ELSEVIER

Applied Ergonomics 37 (2006) 479–490

APPLIED ERGONOMICS

www.elsevier.com/locate/apergo

Human-factors engineering for smart transport: Decision support for car drivers and train traffic controllers ☆

Dick Lenior[a,*], Wiel Janssen[b], Mark Neerincx[c], Kirsten Schreibers[a]

[a] *ErgoS Engineering and Ergonomics, PO Box 267, Enschede, The Netherlands*
[b] *TNO HF, PO Box 23, Soesterberg, The Netherlands*
[c] *Delft University of Technology/TNO HF, PO Box 23, Soesterberg, The Netherlands*

Abstract

The theme Smart Transport can be described as adequate human–system symbiosis to realize effective, efficient and human-friendly transport of goods and information. This paper addresses how to attune automation to human (cognitive) capacities (e.g. to take care of information uncertainty, operator trust and mutual man–machine adaptations). An introduction to smart transport is presented, including examples of best practice for engineering human factors in the vehicle ergonomics and train traffic control domain. The examples are representative of an ongoing trend in automation and they show how the human role changes from controller to supervisor. Section 2 focuses on the car driver and systems that support, or sometimes even take over, critical parts of the driving task. Due to the diversity of driver ability, driving context and dependence between driver and context factors, there is a need for personalised, adaptive and integrated support. Systematic research is needed to establish sound systems. Section 3 focuses on the train dispatcher support systems that predict train movements, detect potential conflicts and show the dispatcher the possibilities available to solve the detected problems. Via thorough analysis of both the process to be controlled and the dispatcher's tasks and cognitive needs, support functions were developed as part of an already very complex supervision and control system. The two examples, although from a different field, both show the need for further development in cognitive modelling as well as for the value of sound ergonomics task analysis in design practice.

Keywords: Traffic control; Decision support; Supervision; Adaptive systems; Cognitive engineering

1. Introduction

In work and daily life, boundaries seem to disappear. Physical transport of goods and men, as well as virtual transport of information increases. Processes need not necessarily be supervised on-site. Travelling transporters have access to actual context information on location, meteorological circumstances, delay, etc. to optimise the distribution processes. Boundaries are being crossed in designing these smart ways of transport. Important aspects of smart transport concern for example:

- receiving the appropriate information in a correct way and at the right time;
- realising trustworthy and pleasant task support and communication;
- preventing human alienation and loss of control of those smart techniques and
- providing access for people with special needs due to visual or auditive constraints or constraints in motion control or cognition.

Substantial research efforts are invested in the development of smart environments around themes like ubiquitous computing, interactive workspaces and mobile communication (Jacko and Sears, 2003). Implementation of this technology involves fundamental changes in the transfer of persons, goods and information, and poses new human-factor questions and challenges. The papers of the IEA2006 symposium 'Ergonomics on the move—Smart Transport' provided some examples, such as personalisation that helps to get the 'right' information and functionality at the right time and in the right way. For such adaptive systems,

☆This paper covers the two keynotes in the symposium 'Ergonomics on the move—Smart Transport', an integral part of the IEA2006 conference, by Wiel Janssen—section 2 and Dick Lenior—section 3.

*Corresponding author.
E-mail address: d.lenior@ergos.nl (D. Lenior).

0003-6870/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apergo.2006.04.021

important questions are how to realise trustworthy and pleasant task support and how to transfer information for adaptive systems (Corritore et al., 2003). In general, a major challenge of human-factor engineering is to guide development of human–machine systems in such a way that they address the diversity of users (Carroll, 1993), interaction styles (Maguire, 2001), work contexts (Neerincx, 2003) and tasks (Fleishman and Quaintance, 1984). Diversity is an important issue in the transport sector, because context information (e.g., location, weather, traffic jams) is being used to dynamically (re)plan the distribution of traffic by the traffic controllers and/or drivers with varying abilities and skills. To address important human-factor issues that arise in the design of smart transport environments, the ergonomics knowledge base and methods need to be extended and refined. This paper presents two best practices with some general lessons we have learned. Section 2 on smart cars and Section 3 on train dispatching show a change of the human role from controller to supervisor. Such a system can be effective when it supports the human capacities, which are crucial to fulfil this role, such as the capacity to anticipate possible conflicts and deal with unexpected circumstances. Cognitive engineering frameworks (e.g., Norman, 1986; Rasmussen, 1986) and human–computer interaction methods (e.g., Maguire, 2001) help to realize adequate task allocation and support. Theories from psychology put forward by Muir (1994) give insight into human response to new technology. Muir states that trust builds up over time. Systems are experienced as being trustworthy when they appear to be serviceable and show persistent and competent behaviour for the users. Due to clumsy user interfaces and system errors, trust may decline substantially (Muir, 1994). Cognitive ergonomics provides the methods for analysis and functional design, and the methods to test interim design proposals in a sound and systematic way (e.g. with mock-ups and simulators, as both cases show). Following such empirical methods, innovative task support can be developed and attuned incrementally to human capacity (Neerincx, 2003). Specific factors, sometimes new ones, are addressed in approaches, such as the uncertainty of information and timing of decision-making (Kerstholt and Passenier, 2000) and the mutual man–machine adaptations (Alty, 2003).

2. What are we going to do with those smart cars?

2.1. Introduction

Traffic accidents are a major life-shortening factor in most countries of the world. For example, every year about 45,000 people die and 1.5 million people are injured in traffic accidents in Europe. As it has become, by now, a platitude to state that accidents are due to human error, it is no wonder that many expect the human-factors profession to point to the solutions that should make these errors go away. The theme of this section is whether, and how, human-factors specialists can live up to that. The focus is on automobiles rather than infrastructure (road) design, if only because the White Paper on European Transport Policy for 2010 published by the European Commission a few years ago has identified the introduction of (semi-automatic) driver support systems in automobiles as the prominent candidate for reducing fatalities on the Union's roads by 50% by the year 2010. Incidentally, it is unlikely that we will see full automation of road vehicles for at least some decades, because:

- the required infrastructure is too costly;
- people, including policy makers, do not want it and
- industries and governments will not be able to solve the liability issue, i.e. who is going to be sued in the case of a technical malfunction.

Thus, this section deals with what is going to happen in the meantime, when partially automated driver support systems (generally termed advanced driver assistance systems or ADAS) will become available to the public. Ideally, we would need to base expectations of the associated safety effects on the following:

(1) The so-called engineering estimate, or initial effectiveness estimate, of a device's expected safety effect; i.e., the accident reduction to be expected on the basis of purely statistical or mechanical considerations. As an example, the seat belt's effectiveness increases the probability of surviving a vehicle crash, which is commonly estimated to be around 43%. This would then be the initial estimate of the reduction in fatalities if the entire population used the belt. Similar engineering estimates can be derived from, for example, collision avoidance systems and others.
(2) The degree of penetration, or use rate, of the device of the relevant population. For devices that rely on the acceptance by the population for their effectiveness, there is the issue of selective recruitment, meaning that the use rate *per se* and/or the effect a measure achieves is affected by self-selective processes in the population. The hypothesis is that those who opt for the device differ from those who do not in respects that are essential to the measure's effectiveness, the particular assumption being that those the least inclined to accept a safety device would profit from it the most (e.g., Evans, 1984).
(3) Changes in the user's behaviour that may be brought about by the device, in particular so-called behavioural adaptation processes.

Presently, our knowledge of all these issues is fairly limited. However, some efforts to model behavioural adaptation have been undertaken by several investigators, and these will be treated later.

2.2. Lessons we have learned from systems that have already been introduced

What can we learn from ADAS support systems that already exist, and of the role the human-factors profession has played in their development?

This is hard to say, since systems that are available on the market are mainly of the in-vehicle information systems (IVIS) type rather than ADAS systems, which act directly on the driving task. Nevertheless, our role has not been acknowledged universally by manufacturers, judging from the quality of some of the IVIS systems that you could buy up to at least the end of the previous century. Janssen et al. (1999) compared a number of radio data system-traffic message channel (RDS-TMC) systems that were commercially available in the late 1990s, in terms of the risk they would generate when presenting an informative message to the driver at the time he was supposed to be devoting his attention to performing certain standard manoeuvres in real traffic. The results are percentages of a large set of manoeuvres that were performed in an unsafe way, as judged by an experienced driving instructor, when the system presented a message at exactly the same time the manoeuvre (like crossing an intersection in a city) was executed (Fig. 1). The baseline to which unsafety was compared was the (legally and socially accepted) condition of listening to the car radio. What became clear was that two of the four systems evaluated in this way were far more unsafe than the baseline condition (which, incidentally, generated a significant proportion of unsafely executed manoeuvres by itself). Without going into great detail, it appeared that these results could be related to the lack of quality of fairly elementary handling and display of ergonomics. Apparently, no one had bothered to check a textbook on these basic aspects before the systems were brought onto the market. It should be acknowledged, however, that we as professionals have not always foreseen some of the effects that would follow the introduction of IVIS systems. For example, the widespread introduction and use of in-vehicle navigation systems has not led to a reduction in excess mileage (which was their primary aim), due to facts such as transport companies planning an extra delivery in the time they would otherwise have lost. This is an example of so-called behavioural adaptation, a phenomenon that we still know little about, although it is of the utmost importance when it comes to the introduction of more advanced support systems, i.e. ADAS (see Section 2.4).

Finally, it should be noted here that designing for the so-called average user is definitely a thing of the past. Elderly

Fig. 1. Percentage of a set of manoeuvres performed in an unsafe way for different commercially available RDS-TMC systems (Janssen et al., 1999).

Table 1
Standardized effect size (i.e., z-score relative to baseline/no IVIS = 0) for steering wheel reversal rate for three difficulty levels of a visual IVIS

IVIS condition	Standardized size of effect
Baseline	0
Lowest level of distraction	0.82
Intermediate level of distraction	1.24
Highest level of distraction	1.31

Values are averages over a number of simulator studies (Carsten et al., 2005).

and handicapped road users are taken very seriously nowadays, as exemplified by the fact that if you look at an average EU Integrated Project there is always a considerable amount of its capacity devoted to so-called specific groups, i.e. to deal with what is now commonly referred to as universal design. The future is that of personalised adaptive systems, which in some ways, either through the use of smart cards or through familiarising themselves with the driver by directly taking driving performance indicators while he drives, take into account with whom they are dealing (see Section 2.5).

2.3. Tools to assess workload and distraction

Besides good things, in-vehicle support systems may generate extra risks. The RDS-TMC example given above shows that unsafe behaviour may actually increase because messages coming from the system may lead to distraction, or to extra workload, at a time the driver should be occupied with something else.

In order to investigate these effects, we need tools and metrics to measure them, so that we can determine the shape of dose–effect functions, e.g. between the level of distraction generated by an in-vehicle system and the level of deterioration in the quality with which the driving task is being performed. As, in turn, the effects of (some of) these performance parameters on accident risk become known, we would then have the means of directly estimating risk consequences of distraction caused by a secondary task (that is, the support).

Recent research has come a long way towards establishing what are the most sensitive parameters of driving performance in this respect. Below is an example from the HASTE Project (Carsten et al., 2005) showing a particular steering wheel parameter, the reversal rate, the frequency with which drivers change the direction of turn of the wheel, as a function of the level of distraction generated by an IVIS of a predominantly visual nature. The steering wheel parameter is so sensitive that it should certainly be included in the tool box (Table 1).

2.4. Behavioural adaptation and should we be afraid of it

Behavioural adaptation is a summary descriptive term that stands for a number of phenomena that may occur as

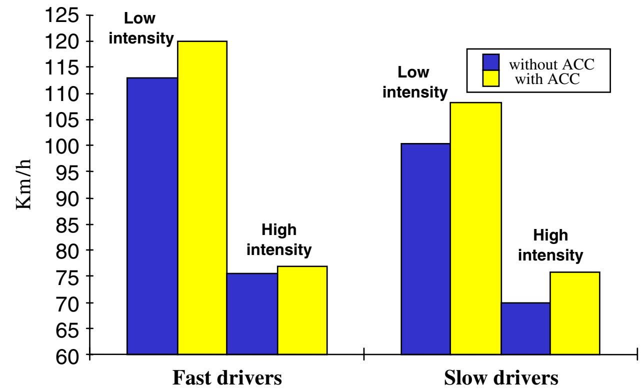

Fig. 2. Speed increase for two types of drivers when driving with an advanced cruise control (ACC) in quiet and busy traffic (Hoedemaeker, 1999).

a consequence of drivers interacting with an element newly introduced into their habitual task environment. The general connotation of the concept is that it is detrimental to the beneficial safety effects. These were originally foreseen to result from the new support system, in which case it is commonly indicated as evidence of so-called risk compensation.

Two forms may be distinguished, direct and higher-order behavioural adaptation.

2.4.1. Direct changes in behaviour

The final word has not been said about risk compensation. While it has been established that drivers do show riskier behaviour in several important cases (anti-lock braking systems (ABS) Aschenbrenner et al., 1994; seat belts: Janssen, 1994; advanced cruise control (ACC) Hoedemaeker, 1999: see Fig. 2), it is not clear (a) whether they will always do this, or what would distinguish cases in which they do from cases in which they do not and (b) whether the compensation is complete, i.e. will eliminate the expected safety effect.

To come to terms with these questions, we would need valid and quantitative models of road-user decision-making. An elementary utility model (see Janssen, 2005) has already been of some service in this respect. In this the road-user is assumed to balance the (dis)utilities of time loss and other costs during the trip plus the possible accident risk against the utility of being at the destination. From this, a choice of speed and possibly of other driving behaviour ensues, so as to be at the optimum of that balance.

It has been derived from this type of consideration, for example, that a device that has an expected effectiveness (i.e. engineering estimate) ε will not reduce accident risk with that factor but with a factor that happens to be

$$\hat{\varepsilon} = 1 - (1 - \varepsilon)^{-1/(c+1)}$$

in which c is a parameter in the function relating speed to risk, which has values of between 3 and 7 for different types of accidents. It is clear that the safety effect to be realized will always be less than the expected effectiveness, see Fig. 3.

While models like this may be useful in the future, they still have to demonstrate their validity when applied to the estimated safety effects of ADAS. What is wise, for the time being, is to at least explicitly anticipate the ways in which drivers might adapt. Thus, the empirical evaluation of prototype systems should be done such that behavioural adaptation can become manifest at that stage.

2.4.2. Higher-order forms of adaptation

Other forms of adaptation that may occur as a result of having the support are as follows:

- the generation of extra mobility, as we have seen in connection with navigation systems;
- traffic behaviour under more difficult driving conditions and
- driving by less-qualified segments of the driving population.

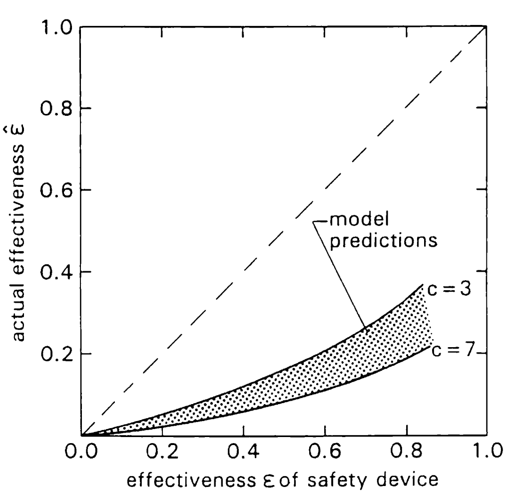

Fig. 3. Expected and actual safety benefits, according to a simple utility model of driver behaviour (Janssen, 2005; Janssen and Tenkink, 1988).

Modelling these effects will be more difficult than the effects for direct changes, simply because less is known about them. Fortunately, thinking about such models is now underway (e.g. see the recent collection of modelling efforts brought together by Macchi and Cacciabue, 2005).

2.5. The future: adaptive integrated systems

Several stand-alone ADAS systems, like collision avoidance or lane departure warning, are about to be introduced for sale to the general public, but in the premium vehicle segment only. In the meantime, manufacturers together with scientists from, among others, the human-factors discipline have started work on the next generation. These are systems that will meet two essential requirements so that drivers will not simply be overwhelmed by the input of all parts of the system fighting for attention. First, they will be adaptive. Apart from the urgency of the traffic situation that should be resolved, they will take the present state of the driver into account . This could range all the way from deducing that the driver must be too busy with a more important ongoing task to receive another message to highly personalised algorithms that conclude that this particular, 55-year-old but inexperienced male driver who has had a bad day at the office needs a really loud beep to warn him for an impending collision. Second, these systems will be integrated. This means that subsystems relate to each other in the technical sense (like sharing common sensors) and in their coordination of actions to the driver.

The ongoing AIDE Project (Engström et al., 2004) and Personalized Co-Drive Project (Neerincx et al, 2006) deal with the technical and behavioural issues related to adaptive integrated systems. A key problem that must be solved to enable the benefits of these new technologies in terms of safety and mobility is how precisely they can be integrated and harmonised with respect to their interaction with the driver. The solution to this problem necessarily involves technological development as well as closely integrated behavioural research. Key challenges include

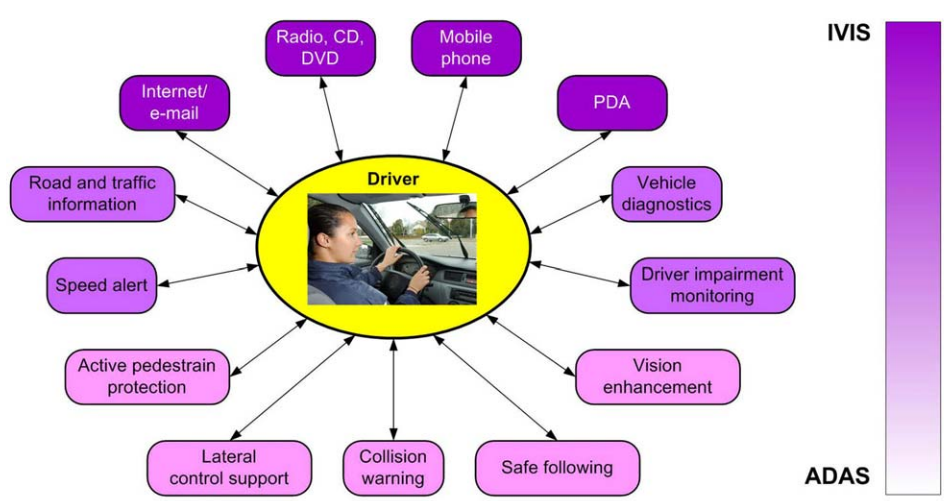

Fig. 4. Examples of existing and future ADAS and IVIS interacting with the driver.

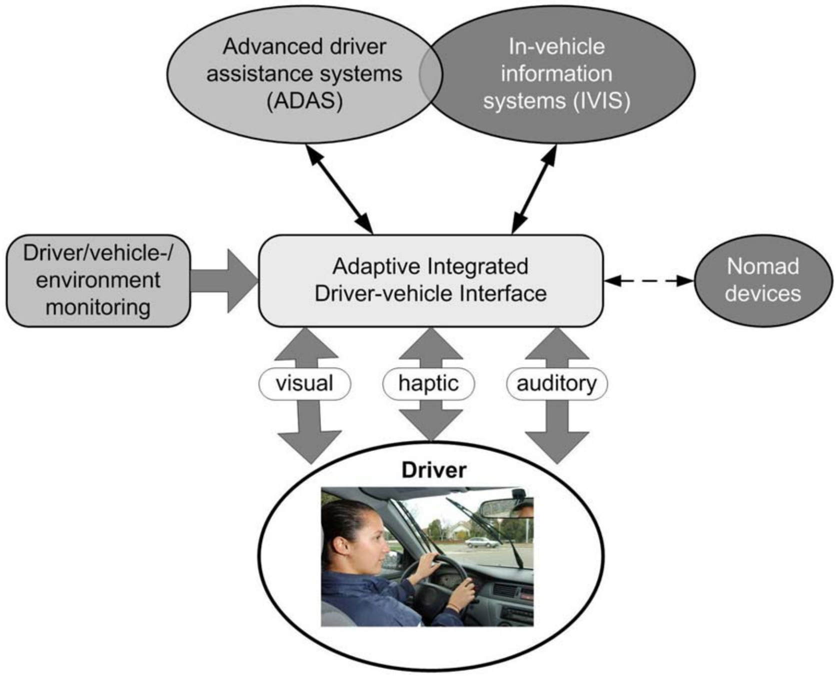

Fig. 5. Illustration of the general adaptive integrated driver–vehicle interface concept.

how to resolve conflicts between different functions, and how to best exploit adaptive human–machine interaction (HMI) concepts to optimise the HMI with respect to the current driving context and/or driver state. This involves the development of valid and cost-efficient methods for usability and safety evaluation of new functions. Figs. 4 and 5 below show how all this should be imagined. It is clear in these approaches that lessons from the past have been learned, in that they recognise the importance of adequate HMI per se, and of personalisation (at least to the degree of taking relevant driver characteristics into account), and of the different ways in which drivers could possibly adapt to the system.

2.6. Conclusion

This section has considered some of the issues that the human-factors and ergonomics profession can, and should, contribute to with respect to systems that support, or sometimes even take over, critical parts of the driving task. Smart in-vehicle aiding devices bear great promises within them to reduce the terrible toll that traffic accidents all over the world take year after year. If we do not design them right, however, we may introduce new accidents or make large investments that would be more cost-efficient if done elsewhere. The way to do it right as it looks now is to make systems that are adaptive to the state a driver is in and that integrate the actions of all separate components, so that the driver is always being talked to in a coherent way. This is our best bet for the future.

3. Design of decision support needs 'cognitive expertise'

3.1. Introduction

The car driver, as discussed in Section 2, gets a lot of influences from outside the car that interfere with the decisions he has to make in order to reach the desired destination. Many of these influences are beyond the driver's control. The same goes for the human operator in the situation described in this section. It focuses on the supervision of a system where several people have to cooperate. Although the system as a whole follows certain rules, in this case the different influences are not within the area of control of the supervisor. Complexity and time constraints are crucial in many process control situations. These two factors form the guideline in the discussion that will be illustrated with a sketch of the development of a decision support system for the supervision of rail traffic.

The literature about decision support systems (e.g., Zachary et al., 1998) shows that great efforts are being made in modelling the cognitive characteristics of the human controller of the system. However, where it concerns highly automated systems, it often is, because of the constantly changing dynamics, hardly possible to model the system completely. This situation is found in many control settings: e.g. see Gray and Kirschenbaum (2000) and Bainbridge et al. (1993) about several industrial processes and fire-fighting. The latter also reveals that in many logistic processes, where more organisations are involved, those constantly changing dynamics occur.

Therefore, it can even be questioned if modelling the way of working of the human controller is a smart way to go.

3.2. Human factors and rail traffic supervision in the Netherlands

One of the transport sectors where automation plays an important role is rail traffic. A main target in this sector is a more efficient usage of the track, i.e. more trains per unit of time. And, of course, safety is a major aspect to deal with. Increasing the degree of automation is one of the developments to meet this target of a higher train density and a high standard of safety. Two decades ago, Dutch Railways started a huge project for modernising and integrating all the (sub)systems for planning and controlling the train traffic processes. At that time it was the first railway company in the world with such far-reaching ambitions. In addition to the necessity to handle more trains on the same infrastructure, management recognised that the task of the different people involved in the control of the train service had already become too demanding and too complex. Therefore, further automation of traffic control was a spearhead in the project. However, management recognised that even with increased automation the human operator would always retain an important role in the control of these systems while train traffic is composed of all sorts of different processes, each with their own dynamics, goals and demands. So, from the very start, human factors were considered to be of vital importance in the project. This view led to an extensive set of human-factor-related activities from which a thorough task analysis of the dispatcher's work was the basis. The newly developed systems basically changed the work of all people involved in the rail traffic planning and execution from 'responding to disturbances that just happened in the process' to 'planning for predictable events'. For more information, see Lenior (1993). One of the last (sub)-systems to be developed in the project was/is a decision support system for the dispatcher.

3.3. Context of the dispatcher

The train traffic control organisation involves four categories: (1) dispatching; (2) shunting; (3) platform processes and (4) coordinating traffic control. The decision support system that we discuss here is meant for the dispatchers. The dispatcher is responsible for dealing with safe and efficient distribution of the rail infrastructure for all trains in a certain region. The main activities are unblocking tracks (signals on green and switches in the right position) in order to permit train movements. Up to 10 years ago, the dispatcher unblocked tracks one by one when a train was approaching or departing. As a result of the project, it is nowadays done by an automaton, which detects and identifies the train, compares the data with the time-table/schedule and, after finding every aspect in order, unblocks the track. So, when everything runs according to the time-table, the dispatcher's job is supervisory and can be slightly boring. However, more or less serious disturbances occur every day: technical problems with infrastructure and/or rolling stock, animals on the track, accidents at unguarded level crossings, suicides, etc. Then the dispatcher intervenes, mostly by adjusting the time-table and, in more serious cases, by switching off the automaton and taking over the actions manually. A description of the research for and development of these aids has been given by Lenior (1993). Controlling with a time-table-based automaton is the first step in automation. Nevertheless, in situations of disturbed train traffic the controller has to intervene by adjusting the time-table. So the cognitive capacities of the dispatcher set the boundaries. Therefore, the development of a decision support system is a logical next step.

3.4. Distinctive features of decision support

Obviously, an effective decision support system leads to smarter transport. It supports the person who needs to take the decisions. In some cases the system 'takes over' and the 'human expert' only supervises. This applies to many situations of supervisory control. In the same way it applies to the automaton, which after some checks, unblocks the tracks for the dispatcher. Although this is a relatively simple automaton, for the development of such an aid it is important to have insight into the tasks to be fulfilled as well as into the cognitive processes that form the basis of the decisions the dispatcher takes. Such decision support entails a shift from human-centred design methods for user interfaces (Maguire, 2001) to cognitive approaches for the development of human–machine cooperation (Hoc, 2001).

When the dispatcher decides to take over it is not necessary that he knows the operational details of the supporting system. After all, the car driver in Section 2 does not have to be familiar with the technical details of the automobile. The driver certainly has to know the likely actions of the other participants in the traffic and the way the car reacts to his steering actions. By the same token, the dispatcher has to know the process state and has to be aware of the criteria used by the automaton to make decisions. If there are some delays, the dispatcher wants to intervene only when the train is driving outside its time-table margins and/or if it is influencing the scheduled route of another train. The dispatcher will leave conflicting train movements to the automaton as long as (s)he does not expect changes in the sequence of trains and/or the opportunities for passengers to change trains at the junctions.

These considerations of the dispatcher may serve as design criteria for support systems. This does not sound too difficult. However, it is not sufficient, as earlier research revealed (Lenior, 1993). The static elements of the process such as the situation of the tracks, the signs, etc. are represented quite accurately in the mind of the dispatcher. This is not the case with the dynamics in the system, e.g. the speed of the different trains, and its relation to the place where they will be at a later moment. The same research brought to light that the information derived from communications also proved to be inaccurate. The dispatcher actually tries to counterbalance uncertainty, for example: does the train really depart or is it held up by a last minute passenger, an undetected technical failure, an inattentive engine driver, etc.? These uncertainties lead to an operating behaviour by which the train dispatcher is not inclined to look far ahead. Even when he has already received information about delays of some trains, he will seldom try to calculate to what situations this might lead to far ahead. The overall opinion of train dispatchers was that with so many alterations that could occur later on, it is pointless to make an early operational schedule. However, analysing cases and discussing the results with dispatchers made clear that in many cases this way of dispatching is inefficient. In short, a dispatcher has to work with assessments of the process state. Therefore, a better decision support system had to be developed, which predicts train movements and gives suggestions for solving the detected problem.

3.5. What cognitive expertise is needed in developing a decision support system?

Clearly, the basic characteristics of the cognitive processes in the job of a dispatcher are anticipation and, if there are serious disturbances, decision in uncertainty. Because of time constraints the dispatcher continuously has to make a choice: is it appropriate to take action or should I wait for or gather more (adequate) information ? The available information can be incomplete or too complex to interpret unambiguously. The examples in the preceding paragraphs will have made clear that analysing and subsequently interpreting the cognitive needs of a dispatcher during the execution of his tasks is not an easy way to go. It is even questionable if such a cognitive approach is fruitful. After all, the cognitive performance of the dispatcher is difficult to investigate and, in heavily disturbed situations it could even be called inadequate.

This last statement of inadequacy was substantiated only after a very thorough situation/task analysis (Lenior, 1993). Until that time one had only conjecture.

Therefore, it is valid to conclude that the incompleteness and/or complexity of the available information make the process state hard to interpret unambiguously, and the complexity holds for the whole task situation. So, in order to adequately design aids to allow the dispatcher to deal with this complexity, it is important to analyse what this really means. Many areas of expertise have dealt with the concept of complexity. It is clearly not an easy concept to grasp (e.g. see Rosen, 1977; Gottinger, 1983; Hollnagel, 1988). Four main aspects will be distinguished here, and each aspect will be accompanied by some applicable remarks. Does it concern:

a. *process aspects* such as the relation between variables: dynamics of the process, time constraints, or difficulty of the mathematical algorithms in the automated loops of the process ?
b. *task aspects* like: are the criteria for correct performance clear ?
c. *aspects of representation of task requirements*, such as: does it fit the mental models dispatchers have of their processes. These models concern the geographical aspects of the system as well as task demands and task execution and
d. all sorts of *environmental factors* in both a physical and a social/organisational sense ?

Before moving on to the design approach for the decision support system, it is desirable to give each of these complexity factors a short, exemplary consideration.

3.5.1. Process aspects

In (petro)chemical industries it is well known that ongoing automation means that operators control their processes from an increasing 'distance' both in a physical/geographical manner of speaking and 'cognitively spoken'. The optimising algorithms include many more variables than can reasonably be grasped by any operator. Think of: use of feed stock, use of energy, risk of equipment damage, etc. Operators often do not know exactly how the individual algorithms work. But they do know the overall behaviour and the results that can be achieved by changing the set points. So when an operator in a (petro)chemical plant intervenes in the process, the consequences are more or less predictable. For the train dispatcher, however, this very often is not the case, because: (1) much of the information he gets is 'filtered' by colleagues; (2) some parts of the information he has to fill in himself and (3) his control loops very often have an open nature. A train driver has to drive at a prescribed speed, but there can be a lot of reasons (e.g. children playing near the tracks) why he deviates. In a nutshell, in disturbed situations of train service there are many things that happen outside the dispatcher's span of control.

3.5.2. Task aspects, especially quality criteria

The considerations of the train dispatcher solving task problems are numerous. One of the task aspects that is crucial for decision support but is often not considered in the analysis concerns the quality criteria each operator uses. He does this often implicitly. So, when not asked explicitly, he probably will not tell. Of course, a dispatcher's goal is allocation of rail infrastructure to all trains in order to make it possible for the transporters to deliver the promised product to passengers and transporters of goods. Criteria for a sound product could be:

- timely discovery of a conflict of train movements;
- correct anticipation of the development (is the conflict becoming more or less likely to occur ?);
- timely consideration of possible solutions *and* consulting other parties about them and

- timely and correct execution of actions to realize the chosen solution

Obviously, timely is a keyword here. The meaning is: 'not too early, not too late' i.e. when does the dispatcher conclude: 'my judgement is good enough'? This often results in just-in-time actions.

3.5.3. Representation of task requirements

Train dispatchers see representations of the occupation of the infrastructure by trains and other activities like maintenance. These representations pretty well fit their mental models. Since they have continuously actualised schedule/time-tables at their desks, they can monitor deviations between the actual process state and the planned product. So, without going into further ergonomics details, their insight into the task requirements can be called rather good. However, this does not correspond with the observation that the 'product' of the train dispatchers is still not at a desired level. Apparently, the simple supporting applications that exist, like the track-unblocking automaton, are not adequate for achieving the desired level of operation. This is due, at least partly, to a misunderstanding of the designers of the quality criteria mentioned in Section 3.5.2. Moreover, as mentioned before, they do not have enough insight into the dynamics of the system (speed and predicted place of the trains) and the communications do not help. So, analysis by a cognitive expert is not a luxury. (See discussions about situational awareness by, e.g. Endsley et al., 2003.)

3.5.4. Environmental factors, especially organisational changes

The physical environment at the control centres is reasonably good. The organisation of the train traffic control itself is rather transparent. But, as mentioned before, in disturbed situations many things can happen outside the span of control of the dispatchers.

This is caused partly by the overall organisational changes in the sector. Over the last decade, there has been a strong tendency toward privatisation in the public sector. This has resulted in, for example, the splitting up of the Dutch Railways Company into a semi-state-controlled company for the management of the rail infrastructure (the infra provider) on the one hand and several private companies on the other. The latter encompass passenger transport, goods transport, stock maintenance, station exploitation, etc. This changed the work of the supervising personnel. In earlier days the department of train traffic control was controlling most of the events that happened in the infrastructure. When there were irregularities, train traffic control took care of the re-establishment of the total transport process. Since the split into public and private companies, train traffic control has the duty to provide transporters with time slots on the different sections between different places. For instance, replacement of rolling stock and personnel is done by the transporters themselves. The allocation of infra-capacity has to be done in a neutral, impartial way. Therefore, dispatchers in the train traffic control no longer focus on solving train traffic problems as a total process. They have to work according to fixed scenarios as agreed upon in the contracts with the transporters. This means, for example, that the communication with the coordinating traffic controllers and dispatchers of the adjacent areas can be restricted. Although these changes do not necessarily improve the insight into the disturbed situation, it makes clear, better than in earlier days, what the responsibilities of the dispatcher are.

It goes without saying that a good decision support system, with well-defined quality criteria, can contribute much to the complex interrelations between the different parties concerned in the rail sector.

3.6. Sketch of the development of the decision support system

The preceding paragraphs reveal that the development of a decision support system for train dispatching was an interesting challenge for technical designers and human-factors specialists. It is obvious that during this development process experienced train dispatchers were consulted intensively. However, the project group had to explore the possibilities for a 'quality jump'. Therefore, in addition to consulting dispatchers, the starting point was an analysis of the process. This was done in the same way as in earlier research, independent of the way problems are solved in the existing situation.

The steps were: (1) description of events; (2) for each of the events description of: (2a) potential effects; (2b) manifestation; (2c) required man–machine system actions; (2d) result of the system actions and (3) from the system actions, system tasks are composed.

Then, as in most ergonomically sound design procedures, a careful process of task allocation revealed the characteristics that a decision support system should have to achieve the desired increase in quality.

In global terms, the system consists of four main modules. The first module, knowing the distinguishing characteristics of the infrastructure and the kind of rolling stock, predicts the future position of all the trains in a rather large area around the dispatcher's own control area. The second module detects several kinds of conflicts. Three categories of conflict can be discerned:

- The first category encompasses conflicts that are the result of calculations revealing that *the predicted time to stop at a station* will be shorter than the minimum time defined in the plan. At the smaller stations, the system will automatically change the departure time. In this way, the predictions downstream will be more accurate. At some (larger) stations, the conflict will be pointed out and alternative solutions for the conflict are proposed. The dispatcher then decides which adjustments should be made. These will depend on the situation at the station, time of the day (rush hour), etc.

- A second category can be described as *planned infrastructure for train movement not available*. This can be due to technical problems with infrastructure and/or because the infrastructure is occupied by a delayed or defective train. The dispatcher gets an overview of all the related train movements and the possible alternative routes. When there is a prediction of conflicting train movements, the system will propose a right of way to one of them. This is because of the different characteristics of trains. For example a faster intercity train must not follow a slower local train. The system carries out the measure when the dispatcher has confirmed a choice of action.
- The third category is in fact an undesired effect of the second. It can be described as *right-of-way measure causes unnecessary waiting time*. This is the case if the predicted conflict is no longer likely to occur. The dispatcher is offered the possibility to remove the right-of-way measure from the plan.

As described above, the system offers the dispatcher alternative solutions when conflicts are detected. This is the third module. An essential characteristic of this aid is that the MMI shows the connection between the conflicts and offers the possibility to change all related train movements in only a few actions. The whole search action and dialogue seldom lasts more then one minute. Therefore, this module gives the dispatcher considerable possibilities to escape from the time constraints as mentioned before. It is even possible to stop the module at any moment and ask for the results up to that point in time. However, during the pilot studies, which were executed at one of the most demanding dispatcher places, the alternative solutions were offered so quickly that there was no need to interrupt the module.

A fourth module is not realised yet, but it is designed and built in a realistic simulator. This module executes a cost:benefit ratio analysis and subsequently offers the dispatcher a package of measures to solve the existing problems. However, usually the system cannot solve all the existing problems, it has to optimise. One key factor in the optimisation is time. The module calculates until the short-term conflicts are being solved and shows the remaining conflicts in future. If the dispatcher has confirmed the choice of solution, the system carries out all the proposed measures. The MMI makes it possible for the dispatcher to use only a part of the solution. This is done by showing the dispatcher the measures in a time sequence. He can then change a certain measure in the sequence and give the system an assignment to recalculate from that point on in the sequence of measures. In this way, the dispatcher can 'build' an optimal solution with the aid of the system.

An important aspect of this fourth module concerns, of course, the cost:benefit ratio criterion. This topic led to a lot of discussion in the design group. For example, it is not adequate to make a package of right-of-way rules based solely on the characteristics of trains (e.g. faster intercity before slower local train). The decision as to which train must get right of way does not depend only on speed. Other important factors are, for example, distance until the first opportunity to pass by and whether a train has reached its final destination at the next station. After analysing numerous cases of disturbed train traffic, the design group had to conclude that only the consideration of the *total result* of a set of measures could function as 'criterion' for the quality of the solution. Therefore, the module provides a kind of decision-making tree and figures out which solutions are possible for each of the conflicts. Each branch in the decision-making tree results in a plan (at a certain, future point in time). Next, the module judges the quality of each of these resulting plans by counting the total amount of delay-seconds and a number of delay-seconds (defined in advance) for each conflict that remains in the plan. So, based on the total number of delay-seconds, a ranking of the solutions is done and presented to the dispatcher. The first (best-ranked) solution is shown in detail. He can then decide to choose one of the other solutions or he can choose to build an alternative solution by adjusting the measures in the solution shown. The 'weight' assigned to each conflict can be tuned in practice. Because of this last feature, the system offers possibilities as a learning decision support system.

3.7. Conclusion, cognitive expertise as the guiding principle

The example of train dispatching is just one chosen out of many process control settings where complexity and time constraints are crucial. In most of these settings, rather advanced systems are used, but full automation is not possible. Specialised human operators are still the experts needed to control. Nevertheless, in attempts to increase the performance of these systems, the efforts of technical designers seem to be directed to replacing the cognitive abilities of the human expert by advanced automation. This seems to be the case even when the systems to be developed are called *support* systems. The example of train dispatching and the fire-fighting example described by Rogalski and Samurçay (1993) show that this 'replacing strategy' is not a fruitful one. The characteristic features of these situations are: (1) there is no best solution for a problem; (2) the way to achieve an optimal solution cannot be determined in advance and (3) a certain mental pressure exists (mostly time constraints) that force the operator to make a choice for the execution of a solution, which might not be perfect but is well considered, i.e. the situation can be described as decision in uncertainty.

These systems can be called complex in terms of changing dynamics and the lack of full control, which makes it impossible to model the system as a whole. This is especially the case when different people in the system have different responsibilities and are in a position to take decisions, thus influencing other decisions. It is then better to opt for decision support in the true meaning of the word, i.e. supporting the specific capacities of the human expert. Therefore, analysis of the system in the light of the cognitive abilities of this human expert is a prerequisite for success. This means: (1) a thorough analysis of the aim and the characteristics of the process; (2) the results have to be translated into requirements for the control of the whole Men–Means–System and (3) design takes into account the cognitive (im)possibilities of the people within the system. The latter encompasses a systematic task allocation.

According to human-factors literature (e.g. Sheperd and Marshall, 2005), the strategy of the Dutch Railway's management to consider human factors of vital importance is not common practice. Certainly not when management has to support (and finance) an extensive set of human-factors-related activities, as was done in this project. Looking back, this strategy may be called a success. Even after 10 years, the original analyses proved useful in designing advanced decision support. Hopefully, this success stimulates more thorough human-factors work in the design of complex systems.

4. Discussion

The examples of technical support systems described come from very different situations but from a cognitive point of view they have important aspects in common as well.

Because of increasing automation, the work situation of the dispatchers is going to show similarities with supervisory control in process industries. In the previous section, we mentioned some features of the dispatcher's work: (1) no best solution for a problem; (2) unknown way to achieve an optimal solution and (3) a certain pressure to choose a solution, although that is not perfect. Comparing this to the supervising operator in industry, we see that the first two characteristics do not apply and the third applies only partially. Therefore, in these situations the degree of automation cannot be as extensive as in process control. The dispatcher's task can be better performed if automation is focused on really *supporting* systems.

The 'work situation'of the car driver shows remarkable resemblances to the dispatcher's work. Because of the continuously changing dynamics of (busy) road traffic, the car driver: (1) does not know a best solution in advance and (2) has to act without knowing if a solution is the best one. These factors, together with the costly infrastructure and the liability issue in the case of technical malfunction, make full automation not feasible for many years.

Developing technical aids for human support absolutely needs human-factors expertise: i.e. knowledge about human behaviour as well as human engineering analysis techniques. The new technologies will change the tasks for the human drivers or operators in a fundamental way. Drivers and operators will adapt their behaviour to the new situation, employ new task strategies, e.g. risk compensation and start new learning processes.

Only adequate harmonisation of new (innovative) technology with both the operational demands and human needs will lead to smart, i.e. effective, efficient and human-friendly transport.

Does the human-factors profession have the required expertise? In theory yes, but is it applicable? Zachary et al. (1998) established that decision theory is well developed but lacks knowledge about the way in which people actually make decisions in everyday settings. In the human-factors literature, the majority of articles deal with modelling cognitive behaviour. Zachary et al. showed the applicability of a developed framework for the cognitive analysis process in tactical decision-making in ship-based anti-air warfare. Grootjen et al. (2002) developed such a framework and applied it to the design of a prototype for the Officer of the Watch on a ship's bridge. In further developments (Neerincx et al., 2003), the same framework 'Colfun' was used to specify with domain experts normal and critical scenarios, and for every scenario support functions, which subsequently were included in action sequence specifications (i.e. information handler, rule provider, diagnosis guide and task scheduler).

These developments in human-factors research and engineering give reason to believe that the profession will have answers to the requirements of design engineers of these support systems. On the other hand, it makes clear that a sound analysis of the future tasks is still the basis for building or redesigning advanced decision support systems. Let us aim for the ideal situation where such an analysis is a general practice for every human-factors practitioner.

References

Alty, J.L., 2003. Cognitive workload and adaptive systems. In: Hollnagel, E. (Ed.), Handbook of Cognitive Task Design. Lawrence Erlbaum Associates, Mahwah, NJ.

Aschenbrenner, K., Biehl, B., Wurm, G., 1994. Mehr Verkehrssicherheit durch bessere Technik? Felduntersuchungen zur Risikokompensation am Beispiel des Antiblockiersystems (ABS). Bast, Bergisch Gladbach, Bericht 8323.

Bainbridge, L., Lenior, T.M.J., Schaaf, T.W. van der (Eds.), 1993. Cognitive Processes in Complex Tasks, vol. 36. Ergonomics, vol. 36. Taylor and Francis, London, p. 11 (special issue Ergonomics).

Carroll, J.B., 1993. Human Cognitive Abilities: A Survey of Factor Analytic Studies. Cambridge University Press, New York. Hoc, J.-M., 2001. Towards a cognitive approach to human-machine cooperation in dynamic situations. Int. J. Hum. Comp. Stud. 54, 509–540.

Carsten, O.M.J., Merat, N., Janssen, W.H., Johansson, E., Fowkes, M., Brookhuis, K.A., 2005. HASTE Final Report. Institute for Transportation Studies, University of Leeds.

Corritore, C.L., Kracher, B., Wiedenbeck, S., 2003. On-line trust: concepts, evolving themes, a model, Int. J. Hum. Comp. Stud. 58, 737–758.

Endsley, M.R., Bolté, B., Jones, D.G., 2003. Designing for Situation Awareness: An Approach to User-centered Design. Taylor & Francis, London, UK.

Engström, J., Arfwidsson, J., Amditis, A., Andreone, L., Bengler, K., Cacciabue, P.C., Eschler, J., Nathan, F., Janssen, W.H., 2004. Meeting the challenges of future automotive HMI design: an overview of the AIDE integrated project. In: Proceedings of ITS, Budapest.

European Commission, 2001. White Paper on European Transport Policy for 2010: time to decide.

Evans, L., 1984. Human behavior feedback and traffic safety. Hum. Factors 27, 555–576.

Fleishman, E.A., Quaintance, M.K., 1984. Taxonomies of Human Performance: The Description of Human Tasks. Academic Press, Orlando, London.

Gottinger, H.W., 1983. Coping with Complexity, Perspectives for Economics, Management and Social Sciences. Reidel, Dordrecht.

Gray, W.D., Kirschenbaum, S.S., 2000. Analyzing a novel expertise: An unmarked road. In: Schraagen, J.M.C., Chipman, S.E., Shalin, V.L. (Eds.), Cognitive Task Analysis. Mahwah, NJ, Erlbaum.

Grootjen, M., Neerincx, M.A., Passenier, P.O., 2002. Cognitive task load and support on a ship's bridge: design and evaluation of a prototype user interface. In: Proceedings of the INEC 2002 Conference, IMarEST, London, England, pp. 198–207.

Hoc, J.M., 2001. Towards a cognitive approach to human-machine cooperation in dynamic situations, Int. J. Hum. Comp. Stud. 54, 509–540.

Hoedemaeker, M., 1999. Driving behaviour with adaptive cruise control and the acceptance by individual drivers. Ph.D. Thesis, Delft University of Technology.

Hollnagel, E., 1988. Cognitive Engineering in Complex Dynamic Worlds. Academic Press, London.

Jacko, J.A., Sears, A. (Eds.), 2003. The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications. Lawrence Erlbaum Associates, Mahwah, NJ.

Janssen, W.H., 1994. Seat-belt wearing and driving behavior: an instrumented-vehicle study. Accid. Anal. Prev. 26, 249–261.

Janssen, W.H., 2005. Modelling Driver's Risk Taking Behavior. In: Macchi, L., Re, C., Cacciabue, P.C. (Eds.), Modelling Driver Behaviour in Automotive Environments. European Commission, JRC, Ispra, pp. 105–112.

Janssen, W.H., Tenkink, E., 1988. Considerations on speed selection and risk homeostasis in driving. Accid. Anal. Prev. 20, 137–143.

Janssen, W.H., Kaptein, N., Claessens, M., 1999. Behavior and safety when driving with in-vehicle devices that provide real-time traffic information. In: Proceedings of the Sixth World Congress on Intelligent Transport Systems, Toronto.

Kerstholt, J.H., Passenier, P.O., 2000. Fault management in supervisory control: the effect of false alarms and support. Ergonomics 43, 1371–1387.

Lenior, T.M.J., 1993. Analysis of cognitive processes in train traffic control. Ergonomics 36, 1361—1368 (special issue).

Macchi, L.R.C., Cacciabue, P.C. (Eds.), 2005. Modelling Driver Behaviour in Automotive Environments. European Commission, JRC, Ispra.

Maguire, M., 2001. Methods to support human-centred design. Int. J. Hum. Comp. Stud. 55, 587–634.

Muir, B., 1994. Trust in automation: Part I. Theoretical issues in the study of trust and human in-tervention in automated systems. Ergonomics 37, 1905–1922.

Neerincx, M.A., 2003. Cognitive task load design: model, methods and examples. In: Hollnagel, E. (Ed.), Handbook of Cognitive Task Design. Lawrence Erlbaum Associates, Mahwah, NJ, pp. 283–305 (Chapter 13).

Neerincx, M.A., Rypkema, J., Passenier, P.O., 2003. Cognitive and functional (COLFUN) framework for envisioning and assessing high-demand situations. In: Proceedings of the Ninth European Symposium on Cognitive Science Approaches to Process Control, EACE conference Series, Amsterdam, The Netherlands, pp. 11–16.

Neerincx, M.A., Hoedemaeker, M., de Gier, E., 2006. Adaptive In-Car User Interfaces Based on Personalized Workload Estimation. Submitted for IEA2006, July 2006, Maastricht, the Netherlands (in press).

Norman, D.A., 1986. Cognitive engineering. In: Norman, D.A., Draper, S.W. (Eds.), User-Centered System Design: New Perspectives on Human–Computer Interaction. Erlbaum, Hillsdale, NJ.

Rasmussen, J., 1986. Information Processing and Human–machine Interaction: An Approach to Cognitive Engineering. Elsevier, Amsterdam.

Rogalski, J., Samurçay, R., 1993. Analysing communication in complex distributed decision making. Ergonomics 36, 1329–1344 (special issue).

Rosen, R., 1977. Complexity as a system property. Int. J. Gen. Syst. 3, 227–232.

Sheperd, A., Marshall, E., 2005. Timeliness and task specification in designing for human factors in railway operations, in:. Appl. Ergon. 36, 719–727 (special issue).

Zachary, W.W., Ryder, W.M., Wincinbothom, J.H., 1998. Cognitive task analysis and decision making in complex environments. In: Cannon-Bowers, J., Salas, E. (Eds.), Decision Making Under Stress, Implications for Training and Simulation. American Psychologal Association, Washington, DC.