A DESIGN PROCESS FOR INTEGRATION OF THE
HMI TO MULTIPLE DRIVER SYSTEMS

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ABSTRACT

The INTEGRATE project tackled the problems that are likely to arise from the introduction of
multiple driver systems each generating their own separate driver inputs and system outputs (i.e.
high driver workload, impaired usability of systems and subsequent implications for safety and
customer acceptance). This paper reports the results of the project, namely a structured human
factors design approach for integrated system design. No other such design process has been
documented in the publicly available literature, nor within automotive R&D departments in the
UK. The content of the process is a response to the industry requirements identified within the
project. Each stage of the process contributes to the main activities of: system definition,
identification of potential conflicts and their likely impact, and resolution of these conflicts
through good human-machine interface (HMI) design. The paper concludes with results of
industry consultation on the implications the approach has for current design processes in the
automotive industry.
1  THE HUMAN FACTORS ISSUES FOR INTEGRATION

The emergence of novel technologies alongside the retention of traditional displays and controls has increased considerably the range of systems that the future driver will need to use successfully. The main aim of INTEGRATE was to produce human factors design advice to vehicle manufacturers and system suppliers working in the area of integrated in-vehicle systems. The focus of the project was the part of the integrated system that the driver will interact with, i.e. the human-machine interface (HMI). The ultimate aim was to improve the provision of coherent, usable and safe integrated systems for the driver.

Drivers only have a limited capacity to interact with multiple systems and information sources at the same time. The driver must still carry out the normal vehicle control functions and associated decision making, so the load from these additional systems must be managed. It is true that some additional in-vehicle systems are designed to reduce sources of loading on driver resources: route navigation removes the need for strategic planning of a route, adaptive cruise control reduces the need for skill-based longitudinal vehicle control. However, these systems also introduce additional demands in terms of information uptake and driver actions. An integrated solution allows driver-system interactions with individual systems to be managed, so that many of the potential problems above can be mitigated. In particular, high levels of driver workload can be minimised and the driver’s interactions with systems designed such that maximum overall driver value is achieved.

2  THE CHARACTERISTICS OF THE DESIGN PROCESS

The guidance from INTEGRATE is designed to be of specific benefit early in the product development cycle, before official supplier nomination has occurred, and where there is still leeway for optimisation of functionality and HMI design. The reason for this is that human factors aspects of system design are often undertaken late in system design. This limits the ability of the designer to optimise the HMI without incurring severe cost and development time penalties. Where system integration is being undertaken, technical decisions must often be made at the early specification stages.

The guidance is set out in a procedural format. Although the advice is currently paper-based (due to resource limitations), the project recognises that this is incompatible with industry requirements (gathered at the beginning of the project) for a visual, searchable tool. The format of the advice is therefore designed to lend itself to future, software-based, exploitation.
3 THE INTEGRATE DESIGN PROCESS

The basis of the process is to define the systems to be integrated, identify potentially serious conflicts and solve these conflicts by applying human factors. The stages are shown in Figure 1.

Figure 1: Overview of the stages

1.0 A: SYSTEM DEFINITION
This stage requires a detailed specification of the functionality being considered for inclusion in the vehicle cockpit. This will include both conventional systems (e.g. steering wheel, radio, HVAC) and more advanced technology (e.g. navigation, collision warning).

2.0 B: CONDUCT DESIGN INDEPENDENT CONFLICT ANALYSIS
This stage consists of an assessment of the defined systems before any input or output design decisions have been made. It enables the designer to identify, at an early stage, which system functions are unlikely to conflict with each other, and which ones need to be assessed in more detail. For example, during urban manoeuvring, there will be frequent use of: navigation instructions, the forward view, mirrors, main controls (steering, gears, brake, accelerator) and indicator. These must therefore be design to work well together. In the same driving
environment there is *unlikely to be any use of*: destination entry, cruise control or a parking aid, so conflicts between these systems will not occur and are low priority in the integrated design.

This stage also helps to identify the key factors which determine the occasions where a system will be used by a driver. The key usage factors are defined by the five basic dimensions that describe driver/vehicle status. An aspect of any of these may define whether a system is used by a driver or not. The five dimensions and examples of corresponding factors are given in Table 1.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Main influencing factors relating to that dimension</th>
<th>Examples of the types of factors that will determine whether particular driver-system interactions occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>Cognitive, emotional and motivational states of the driver</td>
<td>Mental demand imposed by internal and external stimuli, motivation for undertaking the journey, motivation for associated (non-driving) tasks, mood of the driver</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Relationship between the desired and actual state of the vehicle</td>
<td>Actual versus intended vehicle speed, vehicle system status</td>
</tr>
<tr>
<td>Traffic environment</td>
<td>The relationship between the driver's vehicle and other traffic</td>
<td>Relative acceleration, velocity, density and position of other traffic, the other types of vehicles involved</td>
</tr>
<tr>
<td>Road infrastructure</td>
<td>Vehicle's current and future relationship with the road infrastructure</td>
<td>Current relative positioning with regard to route decision points</td>
</tr>
<tr>
<td>External environment</td>
<td>The environmental factors which influence the driver and or vehicle performance</td>
<td>Ambient light levels, weather conditions</td>
</tr>
</tbody>
</table>

Table 1: Dimensions describing the driver/vehicle status

3.0 C: CONDUCT DESIGN DEPENDENT CONFLICT ANALYSIS

This is an assessment, in more detail, of the conflicts that may potentially occur between a given set of in-vehicle systems if the ‘ideal’ design is employed for each sub-system in isolation. The ‘ideal’ HMI will be based on existing human factors guidelines for that technology, e.g. navigation, or (in the absence of these) on the recommended methods for particular Key Design Factors (KDFs) identified by INTEGRATE. The recommendations for *output methods* is shown in Table 2 (the process also includes the equivalent for *input methods*). Conflicts could occur where, for example, information likely to be presented at the same time uses the same output method.
### Output Methods

<table>
<thead>
<tr>
<th></th>
<th>Auditory</th>
<th>Visual</th>
<th>Haptic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tones</td>
<td>Speech</td>
<td>Graphics</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Central</td>
<td>Right</td>
</tr>
<tr>
<td><strong>Key Design Factors (KDFs)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info of high importance</td>
<td>Forward collision warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info of high urgency</td>
<td>Blind spot warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info might be needed later</td>
<td>Current emails</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info presented whilst vehicle in motion</td>
<td>Congestion levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info presented whilst vehicle stationary</td>
<td>Passenger door open</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User will request the info.</td>
<td>Distance to next services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System will automatically present info.</td>
<td>Distance to next turning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info inherently complex</td>
<td>Timetables for other transport modes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info mainly spatial</td>
<td>Topographical relations on map</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info has spatial component</td>
<td>Direction of turning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info mainly verbal</td>
<td>Total trip cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequent presentations likely</td>
<td>Nearest petrol station</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info continuously changing</td>
<td>Fuel level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Info changes intermittently</td>
<td>Adverse weather conditions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**KEY:**
- Output method potentially ideal
- Output method potentially acceptable
- Output method unacceptable

*Table 2: KDFs and design recommendations for output (outlines and arrows relate to Stage H)*
4.0 **D: SELECT DESIGN SOLUTION(S) TO BE EMPLOYED**
A decision point for the vehicle designer, in order to determine the optimum design approach to improve the effectiveness of systems. The design solution(s) required depends on the type of conflict likely. The decision is aided by Table 3.

<table>
<thead>
<tr>
<th>Type of conflict</th>
<th>Recommended design solution(s)</th>
<th>Design stage(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non / late detection of system output</td>
<td>Application of basic human factors principles</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Re-allocation of input/output</td>
<td>H</td>
</tr>
<tr>
<td>Masking of one system by another</td>
<td>Priority setting</td>
<td>F</td>
</tr>
<tr>
<td>System output mistaken for an output from another system</td>
<td>Application of basic human factors principles</td>
<td>E</td>
</tr>
<tr>
<td>Over-use of an output method</td>
<td>Input / output re-allocation</td>
<td>H</td>
</tr>
<tr>
<td>Over-use of an input method</td>
<td>Input / output re-allocation</td>
<td>H</td>
</tr>
<tr>
<td>High decision-making load on the driver</td>
<td>Integration and data fusion</td>
<td>G</td>
</tr>
</tbody>
</table>

*Table 3  Potential design solutions for integration conflicts*

5.0 **E: DESIGN SOLUTION: APPLICATION OF BASIC HUMAN FACTORS PRINCIPLES**
This stage provides a designer with guidance in using the easiest method of enabling systems to work well together - that of employing basic human factors design principles to overcome potential problems between systems. Existing, relevant sources of such design principles are given in full in the process document.

6.0 **F: DESIGN SOLUTION: PRIORITY SETTING**
A method to enable the information elements that multiple systems may present to be ranked in order of priority (e.g. collision warning, then route guidance, then traffic information). This stage of the process helps the designer to choose between fixed prioritisation, dynamic prioritisation (where priorities will change over time and will be influenced by other factors, e.g. time criticality of journey, proximity to next manoeuvre), or a hybrid of the two. It also provides guidance on how prioritisation should be implemented. The full process is too complex to describe here but is based on using the prioritisation criteria shown in Table 4 as a starting point.

<table>
<thead>
<tr>
<th>Scale value point</th>
<th>Potential consequence based on non-optimum driver-system interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Potential severe accident, major injury possible</td>
</tr>
<tr>
<td>5</td>
<td>Potential minor accident, vehicle damage and minor injury possible</td>
</tr>
<tr>
<td>4</td>
<td>Severe impact on journey efficiency, business value and / or driver comfort</td>
</tr>
<tr>
<td>3</td>
<td>Medium impact on journey efficiency, business value and / or driver comfort</td>
</tr>
<tr>
<td>2</td>
<td>Minor impact on journey efficiency, business value and / or driver comfort</td>
</tr>
<tr>
<td>1</td>
<td>No impact on journey efficiency, business value and / or driver comfort</td>
</tr>
</tbody>
</table>

*Table 4: Potential scale for quantitative prioritisation*
7.0 **G: DESIGN SOLUTION: INTEGRATION AND DATA FUSION**
This stage applies well-accepted human factors solutions to the problem of multiple information sources. Three possible techniques are proposed: *spatial proximity* (e.g. provide a route overview map and traffic information adjacent to one another on the same screen); *physical integration* (e.g. provide a route overview map with integral congestion coding such as changing the colour or thickness of congested roads); or *data fusion* (e.g. produce an algorithm which takes account of the route guidance and traffic information, calculates the best action and provides the outcome to the driver as the next route guidance instruction). Guidance is provided in the process to enable choice of the most appropriate technique.

8.0 **H: DESIGN SOLUTION: RE-ALLOCATION OF INPUT/OUTPUT**
This stage provides a designer with guidance in terms of altering the input and/or output method for an individual system in order to minimise the conflicts that may occur between multiple in-vehicle systems. It shows the implications of changing input or output design from that which is preferred for an individual system (as indicated by system-specific guidelines or the recommendations in Stage C) to alternatives which are still acceptable for the integrated system as a whole. For example: *An initial design decision has been made that a route guidance system and a travel and traffic information system will both use a speech output, in a central location. The designer has decided that it is necessary to consider the option of one or both of these employing a visual text output instead, displayed in the dashboard.*

Table 2 shows the implications of moving from a speech output to a visual text output. The columns highlight the two design options, the arrows show the major impacts in terms of being able to satisfy the KDFs. It can be seen that the main implications of the change would be:
- less acceptable for information of high urgency
- better for information that needs to be referred to later
- much less acceptable for information presented while the vehicle is in motion
- better for information that will be presented automatically
- etc..

*For a route guidance system and a travel and traffic information system, the implications above suggest, that in this case, the travel and traffic information system should be re-allocated to a visual text display, and the route guidance system should continue to employ the speech output design option.*

5.2.7
4  INDUSTRY FEEDBACK ON INTEGRATE CONCEPTS

1.0  INTERVIEWEES
Many of the interviewees had been involved in the elicitation of industry requirements at the beginning of the project. They were representative of the target audience for the INTEGRATE design advice (i.e. vehicle manufacturer and Tier 1 supplier staff with an input to HMI aspects of integration). The companies involved, and numbers of staff (in parentheses) were:

Vehicle Manufacturers: Ford Motor Company Ltd (3); Jaguar Cars Ltd (2); Rover Group Ltd (2); Honda R & D Europe UK Ltd (4); Nissan European Technology Centre Ltd (9).

Suppliers: TRW Automotive (3); Alpine Electronics of UK Ltd (1).

Interviewees were requested to be as interactive and open as possible with their comments (comments in the results are not attributed to particular individuals nor organisations). The main aspects discussed were:

- the place of the design advice in the product development process (current and future)
- the relationships amongst vehicle manufacturers and suppliers, its implications for the INTEGRATE design advice, and vice versa
- the integration concepts with most potential to support current/future working (and those that showed least promise)
- other areas requiring design advice or further research

The results presented in the remainder of this paper focus on implications for the vehicle/system development process and relationships within the supply chain. First, comments on the overall approach are presented then comments on each of the design solutions F-H (described above in sections 3.6-3.8)

2.0  FEEDBACK ON THE OVERALL APPROACH
The interviewees welcomed any guidance that would enable them to instil good human factors practice at an earlier stage of the design process. This would reduce the negative constraints that are sometimes placed on a design prior to their involvement. The INTEGRATE approach was seen as advantageous as it addressed their priorities, namely:

- It can provide the all important rationale for justifying human factors design decisions (often against contradicting engineering viewpoints)

- It is driven by user requirements not ‘technology push’ (current system development can often be the converse)

- It is structured and technology independent, so will not become redundant as existing systems change or when new systems are introduced

- It is intended for use early in the development process, when there is most scope for ensuring that effective integration takes place
Other issues which have implications for the development of the INTEGRATE design process are:

- The output of the process needs to be understood by engineers with no human factors training/knowledge. For this audience, the process will aid the human factors engineer in presenting the wider view with regard to the implications of design decisions.

- The tool could be an aid to documenting design decisions and the reasoning behind them, especially in structuring the human factors argument to be presented to the design team.

- Any tool must be flexible enough to cope with continual change in system specification. This occurs as a result of changes in competitors’ products, advances in the underlying technology, changes in customers’ expectations, emerging standards/legislation, safety concerns and conflicting requirements between internal departments.

- Starting a vehicle design with a ‘clean sheet’ is virtually unknown. Most often, core systems are already fixed and changes are limited. The two main reasons for this are: (a) a lot of development time has already been invested in them for previous vehicles and they are simply carried over to the new programme (e.g. an audio system); and (b) an existing system is being tailored to a new market (e.g. a navigation system already sold in Japan and being adapted for Europe).

- Initial product strategy or marketing documents (often 3 years ahead of launch) can often be quite broad, e.g. ‘navigation will be incorporated’ with little detail regarding functionality. The later stage of ‘early system outline definition’ is where the INTEGRATE process would be most appropriate. Currently it is rare for human factors engineers to be involved at this stage, but with the increasing complexity of systems, it will become more critical for this to change.

- Tier 1 suppliers currently integrate at the hardware level, in future, software integration will be vital due to the increasing complexity of systems and the need to share common data.

- The INTEGRATE process has the potential to develop along two routes: (a) to provide a systematic method of thinking through the issues, or (b) to produce decision support software where data is entered and solutions are provided. Feedback from industry suggest that the former is more welcome. The consensus view is that design teams are by no means lacking in ideas nor solutions, but that a method for assessing the pros and cons of each solution prior to direct user involvement would be welcomed.

- A two-tiered process would fit with current processes: a ‘quick and dirty’ approach early, at the demonstration stage and a more sophisticated, detailed approach for the actual design.

- Ideally, from a human factors perspective, the ‘sign-off’ of a product should be on the specification and not on the design.
3.0 **FEEDBACK ON DESIGN SOLUTION F ‘PRIORITY SETTING’**

The concept of prioritisation per se is not new to the vehicle manufacturers’ design process. Multi-function warning displays already employ fixed priorities, e.g. brake warnings are rated above low washer fluid information. The extension of this to more complex information, being prioritised according to the situation could therefore find a place in the development process. Several issues were raised in the discussion and many related to the implications that prioritisation would have for working relationships and data exchange between two or more suppliers and with the vehicle manufacturer. Specific areas were:

- Achieving prioritisation would require a very close link between the suppliers of each sub-system, ideally at a very early stage of system development (prior to system specification). This would require access to, exchange of and linking of base data. This may raise issues of confidentiality and impose new constraints in terms of system incompatibility, e.g. differing data formats. This would negate the current view that hardware needs to be fixed early in the process, but software can still be altered at a relatively late stage.

- The responsibility for prioritisation would, initially, be with the vehicle manufacturer. However, there would inevitably be a push for Tier 1 suppliers to take on this role.

- To achieve real-time prioritisation requires a significant investment. As a result, manufacturers and suppliers would only consider pursuing this avenue if there was proof of a significant advantage of this method over fixed prioritisation (both in terms of safety and customer acceptance).

4.0 **FEEDBACK ON DESIGN SOLUTION G ‘INTEGRATION AND DATA FUSION’**

A few comments were made regarding the implications of display integration for the design process:

- The responsibility for display integration is unlikely to be given to the supplier. This is particularly true if there are strong requirements in terms of brand image and ‘sacred cows’ (i.e. design features which *must* be retained, unless there is a very strong argument against them).

- Those aspects of display integration which require the combination of data from several sources (i.e. physical integration and particularly data fusion) result in a need for increased communication and sharing of data across suppliers at an early stage. The responsibility for this is still likely to reside with the vehicle manufacturer, for the reasons stated above.

- Display integration could be instrumental (in the longer-term) in all driver information moving to the centre console. This could lead to easier production, particularly when designing for left and right-hand drive vehicles. This comment is in conflict with one of the fundamentals of the INTEGRATE project which is to treat the whole vehicle as a potential input/output device (e.g. parking warnings could be displayed in the rear-view mirror). Other aspects of the INTEGRATE design process may counteract such centralisation, e.g.
the advice provided on the optimum allocation of functions to particular input/output methods and locations.

5.0 **Feedback on Design Solution H ‘Re-allocation of Input/Output’**

The process fits quite well with current procedures and could have benefits in terms of further enhancing and structuring designer’s decision making. Several comments are worth noting:

- Trade-off tables are already used for aspects of the vehicle HMI design. Currently they are based on subjective opinion rather than objective data.

- Invariably, designers will have their own design criteria, e.g. rating particular methods in terms of ‘findability, accessibility, operability’.

- The key design factors to be identified by INTEGRATE could prove useful in conveying the human factors issues to engineers. The reason is that the KDFs show the **whole range of factors** which influence optimum choice of input/output method. This would avoid what happens now, i.e. that one factor, e.g. urgency of message, is the focus for design choice to the exclusion of other potentially important factors. Currently this may not be a serious problem, but it will become so in more complex, multiple systems that require integration.

- Input/output re-allocation could be used early in the design process to help define the optimum combination of hardware, and also later in the development cycle to identify the implications of design changes suggested by other departments.

- The concepts described seem to be of most value where the design is based on a ‘clean sheet’, i.e. specifying the design from scratch. This is virtually unheard of in the vehicle industry. Most often an existing instrument cluster is used as a basis for adding or enhancing functionality. The INTEGRATE process needs to develop a design solution which is applicable to this situation.

- The process needs to take account of consistency across models (and within the model range/options). The concepts described, if followed to the letter, could result in a different input or output method for a particular information element, depending on the number of sub-systems to be integrated.

5 **Post Script**

The approach described in this paper takes a human-factors perspective of driver system integration, and it is recognised that human factors (or ergonomics) is only one attribute that is considered within the vehicle design and development process. In particular, design trade-offs must take into account all of the relevant cost/benefit factors, of which the human factors element is only one. Although based on a requirements analysis, and extensive consultation with industry, this approach has not been tested or validated. It is hoped that it can be tested and developed further. The authors would welcome any feedback on the ideas and approaches contained within this document, both from an academic, and industrial, viewpoint.
6 ACKNOWLEDGEMENTS

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7 BIBLIOGRAPHY