these scenarios. Computer-aided systems can only contribute to the improvement of the workplace and the quality of operations if they are coordinated with the dispatchers and their activities.

Potential developments for control rooms caused by technological achievements

In the human-computer interaction (HCI), various concepts for the further development of the user interfaces of interactive maps and control rooms are discussed. Maps can be enriched, for example, by reference to information that lies outside of the illustrated map section by so-called off-screen visualizations [7, 9] or by auditory representations [10]. In this case, for example, Shaer and Hornecker proposed using tangible user interfaces [26]. Schwarz et al. developed operating concepts for the control room of power plants and discussed the use of physical input components such as physical shift and rotary encoders as input [25]. Motivated by the increasing use of multimodal user interfaces in mobile and ubiquitous systems, Heimonen et al. proposed the use of such interfaces even in control rooms [6].

In addition to the study of multimodal user interfaces, the development of new interaction concepts for wall-size displays will further influence the development of control rooms. Here, it can be seen that higher screen resolutions are preferred, especially for text-related applications [14]. It can also be noticed that even on wall-size screens, operators can find specific information quickly and without heavy workload [15]. Thus, it can be assumed that further enlargement of the digital and physical screen area in control centers will lead to improved work performance. However, todays graphical user interfaces need to adapt to ensure the best use of the additional screen space, for instance Lischke et al. proposed a set of high level interaction techniques to utilize the screen space [17]. In addition, classical input techniques with mouse and keyboard reach their limits in screen configurations that are already common in control rooms today. Eye-tracking is currently one of the ways in which input technology can be expanded. The operator can use conventional input devices as usual, but larger mouse pointer movements can be replaced by visual gestures [16]. Another advanced method to interact with wall-size displays is mid-air pointing, Mayer et al. recently developed a new function to improve the mid-air pointing accuracy which enables precise target selection for distant objects such as wall-size displays [19].

A recent development in human-computer interaction is the use of psychophysiological measurements that can quantify physiological responses to mental workload, e.g. electrocardiography or surface electromyography [4]. This could help to understand the mental state of the user during the interaction and to adapt it accordingly. For example, Shirazi et al. used inexpensive brain-computer-interfaces in an attempt to recognize the situational awareness of the users [27]. Following this approach, the computer systems in control rooms could automatically detect whether the operator is aware of the current situation and take action if this is not the case. For example, in the first step, the system could give the operator indications of attention deficits and suggest pausing as the attention wears off.

Another current development that could be used in control centers is the use of gaze tracking during use. Current mobile and stationary gaze tracking devices are inexpensive and allow to determine which point or part of the screen the user is looking at. While commercial devices still require calibration that precludes long-term use in many cases, research prototypes can already perform an automatic calibration [11]. When the user's gaze wanders between different screens or focuses on objects outside the screens, the user can be assisted by visual stimuli to retrieve recently viewed content [13].

With eye-tracking it is also possible to estimate which screen contents the user has perceived and which not. The assumption is that content that the user has never visually focused on has not been consciously perceived. Although the eye of a user fixes a screen area, however, it cannot be guaranteed that the content is also consciously perceived [29]. Nevertheless, eye-tracking can give an indication of what content the user is aware of. This allows the user to be made aware of potentially overlooked content through visual or auditory stimuli. A human-computer interaction attempts to understand better the user's cognitive state, which allows the development of systems that intelligently control the user's attention. While recent developments are focused on mobile [21] and ubiquitous [31] systems, it is likely that the application of attention control in specific environments, such as control centers, will yield results that are useful in the early stage of the development process.

Stress and mental underload and overload in rail-based transport control centers

From the previous sections, it becomes clear that work in rail-based transport control centers places a specific strain on dispatchers and train operators. Workload can be broadly divided into physical and psychological load. The latter includes all factors resulting in mental effects [3]. In the context of workplaces these effects can be regarded as mental stress and they are influenced by organizational, task-related, socially interactive and environment-related factors. However, work-related disturbances inflicted through certain contextual factors generally increase the mental load. For example, the frequency and complexity of on-screen information, as well as time-critical and safety-critical work activities, can be understood as mental loads, which in turn promote mental stress. Workload must be regarded as overload if increased mental stress results in adverse health effects or deficiencies in cognitive or sensomotoric performance [20, 30]. In addition, it is possible that during monotonous work activities mental underload can cause mental stress, too. In the scenario of underload performance reductions can be observed i.e. in the form of a vigilance decrement [5]. There is a particular need for research in assessing how specific and temporally cumulative combinations of mentally demanding work-related factors, regarding mental underload and overload, are expressed by reduced cognitive and sensomotoric performance of the dispatcher or train operator. Apart from possible safety-relevant consequences of rail traffic operations, compromised by wrong decisions, frequent and prolonged exposure to mental stress is associated with musculoskeletal complaints, cardiovascular problems and mental disorders [1].

Further proceeding

In the future denser traffic and larger operating areas will further increase the responsibilities for each dispatcher. These responsibilities will also change the working requirements and widen the set of possible situations. The larger the area that has to be observed the higher is the likelihood of overlapping of independent disruptions. Therefore, to ensure a good quality of operation, in a next step the human-computer interactions need to be evaluated on the bases on the ISO 9241-210 standard [12]. Further, probabilities for wrong actions will have to be determined. The skill, rule and knowledge based classification created by J. Rasmussen [22] and developed further by Rasmussen himself [23] and other authors (e.g. [Reason 24, Martin 18]) provides a framework for identifying the types of error likely to occur in different situations. The resulting error probabilities are time-independent (number of errors per number of actions) [18]. In addition, the mental stress of the dispatchers will have to be analyzed regarding the different scenarios under consideration of the stress-strain-concept [3]. Based on our findings, specific optimized concepts for interactive forms of dispatching can be derived, and the foundations for the development of new, multi-sensitive and situational user interfaces for complex control systems have to be developed to reconfigure the dispatcher workplace further.

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