MIGRATION TOLERANT HUMAN MACHINE INTERFACE CONCEPTS IN THE DOMAINS OF AIR TRAFFIC MANAGEMENT AND AUTOMOTIVE

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Abstract

The steady increasing degree of automation in the domains of air traffic management (ATM) and automotive is a major challenge for the design of human machine interfaces (HMI) to accurately support the use of technical systems. Automation performance mostly increases stepwise and users usually adapt slowly to new environments. Nowadays a system replacement, especially in ATM goes along with a new monolithic HMI solution. This causes significant costs, requires extensive training for users and lowers acceptance for introduced systems. Our approach to avoid these effects bases on the illustrated HMI design concept. This concept enables the adaption of an operator by small and smooth learning steps. Transition phases between different display revision steps should be tolerant against migration and facilitate the user's familiarization. Based on the knowledge of the current state of the art, HMI concepts should consider future developments, i.e. the state of research and technology in a specific domain with the predicted influence on the state of technology. This paper describes why a stepwise iterative HMI design with intermediary states is preferable against a one-step approach. We outline parallels and differences regarding automation and HMIs in both domains and describe tangible migration tolerant implementation concepts as well as potential synergies.

1. NEED OF MIGRATION TOLERANCE FOR HUMAN MACHINE INTERFACES

The human machine interface (HMI) is a core element to use of any kind of support or assistance systems. Therefore, the design of the HMI is very important to guarantee a usability which supports smooth interactions with high performance. Technical, environmental and organizational aspects influence the design of HMIs. Lifecycles of HMIs in the air traffic control domain still have quite long ranges up to decades. The HMIs for advanced driver assistance systems (ADAS) are mostly connected with the market launches of new car series in several years, whereas smartphone user interfaces change much more often depending on their short product cycle.

Based on the knowledge of the current state of the art, HMI concepts should also consider future developments. The state of research and technology in a specific domain has to some extent predictable influence on a future state of technology. Considering this in an HMI design concept would deliver various benefits. Extensive and costly trainings or concerns and low acceptance from users regarding a completely new HMI design development could be avoided if users learn additional and modified functionalities by smooth transition steps during iterative design adaptations mostly on the job.

Transition phases between different display revision steps should be tolerant against migration and facilitate the user's familiarization. This applies especially for the ongoing trend towards a higher automation that can be seen in cockpits of air and ground vehicles, as well as HMIs of air traffic controllers (ATCO). Hence common requirements challenge the automotive, avionics and the air traffic management (ATM) domain.

Having in mind potential future technical final state of automation, support systems and also HMIs could already include modified technical and user aspects guiding users from the current to a future HMI state. In reality however, the automation performance could only be increased in steps. Furthermore human users usually adapt their habits slowly to new environments. Instead of directly switching to a final state of an HMI a migration of intermediary states of the human machine interface design can be beneficial.

This article outlines the need of migration tolerance for HMIs in the transport domain. Chapter 2 describes parallels and differences regarding the automation and HMIs in the automotive and ATM domain. As an example, specific migration tolerant implementation concepts for HMIs in the air traffic control and the automotive domain are depicted in chapters 3 and 4. Finally conclusions of a potential synergy and an outlook for common concepts of migration tolerant HMIs are sketched in chapter 5.

1.1. Performance of Automation

In current decision processes and during action implementation the human mostly acts as the only operator. Having in mind the trend of automation and increasing perfor-

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mance, electronic assistance systems are a key tool to support the human fulfilling his task. The last thinkable state of an autonomous system presumably can only be reached by integrating different steps in between. In the transition phases the human can transfer more and more control to the machine.

Sheridan & Verplank defined 10 levels of automation (LOA) for the cooperative human-machine decision making process [1]. In basic level, level 1 decisions are completely done by the human and may be executed by a machine. In level 2 computers offer various decision alternatives, whereas in level 3 one of them is suggested as a best fitting option. In level 4 the computer selects one action that the human could follow. Only human approval is necessary for machines implementation of the suggested action in level 5. In level 6 humans will just get informed about the machine selected action and is able to stop the process. The seventh level consists of a full decision selection and action implementation of the computer with information for humans on all actions. This information is only given to the human if he asks in level 8. Level 9 is comparable to level 8, but the computer decides if humans will be informed. In level 10 the machine is autonomous in decisions and actions and may be informing humans in important cases.

These LOA also affect corresponding HMIs that are used to select decisions, to get informed or to follow the machines' actions. Technological developments on the way to a full machine autonomy considering various environmental aspects take many years to penetrate the market. In addition the introduction of innovation only takes place stepwise. During the transition phases after market launches and new developments a mixed equipage of vehicles and machines is existent.

1.2. User habits and slow adaptation

The introduction of new technologies in existing work environments or a change in the technical system can raise different problems related to the usability and acceptance of the new technical artefacts by the users. Especially if new technologies cause changes in operation, information presentation etc., users might experience difficulties up to frustration in case the system behavior does not match the expectations based on prior experience with the old systems. This refers to psychological constructs like mental models, experience, expectancy and user habits.

In this context Rasmussen described three different kinds of behavior which is based upon different experience with a system. This is skill based, rule based and knowledge based behavior [2]. Skill based behavior is often an unconscious stimulus response coupling which is highly trained and therefore can be called automated. Certain stimuli automatically lead to stereotypic reaction patterns. Rule based behavior is a conscious behavior based on certain rules of action. Stimuli are related to certain experience like schemas. Knowledge based behavior is often found in unknown situations, where there are no rules of action. It is highly conscious and takes longer time for execution. User habits exist of skill and rule based behavior founded on the prior experience with a system. Habits are rather stable and cannot be changed quickly. As a consequence users are often unwilling to change their well-established behavior because this is often related with additional training effort and performance costs.

The migration of new technology needs to respect prior experience with systems and habits, because users tend to apply the learned stimulus response couplings and rules also to new technology. If well-known skills and rules cannot be applied because certain cues or interaction elements are missing, or stereotypic behavior lead to unexpected system behavior, this leads to frustration, longer task execution times and in the worst case to higher error rates or system rejection by the operators (e.g. [3]). The worst case scenarios may result in a disassembling of the system and a loss of the investment. As a consequence in the introduction of new technologies small steps with few changes are better than big steps with many innovations in this one step. Transition steps should be designed in a way taking into account the user habits, utilize them and iteratively change these habits.

A stepwise introduction can be based on the aforementioned levels of automation. This can be done by either replacing an already existing level of automation, with a next higher one. Between two exchanged automation levels there must be only relatively little change when compared to the direct introduction of the envisioned final state like fully autonomous driving. Another or additional option exists, when not only one level of automation is available to the user but a range of levels of automation, including lower levels of automation which contain familiar operating modes and new, higher levels of automation. The user then can decide which level he wants to take. In case of doubt the user can switch back to a more familiar level of automation, which can be seen as some kind of fallback level. Nevertheless, the levels of automation should be designed as consistent as possible among each other.

One further means to take into account the user habits in the introduction of new technologies and interaction concepts is the usage of design metaphors. Design metaphors try to make use of user experience and habits which they have gained in domains different to the domain for which the new technology is introduced. One famous example for a design metaphor is the desktop metaphor, first introduced at Xerox PARC in the nineteen seventies. In the desktop metaphor the prototype of a desktop with its general features like a typewriter, a trashcan, folders etc. is used for the interaction design for human computer interaction. In the automotive domain the H-, or Horse Metaphor can be used for the design of highly automated vehicles [4].

2. PARALLELS AND DIFFERENCES REGARDING AUTOMATION IN THE DOMAINS OF AIR TRAFFIC MANAGEMENT AND AUTOMOTIVE

There are a lot of parallels between ATM and automotive domain regarding automation and its use. Normally a single human user like a car driver or a controller operates with an automated system. In seldom cases a co-driver or a controller's colleague will use the same HMI for interacting with machines. The past also showed that technical improvements will find one's way into practice. Nonetheless improvement steps take different spans of time until they establish oneself. Subsequent new requirements for using automation functionalities and corresponding HMIs are following.

Nowadays, in many cases assistance systems support the human user with advisories or warnings. Both domains also have in common that some elements get more important while others lose their relevance.

As an example of the automotive domain some instruments lost and will further lose their central importance whereas other will gain importance. A rotational-speed sensor and a tachometer are examples of migrating over different design steps. The analog display of rotational frequency and velocity changed to an alphanumeric number in the cockpit. The needed visualization space was heavily reduced. Additionally there is an advice of the best gear for the current driving situation. In the ATM domain the controllers' focus on assuring separation between aircraft will decrease due to more automatic regulation whereas concentrating on performance parameter like kerosene consumption or noise emission will increase by time. Some more detailed examples will be described in chapters 3 and 4.

Due to humans being transported with high velocities, safety requirements play a central role in all considerations for further improvements. The responsibility in case of accidents should be clarified in order to integrate new automation functionalities in existing car and aircraft guiding processes. Another important issue in context of safety is the traceability of automation decisions and actions and also the ability to anticipate automation behavior. Regardless a reduction of complexity for the human user and easier use is aimed with nearly all innovation in assistance systems for human users. The usability of HMIs therefore is necessary and essential for automation in both domains.

Important differences between these domains may require different concept details for use of automation and HMIs. An air traffic controller is responsible of many aircraft and lives whereas a car driver is at most responsible for his own vehicle and a handful of passengers. Furthermore driving on the earth's surface has the advantage of being able to stop in a relatively short time for a safe position, but ground contact and a very complex and highly dynamic environment results on the other site in very little time for reaction. An aircraft has no real safe position during its flight but in many cases there is more time for reaction than it is the case with ground vehicles. Ground vehicles follow quite fixed ways with additional static information and infrastructure. Aircraft can follow e.g. Standard Arrival Routes (STAR) but are theoretically free of choosing flight routes due to non-existing borders. Also the velocity of an aircraft has a factor of up to 5 compared to a ground vehicle. Furthermore, the media impact of an accident in aerospace is extremely higher compared to the area of individual traffic. This attention causes a very conservative behavior of all participants in air traffic control.

Drivers of vehicles have the chance to affect their journey directly after using their HMI. This is different in ATM: The ATCO is a supervisor using an HMI as input device to determine an action, the command. Their commands influence pilots, who perform the action resulting in a modification of the flight state. Hence, the aircraft cannot be controlled by the ATCO directly. He is dependent on the pilot's reaction.

A controller has a lot of different channels to implement his actions: Radio telephony with pilots, telephony with other controllers, verbal communication with colleagues and evaluation of presented sensor data on an HMI. The car driver mainly has to pay attention to the environment while driving. The use of "infotainment" in a vehicle is commonly done with "learning-by-doing". A controller has to attend extensive and costly trainings.

3. TANGIBLE MIGRATION TOLERANT IMPLEMENTATIONS FOR CONTROLLER HMI

The controller's role experiences a change due to new technological options and organizational modifications. The European SESAR (Single European Sky Air Traffic Management Research) Joint Undertaking has developed the European ATM Master Plan [5] which describes the future development in air traffic management. This plan contains three operational concept steps for the future operation in ATM [6]. The implementation of new operations in the context of SESAR calls for new requirements at the controller working position and affects every flight phase which is taxi/apron, runway, climb, cruise and descent. Today air traffic is guided distance-based with the aid of radar displays and guidance commands. For a more efficient ATM, the three operational concept steps are planned in SESAR: Step 1 consists of a time-based, step 2 of a trajectory-based and step 3 of a performance-based flight guidance approach (see FIGURE 1).

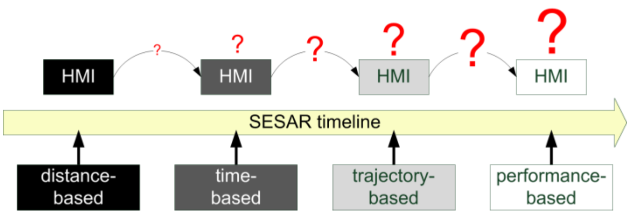

FIGURE 1. Transitions between flight guidance steps adapted from [7]

However, it is not really evident how an HMI should look like in the respective step. Today some research on time-based flight guidance is done [8]. For the other steps which are farer away the exact operation and hence, tasks, support function, HMI and transition phases between states get more uncertain. This is especially true for the HMI element with corresponding developments and evolving requirements of new specific controller working positions.

The research question therefore is how to smoothly get from the current to a future state of controller HMIs and how this future state should look like. Looking into the future it is hard to predict how an adequate environment and setup of the ATM domain looks like in more than ten years. Nevertheless some trends can be seen, that lead to the following described assumptions for the migration tolerant controller HMI concept with small learning steps.

Due to new controller tasks, the regulation of air traffic flows in general becomes more important than interacting with only one specific aircraft to be guided safely. Furthermore, the potential implementation of new research concepts anytime in the future may lead to new controller guidance activities. In short-term new guidance functions could be a late merging or a point-merge concept. Long-term evolutions perhaps include great circle trajectories and a sectorless ATM approach. Additionally i.e. satellite-based navigation and locating of aircraft with higher reliability of position data lead to lower minimum separation requirements or better integration of continuous descent operations (CDO).

A further assumption is a more intensive use of flight movement planning and management systems (XMAN) for arrival, departure, surface, en route or turn around processes. Four-dimensional trajectories can be negotiated between air and ground systems, like a flight management system (FMS) and an Arrival Manager (AMAN) via data link. Though data link has been discussed for long time and still has technical issues to be solved, it is an assumption used in various ATM research projects. In general, a steady increasing degree of automation in different domains is assumed as well as better planning and support systems and legal improvements.

The controller's focus on active managing to ensure minimal separations will more and more be replaced by passive monitoring e.g. of trajectories with acting in emergency or deviation situations. New controller roles could arise. An example for that is a model of collaboration between a planning and an executing controller working together like the Deutsche Flugsicherung GmbH (DFS) uses in Karlsruhe's Upper Airspace Center (UAC) with the HMI VAFORIT (Very Advanced Flight Data Processing Operational Requirement Implementation). Acceptance in automation will probably rise with new generations of operators and machines. The automated selection process of aircraft concerning a controller or not leading to different colored labeling already takes place without human influenced or manual pre-selection.

Experiences from the introduction of VAFORIT at the DFS revealed a desire of avoiding big-bang-integration and costly off-the-job-trainings in case of new HMIs. Conventional HMIs do hardly deliver any support for controllers to handle additional and changing tasks. Concluding, there is a need of task coping and migration tolerant HMI design for ATCOs [9]. In the tangible migration tolerant approach for a controller HMI the described future requirements have to be considered.

Like described above supervision of times, trajectories and performance data will become more important for controllers. To perform the new tasks actual situation data displays are not the best option. On the one hand there is the necessity to support controllers with their new tasks. On the other hand they could be more and more exempted of currently important tasks that will disappear.

In the best case a release of cognitive resources from currently important tasks could be reached by two aspects. The controller could get better support for currently important tasks to fulfill them easier and benefit from reduced complexity of a modified working position. With those possible released resources the controller could focus on new tasks in the future.

In the following a typical actual controller radar display for the approach is explained. Current 2-dimensional displays show latitude and longitude as the position of coordinates on a screen and an alphanumeric value for the altitude. An actual meta state of the art radar display of an air traffic controller can be seen in FIGURE 2.

Yellow round symbols with an assigned label symbolize current aircraft in the airspace. In this example the first line of the label contains a planned landing sequence number and a call sign. The second line shows current altitude and speed. The aircraft type, weight class, vertical change status or technological capabilities are often displayed additionally in such situation data displays.

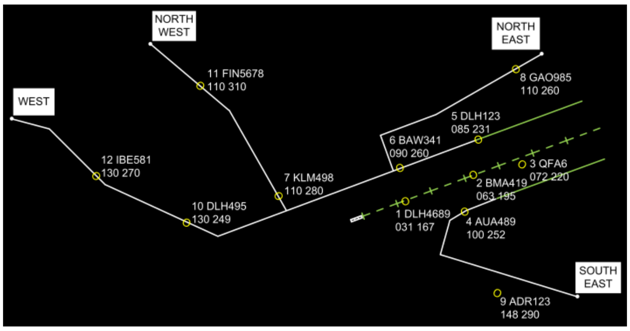

FIGURE 2. Meta state of the art radar display of an approach controller similar to Frankfurt/Main

The white thick line with some black dashes in the center shows the runway 25R of an airspace structure similar to Frankfurt/Main. The Initial Approach Fixes (IAF) are called WEST, NORTH WEST, NORTH EAST and SOUTH EAST. They are shown as a white circle. The green dashed line is the extended runway centerline (in the following called centerline) where every dash and every gap visualize a nautical mile (NM). Five NM are shown by a rectangular small green line to highlight distances. Green solid lines are marking the downwind parts, which denote approach legs in opposite landing direction; white lines are Standard Arrival Routes (STAR). Normally pilots contact controllers before entering the TMA at an IAF. The controller then gives commands regarding heading, altitude and speed to the pilot. The situation data display helps to monitor if the aircraft is reacting on the controller commands as expected. After an aircraft followed any of the STARs or a different approach, the downwind will be reached. A turn of 180 degrees will lead the aircraft onto the centerline and straight to the runway for landing.

Based on the shown state of the art display a controller HMI for easier detection of conflicts between aircraft compared to nowadays would be reasonable to relieve controllers. This is especially true for merge points in current airspace structures for approach controller HMIs. In a later step it is also important for deviations of flight routes from negotiated flight paths. In a trajectory based world a controller has to monitor if the real position of an aircraft deviates more than a tolerance tube from a negotiated conflict-free route. With those additional tasks new controller working positions and new controller teams may develop. In a further step the demands of optimization due to constraints like CO_2 and noise emission, kerosene consumption or delay, etc. could become even more relevant.

During a recent validation study with some controllers at DLR an idea regarding the mileage raised. The mileage lines at the centerline were a good aid estimating distances between sequenced aircraft. An enlargement of this marking to further routes therefore should be tested.

As another step, the defined standard route structure with many curves could be virtually adapted to simplify detection of potential merge point conflicts. Having more reliable location of aircraft and preferably monitoring deviations of aircraft from their negotiated plan, real physical route structures become less important. In an enhanced view (see FIGURE 3), all STARs could be virtually straightened until their merge points onto another route.

An aircraft following the real STAR with curves is displayed as flying straight on its STAR in the direction of the next merge point. Furthermore the conflict or route angles between merging STARs could be homogenized for better conflict detection rates. Physically flown routes do not need to be adapted.

This is comparable to eliminating a “half” dimension regarding current 2-dimensional displays ending in a simplified virtual route structure. The real physical position must not be displayed on the controller HMI as long as the controller can be sure that conflict free trajectories are kept by the aircraft. A monitoring view with eliminated relation to original cardinal direction so called georeference, could deliver better flow control and important guidance elements. As a new task supervising flow regulation controllers monitor if every aircraft follows its assigned trajectory or deviates from it. The controller only needs to know if an aircraft is leaving its deviation tube and flies too high / low / fast / slow / left / right / etc.

An argument against this visualization could be reduced situation awareness of controllers which is one of their main “tools” for safely guiding aircraft. Presuming the above mentioned developments situation awareness could be different to the content of today.

Endsley [10] defined: “Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. It is not clear if this depends on knowledge about the real world. With measuring and mapping real world on a 2-dimensional display is already a transfer. The controller’s mental picture is only relating to a 2-dimensional situation data display (SDD) with the altitude as numerical digit on the aircraft label. Concluding trust in automation regarding position data displayed on a controller’s screen is already necessary in this state.

Ten different migration steps in this concept shall support a smooth adaptation with small learning steps between the display states. State 0 as a meta state of the art display is depicted in FIGURE 2. The fifth display iteration step is shown in FIGURE 3. Four further steps shall guide controllers on their way towards an even more flow regulating and performance based controller HMI.

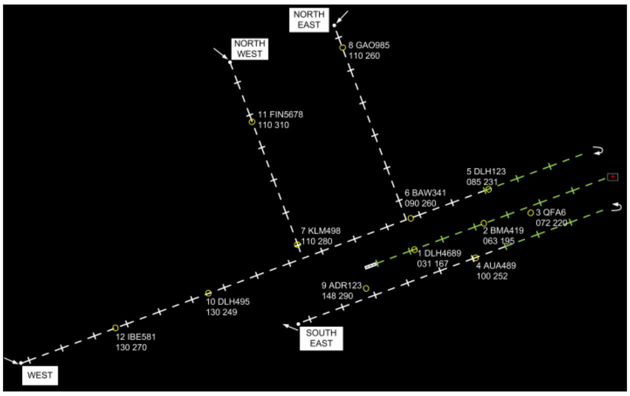

FIGURE 3. Rectangular controller monitoring display for improved merge point conflict detection

Today, the real world already is distorted in a 2-dimensional display. By eliminating the position resolution in migration tolerant displays, the real world will only be distorted further. Increasing passive monitoring tasks could decrease identification with the traffic situation compared to today. However, this must not result in a lost awareness of actual and anticipated situations. Controllers could still have in mind characteristics of aircraft corresponding to their displays. In the case of a long period hypothetical use of 3-dimensional displays with reduction of one dimension to current 2-dimensional displays the sceptic reaction could be the same. Alphanumeric representation however became accepted in the controller community.

Ending up in the foreseen trajectory-based world, controller commands for altitude, speeds and headings might be less in focus due to their modified work tasks. Therefore also the roles of controllers will have to change. Controllers can still give altitude and speed commands to a pilot with the proposed simplified monitoring view. Calculating appropriate heading commands without the original orientation of aircraft in his view is very time intensive, difficult and thus impracticable. The controller using the monitoring view can advise an executive instance to have a look at a certain conflict, to think about a heading command or new trajectory for a certain aircraft. This instance may be another controller working position still having his real world view or even an automated instance if it could perform the task safely.

Military controllers are often responsible for one aircraft at a single time. High velocities and extraordinary flight capabilities demand for this special treatment. Nevertheless, the concept of having one controller for different aircraft during nearly the whole flight instead of areas of responsibility is being researched [11]. Monitoring of aircraft’s behavior, detecting possible deviations and solving them on a trajectory-based way with new displays different to radar screens is essential for this idea.

With this new monitoring display even a comparison of aircrafts’ relative distances to the beginning of the downwind between northern and southern STARs is possible. With an imaginary orthogonal line combining the route WEST and SOUTH EAST, a controller can preregulate aircraft due to their landing sequence and the position of the turn from downwind to final. If two aircraft are flying at the corresponding positions of both ends of this line on these routes and nearly have the same speed, one of them will have to elongate its downwind. An elongation of an aircraft’s flight on its downwind means more kerosene consumption, more time, more CO_2 emission and more noise. This can be avoided by an appropriate command of a controller contacting a pilot already very early after entering the TMA. The example command “DLH123 Reduce Speed 200 Knots” should, after the pilot’s action, lead to a reduced velocity of one of those aircraft. By regulating aircraft flow this early, environmental emissions and economic impacts could be reduced with such a display and an adapted controller role.

The detection of potential conflicts at merge points should be easier based on five and one mile markers with homogenized rectangular routes, which enable quick estimation of future convergence of the aircraft on the different routes. A virtual semi-circle could deliver corresponding distances to merge points on different routes. The display area of runway, centerline and downwind has not experienced any change until this explained display iteration step yet.

It might be confusing that the “downwind” in this monitoring display seems to be very long whereas in reality it is shorter. But controllers using this display should regulate flows and detect conflicts very early instead of turning aircraft form downwind to centerline. This turn is initiated and monitored by an executive instance, which could be a human controller or an automated ground or air system.

Because aircraft stay many years, partly more than 25, in operation the onboard equipment, like flight management systems between young and old aircraft differ considerably in their abilities. An example is the equipment with four-dimensional flight management systems (FMS) that can keep negotiated times at significant waypoints with great accuracy which is not possible for other FMS types. In the transition phase conventional and 4D-FMS-equipped aircraft have to be integrated into one arrival flow. With changing equipment rates over time spans even a backward migration of HMIs may be necessary for optimal support of controllers.

If less technological equipped aircraft have to be handled within a certain airspace structure or in a certain time span, support in a recently common way might be reasonable. Therefore the possibility to get steps back is useful. Different capabilities will also be considered in display iteration steps six to nine.

4. MIGRATION TOLERANT CONCEPTS IN AUTOMOTIVE DOMAIN

The vehicle industry as well as research institutions made great progress in the development of the technical basis for advanced driver assistance systems (ADAS) and vehicle automation. Nevertheless, in today's car's driver assistance systems are still mostly single systems with a single functionality, like adaptive cruise control (ACC) which automatically keeps a set speed and a distance to a vehicle in front, or lane keeping systems which avoid running off the road by active steering. These systems can be activated individually and independent from other assistance systems, they are not integrated in a holistic approach. The initial vision of some vehicle manufacturers is fully autonomous driving, where the human does not need to be involved in the driving task.

To reach this goal several transition steps are probably necessary, starting with the current non-integrated systems over partially or highly automated driving, in which the human is still either actively or passively involved in the driving task or at least, needs to be able to take over the driving task in a defined timeframe. In a level of automation approach, the status of several single systems can be clustered in automation levels. The lowest level mainly includes passive assistance systems. That means that the driver is driving manually and is only supported by information and warnings. This is similar to the kind of driving drivers are used to. The degree of active system involvement in the driving task can then stepwise be increased by adding further, higher levels of automation up to fully autonomous driving. A working group with participants from OEMs and research institutes led by the German Federal Highway Research Institute (BASt) defined five preliminary levels of automation from a legislative perspective [12].

These automation levels are driver only as first level, which is manual driving without continuously active intervening assistance systems. This is followed by level two assisted driving, where either the longitudinal or the lateral driving task is executed by vehicle automation. Level three is partially automated driving where the vehicle automation takes over the longitudinal and lateral driving task and the driver needs to always supervise the systems and must be able to take over control any time. The fourth level is highly automated driving where the system also takes over longitudinal and lateral control but the system is safe enough that the driver does not need to supervise the system any time. Highly automated driving differs from fully autonomous driving because it might be necessary that the driver takes over control in certain situations. Hence it has to be ensured that the driver is able to take over control within a certain timeframe. In the fifth level, fully autonomous driving, the driver does not need to take over control in a defined use case (like driving on a highway). These defined automation levels can also be seen as possible transition steps on the way to fully autonomous driving. On the one hand they contain automation levels which are already realizable today and on the other hand they contain preconditions to realize higher automation levels in the future, and thereby show conditions of migratability.

The definition is still preliminary because it is not completely clear yet if and when important issues to reach the transition steps can be fulfilled. Examples are the necessity and availability of car to car or car to infrastructure communication as part of safe higher automation levels. Today it is not even clear if it can be realized at all to take the human completely out of the whole vehicle guidance and control process, because the technical issues to make fully autonomous driving safe enough are very challenging and the influence of other important issues like acceptance and legal aspects are not completely investigated yet. So it is possible that one of the feasible transition steps might also be the final step at least in a majority of driving environments.

With respect to migration tolerance, the proposed automation levels should not be implemented in an either-or-approach, but rather in form of a stepwise addition of new automation levels to the already existing ones. The driver is then free to choose in which level he wants to drive and is not directly confronted with a completely new system, but can also drive in levels which he knows better from prior experience with already existing assistance systems.

The amount of automation degrees can then be increased when new technology is available. There is first evidence that drivers can distinguish safely up to four levels of automation [13] within one system. The driver has always the option to change the automation level for example when he wants to drive by himself, or as some kind of fallback level. Flemisch et al. proposed a spectrum of automation and control on which different levels of automation can be realized at the same time [14] (see FIGURE 4).

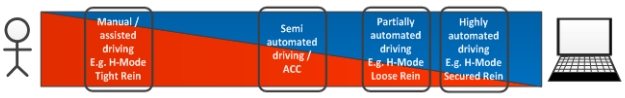

FIGURE 4. Spectrum of assistance and automation with 100% human involvement on the left and 100% automation involvement on the right. The boxes present possible levels of automation

The distribution of control can be shifted between driver and automation dynamically and in dependence of the driver's decision or environmental requirements. In different national and international projects a number between three and four levels of automation were established (e.g. [15] & [16]). The proposed automation levels contain a level of automation where the driver can drive manually and is only passively assisted by automation, in a further, optional level of automation one dimension of the driving task, but mostly the longitudinal driving task is automated. The other dimension is still fully controlled by the human. This level of automation can already be found in current series production cars for example with the adaptive cruise control (ACC). In the next higher level of automation the automation is capable of executing both, the longitudinal and the lateral dimension of the driving task but with a remaining continuous human involvement in the driving task. This can either be achieved by a direct involvement for example with a shared control approach or with passive involvement in form of supervising the driving task.

While in current or upcoming vehicles automation levels up to partially automated driving are thinkable, in future vehicles an additional fourth automation level, highly automated driving where the driver does not need to be permanently involved in the driving task, can be introduced as soon as the above mentioned issues are fulfilled.

One key element in the introduction of more and more automated vehicles is an HMI concept which shows a consistency over all the possible transition steps and enables the driver to easily understand and adapt to handling changes due to the transition steps. Design metaphors and a user oriented, balanced design process are means to reach this goal [17]. The consistency can additionally be achieved by using an underlying generic HMI paradigm, which is the basis for all necessary transition steps, and can be extended by for example new levels of automation. One promising generic HMI paradigm is cooperative vehicle guidance and control.

The way how drivers can interact with the vehicle automation and vice versa, can mainly affect the migratability of partially and highly automated driving. An important factor here is the compatibility of the automations actions with the driver's intentions and actions (inner and outer compatibility see [18]). Thereby it should not be the goal to make vehicle automations behavior exact like human behavior; therefore the variability of human driving behavior is to manifold, but to make it as compatible as possible. The introduction of higher automation levels is less connected with changes in user habits if the automation levels are compatible with user expectancies which are also mainly influenced by user habits and attitudes towards automation.

A human compatible automation is the research goal of the cooperative vehicle automation approach ([15] & [19]). In cooperative vehicle guidance and control several aspects of compatibility are respected. One example to reach human compatibility in cooperative vehicle guidance and control is to make the automations action predictable in order to minimize automation surprises (e.g. [20]). Two approaches to reach predictability are arbitration between user and automation (e.g. [21]) and also the communication of automation uncertainty (e.g. [22]).

In the arbitration approach the automation announces behavior before it is actually executed. This can be reached for example by haptic interaction elements like directed “tics” on a haptic inceptor to announce a lane change or in form of trajectories which are displayed in contact analogue head up displays. In the automation uncertainty approach the automation does not exactly announce behavior but gives feedback about the probability that the environment is interpreted correctly. This feedback is given in form of automation uncertainty and allows the driver to anticipate possible unjustified automation behavior.

Also helpful to reach the goal of high compatibility is the use of design metaphors. Design metaphors make use of knowledge about well-known domains for the design of new technical artefacts, so that certain knowledge can be transferred to use for example new assistance systems. They shall help drivers to get a general idea of how the automation works and how to interact with it. This way new technology in part shall appear quite familiar which makes it easier to understand and use. One example is the H(orse)-Metaphor [4]. Here the relationship between a driver and a well-trained horse is taken as a metaphor for the interaction between drivers and vehicle automation. From this metaphor generic interaction principles are deduced. The interaction mainly takes place over the haptic modality like it is the case in horse riding (cf. FIGURE 5).

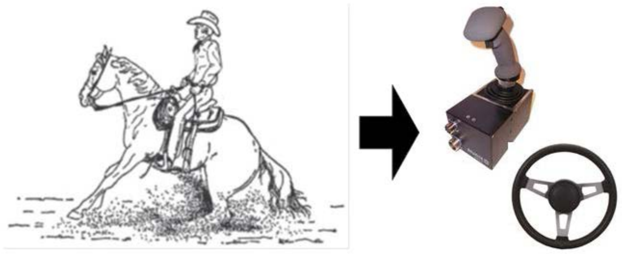

FIGURE 5. H-metaphor – relationship between rider and horse as a prototype for the design of vehicle automation. Here the concept of reins is transferred to haptic interaction based on haptic inceptors like sidesticks or steering wheels and different levels of automation.

The automation gives feedback not mainly by visual or acoustic information but by directed haptic cues on the inceptors. These haptic cues can be based on image or force schemata [23], and contain basic but easy to understand spatial information, or information about the status of the automation (e.g. simulating some kind of heartbeat as automation activity information). In the H-mode approach again the concept of levels of automation is used, here levels of automation and the according human involvement in the driving task are oriented on the input a rider gives to his horse by reins (cf. FIGURE 6).

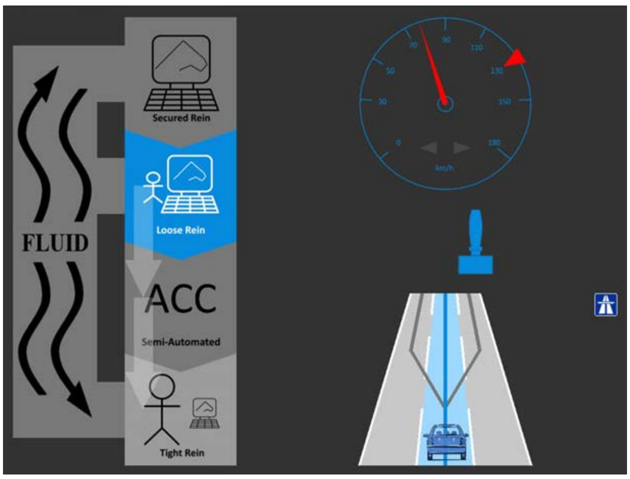

FIGURE 6. Exemplary instantiation of four levels of automation oriented to the H-Metaphor

When a rider wants to execute control he grasps the reins tight, analogously a driver grasps the steering wheel and gives more input over the inceptors (steering wheel and pedals) – therefore the according automation level is called tight rein. When a rider does not want to execute much control and wants to shift control to the horse, he only holds the rein quite loose. In the corresponding automation level “Loose Rein” the driver only holds the steering wheel very loose and just occasionally gives input. When the rider wants his horse to take over control he does not need to hold the reins. The according automation level is called “Secured Rein”.

Tight Rein, Loose Rein and Secured Rein can be different migration steps on the migration towards a highly automated driving that can take decades. And even when highly automated driving is available in more regions, these modes should be offered simultaneously to the drivers, because they represent one of the most precious human treasures: The freedom of choice.

5. CONCLUSIONS AND OUTLOOK

Migration tolerant design of human machine interfaces is necessary due to different levels and stepwise integration of automation and its performance. Major changes from one work environment (human, support system and environment) to the next result in high training costs, high familiarization effort, low acceptance of new functions and low utilization of the functions by the operators. These disadvantages can reduce the customer satisfaction significantly and could result in a loss of investments or customer loyalty. To take care of such effects is especially important if the operator has to use the modified systems or the systems have a long history in use, like cars, in opposite to new tools or functions, like facebook.

In the automotive industry the effects of strong modifications are well known concerning the interior of cars or the body shapes but it also accounts for mental aspects, like the levels of automation and its behavior. Hence, defining implementation steps which take, beside the technical enhancements, a smooth transition for the operator into account are beneficial for introducing and utilizing enhanced systems. The design of these steps have to take into account user habits with their skill, rule and knowledge based behavior. This procedure will nearly always lead to slow adaptations to new technologies which are common in aviation and automotive industry.

Further similarities between air traffic management and automotive domain are e.g. the continuously increasing of automation and the high safety requirements. Strong differences can be found in the velocity, the reaction time due to dynamic environment, safe positions and magnitude of damage which happens in the case of an accident.

Based on these differences the education level as well as selection mechanisms of operators are as well very different. These difference results in different steps sizes and different abstraction steps between the described automotive and air traffic management application.

In air traffic control a future concept for the next ten or more years is already defined. In this concept three future concept steps are described. The concept steps evolve from the current distance based over time based, trajectory based until performance based guidance. During these concept steps procedures to guide the aircraft will be changed several times. This goes along with the decomposition of the georeference in the radar display because the controller tasks evolve from guiding a single aircraft to guiding a traffic flow. The decomposition of the georeference shown is comprehensible within the small learning steps.

Further intermediate controller display states as well as a final one will be presented in a next paper. In addition the results of a study will give an answer on monitoring performance of probands, delegating of conflicts to an executive position, situation awareness, workload, system usability and transitions. During the study ten controllers will attend three simulation runs in which they work with different display steps. Probands are divided in two groups dealing with more or less display iterations. Afterwards a conclusion on the accuracy of learning steps and the feasibility of the monitoring view and new controller roles should be possible.

One potential final state of automation in the automotive environment can be autonomous driving. To reach this level of automation at least three intermediate steps are necessary which encompasses low automation levels. But for each intermediate step several embodiments of the functionalities are possible. Consequently, also in automotive a variety of different implementations are thinkable, concerning difference according to the driving situation, like on highways or in the city or according to the support magnitude. Various defined automation levels could also be used as HMI steps to design small learning steps between different iterations.

Design metaphors like the Horse metaphor using reins are an example in the automotive domain. During the discussion of the automotive example it was stated that the driver (the operator) has the possibility to choose the level of automation he prefers. This approach may be transferable from automotive to air traffic control whereas the single designs so far were seen as stable.

An adaptation of the currently used HMI design dependent on the environmental situation can enrich the presented methodology. The mechanism for the adaptation is to use one step up and down of the current HMI concerning the most appropriate procedures for the actual situation.

Further synergies between both domains can be found comparing concepts and user centered design for smooth transitions between automation and HMI states.

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7. ABBREVIATIONS

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
AMAN	Arrival Manager
ATCO	Air Traffic Controller
ATM	Air Traffic Management
BASt	German Federal Highway Research Institute
CDO	Continuous Descent Operation
DFS	Deutsche Flugsicherung GmbH
DLR	German Aerospace Center
FKIE	Fraunhofer Institute for Communication, Information Processing and Ergonomics
FMS	Flight Management System
HMI	Human Machine Interface
IAF	Initial Approach Fix
LOA	Level of Automation
NM	Nautical Mile
OEM	Original Equipment Manufacturer
SDD	Situation Data Display
SESAR	Single European Sky Air Traffic Management Research
STAR	Standard Arrival Route
TMA	Terminal Manoeuvring Area
UAC	Upper Airspace Center
VAFORIT	Very Advanced Flight Data Processing Operational Requirement Implementation
XMAN	X-Manager (where X could be Arrival, Departure, Turn around, En route, etc.)

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