



This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.


C O M M O N S D E E D

Attribution-NonCommercial-NoDerivs 2.5

You are free:

- to copy, distribute, display, and perform the work

Under the following conditions:



Attribution. You must attribute the work in the manner specified by the author or licensor.



Noncommercial. You may not use this work for commercial purposes.



No Derivative Works. You may not alter, transform, or build upon this work.

- For any reuse or distribution, you must make clear to others the license terms of this work.
- Any of these conditions can be waived if you get permission from the copyright holder.

Your fair use and other rights are in no way affected by the above.

This is a human-readable summary of the [Legal Code \(the full license\)](#).

[Disclaimer](#) 

For the full text of this licence, please go to:
<https://creativecommons.org/licenses/by-nc-nd/2.5/>

HUMAN MACHINE INTERFACE INTEGRATION FOR DRIVER SYSTEMS

Tracy Ross, Andrew May

HUSAT Research Institute, Loughborough University

The Elms, Elms Grove, Loughborough, Leicestershire, LE11 1RG, UK

Tel: +44 1509 611 088; Fax: +44 1509 234 651; Email: t.ross@lboro.ac.uk, a.j.may@lboro.ac.uk

Gary Burnett

School of Computer Science and Information Technology, University of Nottingham

Jubilee Campus, Wollaton Road, Nottingham, NG8 1BB, UK

Tel: +44 115 951 3357; Fax: +44 115 951 4254; Email: gary.burnett@cs.nott.ac.uk

SUMMARY

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: 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 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.

Negotiating heavy traffic conditions is already a demanding task for the driver. They must maintain a mental model of their orientation, visually scan for traffic, other obstacles and junctions, make decisions regarding lane and route choice, perform speed and distance judgements, and undertake physical lateral and longitudinal control of their vehicle. As in-vehicle systems are introduced, drivers must additionally attend to information coming into the vehicle, make decisions and undertake actions based on it, and possibly try to use the system controls at the same time. The result is likely to be high physical and mental workload, potentially resulting in one or more of the following:

- Inappropriate lateral or longitudinal vehicle control
- Incorrect route selection
- Reduction in safety margins in relation to other traffic and the road infrastructure
- Feelings of anxiety and discomfort
- A failure to assimilate the information being presented to them (e.g. not hearing the traffic information, or not realising it is of importance to them)
- Ineffective use of in-vehicle systems (e.g. not picking up the phone call).

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.

INDUSTRY REQUIREMENTS

The project liaised with human factors and engineering staff within vehicle manufacturers and system suppliers (Ford Motor Company Ltd, Jaguar Cars Ltd, Rover Group Ltd, Honda R & D Europe [UK] Ltd, Nissan European Technology Centre Ltd, TRW Automotive, Alpine Electronics of UK Ltd and Visteon Automotive). This enabled the following conclusions to be made about the scope and format of the INTEGRATE advice:

- The target audience will be both OEMs and suppliers.
- Within companies human factors staff would be the prime users of the advice (potential 'secondary' users will be engineering, styling, marketing and design houses)
- The most urgent requirement is for advice on information, communication, entertainment and comfort systems, as these are being integrated within current vehicle programmes. A less urgent requirement is for advice relating to vehicle control and safety related systems; these systems are likely to emerge in the medium to longer term.
- The advice must fit with current company design processes, use industry terminology, be as quantitative as possible, provide examples where appropriate and the rationale behind the advice must be available for justification of design decisions.
- Information must enable trade-offs to be made between different design solutions.
- Basic human factors principles are needed alongside advice specific to vehicle systems.
- The advice should be applicable to any combination of systems and should be future-proof (i.e. not limited only to current technologies)
- The advice should be provided in a spatial/visual manner (e.g. linked graphics and hypertext), rather than detailed prose.

THE MAIN FEATURES OF THE DESIGN ADVICE

The guidance 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 for a visual, searchable tool. The format of the advice is therefore designed to lend itself to future, software-based, exploitation.

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.

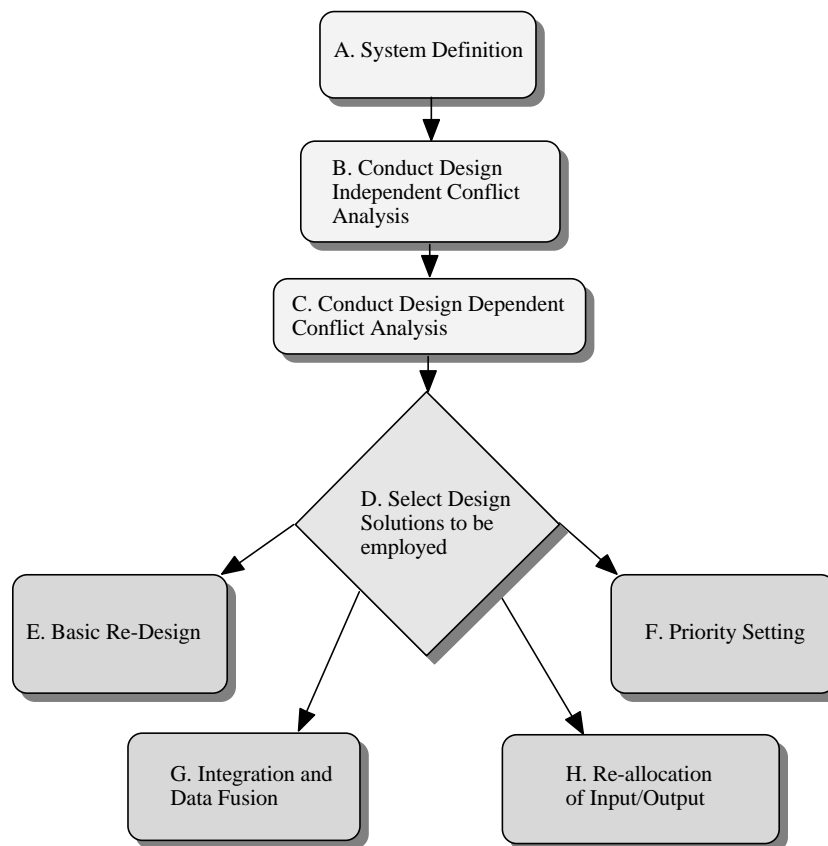


Figure 1: Overview of the stages

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).

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.

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

Table 1: Dimensions describing the driver/vehicle status

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.

Key Design Factors (KDFs)	Examples	Output Methods																							
		Auditory				Visual								Haptic											
		Tones		Speech		Graphics						Text		Vibr.	Force										
		Left	Central	Right	Left	Central	Right	Forward road view	Dashboard	Central column – high	Central column – low	Rear view mirror	Side mirror	Parcel shelf	Forward road view	Dashboard	Central column – high	Central column – low	Rear view mirror	Parcel shelf	Steering wheel	Foot pedals	Steering wheel	Foot pedals	
Info of high importance	Forward collision warning																								
Info of high urgency	Blind spot warning					●																			
Info might be needed later	Current emails					●																			
Info presented whilst vehicle in motion	Congestion levels					●																			
Info presented whilst vehicle stationary	Passenger door open																								
User will request the info.	Distance to next services					●																			
System will automatically present info.	Distance to next turning					●																			
Info inherently complex	Timetables for other transport modes																								
Info mainly spatial	Topographical relations on map																								
Info has spatial component	Direction of turning					●																			
Info mainly verbal	Total trip cost																								
Frequent presentations likely	Nearest petrol station					●																			
Info continuously changing	Fuel level					●																			
Info changes intermittently	Adverse weather conditions					●																			




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)

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.

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

Table 3 Potential design solutions for integration conflicts

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.

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.

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

Table 4: Potential scale for quantitative prioritisation

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.

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.

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.

ACKNOWLEDGEMENTS

The INTEGRATE Project was funded by the EPSRC Innovative Manufacturing Initiative, Land Transport Programme, Telematics. Other partners in the project were Coventry University Knowledge Based Engineering Centre, and the Motor Industry Research Association.

BIBLIOGRAPHY

- (1) Campbell, J. L., Carney, C. & Kantowitz, B. H. (1998). Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO) (Report No. FHWA-RD-98-057). Seattle, WA: Battelle Human Factors Transportation Center/Federal Highway Administration.
- (2) Evans, J. L., Kaptein, N. A., Melchior, E. M., Bosser, T., Stove, A. G. & Gupta, A. (1994). MMI applications matrix. Internal report workpackage 310, (DRIVE II V2065 GEM), Bristol, UK: Sowerby Research Centre.
- (3) Leiser, B. & Carr, D. (1991). Analysis of input and output devices for in-car use. GIDS-DIS1. Haren, The Netherlands: Traffic Research Centre, University of Groningen
- (4) Lerner, N., Steinberg, G., Freedman, M. & Boyd, S. (1998). Human factors integration needs of advanced in-vehicle safety and information systems: Assessment of current status and practice. Contract no. DTNH22-95-D-07019 (Office of Crash Avoidance Research, National Highway Traffic Safety Administration). Rockville, Maryland: Westat.
- (5) Michon, J. A. (Ed.). (1993). Generic Intelligent Driver Support: A comprehensive report on GIDS. London: Taylor and Francis
- (6) Ross, T., Midtland, K., Fuchs, M., Pauzie, A., Engert, A., Duncan, B., Vaughan, G.M., Vernet, M., Peters, H., Burnett, G.E. and May, A.J., HARDIE Design Guidelines Handbook. Human Factors Guidelines for Information Presentation by ATT Systems, March 1996, 530 pp, CEC DRIVE II Project V2008 HARDIE Deliverable 20.
- (7) Stokes, A. F., Wickens, C. D. & Kite, K. (1990). Display Technology: Human Factors Concepts. . Society of Automotive engineers Inc., 1990
- (8) Verwey, W. B. (1990b). Adaptable driver-car interfacing and mental workload: a review of the literature. IZF 1990 B-3 IZF 1990 B-3. Soesterberg, Netherlands: TNO Institute for Perception
- (9) Wickens, C. D. & Andre, A. D. (1990). Proximity compatibility and information display: effects of colour, space, and objectness on information integration. *Human factors*, **32**(1), pp61-77