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Simulator-Based Design
Methodology and vehicle display applications

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Abstract

Human-in-the-loop simulators have long been used in the research community as well as in industry. The aviation field has been the pioneers in the use of simulators for design purposes. In contrast, corresponding activities in the automotive area have been less widespread. Published reports on experimental activities based on human-in-the-loop simulations have focused on methods used in the study, but nobody seems to have taken a step back and looked at the wider methodological picture of Simulator-Based Design. The purpose of this thesis is to fill this gap by drawing, in part, upon the author's long experience in this field.

In aircraft and lately also in ground vehicles there has been a technology shift from pure mechanics to computer-based systems. The physical interface has turned into screen-based solutions. This trend towards glass has just begun for ground vehicles. This development in vehicle technology has opened the door for new design approaches, not only for design itself, but also for the development process. Simulator-Based Design (SBD) is very compatible with this trend. The first part of this thesis proposes a structure for the process of SBD and links it to the corresponding methodology for software design.

In the second part of the thesis the focus changes from methodology to application and specifically to the design of three-dimensional situation displays. Such displays are supposed to support the human operator with a view of a situation beyond the more or less limited visual range. In the aircraft application interest focuses on the surrounding air traffic in the light of the evolving free-flight concept, where responsibility for separation between aircraft will be (partly) transferred from ground-based flight controllers to air crews. This new responsibility must be supported by new technology and the situational view must be displayed from the perspective of the aircraft. Some basic design questions for such 3D displays were investigated resulting in an adaptive interface approach, where the current situation and task govern the details of information presentation.

The thesis also discusses work on situation displays for ground vehicles. The most prominent example may be the Night Vision system, where the road situation ahead is depicted on a screen in the cab. The existing systems are based on continuous presentation, an approach that we have questioned, since there is strong evidence for negative behavioral adaptation. This means, for example, that the driver will drive faster, since vision has been enhanced, and thereby consume the safety margins that the system was supposed to deliver. Our investigation supports a situation-dependant approach and no continuous presentation.

In conclusion, the results from our simulator-based studies showed advantages for adaptive interface solutions. Such design concepts are much more complicated than traditional static interfaces. This finding emphasizes the need for more dynamic design resources in order to have a complete understanding of the situation-related interface changes. The use of human-in-the-loop simulators and deployment of Simulator-Based Design will satisfy this need.

Papers included in this thesis:

Paper 1.
Alm, T., Alfredson, J., and Ohlsson, K. (Accepted). Business Process Reengineering in the Automotive Area by Simulator-Based Design. *Simulation and Modelling: Current Technologies and Applications.* Idea Group, Inc., Hershey, Pa USA

Paper 2.
Alm, T. (2001). How to Put the Real World into a 3D Aircraft Display. In *Proceedings of People in Control: An International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centres 19-21 June 2001*.

Paper 3.
Andersson, P. and Alm, T. (2003). Perception Aspects on Perspective Aircraft Displays. *Displays, 24 (2003),* pp. 1-13, Elsevier Science B.V.

Paper 4.
Alm, T. and Lif, P. (Accepted). The Value of Spatial Cues in 3D Air Traffic Displays. *International Journal of Aviation Psychology*.

Paper 5.
Alm, T., Kovordányi, R., and Ohlsson, K. (2006). Continuous versus Situation-dependent Night Vision Presentation in Automotive Applications. In *Proceedings of the HFES 50th Annual Meeting.*

Foreword

In 1970 I was hired by the Swedish Aerospace company Saab. My main mission was to be responsible for the integration of the Viggen (JA 37) fighter and the computerized ground control system of the Swedish Air Force. At that time this control system was state-of-the-art and communicated with the aircraft using data-link. In the control rooms, the intercept controllers used synthetic displays with automated target tracking based on data from an appropriate set of radar stations. The computers assisted the controllers with intercept calculations and other information. We did not know at that time that this would be given the name "decision support systems". I had been, together with some other pioneers, specially educated to manage this advanced system, from a technical point of view as well as tactically. At the time of this education (1962-1965), the computer science field was not very established in Sweden and very few people had any deep experience. In 1965 the Air Force took over the first site of this new control system. Five years later the new Swedish Viggen fighter was in its early design phases and was supposed to be equipped with computer power to an extent never seen before. This made it possible for this aircraft to understand information and commands from the ground control. This raised the question on how to present such information to the pilot. Used with the synthetic displays from the control system, my suggestion was to have the same solution in the cockpit. Naturally, other people had the same vision, but it was not finally accepted by the Air Force until a couple of years later. For me, this was the beginning of a lifelong interest in display design for vehicle applications.

Another lifelong interest was established during my education and service in the Air Force – simulation. The use of simulators was already extensive at fighter wings within the J 35 Draken system for tactical training and also the ground control system had the capability to be set in a simulation mode for training of all positions and collaborative work. At Saab the first PM (Presentation & Maneuvering) simulator for studies of pilot – system interaction was built. A colleague and I got the assignment to plan for proper design activities for a three-year period using this facility. The idea was to use the simulator as a platform for evaluation of virtual prototypes in combination with hardware-in-the-loop. This became a real success story and contributed to the state-of-the-art position for Swedish cockpit design. At this time we had not heard of expressions like Virtual Prototyping, Human-Machine Interaction (HMI) or Simulator-Based Design (SBD). However, this was actually what we were practicing.

When I retired from industry ten years ago and decided to do something in the academic area, it was quite natural to follow up these interests. I got the privilege to set up a Virtual Reality (VR) lab at the Linköping University, which now has developed into a simulator facility supporting HMI research in various vehicular areas (Figure 1). I also got the opportunity to carry out my own research on display design using this facility. From the beginning, the purpose of the VR lab was exploratory. How could this amazing technology be used in different areas? Architectural activities in city planning, building construction projects, medical applications for less blood-curdling training purposes, navigation in smoke-filled houses, visualization of scientific data, and, naturally, display design issues in aircraft applications. Today the activities of the VR lab are more focused on vehicle design, as mentioned above, as other parties within and outside the university have taken over some of the other original activities.

Figure 1. View of the VR-lab at Linköping University showing one of the simulator cockpits (Saab 9-3) in a city driving situation.

With this background, I believe that the readers can understand why this thesis has a broad approach covering both the methodology of Simulator-Based Design (SBD) and the more narrow aspects of display presentation in aviation and ground transportation applications. My research in the display area has followed the SBD structure and according to my opinion (and experience) the most significant difference between Research and Development in the way to utilize the SBD concept is the way you handle the output of the simulation. In industrial design work the need for rapid decisions makes it hard for time consuming analysis of all available data, which on the other hand is what research is much about. So, in industrial work most of the decisions based on SBD are made by consensus within a group of design experts including test pilots. For more serious decisions, managers and sometimes customers may participate in this rapid evaluation.

In my academic work I like to address some colleagues and friends who made everything possible. First professor Martin Helander, who inspired me to do something useful after retiring from industry, and also became my supervisor until he left for a warmer climate. He was succeeded by professor Kjell Ohlsson, who has not only been my supervisor but also a close partner in many activities at the university. Our visiting professor Kip Smith has been an invaluable supporter the last years and I really have appreciated his right-on advice. I also like to thank all my colleagues at the Industrial Ergonomics division and my friends at ACE Simulation AB for all support. Last but not least I will address my research partner Patrik Lif at the Swedish Defence Reasearch Agency. We have worked closely together through two 3-years program periods within the Swedish National Aviation Research Program (NFFP) and since then another couple of years. His background in psychology and my own engineering background have been a nice mix in the multi-disciplinary world of aviation. This partnership has been the most important prerequisite behind this dissertation so, thanks Patrik!

Contents

1. Organization of the thesis

This thesis is partly a position paper on the utility of Simulator-Based Design (SBD) in development of vehicle systems, and specifically systems where the driver or pilot is involved in the process. This involvement is labeled Human Machine Interaction (HMI). In chapter 2, the background of simulator and vehicle development is briefly reviewed and in chapter 3 the theory behind SBD is outlined. The proposed SBD methodology is then described in chapter 4. In chapter 5, a set of research questions is presented. These questions are further discussed and analyzed based on the research presented in the attached papers. The projects utilized the SBD method and documented its utility. A concluding discussion is presented in chapter 6.

2. Background to Simulator-Based Design

The simulator-based way to proceed in industrial design has not yet had its break-through outside the aerospace domain. This fact is also the basic background to my own advocating for the SBD approach. Another incentive is the absence of formal papers in the area. Many researchers in the aviation field have used virtual prototyping and simulation as tools in their scientific activities (e.g., Andersson and Alm, 2002; Barfield and Rosenberg 1995; Smallman, H. S., Manes, D. I., & Cowen, M. B., 2003; Wickens and Prevett, 1995). Each paper describes the methods used in each specific study including, for example, design and prototyping of some experimental display and the use of some flight simulator, but nobody seems to have taken a step back and looked at the methodology from a meta-methodological perspective and definitively not coupled this to a way to proceed in industry. My ambition is to give a basis for filling this methodology gap.

2.1 The use of human-in-the-loop simulators

Here I present a short review of how human-in-the-loop simulators have been invented and further developed. The pioneers were aviators so flight simulators have a long history, while simulators in the ground vehicle area appeared much later. I will briefly cover these two areas well aware of the fact that simulators are used in many other fields. Maybe the most significant of these fields of simulator usage is in space programs, not the least to give the crews realistic training. Without simulators it would probably not be possible to carry out any manned space-flights. Here I touch upon one of the fundamental advantages with use of simulators. It is possible to do things in a simulator that would be extremely dangerous in a real world situation. In a simulator the price of a human error in a complicated procedure or the loss of engines in a flight take-off situation will not have any other consequences than that the trainee will learn from his/her mistake or the complicated situation. One other main feature of simulator usage is that it is possible to create situations that will happen very seldom in real life and to repeat those situations for training or other purposes in a completely controlled way.

2.1.1 Flight simulators

Flight simulators have been developed and used for different purposes since before World War II. The first known construction was the Linktrainer, developed by the US legend, Edwin Link, in 1929. In this completely mechanical simulator, which still can be seen at several flight museums, it was possible to learn the fundamentals of flying. In the sixties the development had reached more advanced levels and it was now possible to train missions and emergency procedures (Nilsson, 2001). In this period of time, computers got involved, which made it possible to let the pilot fly in more elaborate scenarios. Early in the seventies design activities appeared on the agenda and not late thereafter simulations for research purposes started. However, the research interest in the use of simulators and how pilot performance was affected by these training efforts had been prevalent long before. The new approach in the late seventies was to set up specific simulator activities for more design oriented research questions. In the eighties and nineties the use of simulators for marketing issues became important. To let a prospective customer come and use a simulator to have a hands-on experience with a new aircraft was more practical (and instructive) than to give the prospect a real flight. Another purpose which evolved in the last decades of the 2000th century was to verify new functions in simulators instead of using test flights. Today, at least in the Swedish fighter program, most new functions and subsystems are not verified in real flight at all. A summary of this historic perspective on simulation can be seen in Figure 2.

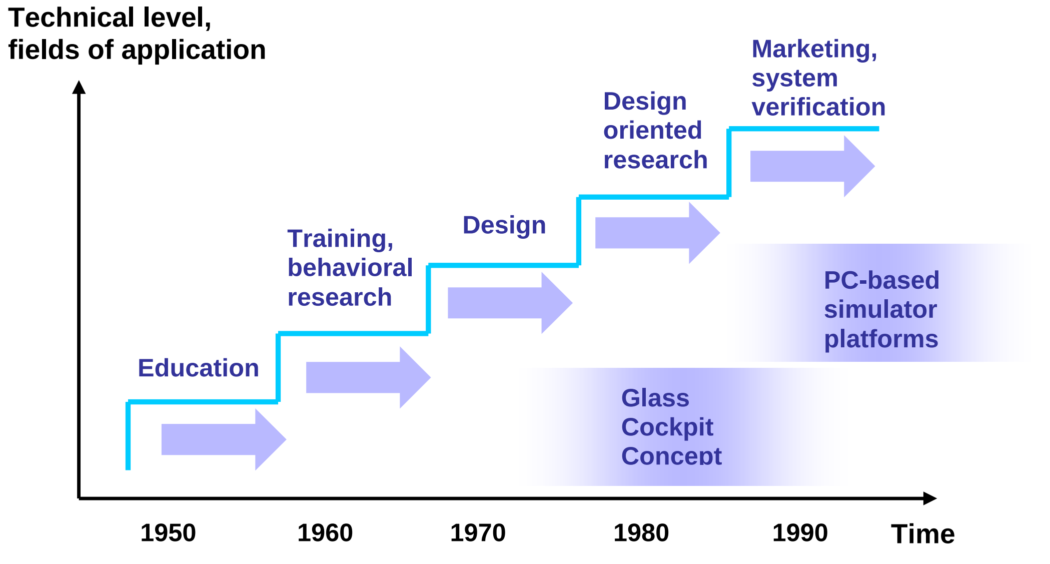

Figure 2. A historical perspective on the evolution of flight simulator usage and of the simulators' technical level.

In Sweden the pioneer in simulator use was the Air Force. At earlier stages Linktrainers were common and it was not until 1961 that the first more advanced flight simulator was introduced to support basic training for the J35 Draken fighter (Nilsson, 2001). The simulator was developed by the US company Curtiss Wright. No visual system or tactical equipment was initially included, but still it was a valuable tool for the basic training purpose, since the Draken was the first delta wing aircraft (in fact double delta) in the Air Force, which introduced new serious troubles like super stall. To have a simulator where procedures to overcome such situations could be safely exercised was a big step forward from a flight safety perspective.

In the Swedish aerospace industry the first simulator was introduced in the late sixties. Much later, simulators became more common in research organizations. The most obvious reason for this late entry was the high level of investment. All flight simulators were running at very expensive Unix systems until the late nineties when the personal computer (PC) development had reached such maturation that PCs were able to replace the Unix machines. This change in computer system options suddenly made it possible for many universities and research agencies to afford simulator investments. Investments in moving simulator platforms, however, were not economically affected by the PC breakthrough. Thus, most new simulators had a fixed-base solution, but in the SBD concept moving platforms bring limited benefits to the design decisions. From an industrial standpoint, problems not possible to evaluate in fixed-based simulators could still be transferred to test flights. However, for flight training, moving-base simulators are beneficial so both military and civilian systems of today generally have this solution.

2.1.2 Ground vehicle simulators

If we agree that the aviation society has climbed all the steps shown in Figure 2, other industrial sectors have additional steps to take. In the automotive area, including research institutions, there is much ongoing research at different driving simulator facilities around the world. Most activities are focused on driver behavior during various conditions and disturbance levels. These are, of course, important issues but they have little to do with concrete product design and how ground vehicles should be designed in the future from a human perspective. In other words the automotive industry has mainly taken the first two steps on the simulator staircase shown in Figure 2 and thus most simulators are developed for training purposes.

As with other kinds of simulators, driving simulators are very different from site to site. This may cause problems in comparisons of research results across research institutions. One possible way to bring some order to this muddle is to classify simulators by level of investment. Following this principle, driving simulators could be classified as low, medium, and high cost simulators (Weir & Clark, 1995).

Low cost driving simulators are typified by being desktop solutions with strong relationship to corresponding game equipment. They have limited graphical displays, where usually some parts of the simulator cab are superimposed on a driving environment for reference reasons. The control equipment (steering wheel and pedals) is separated in parts to be placed on the desk and floor. Mostly, the user has limited access to software entities like the environment model and scenarios. The simulators in this class often have their origin in the driver training business.

Medium cost driving simulators generally offer a more complete driving environment, both in terms of having a wide horizontal field of view with life-sized images and a real car cockpit. Also the audio and the feeling of control are more realistic. Some simulators have equipment for small amplitude motion to simulate high-frequency input to a vehicle in motion and/or simulating initial accelerations/retardations. In this class there are both commercial products and “home-made” solutions. As with low cost simulators, most of the commercial medium cost products have their original application in training.

The high cost driving simulators are characterized by having more sophisticated motion bases, including up to six degrees of freedom. Some simulator sites have full dome presentation systems, which gives visual access to the complete surroundings including traffic. Most of the simulators in this upper class are not based on commercial products, but are developed as a part of the internal research activities. This, of course, does not exclude the use of commercial standard products for hardware solutions or for subsystems like the visualization equipment.

However, the differences between individual simulators are probably so evident that any classification attempt is less meaningful. The perhaps only way to make useful comparisons is to look at specific and important features of each simulator. For example, there are simulators in the upper cost class with moving bases, which are less well equipped with visualization resources. It is not unusual that these simulators have screens for environment presentation mounted just outside the windscreen of the cab. This solution makes the coordination between the moving cab and the surroundings much easier than with a separated visual system. On the other hand, this solution also limits the size of the presentation, which makes the experience of the surrounding entities more unnatural. To avoid these limitations and still keep the features of having both cab and visualization system on the same moving base makes the whole construction very large, which in turn makes the requirements on the movement system much higher and the complete construction become enormously expensive. The most evident example on the use of this strategy is NADS, the National Advanced Driving Simulator at the University of Iowa, USA (NADS, 2007).

The main question in searching for the right simulator platform for simulator-based design activities is not specifically linked to the simulator class. In fact there are more candidates to find in the medium cost class than in the high cost category, since the basic prerequisite for such activities is the possibility to easily implement new in-vehicle systems, which could operate seamlessly together with the entire simulator system. This requirement is not only referring to the simulator software, but also to the cockpit hardware. In the aviation field the glass cockpit notion has been coined, mainly referring to the replacement of hardware instrumentation by programmable screen based solutions. This is a fundamental approach also for simulators in the HMI design business.

In the beginning of this section the possibilities to compare research results from different simulators was raised. This has been investigated in the EU-funded HASTE project and a report by Jamson and Mouta (2004), where results on driver performance using low and medium cost simulators were compared, indicated that the two simulators (one from each class) did not produce consistent relative results. This conclusion is likely generalizable. On the whole there are difficulties in making comparisons of results across simulators, since most simulators are specific in one or another way. While this is problematic in the research field and diminishes the possibilities for repeating studies and draw general conclusions, it is of less importance in the industrial SBD application.

2.1.3 Simulation in the future

This thesis does not deal with every aspect of simulation in general. What it does deal with is the future advancement of simulation technology, which is fascinating and will most certainly have a strong impact on future human-in-the-loop simulators and also on the acceptance of using such simulators on a more common basis. This section is inspired by personal communication with Professor Peter A. Hancock.

One observation is that the gap between what is real and what is simulated is diminishing in many domains. One example is fly-by-wire systems. In the traditional mechanical system, the pilot could experience a direct tactile feedback through the stick based on the forces that worked on the rudder planes. In the fly-by-wire system this natural feedback is replaced by a simulated feedback, which does not necessarily correspond to the actual positions of the rudder planes. Instead, the feedback is based on the intention of a certain steering input. In this case one must ask, what is reality? Another example is in systems where it is impossible to recognize if the operator is working in a real or simulated setting. For example, in most modern air traffic control systems, it is possible to set the whole system in a simulation mode with simulated air traffic. Normally, for ethical reasons, all involved personnel are aware that a session is simulated, but from all other perspectives the simulated session looks exactly like a real operation. Also the further advancement of computer gaming will have effects on both simulator technology and acceptance. On the technology side, the visible scenery is becoming more realistic and, at the same time, the tools for building these sceneries are developing. The progress here should of course be utilized in the simulation area.

In the question of realism it is important to make a distinction between completely and partially virtual environments. In a completely virtual environment there are more problems to deal with in order to reach high realism levels. Most of the difficulties are coupled to lacking natural tactile feedback, while the visual and auditory parts of the simulation are more easily handled. In the mixed reality setting, like in the human-in-the-loop simulator, you may have a complete physical work station where most of the tactile forces could be replicated like, for instance, pulling the stick or pushing a button. The only part that could be out of reach for economic reasons is the motion part in most vehicle simulators.

All these advancement efforts are focused on the visionary goal to make the simulation more or less identical with a corresponding reality. In some areas this is very important, especially for training purposes, but in other areas like in simulator-based design this is not at all necessary. Here we meet the notion of validity. If the striving for reality is successful, we assume that the *absolute validity* of the simulator is high. Thus, many validity tests are carried out with the ambition to prove that a particular simulator has high validity. If it has, the simulator is considered to be a safe resource for scientific studies. However, this does not guarantee that the specific simulator-based study is carried out with high validity. On the contrary, high general validity could contribute to low study-specific validity, since validity problems tend to be disregarded when the simulator platform is considered to have a built-in absolute validity. I will come back to the validity discussion later, but as a summary at this stage there are strong reasons to believe that the realism in simulation will continue to grow.

One issue of great importance for future simulation is to have more standardized solutions for environment modeling and scenario production. Such discussions have begun to take place, both in national and international forums, and substantial results in this direction will make re-use and exchange of model resources more common. This would be very beneficial, since modeling is very time-consuming. Since environmental modeling is usually not the key interest in a project, more resources could be directed to the main issue, to design and evaluate a new interface solution. The statement that the environment model is of minor interest does not mean that the model has limited impact on the results of the study. On the contrary, the environment is of greatest importance for the outcome. It is quite necessary to build the environment in all its details with the specific study purpose in mind in order to maximize the challenge of the research question.

2.2 The technical development of vehicles

Another historical review with strong couplings to the evolution of simulator usage is the technical shift in aircraft and ground vehicles. In the latter category I include personal cars and commercial trucks and busses. Outside these categories there are other commercial ground vehicles in various business areas like construction, mining, and forestry. These types of vehicles are not further discussed, since they show different development trends than the “ordinary” vehicular area. In fact sometimes you will find closer technical links between such specialized vehicles and modern aircraft. Examples of such links could be drive-by-wire systems, extensive use of automation, HMI concepts from aviation like HOTAS (Hands On Throttle And Stick), and the use of sensors for visual enhancement.

The technical development in the aviation area could be briefly summarized as follows. Until around 1960 an aircraft was a pure mechanical engineering product. Computers were included during this decade in order to support some subsystems and all new fighters were equipped with radar sensors. In the seventies CRT screens were introduced and in the end of this decade also LCDs to some extension (often small alpha-numerical displays). In the eighties we could find higher levels of automation and more sophisticated decision support systems. In this period the HMI aspects became even more in focus forced by the growing information content in the cockpit and the glass cockpit concept was realized. This refers to the replacement of hardware interface solutions to screen-based design. By the end of the eighties, the fly-by-wire technique was introduced and the Swedish Gripen fighter became the first system in operation with no mechanical steering control.

A similar development trend has been seen in the ground vehicle area and is still ongoing. Computers were introduced together with sensor technology and some elements of automation. LCDs have appeared in the cockpits to some extent and more will come in the near future. One other example of coming technologies is drive-by-wire systems. It will appear in ground vehicles for the same reason as in aviation; lighter and less voluminous construction with less impact on environmental resources, safer solution thanks to redundancy and no steering-column, and greater flexibility to additional functions. It is, for example, possible to add tactile warning information “on the top of” the ordinary steering force feedback. On the other hand, we know by experience from aviation that this simulated feedback is an important issue in the ambition to provide a system with smooth interaction between the driver and the car. To reach this level, heavy research efforts will be needed and, as in aviation, human-in-the-loop simulators will be of crucial importance.

The share of computer-based functionality in new ground vehicles has already passed 50% as measured in monetary terms and this share is still rising. One interesting observation coupled to this statement is that the corresponding reengineering of the competence profile is heavily lagging behind. From this follows that most of the new technology is delivered by subcontractors, which makes system integration an important area for immediate reinforcement in the car industry.

The most evident difference between these vehicle technology trends is the timing. Early start and an evolutionary pace in aviation compared with a considerably later start and a revolutionary pace at the automotive side. Thus, it is very important for the automotive industry to catch the opportunity to learn from the aircraft business, not the least from a human factors perspective, since most of these technical achievements have a great impact on the operator situation and the interaction processes.

It is also interesting to couple this technical progress to the use of simulation as a design tool. The more computer-based functions in the vehicle the easier is the implementation in the simulator and the greater will the output from simulator activities be. And in the other direction, computer-based solutions in the simulator are easy to convert to real vehicle functions. This is true for the intelligent parts of a future system, while hardware like sensors still need to be implemented in other ways.

Figure 3. The glass cockpit of JAS 39 Gripen fighter aircraft. Photo from Saab AB.

3. Theoretical background for Simulator-Based Design

In this chapter I will discuss theoretical approaches with relevance to simulator-based design (SBD). As mentioned in the Foreword there is not very much written on this methodology, while there are much more on simulation-based design. This activity has its main focus on mathematical simulations of different complicated technical constructions with the purpose to optimize the included design parameters, mostly far away from the human operator. Usually, there is no specific simulator involved here but a simulation program running on a computer, often a high-end computer. However, both simulation- and simulator-based design have their methodological roots in the computer science field, which makes it worthwhile to look into the area of software design and, since the interest is focused on humans-in-the loop, Human-Computer Interaction (HCI).

3.1 Iterative design and virtual prototyping

Simulator-based design is an iterative process. This iterative approach is considered to be best practice in software design. This has not been a mainstream solution in mechanical engineering, since physical prototypes and mockups are expensive to produce. Thus, to make major changes in an iterative way is not feasible here for economic reasons. Also from a psychological perspective, it is repulsive to suggest changes in a product that seems to be finished. In such cases it is easier to accept some drawbacks in the suggested product design. However, for a virtual prototype this is not a problem as for other software products. Since virtual prototyping is one of the key issues in SBD methodology it seems reasonable to adopt the iterative design approach from the software area rather than keeping the sequential traditions from mechanical engineering, especially since the virtual prototype is a software-based artifact. A traditional way to describe the software design process is to go through a number of design steps in a sequential concept adding some control loops as shown in Figure 4.

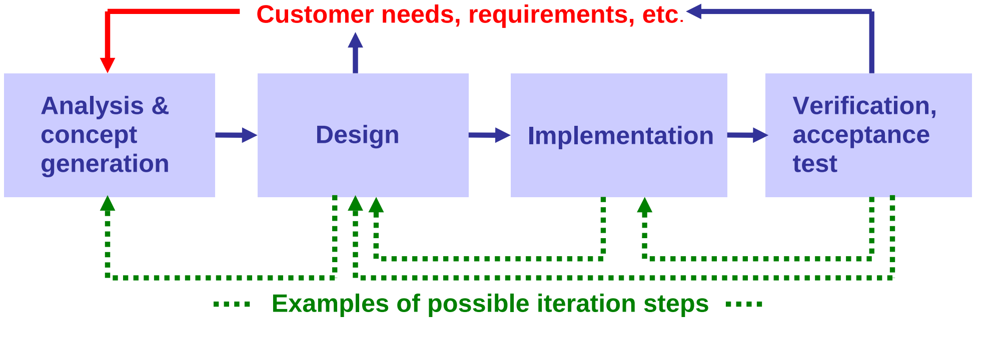

Figure 4. Schematic view on the concept of iterative design in software development.

From these basic principles of the software design process a number of more elaborated models has been developed like the Spiral model (Boehm, 1988), which later was chosen as a norm for system development within the US armed forces. The Spiral model also inspired many other researchers to further develop its principles. Perhaps the most important contribution is the IBM Rational Unified Process (RUP), which originated from the US company Rational Software and the Swedish company Objectory AB who merged in the nineties and later was acquired by IBM. RUP (e.g. Kruchten, 1998) is today a standard procedure for software development. One obvious feature of the original Spiral model was that the iterations were described and motivated at different stages of the process. Another feature was that the Spiral model included repeated risk analyses. Especially in very large projects (like in the defense area) risk assessment may be of great importance and thus should be carried out. This has obviously not been done in many large projects. The most prominent failures have been reported from governmental projects, but there are reasons to believe that there has been a corresponding history in the commercial sector.

In the basic iterative design model, prototyping is not mentioned specifically. However, the iterations imply the presence of prototypes. The first design attempt could be seen as the first conceptual prototype. In the Spiral model this presence is more expressed by including prototype 1, 2, etcetera. In RUP the cornerstones are the iterative approach, management of requirements including an end-user focus, the use of a component-based architecture facilitating system extension, understanding, and reuse in further development steps during the system lifecycle. This approach has been utilized in the software development behind our simulator resource at Linköping University, and thereby it is facilitating the SBD methodology.

In the mechanical engineering field the notion *virtual* prototyping has appeared. The basic idea behind virtual prototyping is the use of realistic digital product models for design and functionality analysis in early stages of the product development cycle before any physical prototype has been produced. Generally the virtual prototype has its basis in a CAD drawing and in the next step simulated functionality and visualization techniques are added to a complete virtual product, which could be studied in a computer-based environment. This means that in product design, virtual prototypes are preliminary steps to a physical product, while a prototype in the software area has a non-physical product, a software program as the goal.

In simulator-based vehicle design, the goal system usually has mixed properties with both software and physical components. For such products CAD drawings are peripheral except for interface solutions where CAD-like commercial tools are available to enhance the development of graphic interfaces. In the end these interface components could be realized in hardware or by screen-based solutions.

3.2 Usage-centered design

In all manned systems the interaction between the operator and the technical part of the joint system is of great importance. To meet this challenge the concept of user-centered design has developed within Human-Computer Interaction (HCI), but strictly speaking, it is not the user per se that is interesting but his/her way to use the system and the user needs (cf. Arvola, 2005). Sometimes the best idea is to bring in the end user during the development stages, but the reason for this should in most cases be to observe and measure the performance, the way this person uses or handles the system. It is the interaction that is important and the outcome of such interactive processes.

Here the term Usability Design is more informative and includes the interaction aspects. Usability has been defined by the International Organization for Standardization in ISO 9241-11 (1998) as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use". It should be mentioned that this definition has the office environment in focus. In traffic environments this definition is relevant but not sufficient, since safety aspects must be included and clearly expressed. This is also the case in other operator-critical real-time systems like, for instance, the nuclear or other process industries. According to Gould, Boies, and Ukelson (1997) the procedure to achieve a usable system includes the following issues:

- Have early and continuous focus on users
- Do empirical measurement
- Do iterative design and redesign
- Do integrated design wherein all aspects of usability evolve together

In the vehicular area, the SBD approach including human-in-the-loop simulation is a way to carry out such design work and satisfy the above mentioned usability requirements. Sometimes there are misunderstandings, particularly in industrial projects, where user-centered design seems to mean that operators are directly involved in designing the new system. This may be appropriate if the goal is to make an existing system operate more smoothly, but if the goal is to design a new generation of, for example, a control system it is a dangerous way to choose. Interaction between the operator and the technical system (HMI or HCI) is the key issue in every manned system (e.g., Billings, 1997, p 3) and thus the process of interaction is dominating the operator experience of the old system. Since the operator has worked with the old system for a long time (the criteria for choosing expert users) the user has learned to live with the old procedures to such an extent that these could be understood as best practice. The risk is then evident that the new system will include the old procedures, despite the fact that new technology had made it possible to make the whole interaction process smoother.

This has a parallel in what used to be called Business Process Reengineering (BPR). BPR was formalized in the early nineties (e.g., Davenport, 1993; Hammer, 1990) when IT systems began to replace earlier procedures in all kinds of organizations. Hammer's article had the revolutionary title: "Don't automate, obliterate". With reference to the BPR message it was necessary to reorganize the core procedures/processes in parallel with the technical investment, otherwise the whole effort was bound to fail, not the least from an economical perspective. To just convert old (often manual) procedures into computer-based solutions ("automate") should be too expensive for any organization.

From the process perspective the rationalization benefits should be absent, which should place the company in an exposed competitive position.

From the usability advocates, there has been strong criticism on the dominating RUP model, which not includes user-related components in the process model except for customer/user needs as input to the process. According to Göransson, Lif, and Gulliksen (2003) there have been alternative suggestions to RUP in order to secure the user aspects through the whole development process. These attempts, however, have had no success which inspired these authors to include additional user-oriented components within the RUP model. The outcome of this effort has yet to be seen.

Participatory Design (PD) is another area in HCI, which apparently is more on the current agenda than user-centered design. PD may have a broader approach and includes activities which could be defined as applications of user-centered design. PD is a set of theories, practices, and studies related to end-users as full participants in activities leading to software and hardware computer products and computer-based activities (Greenbaum and Kyng, 1991; Muller and Kuhn, 1993; Schuler and Namioka, 1993). In PD one important issue has been to avoid crossing back and forth between the developers' domains and the end-users' workplaces and therefore a third in-between domain was defined – the third space in which participants can combine diverse knowledge into new insights (Muller, 2003).

A human-in-the-loop simulator could be seen as one example of a third space, where the system engineer who has developed a product implemented in the simulator system meets the end-user. From the end-user's perspective the simulator will appear as a new experience with some similarities to his/her ordinary "workplace". According to the PD research this third space could be a place for more creative interaction and mutual understanding than any other way to communicate.

HMI has its roots in Mechanical Engineering. Sometimes HMI is interpreted as Human-Machine Interface and sometimes as Human-Machine Interaction. Both expressions are relevant if they are used with caution and the specific meaning is declared. However, it is not very good to have the same acronym for two such close concepts but perhaps this is something we have to accept. HCI has an unambiguous meaning – Human-Computer Interaction and in this scientific area there are signs of definitions for both user interface design and interaction design. There seems to be no firm consensus on the boundaries between these terms, but one way to express the differences is that interaction design answers the question "how should this product work?" while interface design focuses on "how should this product present itself?" (Marion, 2006). Personally, I tell my students that the interface is what you can see (feel, hear, etc.) of a system, while the interaction also includes the way to handle it. So, according to my view, Human-Machine Interaction is the wider expression including both the static interface components and the related procedures and, as mentioned above, the interaction between the operator and the technical system is what really matters, not the human per se or the visible machine interface.

4. Simulator-Based Design

Paper 1 included in this thesis presents the model for SBD shown in Figure 5. This conceptual SBD process model is reviewed and elaborated here. The SBD model describes a process with close relations to the abovementioned software design methods and, as proposed by Göransson et al. (2003), secures the user perspective in the core SBD activity.

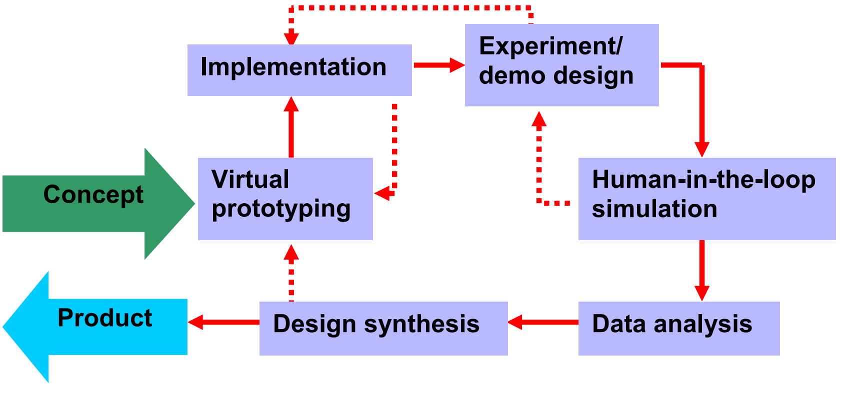

Figure 5. The main steps in the SBD process. The dotted arrows indicate the four most frequently occurring iterations, which are crucial parts of the SBD approach.

In this model the major activities of SBD are included and expressed. The four iterations could be compared with the steps in the Spiral model (Boehm, 1988) and successively refine the original product or system concept. Thus, prototypes 1, 2, 3, etc. are the main results of these iterations.

As mentioned earlier, the main product type where the SBD approach has relevance is in-vehicle systems. Figure 6 describes the different parts of in-vehicle systems and the different approaches one needs to apply to realize a complete system prototype for simulation. This conceptual system model is based on three layers, where layer 1 represents the peripheral parts of the system for data collection and realizing actions, layer 2 is the reasoning part of the system, and layer 3 covers the functions that bring in the operator in the loop. This system model could be also applied to manned systems other than those in the vehicle area. In the following I briefly describe the system model and its basic components.

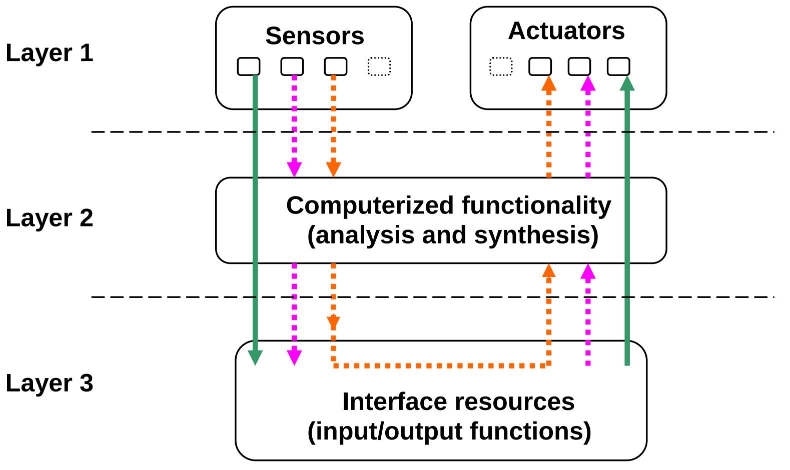

Figure 6. Generic system model for computer-based in-vehicle systems.

Sensors have a broad interpretation in this model; from vehicle-internal sensors measuring vehicle or even driver conditions to sensors for collecting external information and to receivers of broadcast information like GPS or from other systems. In the SBD methodology these sensor categories are realized by data collection from the simulator software. In most cases there are no physical opportunities to introduce real sensors. Real GPS, for example, should be of no use, since the simulator is not moving (at least not much) and, for another example, infrared (IR) cameras should not be able to distinguish between different virtual objects in the scenario, since all objects have about the same temperature on the environment screens in the simulator site. The simulator software on the other hand knows everything about the simulated world and the activities that are going on in this environment. Thus, it is possible to use such data and channel this information in accordance with the capability limitations of a certain sensor.

Actuators have a corresponding meaning to sensors in the simulated world. They are usually replaced by software functions in the simulator. Braking and steering, for instance, has no physical meaning in a simulator. Instead the input activities of the driver are transferred to the vehicle dynamics function in the simulator software, where the input signals are analyzed and transferred to virtual output signals influencing the simulated vehicle, its visual environment, and the movement platform if such equipment is available. This whole procedure carried out in real-time.

The computerized functionality is the heart and brain of the system model. It receives and analyzes the data coming from the virtual sensors or from input activities in the cockpit. In the next step, based on the results of this analysis, the specific activity is initiated affecting the interface or some actuator. In the SBD concept this level in the system is close to a corresponding function in a real system. In the optimal case these computer functions could be directly ported into the final product platform. Computerized functionality means that the content at this level is purely based on software and built in a proper programming language with respect to the final product solution.

The interface level is where the technical system ends or begins. The end is equal to system output, whereas beginning is another word for input, in both cases from the operator's perspective. In the SBD approach it is essential to support the design activities at this system level by having programmable hardware solutions. As mentioned earlier, the expression "glass cockpit" was coined in the late seventies and refers to the change from "iron instruments" to screen-based ("glass") solutions. This facilitates the rapid prototyping of interface components including the interaction procedures involved. When in the future corresponding resources have been implemented in real vehicles the opportunities for fast transfer from the SBD platform to the real vehicle will open up. This is not yet the case because most of these virtual prototypes must still be converted to "iron instruments".

The arrows in the generic system model (Figure 6) indicate different approaches to the design of a specific system and its use of intelligent resources. At the most advanced level (the inner loop) the loop is closed all the way from sensors to actuators. This represents an automated system, but the horizontal part of the arrow tells us that something should happen also at the interface level. This means that it is necessary to keep the operator in the loop through a human-centered approach (Billings, 1997) despite the fact that all actions are taken care of by the system and "the automation must also communicate about its work and progress" (Dekker and Woods, 1999, p. 13). An example of automation in car systems is traction control, where the vehicle will take care of the action under certain conditions and also inform the driver that this process is ongoing, usually indicated by a lamp flushing on the dashboard. On the other end of the system scale, there are functions with no or very insignificant use of middle layer resources. One such example is a night vision system with direct presentation of raw sensor data on a cockpit display.

What is not included in the generic system model as depicted in Figure 6 is the human operator. The reason for this is that the design activities of the technical system are in focus and the SBD methodology shares that approach. However, the way to evaluate the design solutions is to involve the operator in human-in-the-loop simulations in order to evaluate the manned system performance. This mirrors the HMI standpoint that the human must be regarded as a part of the system. By going one step further, the vehicle environment constitutes yet another level of the system, since the manned vehicle interacts with these external entities and is closely related to the environmental situation as a whole. These issues are increasingly important to have in focus, since the borderlines between the operator and the intelligent vehicle are becoming more and more diffuse. Sometimes the operator is acting and sometimes the vehicle automation is operating. This system view will be further discussed later in this thesis.

Going back to the SBD process and Figure 5, the iterations (dotted arrows) are central in this context. The iterations describe the normal procedure in SBD. It is also the way the first virtual prototype is developed towards the final version. One basic idea in SBD is to start this process at very early stages of product development. This usually means that the first prototype is more close to the early concept (the incoming arrow in Figure 5) than to the final product. Depending on the specifics of the actual project such conceptual prototypes could be taken all the way in the SBD sequence to the design synthesis stage. In such cases the first design synthesis answer will be “yes or no”. If yes, the additional information obtained during the SBD procedure will guide the following prototyping step. From an external first view this long procedure could be regarded as a waste of resources since one knows that the complete procedure must be repeated with a more elaborated prototype. This is also the case, but the previous results from all specific steps could be more or less re-used or even copied in the new round. So in the second step (and those following) the main purpose is refinement and not invention of something completely new.

4.1 Fidelity and validity

Paper 1 discusses fidelity and validity as important problem areas in SBD and in simulation activities as a whole. In many contexts the notion *absolute validity* is used to indicate that a specific simulator has the general ability to produce valid results. But, rather often the absolute validity expression is erroneously used when the proper expression should be *fidelity*. Fidelity refers to how natural the total experience of driving a specific simulator is related to real driving. Typically, a high fidelity car simulator has a moving platform, a real cab, and a good representation of the surrounding environment. This, however, does not guarantee valid results in all studies conducted in this simulator. If the researcher or developer has the opportunity to choose between simulators at different fidelity levels in order to suit the specific goals of the study in mind it will have a positive impact on cost-benefit relations, since the costs for improved realism could be considerably higher than the obtained benefits (Reed and Green, 1999). But again, this does not exclude a validity assessment. Does this simulator have the capability to produce valid results in this specific study? For most of the existing high fidelity simulators the possibility to manage SBD activities is limited, since they are not designed to let the experimenter implement any new functions or systems as described in Figure 6 and make them work seamlessly together with the other simulator functions. The only way to proceed in such cases is to bring in additional equipment (functions) and in such cases it is important to question validity. Are the results affected by “clumsy” implementation or not? It is crucial to carry out such assessments in advance, that is, before choosing a specific simulator site.

The validity of an SBD study will not only depend on the technical level of the simulator, as mentioned above, but also the system prototype in focus, the relevance and design level of the environmental model, the scenario design, and the dependent variables to be measured. For all these issues it is important to have validity in mind in the design phase, not only separately but also the interplay between all these parts during data acquisition. In the following I will briefly address validity aspects for each of these steps.

System prototype. This is the object in focus for the trial and it is crucial to have a balance between the actual development level of the prototype and the measurement. If the prototype is an early conceptual prototype, the “questions” in the measurement activity must be tuned to focus on high level measures, ultimately on “yes or no”. If more qualitative measures are included at this stage it would be a risk to exclude a potential winner before any serious design efforts have been carried out. Another important issue for the prototype design, especially at early stages, is where shortcuts could be taken and how they should be designed. Usually, the best procedure for evaluation, no matter who is participating, is to put most of the efforts on the interface resources (see Figure 7), set up some simple rules at the intelligence level, and have a realistic sensor capability. Since sensor data will be based on data from the simulator software, it is trivial what level of sensor performance one chooses from an effort perspective. If any virtual actuator should be involved, for instance an increased resistance in the steering-wheel, this must be done carefully. The same is true for all functions close to the driver.

Environmental model. From a validity perspective the environmental model has to be realistic in relation to the question at hand. If the investigation, for example, is concerned with an intersection warning system, the structure of the intersection must be modeled according to the problem. This will probably mean that sight lines from the car have to be realistically limited, otherwise the warning system will make no difference and the validity of the investigation might be weakened. The type of buildings and their design details are not important, which allows for copy and paste strategies in the modeling activity.

Scenario design. The goal for the scenario design is to implement events and traffic streams to challenge the system in focus. Not the least, ecological validity is an important issue. This means that the events and traffic behavior should be relevant compared to a corresponding real-world scenario. It is also of utmost importance to tune these events to measurements. For instance, as reported in Paper 5, in a Night Vision study the distance to an obstacle at the moment of obstacle recognition is the key measure. In most cases an iterative approach is necessary for scenario design, as is indicated in the SBD process (Figure 5). If, for example, the participating driver has problems entering a traffic stream, no matter what system support he/she might have, the validity of any measurements will be negatively influenced. The pace of scenario events is possible to manipulate without any negative impact on validity. Reliability, however, may be affected if the pace of events is so high that the driver will act differently from his/her normal driving behavior. This has a coupling to learning effects, which could be avoided by different means like counter-balancing and variation in the types of events.

Measurements. The coupling between measurement and validity is obvious, since validity is defined as the capability of a measurement to measure what it is intended to. In general, performance measures in comparative studies are much focused on some certain goal-related factor of the investigated system, for instance, detection distance to an obstacle with a collision warning system. This kind of direct measures is usually safer than indirect measures. Another example of direct measurement is eye-tracking. For this measure there is a need for more careful validity considerations depending on how to use data. If the ambition is to measure the duration of time spent for reading displayed information in the car, where some design alternatives are investigated, this measure may be much safer from the validity perspective than to analyze the same question by comparing time spent head-up and head-down, respectively. In this case some other factors may be influencing the outcome and thereby destroy the validity of the measurement. Eye-tracking data may also be used indirectly as signs of drowsiness or even mental workload. Here the need for caution is obvious with respect to validity, but on the other hand, such measurements are seldom very useful in the SBD process. This is also the case with other indirect measures, since they do not contribute very much to the understanding of specifics in a proposed design.

The use of compound measures is not much used, but is a way to improve validity, not the least for mental workload measurement using psychophysical indicators like heart rate, blood pressure, and ECG. Magnusson (2002) has compared a set of such workload measures in simulated and real flight missions and found similar reaction patterns in both settings, however at a significantly lower level for the simulated flight. This indicates that it is difficult to assess absolute measure results in the simulator, while comparative studies, as suggested in the SBD approach, will offer more valid results. On the whole, different measures in combination are recommended in SBD projects since most in-vehicle systems will affect performance in many ways.

In concluding this section, it is important to understand and secure the possibility of having reliable and valid results for each study, where the SBD approach is deployed. One common problem in simulator-based activities in general is the appearance of simulator sickness. This problem has been studied extensively (e.g., Casali, 1986; Kennedy, Hettinger, and Lilienthal, 1988) not the least for simulator-based training. This problem is a reality, no matter what fidelity level the simulator has. If a participant has tendencies for simulator sickness at any level, the recommendation will always be to break off, not only for hygienic reasons, but also for securing a reliable outcome of the current study. The performance of a participant, who is affected by simulator sickness will always be degraded, and therefore the measurements in such a situation will be less reliable. I will not go deeper into this matter, but the risk for simulator sickness seems to be higher the more visual details the environment presentation include (Watson, 1997). In our own studies we have noticed more problems in daytime city driving compared to nighttime highway driving.

One way to handle this problem is to always include a substantial training session. This will not only give the possibility to assess potential simulator sickness, but will also make participants comfortable with driving in the simulator.

4.2 Conclusions

To conclude this section on simulator-based design it should be mentioned that there are few existing simulators in the automotive field that meet the requirements of SBD. These requirements are discussed in Paper 1 and they all have a great impact on validity, and also reliability, but do not necessarily have the same influence on fidelity. However, the commercial simulator (software) producers are market-driven companies and when the automotive industry realizes the possibilities in SBD and start to demand such design tools the simulator producers will meet these demands. The motives for the industry to introduce SBD are similar to the corresponding development in the aviation area:

- To meet the technology shift in ground vehicles with corresponding design methodology
- To have proper tools for systems integration including sub-contractor products
- To speed up the design process of new systems
- To give early answers on design questions
- To secure product quality
- To minimize cost-consuming real tests
- To get more profits

5 Theoretical issues for design of 3D situation displays

In this chapter the prerequisites for simulator-based activities are left behind and the focus will turn to more narrow, but still very important aspects, of one focus area in SBD, the interface design issues, and specifically on the design of 3D situation displays in aircraft and ground vehicles.

5.1 Background and research questions

One major incentive behind my display design research was the lack of ecological approaches in existing air traffic and navigation displays ten years ago. With reference to Vicente and Rasmussen (1992), an ecological interface could be defined as when the display configuration reflects the constraints of the physical system it represents. Obviously the 2D view of an air traffic situation is far from this definition. This lack of ecology in traffic displays is still the case, especially in civil aviation. One obvious reason is the certification procedures involved. Major changes always take time to introduce. For the less regulated ground vehicle applications, the introduction of electronic displays has recently started and this will facilitate the implementation of new driver interface principles. These new principles could benefit from a knowledge transfer from aviation including the huge knowledge-base from decades of research.

The applications I have focused on are 3D situation displays, primarily for air traffic presentation, but lately also for night vision presentation in ground vehicles. In aviation there are, according to my opinion and supported by research results (Prinzel, Kramer, Comstock, Bailey, Hughes, & Parrish, 2002), reasons to believe that widespread use of 3D perspective displays with topographic information could eliminate CFIT (Controlled Flight Into Terrain) accidents, where perfectly functioning airplanes crash, often in mountainous terrain during low visibility conditions. Our ambition, however, was to demonstrate that the 3D format also could be the best solution for traffic information, which should imply that the same display format could be used for all cases where information on the surrounding situation should be presented.

In this chapter I will discuss some important theories with relevance to the design of 3D situation displays and successively couple these discussions to the remaining papers (2-5) in this thesis. Paper 2 is by itself a more theoretical discussion on the applicability of using spatial cues to improve the understanding of the display content. The remaining papers are based on experiments performed in simulator facilities with humans in the loop. In other words they are describing projects where the SBD methodology has been applied.

All the included experimental studies (Papers 3-5) focus on basic design questions and do not discuss complete display solutions. The purpose of the studies was to give important input for such design efforts, but not deal with all questions involved in these activities. In summary, the questions we investigated were as follows:

- Symbol shapes in 3D aircraft displays, is there an optimal solution? (Paper 3)
- Do operators understand spatial relations between different objects on the 3D display? (Papers 3 and 4)
- Do additional spatial cues contribute to improved situation assessment? (Paper 4)
- Do these cues make the same difference in different operator tasks? (Paper 4)
- How important is real-time simulation compared to static assessments in these kinds of investigations? (Paper 4)
- Does continuous presentation of enhanced visual information in night-time car driving have drawbacks like negative behavioral adaptation? (Paper 5)
- Does situation-dependent presentation have a positive impact on driver performance in the use of night vision systems? (Paper 5)

All display solutions in the experiments are 3D pictorial, which means that they depict a natural three-dimensional view and transfer this picture to a flat screen in the cockpit. In the aircraft applications the presentation is synthetic, which means that all information is mediated by a computer and that the original information sources are of less interest from a design perspective. It could be information from different air-borne sensors and databases or information transmitted from the ground control system or even other aircraft. Synthetic presentation has long been best practice in aviation, while night vision displays in car applications are utilizing raw sensor information (so far).

5.2 Why three-dimensional presentation?

In situation displays the purpose is to present a view of a situation from the real world. The reason for this "transfer" is usually to reach beyond the human visual range with respect to visual conditions like darkness and the distance to objects of interest. In aviation applications this presentation has traditionally used a two-dimensional display format with a so-called God's eye view, which means a vertical view of the scene. In most cases the situation is overlaid on a map presentation, which makes it possible to have richer information on where different objects are situated. In aviation displays (both airborne and in the ground control) this planar presentation has to be supplemented by digital altitude information in order to support a more complete understanding of the situation. Generally, this supplementary information also includes other details about the flight.

In aviation both flight controllers and pilots have to mentally combine this diverse information into a 3D mental model of the real situation. This mental operation is demanding and capacity-consuming (e.g., Wickens and Hollands, 2000, p. 129), especially since the information is critical from a safety perspective. For pilots operating in visual conditions it is even more demanding to try to compare this mental model with what they see through the windshield. This is the background to the interest in 3D displays in both industry and research.

When 3D displays are discussed in this thesis, real stereoscopy is excluded. One motive for this is that stereoscopic displays are hard to implement globally both for technical and economic reasons. Furthermore, there is evidence indicating that real stereoscopy has no evident advantage to 3D perspective displays if the displayed situation is dynamic (motion must be involved) and if the perspective display provides a sufficient number of relevant spatial cues (Naikar, 1998). Such cues are discussed in detail in Paper 2. One conclusion in this paper is that a combination of natural and artificial cues may be optimal in many applications. By natural cues I refer to what we use in real life when we assess a certain scene. These cues are discussed by Gibson (1979). Wickens and Hollands (2000, pp. 139-141) take this discussion further into the display design field. Artificial cues are not available in the real world situation but can be inserted in the display based on calculations by the computer. Examples of such cues are ground surface grid and drop-lines between flying objects and the ground. A grid enhances the important linear perspective in the 3D scene and drop-lines may contribute to location assessment of a flying object, in the depth dimension as well as horizontally and vertically.

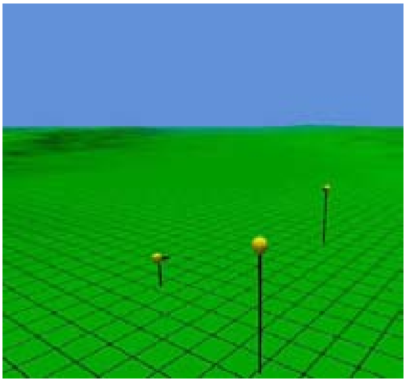

Figure 7. 3D perspective display with ground surface grid and flying objects (symbols) with drop-lines. The grid follows the terrain in a cardinal direction orientation.

Many studies have investigated performance differences between using 2D and 3D displays. Haskell and Wickens (1993) and St. John, Cowen, Smallman, and Oonk (2001) have in their studies also contributed with summaries on other research in this field. Although they report on comparison difficulties due to differences where tasks, measurements, and display design solutions could vary, it was possible to see a pattern. More integrated tasks were well supported by the 3D alternative, while 2D displays were preferable in focused-attention tasks or where single-dimension measures were included. The 3D alternative was also best suited for shape understanding, like topographical assessments. Navigating from A to B was a task best supported by a 2D display. These findings speak to a situation- or task-dependent use of display formats. However, format changes are problematic (St. John, Smallman, Bank, and Cowen, 2001) in the same way as mentioned above where mental rotation between the outside world and the 2D map display was discussed. One way to minimize these difficulties is to use real or artificial landmarks to bridge between the two formats as suggested in the concept of visual momentum (Woods, 1984). Another way to tackle this problem is described in Paper 4 in this thesis, where adaptive cueing is suggested. In this approach there will be no need for changing format but keeping the 3D display format for all kinds of tasks. Tasks which include more single-dimensional assessments or precise spatial judgments should be supported by adding specific cues.

It should be mentioned that the discussion here on 3D displays does not include head-up displays (HUD's) with look-through capability. Such displays have been used in military aircraft since the late sixties. The basic format here is 3D perspective for all information related to the surrounding environment, but the HUD is also used for supplementary information like horizon, air speed, and altitude. The reason for introducing HUD's was to allow the pilot to maintain the head-up position in specific tasks like landing or target acquisition. To use the 3D format for supporting such tasks has never been questioned.

In our own experiments we have not made any 2D/3D comparisons. Our underlying approach has been as in this question: If/when 3D displays will be introduced in aviation, how should they be designed to support the operator in the best way? Our first activity in this design effort was to investigate symbol shapes.

5.3 Symbol design

Symbol design has been a research interest since decades. A great part of this research has had a broad approach with no specific application area, another part has focused on computer-based applications, the design of icons, and a smaller part has focused on more specific applications like symbols in situation displays (e.g., Barnard and Marcel, 1978; Moses, Maisano, and Bersh, 1978; Smallman, St. John, Oonk, and Cowen, 2000). In military organizations there has been a long-lasting use of symbols for identification of military forces. This "language" has developed into an international military *de facto* standard and is extensively used in battlefield map-based overviews. The main feature of these symbols is a high level of abstraction. This means that the military people have to learn the principles behind the symbol components in order to understand the reality behind each symbol. This abstract language is in sharp contrast to naturalistic design principles. In its most extreme form such naturalistic symbols are simply pictures of the real world objects.

In map displays the use of symbols representing different kinds of objects also has a long tradition. Generally these symbols are abstract, which means that an aircraft on the flight controller's display, for example, having the shape of a square and a triangle may represent a position of a fix point for navigation. Typically, the displays are two-dimensional and so are also the symbols. However, when 3D displays are in consideration the question arises on the principles for symbol design. Should they be two- or three-dimensional and if 3D, should they be abstract or naturalistic? These questions together with the traditional way to present in different areas have to be considered in each application. The Pacific Science and Engineering Group Inc. in San Diego, USA, has investigated these questions extensively and produced several reports (e.g., Smallman, St. John, Oonk, and Cowen, 2001; Smallman, Oonk, St. John, and Cowen, 2001). They released a symbol concept for 3D situation displays called Symbicons with close relationship to the existing NATO standard. Symbicon is a combination between the military heritage and realistic icons and was presented as 2D objects on the 3D display. The shape of the symbicons was to some extent realistic with, for instance, aircraft objects having an arrow-like shape. Inside the symbicon there was alpha-numerical information indicating the more specific identification. Interestingly enough, the research team had adapted a concept for symbol rotation on 2D displays that I proposed a couple of years earlier (Alm and Ohlsson, 2000). This design principle implied a rotation of the icon, but still keeping the alphanumeric information horizontally presented on the display in the case of target turns. In the Symbicon study (Smallman et al., 2001) the researchers investigated three symbol approaches, (military) symbols, icons (realistic), and symbicons and found that this combined concept produced the best and fastest results for operator identification performance. All three alternatives had constant symbol size irrespective of distance to the observer's position.

It could be discussed if two-dimensional symbols are well suited for 3D displays. It is even more questionable to keep constant symbol size irrespective of distance to objects since relative size is one important cue (Paper 2) in the 3D situation assessment. In my opinion constant symbol sizes will degrade the situational assessment in general and especially the depth (distance) perception and this is not a prize to pay for keeping alpha-numerical information visible (legible) inside the symbol. In our approach for aircraft situation displays we have used three-dimensional symbol shapes and dynamic symbol scaling. All symbols had the same nominal size. This design decision is supported by a study of DeLucia (1995), where she found that the use of different nominal symbol sizes destroyed the possibilities to correctly judge collision risks in an air traffic situation.

In order to manipulate symbol shapes and colors and also make it possible to turn around the symbols (representing different viewing angles) we developed a desktop tool, a virtual prototyping tool for symbol design. This facilitated the prototyping step in the SBD process. Using this tool we developed five different symbols, where a sphere was the most abstract symbol and two slightly different arrows were more realistic (aircraft-like). The non-arrows had direction indicators. In our first experiment (reported in Paper 3) we found that the most abstract symbol, the sphere, showed great advantage compared to the other shapes. Since object scaling was an important component in our design approach, it became evident that the symbol size should not be affected by anything other than distance. The sizes of all other shapes depended on aspect angle. This viewpoint-related problem is also recognized by, for instance, Tarr, Williams, Hayward, and Gauthier (1998). If the arrow, for example, is heading towards the viewing-point or is perpendicular to the viewer, the object size at the screen will change. This change will affect the distance assessment or, more correctly, the distance component in the 3D view. Thus the sphere shape became the symbol design approach we used in all remaining research activities.

For discrimination between different kinds of aircraft (e.g., friend or enemy, prioritized, etc.) color coding was used later on in our simulator-based experiments (Paper 4). This together with the use of supplementing alpha-numeric information (if necessary) could be further developed. However, the alpha-numeric information should be displayed outside the symbol as has been the case in most 2D display applications.

3D displays are now being introduced in aircraft (synthetic vision displays, air traffic displays, etc.). In all applications I have found aircraft are represented by naturalistic icons ("real" aircraft). This is not good, since there is strong evidence for opposite approaches. Smallman and St.John (2005) discuss what they call naïve realism, where people tend to prefer realism in (3D) displays despite the fact that the same people under-perform in such settings.

In summary, symbols representing aircraft on 3D displays should have the sphere shape with vectors added representing heading and velocity. Color coding should be used for discrimination and additional information should be available at request or by automated decisions outside the symbol.

5.4 Spatial relations between objects

In aviation, relative measures are of great importance and from a flight safety perspective are even more important than absolute measures like altitude, or absolute position, or absolute velocity. This is similar to other dynamic environments. Ground traffic and maritime situations are such examples. Thus, to understand the ownship situation in relation to other objects is a key issue for situation displays. For example, if two objects (aircraft) have intersecting headings in the 3D space at least one of them will (hopefully) change course and/or altitude. This procedure will be controlled by the Air Traffic Control (ATC) in most situations, but when the Free-Flight concept is introduced this may be a flight crew responsibility. In this concept a greater responsibility for air separation will be put on the pilots, and this is one reason for introducing air traffic displays in commercial aircraft. How information about other aircraft positions etc. will be captured is a question outside the scope of this thesis, but data-link from ATC is one option and GPS-based information transmitted by each commercial aircraft is another possibility. This kind of GPS-based information exchange has already been introduced in the marine transportation business.

What has not been discussed so far is the perspective in the display. One question is whether it should be egocentric or exocentric. In the first case the viewing-point or the virtual camera position is in the cockpit. This perspective has the advantage of being equal to the view when the pilot is looking out through the windshield. However, this perspective may cause difficulties in the assessment of relations to other objects. Here the exocentric perspective is more supportive, since one can see the ownship together with the other objects in the display (Wickens and Prevett, 1995). In this solution the virtual camera position is situated behind the ownship. The second question with respect to camera position is at which position in the 3D space the camera should be located. In our simulator-based design studies (Paper 4) we used the geometry shown in Figure 8, with the camera position 2000 meters behind and 18º above the ownship altitude.

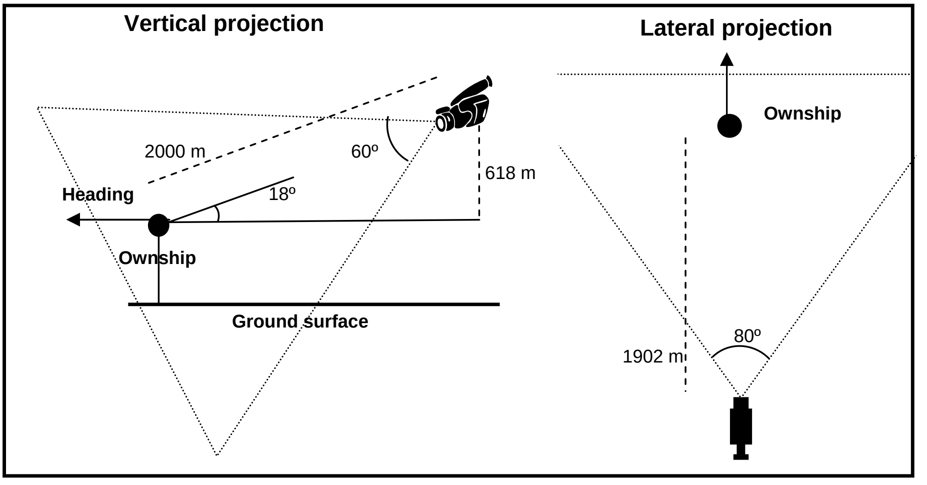

Figure 8. The exocentric perspective used in the air traffic display simulations.

The perspective geometry used in our simulator-based experiments was developed with requirements coupled to the existing screen format, the design decision to have the ownship symbol at the geometric center of the screen, and the ambition to have the horizon visible in most ownship attitudes. This last requirement made us use the 18º aspect angle. These design requirements could be discussed and ought to be optimized for each real world implementation together with the scaling factors. It is far from optimal (or even possible) to have the same scale factor for all parameters in the displayed 3D situation. These parameters are the three axes X, Y, and Z together with the symbol scaling. In our approach, we separated the symbol scaling from the scale factors used for the terrain presentation in order to keep the symbols visible at all times. Moreover, the nominal symbol size was over-dimensioned compared to the terrain scale.

All these parameter settings affect the possibility to correctly assess spatial relations between objects. These questions and the resulting distortion problems have been addressed in many studies (e.g., McGreevy and Ellis 1986). The overall design goal must be to display the situation in order to optimize the operator's performance. To do so it is, for example, better to limit the displayed scene in the horizontal plane instead of distorting the scale too much. In the vertical plane it is necessary to compress the scale in relation to the lateral and horizontal planes in order to cover realistic flight levels and still keep the ground surface visible within the screen. The scale in the lateral plane is to a large extent a question of context and the current task. However, the relations between the lateral and horizontal scales must be coordinated in a way that makes sense to the operator. All these concerns can be addressed using SBD and its iterative approach.

About the camera aspect angle the optimal solution in a 3D display is 45º according to Hickox and Wickens (1999). This angle gives similar conditions for elevation and azimuth assessments, which are the basic components in the important 3D bearing assessment, the bearing from the ownship to some other object of interest. From an aspect angle of 90º (the God's eye view) it is fairly easy to understand that elevation assessments are impossible to conduct, since all target symbols seem to be located on the ground surface. If you choose an aspect angle of 0º (right behind the ownship) the view of the virtual azimuth plane is through the plane and this condition makes the azimuth assessments very difficult. (However, for altitude/elevation assessments this angle is optimal.) It is possible to see on which side of the ownship heading the target is, but the correct angle is difficult to assess. You need some angle of incidence to the virtual azimuth plane to support more precise assessments and ideally the aspect angle should be 90 º. These relations in the design of 3D perspective displays have been studied intensively by many researchers (e.g., Lind, Bingham, and Forsell, 2002; Sedgwick, 1986; Todd, Tittle, and Norman, 1995). Thus, to have a good opportunity to correctly assess a 3D bearing, the underlying angular components are necessary to capture, however, in an intuitive way. The bearing assessment is a key factor in understanding a situation. It answers the question in what directions other intervening objects may appear.

The chosen camera aspect angle in our experiments is consequently not optimal from the assessment perspective, but brings the perspective closer to the normal out-the-window view while allowing for the horizon to be visible on the display. These two motives are important so the final solution must be a compromise between all the involved factors. The experiments reported in Paper 4 produced good bearing assessment performance using this 18º aspect angle. It may also be mentioned that training together with contextual experience will further strengthen the performance. In our case we used students as “pilots” with no prior flight education. This choice was made since we did not want to introduce any education bias in the results.

One remaining factor determining the spatial relations between objects is distance. Through the bearing assessment we know the three-dimensional direction, but to answer the question “where” the distance also must be assessed. Object scaling gives an answer measured in relative terms (DeLucia, 1995). The smaller the object symbol, the greater the distance from the virtual camera position. A bigger symbol is always closer than a smaller. For more exact distance assessments the 3D display format is less supportive than the 2D format, but with additional cues like drop-lines from the symbols to a ground surface grid this assessment could be more precise.

Spatial relations between objects are the key issue in air traffic displays. The perception and understanding of these relations and how they change over time are the basic components that build situation awareness (SA) applied to a flight situation. The user construct called SA (Endsley, 1995a) has been debated extensively in the Human Factors community. Smith and Hancock (1995) proposed a more dynamic view of SA, where task-dependent constraints determined what was good or bad SA. In other words there are components in a situation which are relevant to the task, while other components in the same situation are not of any relevance. With another task in mind the constraints for the same situation will change. They also suggested that this task dependence should be considered in display design, so that the critical aspects of a situation (related to the current task) are brought to awareness. Such design studies are complicated but are possible to address using the SBD approach. This task-dependant view on design is fundamental in the ecological approach (Vicente and Rasmussen, 1992), a subject I will return to later in this chapter. I will not go further into the theory of SA and the methods used for SA measurement (Endsley, 1995b), since we chose a different approach to investigate the features of 3D displays for air traffic information. However, Endsley's SA definition with its third SA level on the possibilities to predict is crucial in air traffic as well as in many other contexts. Thus, we included a predictive task in our series of experiments (Paper 4), a collision risk assessment in a dynamic flight scene. In conclusion, if the 3D perspective display supports assessment of spatial relations and how these will evolve in a dynamic environment we have a good solution for future air traffic displays.

5.5 The use of additional cues

In our design approach for 3D air traffic displays we have built in a set of spatial cues in the basic display design. As mentioned above we strengthened the linear perspective by adding a grid to the ground surface and we introduced distance-related object scaling. The SBD approach made it possible to implement dynamic shading with a constant source of light (fixed screen-related position), which affected both symbols and the underlying terrain. These basic features were not evaluated per se, but from a theoretical perspective, we know that a number of cues are necessary to implement in order to make the perspective display useful for the operator (e.g., Mazur and Reising, 1990; Ware, 2000). On the other hand, we also know that display clutter could be a problem (e.g., Wickens and Hollands, 2000, p. 167) and thus, we tried to avoid too dominating elements, which could disturb the target perception.

In our experiments, presented in Paper 4, we investigated the impact of drop-lines for different tasks and found that drop-lines only contributed to better operator performance in certain tasks or for some ownship-target spatial relations. This conclusion emphasizes the need for an adaptive design approach in order to minimize the negative cluttering effects as much as possible. This means that for certain tasks the pilot should be able to momentary add drop-lines for all surrounding objects or for chosen objects, and for certain ownship-target relations the system should insert drop-lines automatically. In the latter case this automatic choice of objects to reinforce must be dependent on other characteristics in the display design, primarily the aspect angle of the virtual camera. In our case with an aspect angle of 18º the problematic target positions appeared in the forward-downward sector. These targets were located close to the 18º plane from the virtual camera through the ownship. Thus, it is possible that a steeper camera aspect angle may change the relative location of the problematic spatial volume. It is also possible that this area would change also for horizontal variations of the camera position. By using the SBD methodology, investigations on these design parameters could be easily performed.

This discussion should have even more relevance in design solutions were the operator is given the authority to dynamically move around the camera position. We have briefly studied but not published this solution in an ATC (Air Traffic Control) application, where the SBD activity showed difficulties in operator orientation. One problem behind this disorientation could be the use of different scales for x, y, and z, which may add a continuously changing distortion to the perceived view (c.f., McGreevy and Ellis, 1986). Thus, if the operator has the possibility to freely move around it is easy to get lost and it is necessary to find design solutions to mitigate such problems. On the other hand, this moving around concept has probably appeared, since different target locations are better identified from a diversity of camera positions. The dynamic cuing concept is another way to strengthen this identification process without risk of losing spatial orientation and, in my opinion, this is a safer way to choose.

We have not investigated any other additional cues than drop-lines. There may be other cues or elements of information which could enhance the operator performance. In the ATC (2D display) environment, supplementing target information has long been prevalent with the possibility for the controller to choose if this information should be presented or not. Similar approaches may be supportive also for 3D air traffic displays. Also automatically appearing predictors for intervening objects should be useful. Such aiding tools already exist in ATC. In airliners the Traffic Collision Avoidance System (TCAS) gives a verbal warning and avoidance information based on transmitted flight data regarding other aircraft in the area. Such information could also be visualized in 3D displays as well as in existing 2D displays.

The topography has not been discussed here in detail, but is a natural part of the suggested basic display design. The reason for not dealing with this important part of the display is that we were mainly interested in air traffic situations, where the three-dimensional presentation has been more in question. The 3D format is superior to the 2D format when it comes to topography, and as demonstrated by Printzel et al. (2002), 3D displayed topographic information in the cockpit might even eliminate CFIT accidents. The superiority of 3D over 2D for shape-understanding is also demonstrated by St. John et al. (2001), and shape is very close to topography, which speaks for the benefits of 3D presentation of such information. An additional cueing concept for terrain presentation is to dynamically stain mountain peaks above the ownship altitude (for instance, in red). This concept has been demonstrated in commercial 2D applications as a way to diminish the disadvantage of the 2D format in this context.

5.6 Task- and situation-dependent presentation

Through this chapter the need for a more dynamic and adaptive display design approach has been touched upon several times. This is really not a new idea in designing operator interfaces for complex systems. According to Rouse (1991, p. 150) the concept of adaptive aiding emerged in the mid-1970s in the course of a project that was concerned with applications of artificial intelligence (AI) to cockpit automation. In this work it became evident that there was a need for “cooperative intelligence” between the human operator and the machine. These ideas seem to have inspired many researchers around the world to participate in the progress of this new concept for Human-Machine Interaction.

Close to this approach new theoretical foundations were developed within the concept of Ecological Interface Design (EID) (Rasmussen and Vicente, 1989; Vicente and Rasmussen, 1992). EID is in turn influenced by the taxonomy of cognitive control as proposed by Rasmussen (1983) where three control levels were defined: Skilled-based, rule-based, and knowledge-based behavior. This framework describes the various mechanisms people utilize in processing task-related information. In short, skilled-based behavior is more or less automatic and depending on the operator's degree of expertise. At the next level the operator has to refer the specific situation to relevant rules, which is more mentally demanding. On the third level it is necessary to apply deeper knowledge and analogous reasoning in order to cope with the situation. In the EID concept the idea is to support the operator in a nuanced context-dependant way, since each control level may demand specific cues or kinds of information. This approach is also supported by Ware (2000) who proposes task-dependent cuing.

It may be emphasized that the purpose of the EID approach as for my own SBD methodology is not to replace all other methods. On the contrary, there will always be a need for a battery of methodological approaches in designing complex systems. In the textbook Ecological Interface Design, Burns and Hajdukiewicz (2004) dedicated the concluding chapter to this issue and explained how EID will fit together with other methods like Cognitive Work Analysis, Participatory Design, User Interface Principles, Usability Evaluation, etc.

There is also a consideration in the EID approach on information optimization to not overload the operator with information of less relevance to the level of control. This could be referred to as a decluttering strategy. In principle, there are two opposite ways to dynamically optimize the display content to make the operation more effective, highlighting and de-cluttering. In a strict highlighting concept all information is available on the display and the most important information is made more visually salient compared to the remaining information. This is usually done by changing color, making the current color brighter, or letting the information twinkle. However, these manipulations must be carefully done, since a bad color contrast ratio may jeopardize legibility. In case of a resynchronization, the twinkling might be considered a distractor instead of an enhancer of information. Also in the basic decluttering strategy all information is available, but information of less importance is made less visually salient, usually by dimming the information.

One problem with the highlighting strategy according to St. John, Smallman, Manes, Feher, and Morrison (2005, p. 509) is "that because it is such an effective form of cuing, it can impede the detection of important objects that are mistakenly left un-highlighted (and hence un-cued) when the automation is imperfect or the situation is uncertain". This statement is supported by Alexander, Wickens, and Hardy (2003). Since Smallman et al. advocate the decluttering strategy their implicit message seems to be that this problem will diminish for this alternative. However, the underlying problem of uncertainty is still the same and the automation behind is thereby a problem, which the authors also address in their paper. In the paper Smallman et al. also referred to research findings on the highlighting approach with significant time-savings in operator performance, which also was the case with decluttering in their own study. In the experiment, they compared two levels of decluttering in relation to a base-line display with no decluttering and except for timesaving they found a better situation assessment performance for the decluttered alternatives. However, they did not include a highlighting alternative, which could have been interesting.

In our research reports we have discussed clutter in connection to additional cuing, not for the basic display information. Our philosophy is similar to Smallman et al., since we propose a decluttering approach. Information that is important in some tasks or situations should not be constantly displayed in order to minimize the cluttering problem. However, in our basic display development, clutter was an issue and much discussed, especially when the ground surface grid was introduced. In that case we found it more important to strengthen the linear perspective and the cluttering effects were considered less important. This finding was supported by the SBD approach, where both conditions were assessed by the research team.

From a common sense perspective, the SBD way to carry out display design is beneficial in vehicle systems. However, there are two major problems involved. First, which pieces of the available information suit the current level of control? Second, who will be in charge of the activating procedure? For the last question there will be at least two possibilities. Either the human operator will be responsible by initiating mode changes in the system or will the procedure be taken care of by the intelligent technical system. There will probably be alternatives between these extremes and in aviation there is also a possibility to give the ATC such responsibilities, at least theoretically. Here we come close to the scientific discussion on Adaptive Function Allocation, which refers to the dynamic control shifts between the operator and the "machine". Function allocation was originally based on a static approach, based on considerations of the superiority of the human operator and the machine, respectively in solving different tasks. This technique was introduced by Fitts (1951) and he presented a list that divided tasks between the operator and the machine. However, as Scallen and Hancock (2001) point out, this list was intended to be a basis for further discussion and investigations and not to be regarded as a "final" design guideline. However, this way to statically divide tasks is "frustrating to the designer, ineffective for operations, and incomplete as a descriptive structure" (Hancock and Scallen, 1996).

The research on static and adaptive function allocation refers mainly to control issues. However, also interface resources have functions, input and output functions, which could benefit from an adaptive allocation approach, where the adaptive interface will change dynamically depending on the contextual circumstances. These changes could be associated to control shifts, as mentioned above, but should also be strongly considered for other contextual changes, where the authority of the system is not changed. In aviation, there is a long tradition of mode concepts coupled to specifics in the display design. For example, when the pilot chooses a landing mode, task specific information will become available at various displays. Such couplings to specific stages of a flight are rather easy to understand and support through the display design. But, when we decompose the flight into smaller parts, it is no longer easy to anticipate (and thereby give the technical system authority to act) what is most relevant. This discussion could be related to the huge efforts in the nineties on projects like "Pilots Associate" (Banks and Lizza, 1991), which aimed for "super-intelligent" system solutions with capability not only to optimize the display of information, but also to advise the pilot and even take over the authority when the pilot became overloaded or made mistakes. Except for task-related conditions, there are other characteristics of mission situations such as, for example, weather, light conditions, and the surrounding traffic situation. These conditions are easy to capture and may be used as input for automated mode changes in the display interface. This could also be in combination with operator induced mode changes.

In the experimental activities reported in Paper 4, we studied the importance of one piece of display information, drop-lines, and our conclusion was to insert such cues for certain conditions in relation to the current air traffic situation, and the chosen position of the virtual camera. In the discussion above, I also suggested that the pilot should be given the necessary means to manually insert drop-lines to support specific tasks. This mixed approach for meeting the challenge of EID could be generalized to a design strategy as described in Figure 9.

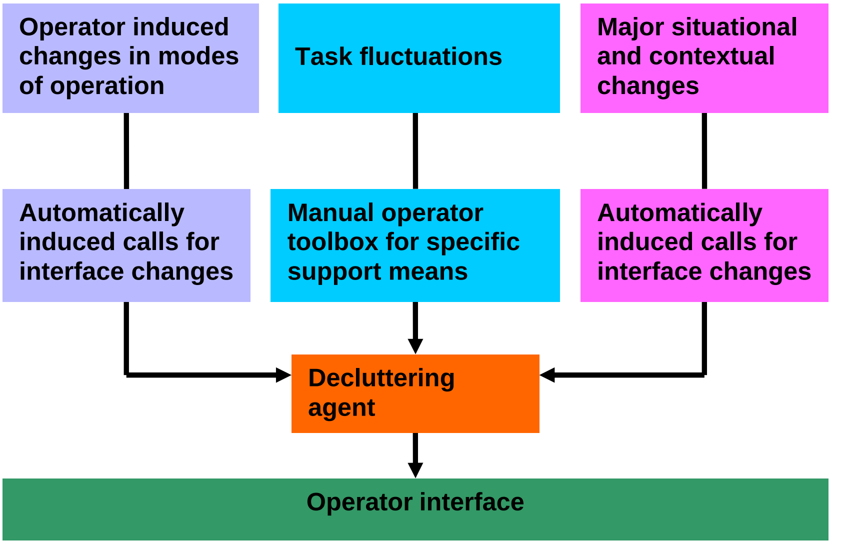

Figure 9. The mixed strategy for EID application in vehicle systems.

There is for all kinds of applications a need to define the specific criteria for the change processes involved as well as to design the support means, both the operator-induced and the automatic functions. For automatic functions it is also important to implement means for keeping the operator in the loop. It is not only by monitoring the results of an automation activity, but also to answer the question why, which means that information about what was behind the change must be presented in a proper way. In the case of operator-induced mode changes (for example, from cruising to landing approach in the aviation domain) the resulting changes in the interface are obvious, but if the external situation is changed the corresponding automatic interface changes may be more ambiguous.

Task- and situation-dependent presentation must at least partly introduce automation for managing the information presentation. Most literature on automation in the aviation field does not discuss this kind of automation, focusing instead on automation coupled to the primary control systems of the aircraft. In many cases it is relevant to transfer theories from control design to information design. Information design is generally also involved in the automation area, but still connected to the aircraft control situation. Sarter and Woods (1994) coined the expression “strong and silent” to describe the characteristics of many observed aircraft automation systems. Such systems do not keep the pilot in the loop and may lead to automation surprises, events which erode human operator trust in the systems (Sarter and Woods, 1992). To avoid such problems it is necessary to give the operator information on the “why question” as mentioned above.

In Figure 9 the sequence to the right, major situational and contextual changes, is the main target for automation and design solutions, which not only include the specific change criteria and resulting consequences for the interface, but also securing the goal to keep the operator in the loop. In a recent simulator-based study on a situation-dependent dialogue management system for car applications (not published) the participants reported frustration when they did not understand the purpose of a specific action by the system. Again the “why question” appeared and since the participants did not receive the proper answer from the system, trust in the system eroded however good the system solution was from an outside perspective.

This discussion is very much about adaptive interfaces and interaction. Such concepts leave traditional approaches to interaction design far behind, both about the design itself and the applied methodology. The old design approaches could be characterized as static interfaces where certain information always appeared at the same place and design approaches like the Proximity Compatibility Principle (PCP) had its foundation (Wickens and Carswell, 1995). According to this principle information components should be located closely on the display if the information components are used in the same task (process). In the adaptive interface information will be tailored and located to the most proper display (visual, tactile, or auditory) with respect to the current task and situation. In this case it will consequently be impossible to let each information component constantly appear at the same place. However, other important design principles as the PCP should still be applied in the adaptive interface. It is also important to set limitations for automatic interface changes. The strategy described in Figure 9, is one way to limit and organize this design space and thereby give a foundation for keeping the operator in the loop in the human-machine system. This concept could be further developed for different vehicular areas. In this complex domain it will be of greatest importance to have tools and processes as suggested in the SBD framework.

5.7 Design evaluation through real-time simulation

Design solutions for human-vehicle interaction are often very complex, even if the result is meant to be more or less intuitively understood by the operator. The complexity level is still higher for adaptive interfaces. This is the background for proposing the SBD approach. It is not possible to fully understand the consequences of a design solution in some static evaluation. On the contrary, it is even possible to take wrong design decisions if one does not evaluate the proposed design in a dynamic setting. These statements could to a large extent be referred to theories of visual perception, since visual perception is the dominant component in the human understanding of a situation (Gibson, 1979).

The principal difference between a static scene and a dynamic situation is motion. Gibson (1979) discussed motion and stereokinesis in his book, where he, for instance, referred to old findings where depicted circles were perceived with no depth disparities in the static condition, while set into orbital motion they were perceived at different depth positions. Obviously, motion, and especially relative motion, is important when you try to understand a displayed situation. Relative motion refers to the fact that distant objects seem to move more slowly than proximal objects (Wickens and Hollands, 2000). Motion is also the main difference between our experimental settings in Papers 3 and 4. One of the tasks we investigated was bearing assessments from ownship to target position. This task was carried out in both the static experiments (in Paper 3) and in the simulator experiments of Paper 4 where the situations developed over time, which consequently meant that motion was involved. After the static experiments, we were rather pessimistic about the possibilities of using 3D perspective displays for air traffic information, but when we got the possibility to move our experiments to a human-in-the-loop simulator we got quite different and positive results. In Paper 4 we also made a direct data comparison between the two conditions and found significant differences between assessment results. It is obvious that if we had made the evaluation and design decision based on the static experiment we would have made a wrong decision.

Here the focus has been on visual information and perception, which is one part of the complete interaction between the operator and the vehicle. It was also here the main focus of my own research projects was located. However, there is no evidence that speaks against expanding the findings on using the SBD approach to the remaining parts of the human-machine interaction. The most significant of these remaining parts is the operator input activities like steering, braking, and pushing buttons (selecting functions). All such actions must be recognized as parts of the system control procedure. One basic characteristic of a procedure is the duration of the operation. Thus, a procedure takes time and time in a dynamic situation means movement. The ownship moves and so do most other participants in the situation. My point here is, since time consumption and movements are involved also in procedures, such parts of the human-system interaction must be assessed in dynamic settings. Again, simulators are important tools in the complete interaction design and evaluation process.

5.8 Visual enhancement in ground vehicle applications

The last paper included in this thesis (Paper 5) investigated the effects of using night vision systems in ground vehicles. Such systems are now available on the market and typically they are based on sensor information from infrared (IR) equipment. Two system principles exist, called Far Infrared and Near Infrared techniques. The first concept is passive with only receivers measuring the surrounding temperature variations. The second is active with both transmitters and receivers involved. The expressions “Far” and “Near” refer to the operational ranges of the systems. Two main presentation alternatives exist at the market, one with windshield presentation (HUD with see-through capability) and one with presentation on a separate screen somewhere on the dashboard (head-down display, HDD, no see-through capability). In the HUD alternative the presentation is a mirrored image, while the HDD is an LCD. Without going deeply into the location of the NV screen it should be mentioned that there is strong evidence for having the information presented close to the driver’s attention focus (looking out at the road) according to the proximity compatibility principle (Wickens and Carswell, 1995). The closest alternative is of course the HUD alternative, while some existing HDD solutions are really bad from the PCP perspective. Horrey, Wickens, and Alexander has (2003) studied different display locations in a simulator-driving task and found that the HUD solution contributed to better performance in hazard response time. However, they also addressed the clutter problem which might have negative influences if the HUD is too dominating to the outside view.

The relation to the 3D perspective displays discussed earlier is evident. Also here we have a perspective presentation on a flat screen and the presentation is depicting a three-dimensional situation on the road ahead. One difference from the aircraft applications is the direct use of raw sensor information, which limits the possibilities for more advanced presentation concepts. Raw sensor data was also the standard solution in aviation when radar sensors were introduced, but today almost all sensor-based information is synthetically displayed in aircraft and ATC systems. This shift may also come to the ground vehicle area in the near future.

No matter which technical solution is chosen for the night vision (NV) system there are some common features to summarize. During nighttime driving the NV system will expand the visual range compared to headlights only. In some conditions the range will be more than doubled (> 200 meters). This sounds good for safety reasons, but there are some problems. One is that the driver is looking through a keyhole, since the IR beam is narrow in relation to the overview the driver normally has during daytime conditions. This means that for the range the condition is almost like daylight, but for the peripheral perception the conditions are severely reduced. The other problem is about attention. For the simplest systems it is what you happen to see that constitutes the information base since it is not recommendable or even possible (e.g., for fatigue reasons) to continuously look at the display. In more advanced NV systems this attention problem has been taken care of by introducing warning sounds and a target pointer in the visual display.

There are many questions on NV systems which need to be further investigated in the future. As for air traffic displays it is necessary to study the drivers' capabilities to understand the 3D scene depicted on a flat screen. One more specific question here is if there is time enough to really evaluate an upcoming situation, probably less than 200 meters and 5 to 10 seconds ahead. Another is whether driver performance is ruled by the warning information (obstacle ahead). If this is the case, the situation display may be displaced by a warning display. If the situation display alternative is retained, then the question about raw sensor data or synthetic presentation should be investigated. Also the display location ought to be studied as well as how this display resource could be more effectively used, not the least for daytime driving. Such assessments lead themselves to SBD.

One serious question for all driver assistance systems is how the presence of such systems affects driver behavior as a whole. Does the presence of these assistants promote more careless driving when the driver believes that the system will take care of "everything"? Here the notion of negative behavioral adaptation has evolved and has been discussed in several recent papers (e.g., Brown, 2000; Kovordányi, Ohlsson, and Alm, 2005; Rudin-Brown and Parker 2004). Brown (2000) investigated adaptation problems for lane-departure warning systems, Kovordányi et al. (2005) and Rudin-Brown and Parker (2004) discussed different design strategies to overcome the problem of negative behavioral adaptation for adaptive cruise control (ACC) systems. In the study included in this thesis, we wanted to investigate speed performance using a NV system or more precisely, whether the experience of enhanced vision during nighttime driving makes the driver go faster. A general conclusion from these and other studies is that the risk for drivers taking advantage of these intelligent agents is a reality and must be considered in the design of future assistance systems. Such considerations must also be applied in the outside environment. Ward and Wilde (1996) reported that increased sight lines at intersections and railway crossings have been shown to increase the speed of passing vehicles to the extent that no net effect of the improved sight conditions was obtained.

In the simulator-based study presented here (Paper 5), we made a comparison between continuous NV presentation and a corresponding situation-dependent approach. This alternative could be regarded as a warning approach, since no information was available on the screen until a "dangerous" object was captured. At that moment the screen was lit, which gave warning information even before the driver had evaluated the situation. We found that the speed was higher with continuous presentation, however not at a significant level. In our analysis we referred this lack of significant data more to defectiveness in the experimental design (including loss of some data) than to the lack of a speed effect. This, of course, has to be confirmed in a future experiment. We compared two design alternatives, but also the alternative to have no system at all should be studied, since there might be a priming effect, that is, the driver's knowledge on the presence of an assistance system, however "invisible" most of the time. This kind of awareness of an invisible assistant is similar to most of the other areas of assistance systems. This discussion could be synthesized into a hypothesis as follows:

If the assistant is continuously visible (level 1), the effects of negative behavioral adaptation will be higher than if the assistant is invisible during normal conditions (level 2), and in this case the effects will be higher than without any corresponding assistant (level 3).

This hypothesis has similarities to the following conclusion by Hedlund (2000): “If the users do not know about the safety intervention, then they would not be expected to alter their behavior in response to it”. This is close to the level 2 condition with the assistant (= safety intervention) invisible most of the time. If the suggested general hypothesis for negative behavioral adaptation is true when assistance systems are introduced, there will still be problems to solve on more detailed levels, which may lead to different design implications for different systems. For NV systems the difference between level 2 and 3 could be small due to the fact that the alarm frequency is very low, provided that the alarm criteria is optimized, while the corresponding difference for blind spot detection systems are high. For this kind of system, the alarm frequency will be much higher, especially in urban driving. The result of this high frequency is that the assistant will be more visible, however still not on a continuous basis. To verify this hypothesis, many studies must be performed. Some of them will be well suited for simulators, while other may be better supported in field studies. For the latter category I would recommend studies on long-term effects, since it is reasonable to believe that negative behavioral adaptation also will grow over time, especially for “level 1 systems”. In our study (Paper 5) we saw immediate effects due to system levels 1 and 2 in a drive lasting for only 30 minutes, but we know little about the effects of, for instance, a use period of one year.

The final question on NV system design is about other differences between the two design approaches. The most surprising finding was about driver acceptance and preferences. All participants in the study preferred the situation-dependent approach due to reported workload demands in the continuous presentation. To be “forced” to pay serious attention to a small display with a rather blurred presentation (raw sensor data) at the expense of a more normal scanning of the outside world was a demanding experience. Also the performance in object perception and reaction showed much more consistent and safe results for the situation-dependent alternative. However, new approaches to NV systems have occurred, where these negative factors of the continuous presentation have been mitigated by introducing algorithms for object recognition coupled to a more advanced warning presentation. With these new NV features it should be quite natural to ask why they still keep the continuous presentation. Except for this, this new design approach is similar to our situation-dependent concept.

6. Concluding discussion

Simulator-based design does not support all stages in a complete design process, since the original design parameters, labeled in Figure 5 (page 13) as “Concept”, must be developed prior to the first prototype. In Figure 4 (page 9), however, there is more information applicable to these very early stages as well as high level requirements coupled to the concluding evaluation. Such requirements are usually not directly applicable to the SBD performance measurements, since these are not expressed in general terms like “contribute to traffic safety” or even “contribute to decreased workload”, which usually is the kind of language that represents the “customer requirements”. So, there is a need to decompose customer requirements (and internal requirements) into parameters which could be measured in the simulator. How this decomposition will be expressed more precisely is only possible to elucidate within the specific project.

However, it should be emphasized that these measurement parameters are not necessarily the same as the design parameters included in a system solution. The measurement parameters are goal-oriented and mirror the expected outcome of the system, while the corresponding design parameters are solution-oriented. Measurement parameters could be direct or indirect. Examples of direct measuring are distances to other cars or objects of interest, speed accuracy according to speed regulations, eye-tracking indicating attentional behavior, braking behavior, steering-wheel performance, reaction time to warnings, etc. Descriptions on such measuring could be found in research publications, but most published studies do not include any large set of measures, since the most common research approach is to focus on one single measure and, for example, report on effects on driver reaction times during some conditional variation. This single-measure approach is not good for system design evaluation, where it is necessary to investigate all features of the current system, and also this system as a part of the entire vehicle system. This situation leaves the SBD practitioner presently quite alone and it should be of great importance to fill this gap in the near future.

Also for indirect measurements there has mainly been a single-measure approach. The most common concepts are workload measurements using secondary tasks or self-assessment tools like NASA-TLX (Hart and Staveland, 1988). Many of these methods are validated and extensively used, which makes them safe to apply in any studies, but for the SBD approach they will usually only give answers of a global nature for the current design evaluation. Such information is valuable, but not at all sufficient for design decisions.

In conclusion, measurement included in the SBD methodology is preferably based on a combination of direct measures relevant to the current system and its goals. It is also important to emphasize that the most valid results will be captured in studies that compare different system candidates or with a baseline alternative. Such evaluations will have good chances to select the best system candidate with reference to specific criteria and how much better this system is in relation to the alternatives. But to have absolute results on exactly how good a system might be is not achievable, since this kind of evaluation will always suffer from the more or less non-realistic conditions in the simulator setting (Magnusson, 2002). Such questions will only be possible to answer through long-term field studies, an approach which is too time-consuming and costly to be realistic in commercial business. Field studies could also be problematic from a methodological point of view, since random variables and artifacts might play a crucial role for the outcome.

In the studies presented in Papers 4 and 5 we have applied this comparative approach. In Paper 5 we had two candidate systems and we could select the winning concept. Still we know that this winning concept was not at all optimized. We had two very different approaches, continuous or situation-dependent presentation, where the latter alternative must be regarded as a warning system. So, what we really found was that the warning approach was better than having a continuous presentation. With this answer at hand the next iteration in the SBD loop would be to optimize this warning information and study how this information should be designed in order to meet the goals of the system.

In Paper 4 more detailed design questions were in focus. Should we have drop-lines or not, and if drop-lines improved operator performance, in which situations or tasks? The high-level answer on 2D or 3D was already given by other researchers, who used human-in-the-loop simulations for their investigations.

These examples show the possibilities of SBD methodology and the way to proceed from high-level questions to the specific design details. Most if not all assets developed in the high-level round could be reused in the detailed design phase, which implies that the only mandatory activity (except for the evaluation part) in “round two” will be to design and implement new prototypes. The time-consuming experiment-related assets (environment model, scenario, measurements etc.) should ideally be kept unchanged. This is the background to the fact that the initial rounds will be more demanding in every aspect than the following activities. This finding is equally true within a specific project as between projects.

In order to reach such high levels of productivity it is also necessary to have relevant simulator experts firmly coupled to the simulator resource. Their customers are project related people who own the systems to be evaluated, and they are responsible for the prototyping activities. When Simulator-Based Design has been implemented as a core activity for HMI-related systems development in the firm, this interplay between internal customers and simulator personnel will be synchronized and cost-effective. Until then and perhaps without any simulator specialists it will even be impossible to realize the greatness of the SBD methodology. There again, the positive experience in the aerospace industry must be considered and used as a reference to take the necessary strategic decisions for the implementation of Simulator-Based Design.

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Paper summaries:

Paper 1. Accepted book chapter manuscript for *Simulation and Modelling: Current Technologies and Applications.* Idea Group, Inc., Hershey, Pa USA.

Business Process Reengineering in the Automotive Area by Simulator-Based Design

Torbjörn Alm, Jens Alfredson, and Kjell Ohlsson

This book chapter has the purpose to introduce Simulator-Based Design (SBD) as an important design process to adopt by the automotive industry. One motive for this proposal is that the automotive industry has to a large extent kept its design competence profile since the days when a ground vehicle was a pure mechanical product. Today more than half of the technical content of the vehicle is computer-based and interface resources are slowly changing to glass cockpit solutions. This means that most of the built-in computer-based systems we find today are developed and produced by supply companies. To effectively handle this situation the car manufacturers need to either radically change the internal competence profiles or strengthen their roles as system integrators. This background is further developed and described in the chapter.

Both for systems integration and specific systems design in the area of HMI-related systems (all systems which involve the driver) the use of human-in-the-loop simulators is of crucial importance. It is quite necessary to study dynamic driver-related systems in dynamic evaluation resources, which incorporates the driver. The options are to go through the entire design cycle and produce hardware prototypes, implement these products in test-cars and start real world driving or to take an intelligent short-cut. This later alternative implies implementation of virtual system prototypes in the simulator at all stages of system development, from the first conceptual prototype to the final virtual solution, and make the evaluation during the strictly controlled conditions a simulator offers. This is not possible to the same extent in test-car driving. This means that the proposed procedure will give better design solutions in shorter time. Hence, this will lead to a better cost-effectiveness for the manufacturing company and more user-friendly products with greater sales results. This will improve the whole economy for these companies, which seems to be necessary not the least for major US producers.

The chapter also describes the requirements for design-oriented simulators, since the basic SBD process includes implementation of in-vehicle system prototypes, which need to work seamlessly together with the entire simulator system. These requirements are of crucial importance to follow up, since most commercial simulators have been developed for training purposes and do not have proper software architecture for prototype plug-ins. In relation to the technical simulator criteria also the important questions on fidelity and validity are discussed. One important conclusion is that the validity in design conclusions seldom has a coupling to the degree of simulator fidelity. This means that you do not need to have a completely realistic simulator facility with a 6 DOF moving platform to obtain the goals in SBD, since the results are expressed in relative measures. Concept 1 is X % better than concept 2, which in turn is Y % better than without any such system. This exemplifies typical outcome of an SBD project. All main phases in the SBD process are described and exemplified and the chapter ends with two project examples, where the process steps are further discussed.

Paper 2. In *Proceedings of People in Control: An International Conference on Human Interfaces in Control Rooms, Cockpits and Command Centres 19-21 June 2001.*

How to Put the Real World into a 3D Aircraft Display

Torbjörn Alm

For the past two decades perspective displays ("3D-displays") have been of interest as more or less substitutes for the 2D map displays in aircraft of today. Despite all research efforts as well as activities in the industry in this area the impact on real design has been limited.

As far as this author has seen, the lack of valuable depth cues in display prototypes, used for demonstrations or research activities have been obvious. In this paper the nine, perceptual real-world depth-cues summarized by Wickens (1992) were used as a base for further implementation oriented discussions.
In this implementation discussion also artificial cues were discussed as a complement to the real-world cues. Examples of such cues are superimposed grid on the ground surface and object-oriented shadows from a virtual source of light. Examples of real-world cues, which should be implemented, are Linear perspective, Interposition, Relative size and Relative motion.

The overall conclusion from this analysis was that, with few exceptions, these cues are possible to implement and that this implementation has the potential to bring 3D perspective displays to the marketplace. This will give a substantial contribution to Situational Awareness and, thereby, to Flight Safety.

Paper 3. *Displays, 24 (2003),* pp. 1-13, Elsevier Science B.V.

Perception Aspects on Perspective Aircraft Displays

Patrik Andersson and Torbjörn Alm

This report presents two experiments in the area of 3D perspective aircraft displays. The research focus was to explore the possibilities to understand symbolic shapes and spatial relations between symbols in the 3D environment. For these experiments we developed a basic display design based on the at that time existing tactical display format in the

Swedish Gripen fighter. Much of the cuing concept presented in Paper 2 was used except for relative motion, which was not applicable in these two static experiments.

The purpose of the first experiment was to investigate the participants' performance in symbol recognition and target heading assessments. We had developed five symbol shapes, sphere, cube, pyramid, and two different arrows. The non-arrows were supplemented with a direction indicator. The display perspective was egocentric, which means that the virtual camera position was "in the pilot's seat". The participants were exposed to a sequence of different target appearances with time slots for answering between each presentation. During this time slot the participants were exposed to an answering tool, which replaced the target presentation on the screen. The answering tool had five buttons, one for each symbol shape and a movable answering arrow, which was manipulated by an ordinary mouse in the 3D virtual space. Through this tool the participants were able to press an identification button, telling which symbol shape they had recognized, and turning the answering arrow in the perceived 3D heading of the target. The conclusion of this experiment was that the sphere symbol gave the best performance. However the assessments of target headings were generally far from correct.

For the second experiment we used the same screen format and chose to continue with the winning sphere symbol. The perspective in this experiment was exocentric and included a presentation of the ownship in the center of the display and one appearing target. The motive for choosing the exocentric perspective was to utilize the relative size cue. The nominal size and shape of the symbols were equal. Thus, if the target size was smaller than the size of the ownship this indicated that the target was somewhere ahead. In the opposite condition the target was behind the ownship or more specifically closer to the virtual camera position, which was the fix point for distance calculations and thereby symbol scaling.

Also in this experiment the participants showed evident difficulties in the direction assessment, in this case the bearing between the two symbols. The answering tool and procedure was the same as in the first experiment except for that the symbol shape buttons were excluded.

The overall conclusion from the experiments was that judgment of direction in 3D presentations was very difficult in these static scenarios, which made us conclude that the future experimental activities should be carried out in dynamic simulations. However, the statement on the superiority of the sphere symbol shape and the way to use symbol scaling in this context was strongly supported by the experiment results.

Paper 4. Accepted paper for the *International Journal of Aviation Psychology,* Lawrence Erlbaum Associates, Inc.

The Value of Spatial Cues in 3D Air Traffic Displays

Torbjörn Alm and Patrik Lif

This paper reports on the continued experimental activities focusing 3D perspective displays for air traffic presentation. Two major changes were introduced in this series of experiments compared to the approach used in Paper 3. The perhaps most important step was to leave the generic laboratory with its work stations and enter the new simulator facility at Linköping Institute of Technology. In the generic simulator cockpit with one screen for head-down presentation we decided to change to a landscape format for the tactical display. This opened for a wider field of view and a more natural relation to the environment presentation outside the cockpit.

Another thing, which was introduced here, was an additional cue, drop-lines from object symbols to the ground surface. This drop-line condition was manipulated through the entire experiment series by having or not having drop-lines. The purpose of this was to investigate in which tasks this additional cue was improving task performance. Drop-lines were supposed to support more precise position assessments, since the drop-line connected the flying symbol to the underlying ground-surface grid. At the same time the current length of the line was supposed to support height estimations.

We carried out three separate experiments and made one comparative analysis between the bearing assessment data from the earlier static experiment and the new dynamic experiment in the simulator. In this analysis we used the no drop-line data from the later experiment, since no drop-lines were introduced in the static experiments. We found in this comparison that the bearing assessments were significantly better in the dynamic scenarios, which proved that any conclusions based on static assessments in this area were doubtful. These results are supported by basic research, where the motion gradient or parallax is an important cue in understanding a real-world (3D) situation and this statement should also be relevant for perspective display applications.

In the first experiment, where bearing assessments were executed between the ownship and one highlighted target, we found that in most ownship-target spatial relations the assessments were close to correct in the two experimental conditions, with and without drop-lines. The only situation were the results were improved by drop-lines was in situations with targets below the ownship altitude in combination with forward sector appearances. This result may depend on target appearance against the ground surface combined with the chosen virtual camera position behind and above the ownship. These results speak for a situation-dependant use of drop-lines for targets in the forward/downward sector, while not having drop-lines for the remaining target appearances to avoid display clutter effects. The 3D bearing assessment could be defined as an integrated task since the 3D bearing has two basic components, azimuth and elevation.

In experiment 2 we changed to a focused-attention task, relative height assessments. A focused-attention task in this context could be defined as having only one dimension, since height is not possible to decompose. In this experiment three targets were highlighted and the participants had to answer which target was most distant above or below the ownship altitude. The symbols were color coded and the participants had to reply by pressing a corresponding colored button. The results showed that drop-lines contributed to significantly improved assessments, which made us conclude that the possibility to choose drop-line appearance for focused attention tasks should be available.

In the third experiment we returned to an integrated task, collision-risk assessments. This task includes 3D bearing and speed/time to contact assessments. Color-coding of object symbols and corresponding answering buttons were used for responding on the collision assessment. In general these assessments were performed very correct in both display conditions despite the fact that the passages of the non-collision objects were very close to collision, which means that the differences between the collision object and the other objects were really small. Also the fact that all participants were university students with no pilot education (as in all our experiments) made the results even more impressive.

In conclusion, the results of this experimental series showed that for these three important tasks in real-world aviation the 3D perspective display offers good capability to support the pilot. For certain tasks and in certain ownship-target spatial relations drop-lines should be available to improve pilot performance.

Paper 5. In *Proceedings of the HFES 50th Annual Meeting, 2006.*

Continuous versus Situation-dependent Night Vision Presentation in Automotive Applications

Torbjörn Alm, Rita Kovordányi, and Kjell Ohlsson

As the number of advanced driver assistance systems in modern cars increases the question of possible negative behavioral adaptation is raised. We have investigated this phenomenon for night vision (NV) systems in the driving simulator at Linköping University. One common opinion is that there is a risk for using the enhanced visual conditions that come with these systems to increase speed during nighttime driving and thereby eliminate the safety margins the system was designed to provide.

In our study two system approaches were compared, one with continuous presentation, as such systems appear at the market today and one approach with presentation only when dangerous objects were detected by the system. In both conditions the night vision display had exactly the same design, a black and white picture of the scene ahead overlaid the environment presentation in front of the simulator cab. This technical solution has its correspondence in a windscreen see-through presentation.

The situation-dependant approach was meant to minimize the risk of negative adaptation, which was partly confirmed in the study. Here we compared the average speed during a time slot early in each simulated session and found that the participating university students kept a higher average speed (6 km/h) with continuous presentation, although not significantly higher. We believe that this lacking significance was due to the instructions given to the participants. They were all told that they should drive at a road with a speed limit of 90 km/h. A minor group of participants ignored this instruction and reported that they chose a speed that was comfortable. In this group the average speed with continuous presentation was 12 km/h higher than in the situation-dependent condition.

Moreover, the results showed better and more consistent driver performance with the situation-dependent system measured by target distance at detection. This could be referred to the warning effect of turning on the display when an obstacle was measured. In the continuous presentation the participants could not constantly focus on the display but had to frequently scan the driving environment outside the narrow screen angle. This drawback made the “target acquisition” more or less accidental. This difference on consistency between the two conditions was significant.

All participants preferred the situation-dependent approach. The motives were workload-related according to interview results, which were partly supported by NASA-TLX results.

The existing NV systems at the automotive market are all based on continuous presentation of raw sensor data. Sometimes this presentation is located far away from the drivers’ normal direction of sight. With such combinations it is not very likely that there is any positive contribution traffic safety. On the contrary this impact may even be negative.