Recognizing Complexity – A Prerequisite for Skilled Intuitive Judgments and Dynamic Decisions

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1 Introduction

There are two main approaches to intuition and expertise within the decision-making literature: heuristics and biases (HB) and naturalistic decision making (NDM). They often come to different conclusions regarding two topics: whether professional decision makers and experts can be trusted and whether algorithms should replace informal judgments or not. Interestingly, proponents from the two perspectives seem to agree on the fact that evaluation of the quality of intuitive judgments requires an assessment of the predictability of the environment in which the judgment is made, and of the individual's opportunity to learn the regularities of that environment (Kahneman & Klein, 2009, italics added). In this paper, we elaborate on this conclusion in two ways. First, we propose that a third approach, dynamic decision making (DDM), (see Brehmer, 1992, for an introduction), for assessment and evaluation of human decision making in general and professional judgments in particular should be considered when discussing human intuitive judgments. Second, when the time factor is included in the analysis of decision-making of experts, it is our experience that intuitive judgments and decisions are best understood if the evaluation is based on an assessment of the strategies employed by the individuals during the decision-making process. A first purpose of this paper is therefore to describe how experts make immediate judgments and how they take measures for action based on continuous evaluation of the ongoing decision-making process, i.e. how decisions are made with respect to two time horizons. In order reach such a description, the decision-making task must be separated from the use of the current decision support system, i.e. what do the decision strategies look like when the effect of the decision support system is controlled for. We have previously carried out such analyses, all of them in representative decision contexts, i.e. Erlandsson & Jansson, 2007, 2013a; Jansson, Olsson & Erlandsson, 2006; Jansson, Olsson & Kecklund, 2005; Olsson & Jansson, 2005; 2006. The description of skill-based decision-making processes presented in this position paper is based on these studies.

Once the goal-directed decision-making process is separated from the measures directed towards the current system, it is possible to understand the actions taken by the decision-maker in relation to what he or she tries to achieve. It is then also possible to evaluate in what way a particular decision-support system contributes to the predictability of the task-artifact environment, and to evaluate the experts' opportunities to learn the regularities of that environment. This will hopefully shed some light over the questions of, under what conditions algorithms can replace informal judgments, how algorithms must be designed in order to fit into a sociotechnical system, as well as, what principles there are for visual display of information supporting skilled experts in their decision-making.

2 Background

In order to conduct analyses of decision-making strategies, there are a number of methods available. Within the DDM-approach, one attempt was based on the use of computer-simulations, i.e. microworlds (see Brehmer & Dörner, 1993 for an introduction). Microworlds can be seen as a way to expand Brunswikian psychology, i.e. as an elaboration of representative design by extending Brunswik's conception of task properties to include changing task properties, thus adding the dynamic character to decision-making tasks (Hammond, 1999). So far, however, the microworld approach has focused on empirical studies with little or no theoretical progress. There are mainly two reasons for this: 1) the choice of task conditions has so far been arbitrary since there is no appeal to a theory of tasks; and 2) the results coming out from experiments with microworlds have been quite short on psychology, i.e., performance and behavior of subjects interacting with microworlds are mostly described in non-psychological terms (Hammond, 1999). Without theoretical progress on relevant psychological constructs, it is not possible to apply the results from the microworld studies in real-world contexts and situations. However, the most important contribution from research using microworlds is perhaps the fact that assessing the strategies people employ when confronted with a dynamic decision making task is a prerequisite for understanding what kind of knowledge or model they are basing their judgments upon (Brehmer & Allard, 1991; Brehmer, 1992; Jansson, 1995; Jensen, 2003). In this paper we describe the results from using a new method for evaluation and assessment of the strategies people employ when confronted with real-world decision making tasks.

3 Method

The methodological approach applied throughout the three studies described below is on a general level perhaps most properly described as participatory analysis. Members of the research team spent a considerable amount of time studying decision-makers in three decision contexts, i.e. train-driving, high-speed ferry operation and train dispatching, carrying out cognitive field studies. These studies include the use of different verbal reporting procedures, different forms of interviews, quasi-experiments, recognitions tasks, participatory design sessions, and surveys. The overall purpose was to evaluate and assess what kind of strategies people employ in a representative decision context. Most of the methods gave interesting information on observable behaviors, but were more limited when it came to non-observable behaviors. The assessment of strategies demanded some form a method that could elaborate on the non-observable behaviors while the experts made their judgments and decisions. For this purpose, a new method, collegial verbalization, was developed.

3.1 Collegial verbalization

The collegial verbalization method was developed inspired by ideas in ecological psychology in general, and specifically the work by Brunswik (1952; 1954; see also Hammond, 1966), Hammond (1993), and Hammond, Hamm, Grassia & Pearson (1987), but also the work by Brehmer (1996), Rasmussen, et al. (1994) and Vicente (1999). It was developed in response to the inability of traditional information acquisition methods to deliver data that could shed light over the routine actions carried out by skilled users in professional work contexts. For the purpose of being able to understand the non-observable actions, i.e. the judgments made and measures applied by the decision makers, a new method for knowledge elicitation, collegial verbalization (Erlandsson & Jansson, 2007; 2013a; 2013b) was developed. The rationale behind this method is that close colleagues often are able to verbalize on the strategies employed by their fellow colleagues, given the fact that they have been working together in the same team, with the same decision task and the same equipment for a long time. This gave us the idea to develop a method on the premise that close colleagues can share strategies with each other since they have experienced the same kind of working tasks over and over again. These experiences have shaped their strategies to the extent that it is no longer possible to claim that the behaviors exhibited in these situations are independent from the tasks. On the contrary, it is possible to predict that if colleagues have worked under the same behavior-shaping conditions, we expect the tasks to affect the operators in a similar way. One consequence of this way of reasoning is that it is not only possible for a close colleague to predict the strategies to be employed by his fellow colleagues, but also to verbalize the process of thought running through the mind while exploring and making this strategy explicit. For a discussion of the differences, as well as methodological advantages and disadvantages, between the CV-method and the more traditional forms of verbalization procedures, i.e. retrospective and concurrent probing procedures, see Erlandsson & Jansson, 2013a and 2013b.

Table 1 below shows the case study design of the high-speed ferry study. One crew participated in the video capturing phase on the way to the island of Gotland, and on the way back to the mainland of Sweden. Four other officers, highly familiar with the vessel, the route and the equipment, participated in the verbalization session.

On-site video capturing	**Collegial verbalization**
Participating crew, four officers on the bridge	A: Captain
	B: Navigator
	C: Captain
	D: Navigator

Table 1: The case-study design and the participating officers

Table 2 below shows the design of the train-driver study. The drivers that participated were only involved in either the on-site video capturing or in the collegial verbalization phase.

On-site video capturing	**Collegial verbalization**
Four drivers participated, one on a long-distance train, one on a middle-distance train, and two on commuter trains	A: Train driver
	B: Train driver
	C: Train driver
	D: Train driver
	E: Train driver
	F: Train driver
	G: Train driver

Table 2: The ad-hoc study design and the participating train drivers

Table 3 below shows the quasi-experimental design of the train traffic control study. Four highly skilled train dispatchers participated. First, each one of them participated as target operator in a video capturing session. The four sessions where captured on different days, but on the same work station at the same time of the day and focusing on the same control domain. A couple of weeks later, each one of them verbalized retrospectively on their own actions as well as performing a collegial verbalization on the actions of one of his or her colleagues.

On-site video	Retrospective ver-	Collegial verbali-
Task 1	A: Narrator	D: Narrator
Task 2	D: Narrator	C: Narrator
Task 3	C: Narrator	B: Narrator
Task 4	B: Narrator	A: Narrator

Table 3: The quasi-experimental design and the distribution of narrators over tasks

4 Results

Results from three different cognitive field studies are presented below. The results focus on the actual decision making tasks, e.g. when to start brake approaching a platform (train-driving), how to reschedule trains in order to avoid up-coming conflicts (train-traffic control) or when to alter the speed due to fog in a narrow passage (high-speed ferry). Since the most elaborate analyses were carried out at high-speed ferries, the presentation of the results starts with this domain.

4.1 High-speed ferry operators' spatial separation of the route

The four officers were asked to divide the trip into subparts were each part involves substantially different work tasks. Most officers considered that it was worth distinguishing between the following four subparts, see table 4, while some officers also mentioned start-up, standby and shut-down phases as important.

Departure
Open sea
Confined waters (archipelago, narrow fairways, shallow water)
Berthing

Table 4: Subparts of a journey that the officers identified as worth distinguishing between

Complementing the division of a journey into subparts, several officers also made a distinction between "safe water", the fairway and the ships predefined route. That is, instead of dividing the journey with respect to the position from start to end, the journey is instead divided sideways in respect to the ships route. They referred to "safe water" as areas where the specific ship can travel safely without e.g. run aground. Safe water areas can often be larger than just the fairway. They were mainly concerned with safe water areas at open sea, while the fairway was more important in archipelagos and shallow waters. The predefined route was used as the default scenario, since the autopilot was mostly active. Since the studied ferry runs commuter traffic in an area with low traffic, the officers followed the predefined route almost every day.

From the transcriptions of the collegial verbalisation, it is clear that the officers' work differs significantly between different subparts of the journey. Here follows some descriptions of specific work that have relevance to the distinction between subparts.

Radio communication is an important part of the work, especially during start-up, departure, berthing and shutdown phases. At the departure of this particular ship there are much communication, such as radio communication with crew in the stern about distance to the quay, the staff at the quay about the releasing of the ship, the staff at the terminal about the number of passengers, the crew at the cargo decks to know if they are closed, the personnel at the engine room about their status, and VHF communication with the Vessel Traffic Service (VTS) to announce that the ship is departing. Not to forget all the verbal communication on the bridge, the broadcasted messages in speaker systems and VHF-units, as well as all the noise.

Different crews used different steering devices at different stages of the trip, but the general idea among the officers was to let the ship be controlled by:

(a) The autopilot at open sea.

(b) Manual control in confined waters (archipelago, shallow waters, narrow fairways or anything else that might demand large rudder changes).

(c) The captain, on the bridge wing, during berthing and departure.

Some officers also considered using the autopilot in confined waters. They all agreed that the autopilot were more accurate than manual control, but that they could not trust it fully since there might be an error of some kind, e.g. erroneous GPS-data. Two officers mentioned that, except for the joysticks, they mainly use the rest of the instrument panels during start, standby and shutdown phases, or if there is an alarm.

All officers considered radar monitoring as an important task while at open sea. They also commented on the importance of double-checking information, especially concerning the correspondence between real world objects and to the ones found in radar and electronic charts. They argue that they cannot trust electronics to 100 %, but that they have to rely on it when there is thick fog. One captain said that by double-checking radar information when it is good visibility he learns how much he can trust the radar when it is low visibility. There seem to be consensus among the officers, about the importance of direct visual information as compared to electronic information. Furthermore, the usage of direct visual targets is described as being most important while berthing and departure. The officers also mentioned that everyone had his own landmarks as guidelines, e.g. “stopping when positioned at the welded seam at the quay” or “turning when one is seeing straight through the passenger gangway”

4.2 High-speed ferry operators’ temporal perspectives

The temporal perspectives described here are not temporal segments like the previous division into subparts. It is more similar to the predefined route / fairway / safe water distinction in the sense that the time perspectives complement each other and the operators can switch between them as they find appropriate.

Different work task identified in the ship officers’ work suggested that a similar pattern could be identified there as well. Here follows some examples of such work tasks found in the HSC-operators’ work:

(d) The long-range interval involves route planning, and observation of radar and electronic charts, etc.

(e) The short-term interval contains things like manual steering that takes place when the officers needs faster manoeuvres, e.g. when giving way to ships, passing through channels or navigating in archipelagos.

(f) The immediate sense interval is found while the officers are berthing. They make slight modifications to the joysticks as a reaction to variations of the sound of the engine, as well as based on the current acceleration or deceleration of the ship.

These different time intervals were also found to have a relation to the different subparts identified. The long-range interval has a close connection to the open sea part of the trip, where not so much is happening and the ship is following its predefined route. The short-term interval is for example related to confined waters where direct visual information and manual control is crucial. The immediate sense interval is closely related to departure and berthing where ship feedback and control is performed at a much quicker pace.

The distinction between different time intervals was partly also supported by the results of the past, present and future analysis. All work related topics in the transcription of the videotaped trip was categorized into three categories; past, present or future. These topics are visualized in their sequential order in figure 1. The figure shows that officers continuously talk about what is presently going on, but during the open sea they clearly also spend much thought on future events.

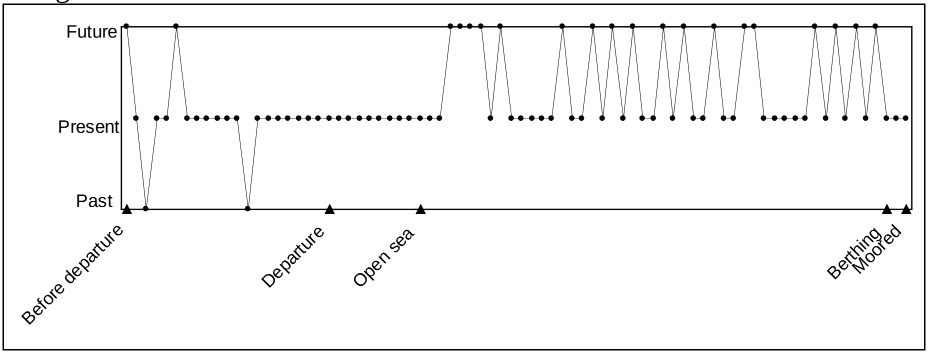

Figure 1: Past/present/future-categories in their sequential order. Each entry in the figure corresponds to a single topic discussed by the officers

Large vessels typically have long delays from the point in time when a steering command is executed until it makes any significant changes to the ships direction or speed. Ferries, especially smaller high speed ferries, react much faster than cargo ships. The studied ship is a large high speed ferry (1500 passengers), were actions must be taken several nautical miles in advance of a potential collision. This makes it necessary for the officers to predict events and give steering commands long in advance. One officer described that he has the radar set on 20 nautical mile scale with off-centre mode, and that the ship is moving approximately one nautical mile in two minutes. From this, he concluded that he knows where the ship will be in 40 minutes. Another officer reasoned that, if there is another ship that should be giving way but is not, you need consider evasive manoeuvres five to six nautical miles in advance, and this is still not so much time if you have a ship on collision course. Furthermore, all officers mentioned some general strategies of their own, such as “in the archipelago I consider at what in distance my ship would come to a complete stop, given the current speed” or “if I know that I will catch up with a ship, I plan ahead by altering the course by a few degrees, so that I pass it nicely”. These topics are visualized in their sequential order in figure 1.

4.3 High-speed ferry operators’ goal orientation

The officers were asked to rank the five goals found in the analyses. The result is presented in table 5 below. As expected, the results indicate that safety aspects are top priority. Furthermore, the officers argued that it is important to follow the timetable, since it was considered an agreement between them and the passengers.

Ship officers' goals:	**1.**	**2.**	**3.**	**4.**	**Sum:**
Safety for yourself, your crew, and passengers	1	1	1	1	**4**
Safety for third party (e.g. other ships)	1	1	2	1	**5**
Following the timetable	2	2	3	2	**9**
Maintaining passenger comfort	3	3	3	2	**11**
Minimizing fuel consumption	4	4	3	2	**13**

Table 5: Four officers' ranking of goals. '1' is the highest rank and '5' the lowest rank

When asked about any conflicts between these goals, several officers described a conflict between following the timetable and minimizing fuel consumption. One officer also mentioned that it is a dilemma to keep the timetable in thick fog. He argued that it is dangerous to go with high speed into a harbour, especially with low visibility, and that the timetable would be ignored in these circumstances. Another officer mention that when they go with 30 knots in thick fog they have to trust the radar image, causing any small boat not visible on radar to be run over. Much like in air and rail traffic, the distance needed to stop a large ship is much longer than the sight distance in low visibility. However, this is a clear example of how the officers realise goal conflicts between safety and efficiency. One officer referred to the motto: "Safe between A and B, to the least cost possible". Another captain said "We never put the ships' safety at risk! I reduce the speed if necessary. If it is bad weather, we get delayed".

4.4 Train-drivers' spatial separation of the route

In the studies on train-driving it was found that the train drivers' work can be divided into three different categories (see table 6). These categories mean very different things for the train-driver when it comes to what measures to take and what level of control they employ.

Leaving a station
Out on the route
Approaching a station

Table 6: Subparts of a train journey, identified during the analysis

Another interesting result from these studies was that the train-drivers' judgements are performed in an information vacuum when it comes to the traffic situation ahead of the train. This is due to the interaction with the current ATP-system, and can be summarized as a lack of complete information to support judgements and decisions during the driving, inadequacies concerning how the information is presented and updated, and its insufficient integration. From previous experience and route knowledge, the driver can guess the exact location of a stop signal, but can never be sure. If the train must brake repeatedly because of stop signals, the driver can assume that there is a slow train ahead and reduce the speed to give the passengers a smoother journey.

4.5 Train-drivers' temporal perspectives

In the same way as the high-speed officers, the train-drivers stated that there are different time-horizons to take into account when running a train:

(g) A long-range interval with an interaction between the train and a rather distant environment.

(h) A short-term interval, with an interaction between the train-cab and the visible surroundings.

(i) An immediate sense interval, with an interaction mainly in terms of braking and feed-back from the stopping train.

For the long-distance trains, the long-range interval is critical. Travelling in 200 km/h, you need a good plan. For commuter trains, the interaction with visible surroundings is critical. Drivers of these trains often mention markers in the geographical surroundings as pointers for when to start brake approaching a platform. And once at the platform, they focus most if not all their attention on passengers' behaviours.

4.6 Train-drivers' goal-orientation

Train drivers' goals:	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**Sum:**
Safety for yourself and passengers	1	1	1	1	1	1	1	**7**
Safety for workers along the rail	2	2	3	2	2	2	3	**16**
Maintaining passenger comfort	3	3	2	4	3	4	4	**23**
Following the timetable	4	3	4	5	4	3	2	**25**
Safety for unauthorized people	5	2	5	3	5	5	5	**30**
Minimizing fuel consumption	6	6	6	6	6	6	5	**41**

Table 7: Seven train drivers' ranking if goals. '1' is the highest rank and '6' the lowest rank

Table 5 and table 7 show a similar ranking of goals. Comparing the two tables show rather similar results between the two different vehicle types. The ship officers' slightly higher ranking of the timetable as compared to passenger comfort, was discussed by the some officers. They argued that they could not affect the passenger comfort on their large high-speed ferry to any larger extent, rather than just using their stabilizers. They stated that it was the weather conditions that caused discomfort among the passengers. The results of the train drivers' goal-orientation show that they have a slightly higher ranking of passenger comfort as compared to the timetable. It is not surprising, since their driving style has a greater impact on the passengers.

4.7 Train-dispatchers' spatial orientation

It is important for the train dispatcher not to place trains in uphill slopes, and therefore they need domain knowledge of the particular section they are in charge of. A train-driver immediately knows if there is a train dispatcher that lacks this knowledge. The train dispatchers also have good knowledge of the characteristics of the different switchgears and signal-boxes and where they are placed. A third characteristic with connection to the train dispatchers' spatial orientation is that they have to be aware of the trains approaching the section they are responsible for. If trains are late this will affect their decision strategies. This means they have to keep track of how the colleagues in the train traffic control center are doing.

4.8 Train-dispatchers' temporal perspectives

The train dispatcher normally assumes two different roles: the planning role and the executor role. The first of these two roles mainly concerns the task of maintaining the traffic plan, and the latter is about manually executing actions to control the traffic. Manual execution is primarily utilized when there are technical malfunctions that hinder the automatic execution, which means that when there are a lot of activities going on caused by some unexpected situation, the train dispatcher spend a lot of time in the immediate future, trying to fix problems. When things run smoothly, he or she can devote more attention to the plan, and reschedule trains in the planning horizon. Doing so, there is need for continuous development of the actual situation, which means they need to know the history of a particular train. This may be so, because it may travel with some restrictions caused by malfunctioning materials, for example wheels or brakes that work in a suboptimal way. More than one might expect, the train dispatcher continuously switches between history and the planning horizon. The history is of greater importance for the train dispatcher than it is for both the train driver and the high-speed ferry operator.

4.9 Train-dispatchers' goal-orientation

The goals pursued by the train traffic controller are different depending on to what degree the support system allows him or her to work on a traffic level or on a lower technical level. It used to be that the controllers switch gears and rearranged the planning on a rather low technical level, but new control philosophies make it easier and possible to decide what train to prioritize. And, of course, the goal formulations are highly dependent on the actual and up-coming traffic situations.

5 Discussion

Figures 2 - 4 show how decision-makers in all three domains exhibit immediate and intuitive judgments as well as decisions in terms of evaluation and control functions. The figures also show that experts switch between immediate judgments and decisions for control, and sometimes they base their judgments on historic events. Note that, in contrast to figure 1, these figures are not based on data. They are conceptualizations of the differences found in the analyses when comparing how the operators in the three domains use the time factor as part of their control strategies. Despite differences in the how they use the time factor, it is evident that it is of crucial importance for their ability to predict and control as well as to interact and change according to their long experience. Recognizing the importance of the time factor is of vital interest since it is the same thing as recognizing the complexity of their work tasks – they continuously check for changes and plan for measures to take care of upcoming situations.

As can be seen from figures 2-4 below, decision making in all three domains is a matter of immediate judgments, as well as implementing measures in a control perspective. Decision makers in these domains do not make judgments as if these topics are isolated in time and space. The question is: how do the decision support systems contribute in these situations. We close this presentation with two examples of good design solutions and one example of a solution that did not meet the requirements from the operators.

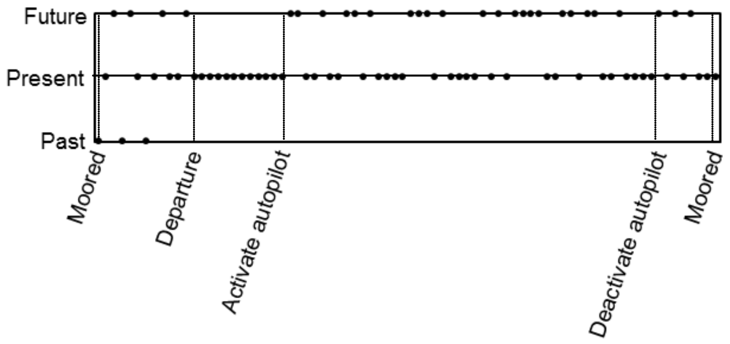

Figure 2: Past/present/future-categories in their sequential order on a general level for high-speed ferries

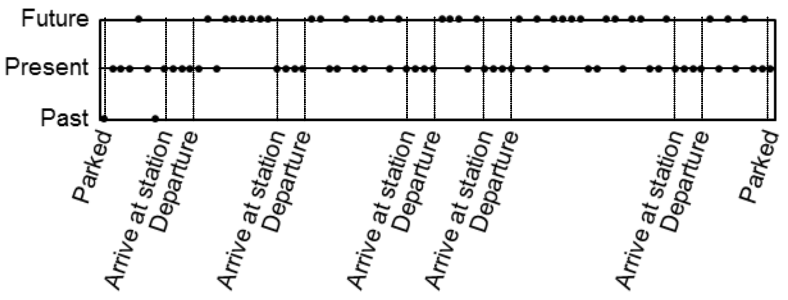

Figure 3: Past/present/future-categories in their sequential order on a general level for train-drivers

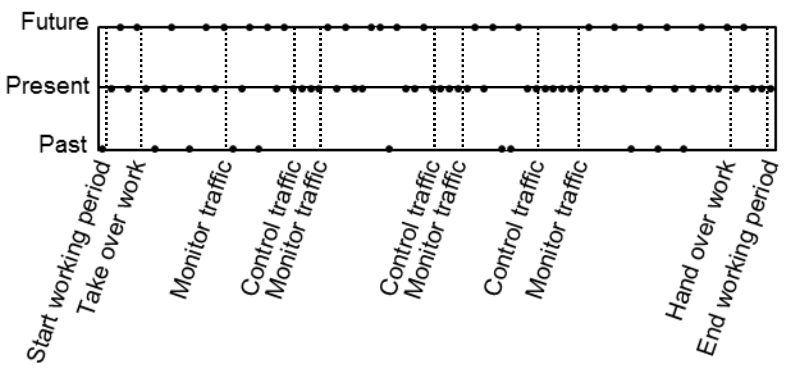

Figure 4: Past/present/future-categories in their sequential order on a general level for train dispatchers

5.1 Examples of good and bad design solutions

Below, figures 5a – 5c show how the different decision support systems look like. Each design solution supports the experts differently in relation to the actual decision making task. In the train-driving task, the drivers more or less drove in an informational vacuum before the design of the new system was around. They were not able to find out about the traffic situation ahead of them, and therefore not being able to drive as effectively as they wish. The new interface was developed in a participatory design process, resulting in a design that supported the most important part of their work. The train dispatchers also lacked important information, with the consequence that they had to calculate manually how to direct the trains. Their work tasks were sometimes very cognitively demanding. The new interface was developed over a series of years, and always with representatives from the train traffic control organization. The end result is seen as a very good solution. The high-speed ferry example, on the other hand, was developed without any more elaborate analyses of the working tasks on the bridge. The design solution did not support the most critical aspect of the work task of controlling a high-speed ferry. Even though they too initially had more severe problems, i.e. they had to switch between different configurations of the equipment, partly in conflict with the goal of having continuous control of surrounding traffic. But the solutions were far from optimal and this was the rationale for focusing more on their work tasks.

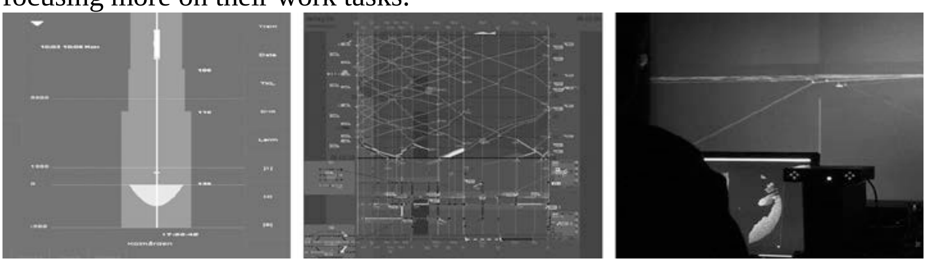

Figure 5a-5c: Three examples of design solutions for train-driving, train-traffic control and high-speed ferry operation, respectively.

The design solutions in figure 5a and 5b were well received by the operators, while the design solution in Figure 5c did not meet the demands of the crew. For principles for visualization for skilled professionals, see Andersson et al. (2013). Here, we end this paper by concluding that if algorithms are to replace human judgments, the design of the visual information must make it possible for the operators to follow and easily take over the control whenever the situation demands this. Predictability of the environment and individuals' opportunities to learn the regularities of that environment is the best way to recognize the complexity of their work tasks, and the time factor is of crucial importance to understand when designing for complexity.

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