PILOT STUDY FOR AN ITALIAN HUMAN-CENTERED DESIGN (HCD) STRATEGY

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Abstract

Current railway Automation & Control Systems allow centralizing the traffic management for a growing number of rail network nodes by using increasingly robust features both for operational and safety interventions. To adequately manage such large set of data it will be necessary to take into account the interaction between Dispatchers and technology. Indeed, a great variety of parallel stimulation (e.g. visual vs. auditory, digital vs. analogical) must be correctly deployed for keeping the operators on adequate situation awareness and safety levels, but also for meeting the desired timeliness and meaningfulness information to passengers. With that in mind, we devised an exploratory study adopting Human Factors and Ergonomics methodologies and tools for the analysis and optimization of cognitive and physical interactions within an Operation Control Center (OCC). Interviews and instrumental measurements (i.e. eye-tracking and motion capture) allowed us to model operators' interaction with their workstations in different scenarios (e.g. time of the day, traffic loads) and the physical and cognitive outcomes of such interaction (e.g. fragmentation of the information flow, use of the cervical spine). The log file data analysis allowed us to identify peaks that may be suggestive of a periodicity in performance. This finding could be eventually used to check whether the cyclical pattern found reflects the allocation of mental resources. Overall, the present exploratory study served as a basis for devising an innovative Italian railway Human-Centered Design (HCD) vision which could allow defining novel requirements as well as assessment strategies and certification protocols. The activity carried out so far confirmed that an HCD approach can improve operators' performance and the acceptance of novel technology.

1. Introduction

This pilot study played a pivotal role in the birth of an Italian Human-Centered Design railway strategy for Operation Control Centers (OCCs), Human-Machine Interfaces (HMIs) and Graphical User Interfaces (GUIs). Likely, the activities carried out in the Centralized Traffic Control (CTC) of Foligno-Terontola-Montecarotto and the Electronic Interlocking ("ACC" in Italian terminology) of Roma Tiburtina, are the first structured Human Factors and Ergonomics (HFE) actions in this field. Rete Ferroviaria Italiana (RFI) exploited this project for running both ordinary and innovative R&D activities. The former concerned contextual investigations (i.e. observation and interviews) aimed at verifying the presence of technology-related Human Factors issues as documented in the literature (e.g. poor usability, sub-optimal physical design, and technology location, habituation to alarms). The latter was achieved by focusing on understudied topics (i.e. transport data recordings) and applying innovative technologies to record and evaluate human-machine interactions (i.e. eye-tracking and motion-capture system). Nonetheless, as clarified by the wording “pilot study,” we are far from presenting conclusive results. We thought convenient using the current report as a general introduction to the launched research topics (mentioning some preliminary findings) foreseeing an accurate presentation at the end of any ultimate achievement on the roadmap.

2. Description of the research activity

Research activities started from a review of the technical-regulatory and scientific literature, which was carried on for investigating the state of the art in the application of tools, methods and Ergonomics techniques in the railway sector and to verify Italian contributions to this context. The outcomes, as expected, are a growing number of European and International HFE rail publications highlighting the role of human performance decrement in casualties and incidents. Thus, recommending HFE activities to expand several topics (e.g. usability, mental workload, situation awareness, vigilance) and to improve safety and performance accordingly (e.g. Roth et al., 1999; Sandblad et al., 2010; Wilms & Zelistra, 2013). Hence, several exploratory activities were started in consideration of the limited Italian contribution to this discussion. We conducted participatory (interviews and questionnaires) evaluations of the CTC Foligno - Montecarotto through semi-structured interviews with a sample of 10 DCOs (“DCO”, in Italian terminology, means Operation Control Manager) composed of 9 males and one female (mean age = 53.7 yrs.; std dev = 7.7). Each interview lasted about 90 minutes, and the operators were asked to answer a series of questions related to their procedures, issues, and needs. Starting from DCOs’ verbalizations, it was conducted a coding activity to define response trends. Beyond users’ direct involvement, the process continued with specific instrumental measurements (i.e. inertial motion capture systems and eye-tracking). We carried out these activities by adopting an integrated approach aimed at considering the existing close interrelation between physical and cognitive Ergonomics elements concerning the actual modalities of interaction with the workstations. To verify the real physical interaction of five operators with two control workstations, which had relevant dimensions, we acquired samples of motion captures (lasting from 12 to 58 minutes) through an inertial system (MVN Biomech, X-Sens, NL). The inertial system

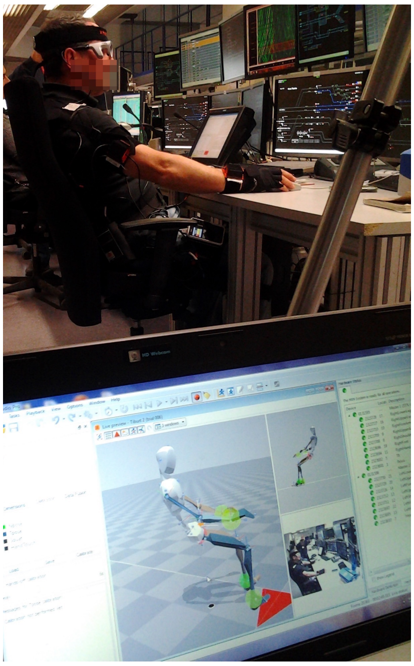

Figure 1. The figure shows an example of an operator wearing both the eye-tracking glasses and the inertial motion capture system during control activities.

consisted of 17 integrated sensors (accelerometers, gyroscopes, and magnetometers), positioned on the operator’s body and connected, thus allowing to obtain an accurate reconstruction of the movements and postures assumed by the operators while performing control activities. As for the cognitive part, we studied the visual interaction with the GUIs. We used eye-tracking glasses (Tobii Glasses 1, Tobii, SE) for recording the operators' visual scanning of the scenario with a sampling frequency of 30 Hz. The recorded "scanpath" is a repetitive sequence of fixations (when the eye is stationary within a pre-defined space-time window) and saccades (rapid, ballistic movements of the eyes abruptly changing the point of fixation). Five DCOs involved in their normal operations participated in this phase. Each session took place during a high workload timeslot (7AM-8AM) and lasted about 20 minutes. The number, duration and sequence of the fixations were qualitatively and quantitatively analyzed. Finally, we analyzed three weeks of CTC Foligno-Terontola-Montecarotto control center log files. These are valuable data about the system and operators’ behaviors that too often are just archived and no further analyzed (see Walker & Strathie, 2014 for an account in the rail transportation domain). Our exploratory analysis was carried out to check whether the performance of operators is subject to cyclical variations, thus indicating an underlying ultradian rhythm (i.e. a recurrent period or cycle repeated throughout a 24-h circadian day). Ultradian rhythms in mental functions have been reported in the literature for prolonged vigilance tasks (see Conte, Ferlazzo & Renzi, 1995; Smith, Valentino & Arruda, 2003) and in the allocation of mental resources (Di Nocera, Ranvaud & Pasquali, 2015). The identification of a periodicity in the performance of control room operators would be crucial in the design of future systems featuring dynamic automation support.

3. Results

3.1. Physical Ergonomics: data acquisition using an inertial system

Results are in agreement with the evidence reported in the literature concerning the integrated movements of the eyes, the head and the lumbar rachis performed by the operators while looking at displays located in progressively more uncomfortable space areas (Villaneuva et al., 1997, Lee et al., 2013, Nimbarte et al., 2013). The operators tend to move the head when the width of the ocular movements, which lead the vision, exceed 20 deg (e.g. Hallet, 1986) and the lumbar rachis when the head deviation exceeds 30 deg. Although the movements of the cervical rachis were not associated (both on the horizontal and the vertical planes) to extreme and prolonged awkward postures, the reference to the technical rule ISO 11226 “to maintain the sight line below the horizontal line” was often not satisfied. In fact, the operators of the control workstations looked for a significant amount of the time (neck extensions exceeding 50% of the capture time, Fig. 2, panel A) at the information reported on the displays maximally relevant, located on the superior row of the workstations. These results confirm the need to verify that the primary functions would be positioned in space areas allowing both the maximal effectiveness while detecting visual information (“recommended areas,” UNI EN ISO 894-2, Fig. 2 panel A) and to reduce the overload of the cervical rachis. Moreover, the “Average angular velocity” was calculated to assess the average velocity (deg/s) of the head’s angular movements, neglecting the awkward postures. These data have shown that ACC Roma Tiburtina significantly involved the neck: 7.4 deg/s against 3.8 deg/s of the CTC in the horizontal plane, and 2.6 deg/s against 1.8 deg/s of the CTC in the more sensitive vertical plane.

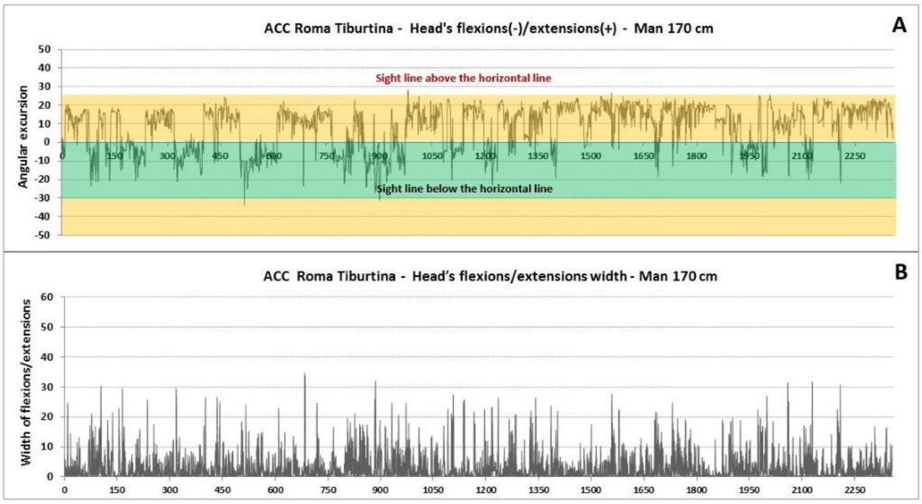

Figure 2. Panel A shows an example of the time course of neck's flexions(-)-extensions(+) captured in ACC Roma Tiburtina by means of the inertial system. The green and orange areas represent the "recommended" and "acceptable" areas defined in standard UNI EN ISO 894-2 respectively. Note that the "acceptable" area above the horizontal line may also be associated to neck's biomechanical overload (ISO 11226). Panel B shows an example of the width of neck's flexions-extensions, which increased along with workload.

That confirms the existence of a tight link between the movements of the neck and the workload. Indeed, in the case of the ACC Roma Tiburtina, wide transitions of the visual focus among the different displays were more frequently requested, due to the greater amount of traffic to be managed. That caused a greater involvement of the cervical rachis. Regarding the movements of the lumbar rachis, operators showed the tendency to bend forward towards the display, mainly to better focus some details of the interface (e.g. font sizes too small in respect to ISO 9241). Such movements (e.g. prolonged and/or frequently repeated flexions) caused a missing use of the lumbar support and, from the biomechanical point of view, an increased overload of lumbar rachis.

3.2. Participatory activities

DCOs reported to carry out continuous monitoring to manage several issues with: automatic Public Information Sub-system (e.g. do not charge some delays, and/or delays reduction, and/or crossing exchange); Train Describer-TD (e.g. loss of train number); Train Graph-TG (e.g. the timetable's resource conflict, in case of delay, modifying the provisional route) and, more generally, automatic train-path service&detection (e.g. failed departure of a train) and of the entities that are run by it. Summarizing, they work mainly with automatic train-path, but continuously anticipating the system to prevent malfunctions (e.g. level crossings not operating correctly), trying to avoid delays (e.g. keeping closed a level crossing to allow the passage of two trains close together) and avoiding that wrong information is disclosed to the passengers. In this scenario, the operator's ability to detect and identify a problem is essential, but it does not appear continuously supported by the system (e.g. a stalled train is not reported). This not optimal support to the DCO's situation awareness by the system affects as much minor issues related to the simple regularity of the circulation as the critical aspects of the alarms to which the DCOs appear to have undergone a process of habituation.

3.3. Eye-tracking

We analyzed the fixations on each system through the definition of Areas of Interest (AOI): Public Address panel; Train List from Assisi; Train List from Perugia; Station Describer Panel; Low TD; High TD; TG; Other workstation (Foligno-Terni); Fixations outside all the other AOIs (indicated by the wording "not on AOI"). Eye movements analysis allowed to study the visual behavior of five DCOs, measuring where the eye rests, how many times, for how long and in what sequence to assess the cognitive aspects, such as visual search.

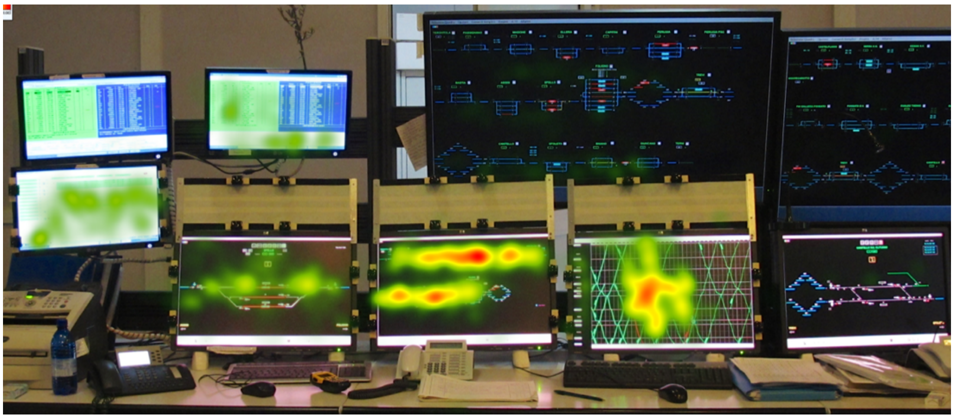

Figure 3. Total visit duration (how much time, on average, the DCOs spent watching each AOI) heatmap

The DCOs pay the greatest attention (i.e. calculated through the total time spent on every GUI) on the TD (32%) followed by the TG (26.9%) and the QL (13.6%). The TD and TG are significantly more observed than all the other systems while there is no significant difference between them. However, the viewing/search strategies are characterized by a high number of transitions between the GUI which was also highlighted by the head movements that, as observed with the inertial system, support and follow those eye movements. In summary, although the greatest visual attention is devoted to the TG and the TD, frequent transitions from one GUI to another can be observed. That is suggestive of a lack of sub-systems integration, with consequent widening of the visual scenario that the operator has to explore to gain the awareness of the state of the line and to intervene if necessary. The use of short-term memory for visuospatial simultaneous activities on primary (i.e. for command and control) and secondary (i.e. support for the circulation) GUIs increases the cognitive request accelerating vigilance decrements (Caggiano & Parasuraman, 2004). These dynamics should be further analyzed to optimize the presence/arrangement of information and commands.

3.4. Log files analysis

We analyzed three weeks of log files as time series (1-minute frequency) separately for system variables (the number of: conflicts, the number of trains, administrative measures on train-route service and loudspeaker announcements) and individual variables (number of operations carried out by the team of operators using the interface).

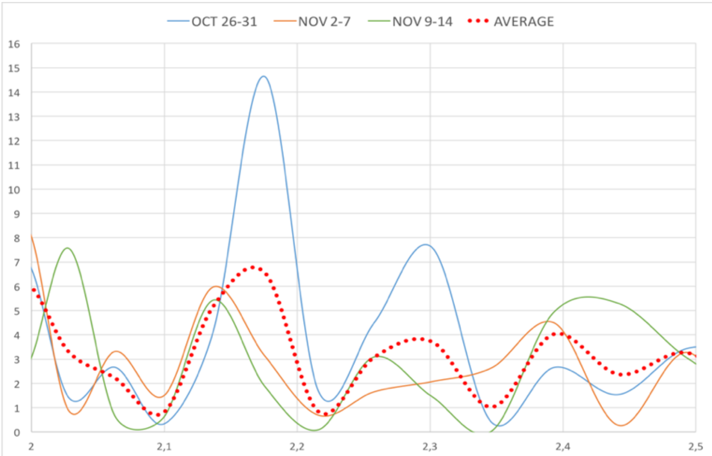

Figure 4. Periodogram of the team activity in the 2-2.5 bandwidth featuring at least one peak that may be suggestive of a periodicity in performance.

The available data were aggregated for the entire team. Therefore, the results of the following analysis do not address the single individual. Week-ends data were examined separately, as they reflect a different system activity and taskload. Prior running the Discrete Fourier Transform (DFT), time series were smoothed (3-point moving average) and the linear trend was removed. Visual inspection of the average periodogram obtained from the three-week recordings shows peaks aligned with 24-, 12-, 8-, and 6-hour frequencies for all variables (except for administrative measures on train-route service in the 11-13 bandwidth). This cyclical pattern is clearly due to the railway system timetable. A close-up inspection of the 0-5 bandwidth showed an indented pattern in which only a peak in the 4.5- and 5-hour frequency is clearly identifiable, whereas the authenticity of the others remains questionable. The inspection of the “operations” periodogram allowed to further analyze the low-frequency bandwidths. As it is shown in figure 4, the bandwidth 2-2.5 features one peak at least that may be suggestive of a periodicity in performance. A frequency of two hours would be compatible with a recurrent data collection (1-hour rate) of subjective measures of mental workload to check whether this cyclical pattern reflects the allocation of mental resources.

4. Conclusion

Participatory activities and technical-instrumental evaluations revealed a close interconnection between the physical and cognitive ergonomics components and various inefficiencies, including but not limited to:

- reduced optimization of physical workstations (e.g. monitors number and layouts) and the allocation of technology and related functions;
- ineffective presentation of information and feedback on GUIs;
- reduced integration between systems and poor GUIs usability;
- inadequate decision and situation awareness support;

- habituation to alarms/notifications.

Working on these issues would improve the healthiness of control rooms (e.g. reduction of awkward postures of the cervical and lumbar spine), the GUIs effectiveness and efficiency (e.g. usability), the individual performance (e.g. vigilance, errors, management of critical situations). Consequently, the overall effectiveness of the railway system (e.g. trains punctuality, quality of service to passengers) will increase. Not surprisingly, a recent study (Tschirner et al., 2014), estimated a 25% benefit of energy savings and a 10% increase in punctuality by applying a Human-Centered Design (HCD) process to the development of new TG and CATO (Computer Aided Train Operation) systems.

5. Roadmap

Based on the evidence reported below, RFI intends to launch the second phase of research and development to expand the results of the ongoing activity through the achievement of the following objectives:

- Extend the on field research activity to consolidate and confirm the results of this study, increasing it in relation to the various types of workstations and the related GUIs.
- Develop requirements for OCCs, HMIs and GUIs, as much as possible self-contained, so that RFI could consider to adopt it for their work (e.g. updating of technical specifications, standardization of a Human-Centered process for the design and realization of the control centers).
- Apply a Human-Centered Design pilot process (according to ISO 9241-210) for next generation GUI design: iteratively Verify and Validate (V&V) these GUIs within the different design and development phases by identifying critical elements, matching them with the operational processes and operators' mental and physical characteristics, therefore indicating solutions leading to improvements.
- Apply a Human-Centered Design pilot process (according to ISO 11064) for the design of a new generation control room taking into account the following features/factors:
  - reference users and adaptation to their psycho-physical characteristics;
  - type of activities and tasks performed by users;
  - reduction of biomedical risks associated with the carried out activities;
  - usability (measurement and optimization);
  - ease and rapidity in the adaptation and change of the features.
- Collect and analyze activity logs along with subjective measures of mental workload for monitoring the operator functional state and the system effectiveness.
- Define ergonomic design guidelines aimed at any subsequent applications for Ergonomic Certification of projects and products (e.g. implemented working workstations) released by ErgoCert (Certification Body for Ergonomics) based on Disciplinary and dedicated Technical Specifications.

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