FROM HUMAN FACTORS TO HSI AND BEYOND: DESIGN OF OPERATIONS CENTERS AND CONTROL ROOMS

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Abstract

Currently, Human Factors does not just cover human performance and human centred design but also the evaluation and influencing of human behaviour in complex environments. In particular in the design of operations centres and control rooms, the functioning of humans and systems must be considered in an integrative manner, taking into account gains as well as negative effects such as underload, complacency and skill loss. Furthermore, goals and constraints on the organizational level should be addressed. In designing the command bridge for the Dutch patrol vessels, not only all technology had to be considered, but also the types of operations, available shore support, and the number and type of operators. When planning the central operations centre for the Dutch railroads, we not only designed the workspace but also the collaborative model of participating organizations, which often have conflicting interests. This illustrates how Human Factors work is evolving while pursuing its aim to optimize human functioning in increasingly complex environments.

Keywords: Human Factors, Ergonomics, Control rooms, Human System Integration.

1 INTRODUCTION

What do Human Factors experts work on? Do they just focus on ergonomics, the adaptation of the physical environment to users, or do they cover a wider field and deal with human performance, safety and training? Our view is that Human Factors is even broader and considers the evaluation and influencing of human behaviour in all kinds of complex environments. One area where the necessity of such a comprehensive approach is demonstrated is the design of operations centres and control rooms. In these environments, the close cooperation of operators and systems should lead to optimal situation awareness and decision making, which means that the functioning of humans and systems must be considered in an integrative manner. For example, when introducing systems with higher levels of automation, it is not sufficient to just look at gains occurring because human tasks are taken over by systems. One should also take into account how operators will interact with these systems and how negative effects such as underload, complacency and skill loss can be prevented. Human Factors research must, however, even go beyond human-systems integration because choices of roles and tasks of humans and systems can only be made when goals and constraints on the organizational level are taken into account.

The evolution of Human Factors design at TNO for the Royal Netherlands (RNL) Navy, shown in Fig. 1, illustrates the development that Human Factors has undergone in the last decades (see also [1]). Thirty to forty years ago, ergonomics and human centred design were major elements of the research, providing solutions for issues such as usability and reliability. Traditional use of full-size mock-ups was combined with the novel use of computer-aided design.

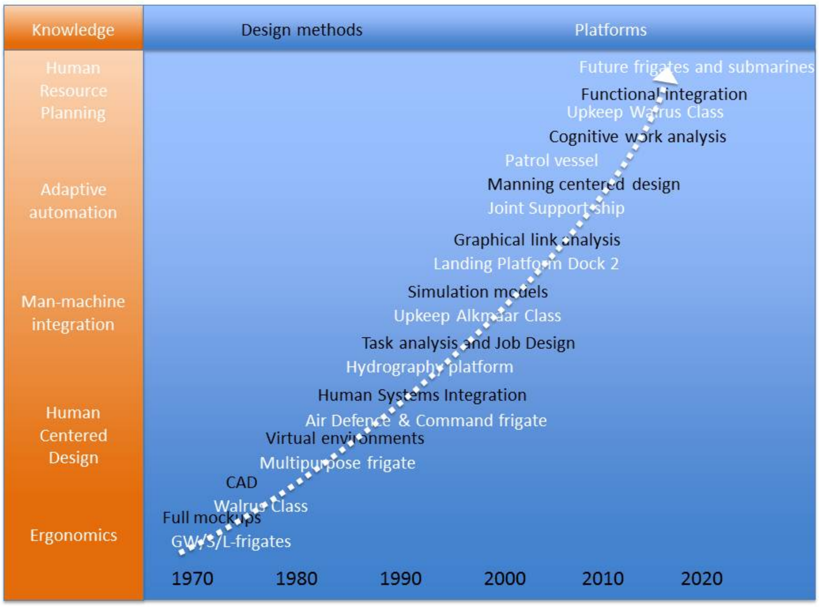

Fig. 1. Evolution of Human Factors design at TNO for the Royal Netherlands Navy

In the following decades, Virtual Environments were introduced as a new tool and man-machine interface design evolved into design based on Human Systems Integration. Techniques for Task Analysis, Job Design and Link Analysis were introduced to address the need to speed up the design process, achieve better man-machine integration, and come up with leaner manning concepts.

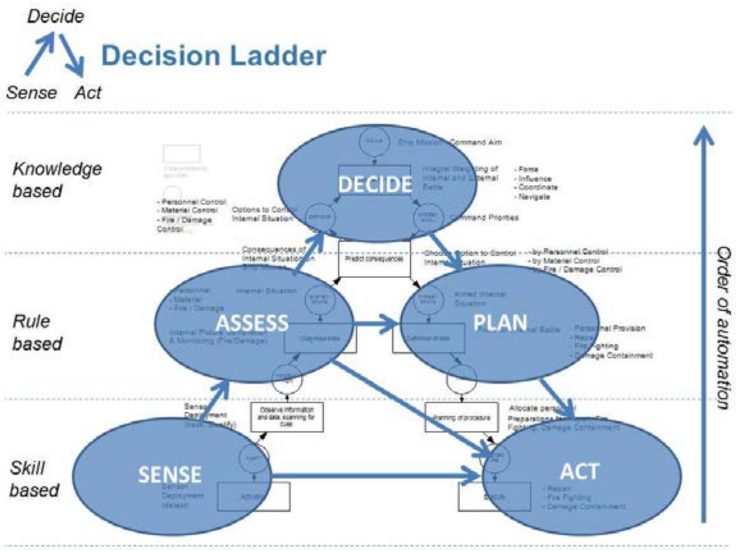

Fig. 2. Simplified Decision Ladder

In more recent years, the requirement of reduced manning has become even stricter, driven by financial constraints but also by the simple fact that qualified personnel is becoming more and more scarce. Fortunately, several solutions are now available for this problem, such as increased automation, remote support, and intelligent interfaces for support of situation awareness. However, these technologies must be combined with specific Human Factors measures to prevent negative performance effects e.g. due to skill loss. In addition, reduced manning is associated with reduced redundancy and thus a higher risk that major failures already occur when only few crewmembers are incapacitated. Thus the mapping of work on humans and systems must be combined with an analysis of the resilience of the solution. In order to achieve this, a Cognitive Work Analysis framework ([2], [3], [4]) is used, which has the advantage that different types of constraints can be modelled. In addition, a Control Task Analysis is performed, considering tasks on a more detailed level, and resulting in Decision Ladder diagrams ([2], see also Fig. 2). In essence, the Decision Ladder represents a combination of the well-known SRK model ([5]) with a decision tree. Because task difficulty increases towards the top of the ladder, it facilitates the identification of tasks that are suitable to be automated. A final step in Human Factors design that is taken currently is the functional integration of all units of a ship and the "marriage" with of state-of-the-art knowledge of technology (sensors, weapons, protection, propulsion etc.). Only by doing this, gaps between Human Factors design and implementation of technology can be prevented. This is crucial because, while such gaps may have been a nuisance when enough crewmembers were available to deal with them, they are potentially devastating when manning is strongly reduced. Functional integration should be combined with a more holistic view on personnel, considering not only the manning of an individual vessel and their work schedules, but also the recruitment of and general availability of personnel, and their training and career lines. This is necessary to make sure that sufficient and adequate personnel will actually be available to man future vessels.

2 EXAMPLE 1: DESIGN OF THE OPERATIONS ROOMS OF THE DUTCH OCEANGOING PATROL VESSEL

When the RNL Navy started the development of four Oceangoing Patrol Vessels (OPVs), financial constraints dictated that high demands should be set on efficiency and effectiveness, and that the manning should be limited to 50 persons. In order to provide input to the design of the operations rooms, TNO used a Manning Centred Design framework, consisting of four levels (see Fig. 3):

- At the highest levels are the strategic ambition to be pursued with the platform and the associated functional demands, describing the type of missions and tasks to be performed, the type of situations that will occur, and the variety of scenarios that must be dealt with. In the case of the OPVs, planned missions would predominantly be brown water rather than blue water and at a low to medium level of violence. Examples are anti-drug-trafficking, anti-piracy and humanitarian support missions. Scenarios would involve for example interdiction, reconnaissance, search and rescue, and small-scale interventions.
- At the conceptual (or Operational Design) level, the functional demands are translated to an organizational structure, task and work processes, and a global system architecture. This level determines which tasks and functions should be performed by humans and systems and includes choices of sensor, weapon and propulsion systems and the required protection.

- At the detailed (spatial) design level, it is determined in what way tasks and functions will be executed and what division between humans and systems is to be made. Working relationships are defined, including required resources and interconnections, and, eventually, a lay-out of the working environment is made, including a design of individual work stations.

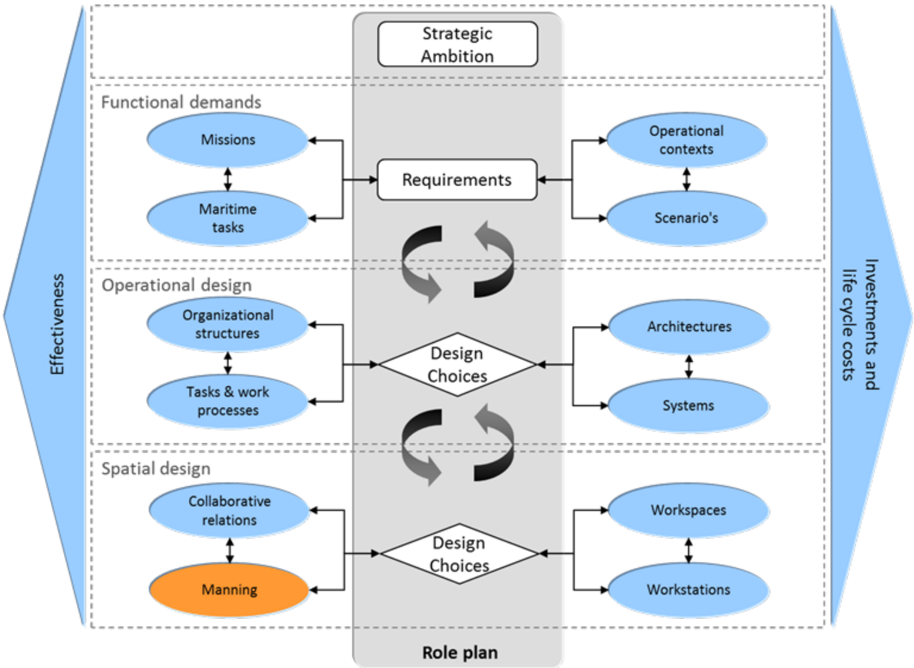

Fig. 3. TNO's Manning Centered Design framework

While the propagation from higher to lower levels in the model represent the most logical direction, the model must actually be used in an iterative manner. One reason for this is that there may be a priori requirements at lower levels. These can be predetermined choices for certain weapon systems of sensors, entering at the functional level, or a limit on crew size, which represents a requirement on the detailed design level. A second reason is that multiple iterations are normally necessary to keep costs within budget.

The design was made in close cooperation with representatives of the navy. A Human Factors Engineering Team was created consisting of Human Factors experts, equipment, network, and Combat Management System specialists, and future operational and technical users. When necessary, other subject matter experts were invited, for example sensor, weapon or communications specialists. During the design sessions it became clear that the stringent requirements for the OPV imposed a challenge for the lay-out and design of the operations rooms. An important design innovation that came out of the session was the command bridge, the combination of the bridge and the operations room in a single operations room. This made it possible to reduce the staff, for example because the officer of the watch could also act as operations room manager. In addition it facilitated communication between the entities. An evident disadvantage is the increased vulnerability of the operations room, which was deemed acceptable given the types of operations of the vessel, and which was mitigated to some degree by installing a thick sliding window behind the bridge. In total, four operations rooms were considered in the Human Factors design: the navigation bridge, the command information centre, the briefing room and the technical office.

Because a high level of mechanization, automation, and integration was to be used, a closer link between the traditionally separated rooms was introduced.

Much attention was given to the command bridge (see Fig. 4). A detailed 3D model was created in a Virtual Environment, using stereoscopic presentation. In this way, future users could get a realistic impression of the novel environment, and designers could evaluate lines of sight, and how collaboration was enabled by the setup. Full-scale mock-ups were made of the individual workplaces to evaluate their ergonomic features.

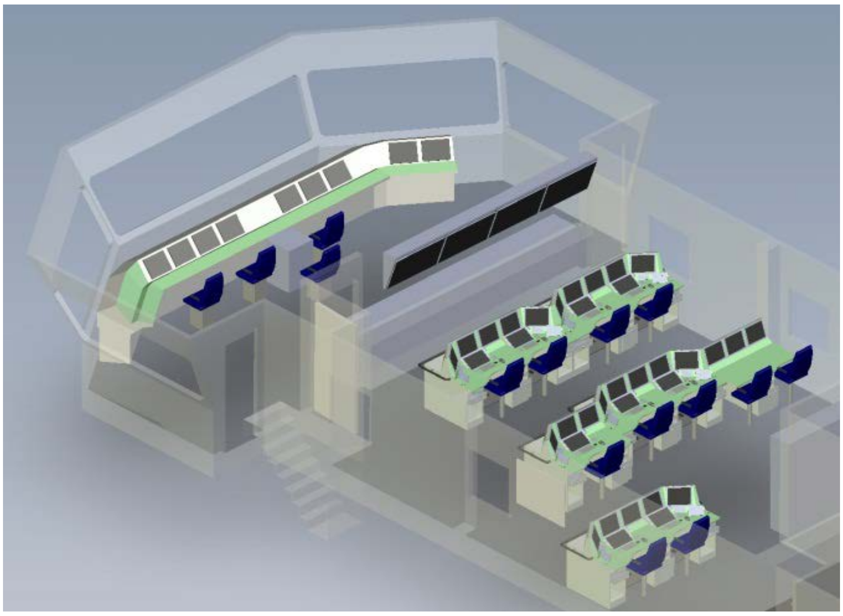

Fig. 4. The command bridge of the Dutch OPV

When the vessels were being built, a functional evaluation of the command bridge was performed. A simulated version was built at TNO and the actual crew of the first vessel participated in various demanding scenarios, which had been designed in close cooperation with the RNL Navy and with civil authorities such as the coast guard. One scenario, for example, featured the occupation of an oilrig in the North Sea by terrorists. This evaluation identified several bottlenecks that were addressed in the final manning design. In addition, it allowed the crew to be trained before the vessel was delivered.

The Human Factors design of the OPV is seen as a major innovation and success by the RN Navy. It is currently functioning well and the reduction of the crew size results in a large reduction – an estimated 30 to 50 Million Euro – of the total costs of ownership of the vessel.

3 EXAMPLE 2: DESIGN OF THE OPERATIONAL CONTROL CENTER RAIL (OCCR)

The Dutch railway network, with its 6800 km of track, 3000 crossings and 7500 switches, is not only the busiest in Europe but is managed and used by many, partly competing, organizations. In 2005, a failure of one of the local control computers caused a national disruption of the train traffic that lasted for several days. This triggered the decision to better organize the national rail traffic management. Initiators ProRail, NS and Railion (the main railway companies in the Netherlands) decided for a closer cooperation of their national services in a common workplace. TNO was first only asked to assess the organizational consequences of such a cooperation. Subsequently, the request came to describe the collaborative model and to design the control room layout and workplace design. In addition, TNO advised on cooling, lighting and acoustics.

The research started by analysing the current procedures and modes of operation. It appeared that there were not only problems in the interactions between organizations, but also between departments within an organization, for example the regional networks of ProRail. Further issues were differences in organizational culture and the large number of users of the railway system, who should all be treated in a non-discriminatory manner. The organizational model that was developed contains units that represent (main parts of) the participating organizations, which are each led by a director. Decisions are whenever possible taken in consensus by the directors. However, a National Coordinator Rail (NCR) is also appointed who has the authority to decide when consensus cannot be reached. The OCCR not only houses the directors and the NCR, but also the units consisting of teams of operators. To prevent escalation of too many minor events and incidents to the director level, horizontal communication between the units is stimulated and a separate coordinator is appointed who has the authority do deal with small incidents. On the basis of the collaboration model and after performing a link analysis a control room layout design was made and a functional set of requirements was described. Also the new control room desk was designed by TNO. Important elements of the design are the use of similar blocks of workplaces, central video walls used for creating shared situation awareness, and acoustic and lighting design that minimize interference and improve well-being. A separate crisis room was designed for handling of major crises by the NCR and directors. Because the OCCR has no fall-back facility that can house all participating companies TNO also made an alternative collaborative model. The OCCR was put into operation in October 2010 (see Fig. 5).

Fig. 5. The OCCR in operation

In the realization phase TNO stayed involved to check deviations from the functional requirements against the original objectives. Furthermore, TNO was asked in 2013 to evaluate the quality of the rail incident handling by the OCCR in the first years of its operation. It appeared that, since 2010, the average duration of rail calamities had dropped by no less than 20%. Interviews also revealed that information sharing, mutual understanding and collaboration were rated as more effective than in the past. Although further research is required to analyse the exact contribution of the OCCR, no alternative causes for this rather spectacular improvement could be identified. Thus the conclusion seems warranted that the implementation and operation of the OCCR has indeed been very successful.

4 DISCUSSION

The application domain of Human Factors has broadened from workplaces to human-system collaborations to complex socio-technical systems. This is made possible by a multidisciplinary approach and by the use of novel techniques and methods. This paper summarizes the evolution of Human Factors research at TNO and illustrates it with two examples.

Both examples describe designs that have proven to be successful, and demonstrate the enormous value of Human Factors knowledge applied in early design phases of complex systems and environments. However, things are not always as bright as this for Human Factors specialists. More often than not, they are not asked to participate in such early phases of design and development, and are only involved much later, when problems in human functioning are emerging. One reason for this is that Human Factors contributions to design and development are seen as costs and not as investment. Furthermore, in particular when they involve social innovation, they are not appreciated by managers and project leaders used to thinking in terms of technological innovation.

One way out of this is to tightly couple Human Factors innovations to technological innovations. The design of operations rooms with reduced manning is a good example of this, because advances can only be made when knowledge of automation and Human Factors go hand in hand. Also the innovations in soldier systems show a close connection between technological developments and Human Factors design, not only because the human is the wearer and user of the system, but also because of the unique challenges imposed by the operational environment of the dismounted soldier.

A positive trend that helps Human Factors experts in their efforts to be involved in design and development is the increasing use of total costs of ownership as main financial parameter. Good Human Factors design often increases the initial costs, but pays itself back during the lifetime of a system or platform. For maritime vessels, it is for example estimated that almost half of the total costs of ownership are costs related to the crew size. A recommendation for Human Factors experts is, therefore, that they should pay more attention to the return of investment of their innovations, not just in a qualitative manner but using quantitative methods wherever possible.

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