32 Driver Distraction Injury Prevention Countermeasures—Part 3: Vehicle, Technology, and Road Design

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32.1 INTRODUCTION

A number of design challenges are created by the proliferation of systems and functions that interact with the driver in the vehicle and the road environment. These include technology-related design challenges (e.g., integration of many functions, life cycle gaps, false alarms) and safety-related design challenges (e.g., distraction, drowsiness, automation, and behavioral adaptation).

This chapter addresses the challenges that exist in designing systems and functions that minimize the impact of distraction on safety while maximizing the possibilities that are offered by new technology. It presents and discusses countermeasures that relate to the vehicle itself, the technology brought into or added to the vehicle, and the road environment in which the vehicle is traveling. The first section focuses on what designers of vehicle systems and functions can do to prevent distraction, both in the design phase before manufacturing and during driving (in real time). The second section deals with what designers of the road environment can do to limit distraction.

32.2 VEHICLE AND TECHNOLOGY DESIGN COUNTERMEASURES

32.2.1 Background

The number and types of technologies—vehicle-integrated, aftermarket, and nomadic (portable)—entering the vehicle cockpit that have the potential to distract the driver is increasing rapidly. There is evidence (see Chapter 16) that distraction deriving from driver interaction with technologies whilst driving accounts for around 15–20% of all distraction-related crashes. Hedlund et al.[1] highlight (p. vii) several trends in the rollout of vehicle and nomadic technologies, which they believe challenge traditional methods of ensuring the safety of vehicles and equipment through regulation:

- "Electronics and telematics devices are becoming multi-functional. For example, the device "previously known as a cell phone" now can send and receive email, take pictures, and provide location and route information.

- Devices are becoming increasingly portable, no longer attached to a telephone line or an automobile. Consumers can bring their communications and entertainment with them wherever they go.
- The industry is highly diverse, ranging from traditional suppliers of original and aftermarket automobile equipment to consumer electronics manufacturers. It does not fit well within the traditional automobile industry regulatory structure.
- New products are developed, introduced, and modified very rapidly. For example, a typical user replaces his or her cell phone every 18–24 months."

Two additional trends are also noteworthy in this respect. First, interfaces within the vehicle allow nomadic devices to communicate with other devices built into the vehicle. For example, nomadic devices (such as mobile phones) can now display information on dedicated screens within the vehicle. Second, information outside the vehicle, such as speed limits, destination information, and the location of speed cameras, can be duplicated inside the vehicle.[2,3]

As Hedlund et al.[1] point out, the challenge is "to assess the distracting potential of new technology and take proactive steps to prevent it from increasing crash risks, while preserving its potential benefits" (p. 7). These technology trends challenge traditional design methods to adapt to rapid innovation and development.

In the next two sections, a number of countermeasures addressing distraction-safety concerns are made with regard to driver use of in-vehicle technologies while driving. We focus first on what designers of systems and functions can do to "design-out" distraction in the design-phase, before vehicles and other technology are manufactured. Thereafter, we focus on what can be done by designers of real-time distraction prevention and mitigation systems.

32.2.2 Design-Phase Distraction Countermeasures

One main countermeasure is to *design systems so that they do not distract*. But *who* are the designers, and *how* do they know what is distracting? These are deceptively simple questions requiring consideration of many issues. The following section presents and discusses some of the main issues, which are taken up in greater detail elsewhere in this book (e.g., Chapters 22 through 25 and Chapter 33).

As noted by Stevens (Chapter 22), individuals at a number of organizations are typically involved in designing, producing, and providing elements of systems. These include vehicle manufacturers, aftermarket system producers, providers of nomadic device functionality, manufacturers of parts enabling the use of nomadic devices while driving (e.g., cradle, connectors), and information and service providers. Thus, in an answer to the question "who are the designers?" it can be concluded that organizations as well as individuals must be regarded as "designers" and countermeasures should be implemented in organizations as well as by individuals.

32.2.2.1 Guidelines and Standards as Countermeasures

Designers must balance safety with many competing priorities such as cost, packaging, complexity, esthetics, and so on (see Chapter 33) and are often faced with hard questions such as, "Do the safety benefits achieved by moving this display up 5 cm motivate the costs of redesign?" System design and construction includes overall design, installation, information presentation, interaction with displays and controls, system behavior, and information about the system.

Ergonomic guidelines and standards (see Part 7 of this book) are important tools that can be used at different stages in the user-centered design (UCD) process to support the ergonomic design and evaluation of vehicle-human-machine interfaces for driving-related systems. Various distraction-related interface design and evaluation guidelines and standards have been developed around the world, and problems associated with them are reviewed in Part 7 of this book. Guidelines and standards can be seen as the main distraction countermeasures in the design-phase. They describe *how* to know what is distracting and *what* to do about it.

There are three general types of standards (see Burns, Chapter 23):

- *Design standards* provide precise specifications for a vehicle or vehicle system in terms of, for example, physical attributes or geometry.
- *Performance-based standards* set out the minimum level of performance that a system must meet when tested in accordance with a prescribed test method.
- *Process-oriented standards* are concerned with the systems and procedures that an organization should establish and follow during its development and implementation cycle.

Ideally, a combination of the standards should be used because each type of standard has its limitations. Design standards are the most straightforward to implement, but limit innovation; whereas process-oriented standards support innovation, but require a great deal of organizational commitment to implement. The development of performance standards should be a cooperative effort, involving many stakeholders: governments, the technology industry, product manufacturers, service providers and consumer groups.[1]

Design and performance standards. Since design and performance guidelines regarding distraction are typically combined in the same documents, these two types of standards will be considered together here. A number of design and performance guidelines and standards exist, such as the European Statement of Principles (EsoP), the American Automobile Manufacturers (AAM), and the Japan Automobile Manufacturers Association (JAMA) guidelines, and the ISO standards, which aim to limit distraction deriving from in-vehicle information and communication systems. These are reviewed in Part 7 of this book, and the issues that remain to be resolved in ensuring that they achieve their intended purpose have been discussed. Here, a macro perspective is taken to elicit some more general conclusions.

Ideally, the approach to develop and implement mandatory performance standards for vehicle electronic devices, similar to the vehicle safety standards currently in effect in many countries,[1,4] would prescribe "practical, repeatable methods to measure the distracting effect of these devices and reliable benchmark levels of unacceptable performance" (Ref. 1, p. 7). These should be consistent for original, aftermarket, and portable devices, and should not stifle product innovation.[1] The state of the art has progressed, as can be witnessed in Part 3 of this book, but more research on this topic is needed to achieve consensus on many of the performance-related guidelines and standards.

The following main issues are identified with regard to the *content* of existing design and performance standards:

- One main concern is the current lack of scientific knowledge to provide unequivocal assessment and robust compliance criteria (see Chapters 22 through 25 and Chapter 33). Further research is needed to develop new principles and performance criteria for good interface design, and to confirm and refine those that already exist.
- There remains a research gap in how to combine individual methods for assessing the level of distraction deriving from interaction with in-vehicle information system (IVIS) technologies into an overall integrated methodology to make predictions about safety in use. Stevens (see Chapter 22) outlines the issues that would need to be addressed in doing so.
- There is a particular need for more detail among the elaborations supporting the principles, including more emphasis on concise, unambiguous, and traceable references (Chapter 23). Insufficient detail may lead to variations in design and a lack of reliability between experts. Guidelines and standards still range from those that are more precise and detailed to those that are less prescriptive and rely on expert judgment. When existing guidelines and standards are less prescriptive, it is usually because there exists insufficient scientific research and data. Some degree of expert judgment will always remain necessary.
- Guidelines and standards should themselves be designed from a user-centered development perspective, and properly evaluated to ensure they are valid, reliable, effective, user friendly, and acceptable to end users.[5]
- Current guidelines have been developed principally to reduce the amount of distraction deriving from driver interaction with vehicle information and communication systems. Consequently, the primary focus of these guidelines is on the ergonomic design of systems, unrelated or secondary to driving, rather than on the design of systems that are integral to driving itself; although many of the principles contained within them are relevant to the design of interfaces for driving-related systems. As noted in Chapter 3, driving is a multitask activity and, as such, some elements of one driving task (e.g., changing gears, reading a speedometer) may distract the driver from elements of another (e.g., monitoring for traffic hazards). It would seem appropriate, therefore, to expand the scope of existing guidelines and standards to incorporate design guidance that seeks to minimize distraction from driving-related systems that could distract the driver from other driving-related activities.

Akumatsu (Chapter 24) and Stevens (Chapter 22) discuss the role that checklists, in addition to guidelines and standards, can play in enabling experts to make rapid and structured assessments of key safety-related features of an IVIS in a standard way, to identify where more detailed assessments may be required, and to determine whether human interaction with the device complies with the principles contained within industry guidelines. As Akamutsu points out, however, automotive companies often have their own checklists for in-vehicle human machine interface (HMI) design, which are usually confidential and are not made available to the public. The Transport Research Laboratory checklist, described in Chapter 21, would seem to provide a good platform for the development of a more globally acceptable checklist that incorporates what vehicle manufacturers have learned. Another promising example is the SafeTE checklist, which was developed in Sweden by Volvo Technology and the Swedish National Road and Transport Research Institute (VTI) for the Swedish Road Administration.[6] Table 15.5 in Chapter 15, provides a framework for a checklist that would focus more specifically on the assessment of distraction.

In Chapter 33, we invited two representatives of the automotive industry to provide their views on driver distraction. The following, general recommendations are distilled from the contributions made by Eckstein (BMW) and Hammer (GM Holden) with regard to design-phase countermeasures and the *implementation* of guidelines:

- The availability and presentation of information and communication functionalities while driving is a responsibility shared by many stakeholders. Specialist suppliers must increasingly share responsibility for designing systems that minimize distraction.
- All stakeholders need to develop information and communication systems to the same standard, independent of their functionality and degree of integration.
- The development of HMI design guidelines, such as the ESoP, AAM, and JAMA guidelines, is not in itself sufficient to ensure that distraction is minimized. Accompanying measures are needed to ensure that all system types (vehicle integrated, aftermarket, and nomadic) are designed in accordance with the guidelines and that drivers install and use them in a responsible manner. The final report of the e-Safety Working Group on HMI[7] summarizes those measures deemed necessary in Europe.
- Automobile manufacturers and suppliers should actively contribute to HMI research, standardization, and guideline development. The automotive industry, in particular, needs to be proactive and to establish agreed-on, voluntary design guidelines where this has not been done.
- Cars are no longer designed for a single country, so HMI guidelines need to be made available as harmonized global industry guidelines to achieve real societal road safety benefits.
- Smaller countries need government partnerships to help defray the large capital investments required for test facilities. Sweden is considered an exemplar in this area.

Eckstein argues, in Chapter 33, that road authorities should in several ways play a decisive role in limiting distraction from vehicle technologies as follows:

- Ensuring that HMI design guidelines are effectively disseminated, known, and used by all responsible stakeholders

- Providing general information to drivers on safe use of in-vehicle information and communication systems
- Promoting self-commitment, by the manufacturers and suppliers of aftermarket and nomadic devices, to comply with automotive HMI design guidelines such as the ESoP
- Monitoring the impact of HMI design guidelines on the market for aftermarket and nomadic devices
- Evaluating the safety impact of in-vehicle information and communication systems by collecting and analyzing crash and naturalistic driving data
- Taking measures to ensure (a) secure fixing of devices in accordance with relevant guidelines; (b) hands-free use of nomadic devices, and (c) restricted access to drivers while playing movies, TV, and video games

Process-oriented standards. A process-oriented standard, or code of practice, outlines the iterative steps that should be undertaken in designing, developing, evaluating, and deploying a vehicle system, device, or product from a UCD perspective. Process-oriented standards already exist for the user-centered procurement, design, development, evaluation, and deployment of systems in other domains, such as the military.[8]

Like Ekstein and Hammer, Burns (Chapter 23) notes that existing voluntary design guidelines and standards are insufficient by themselves. Burns argues that a process-oriented safety management systems (SMS) approach is needed to (a) ensure that designers are aware of guidelines and standards and have the resources and expertize to apply them, (b) ensure that the risks of driver distraction are routinely considered within the product development process, and (c) ensure that safety and usability testing in the automotive industry is prioritized and implemented more effectively. An SMS approach resembles the automotive industry process standards except that the targets are product "safety" rather than "quality." SMS stems from James Reason's work on managing organizational risk and human error.[9]

As yet, such a standard does not exist in the automotive sector. Transport Canada is promoting an SMS approach, working with the automotive industry and other relevant stakeholders to ensure that systems entering the market meet certain minimum requirements (Chapter 23). The parliament of Victoria also recommended in its Report on the Road Safety Committee Inquiry into Driver Distraction[10] that Australia go down a similar path. In the absence of process-oriented standards, there will remain considerable variability in the ergonomic quality of vehicle cockpit system interfaces across makes and models of vehicles. The development of such a voluntary process-oriented standard, or code of practice, is certainly an important priority for countermeasure development. Key components of the SMS approach[11] include voluntary commitments to:

- Define clear accountabilities and responsibilities that commit senior management to safety policies, measurable safety objectives, and clear organizational responsibilities and accountabilities for safety
- Monitor safety performance to comply with best practice human factors and ergonomic guidelines, checklists, and standards
- Develop a safety assessment process

- Communicate the SMS to all relevant parties
- Hold safety training
- Perform periodic audits
- Document the SMS

32.2.2.2 Guidelines and Standards for Advanced Driver Assistance Systems

Advanced driver assistance systems (ADAS) that automate partly, or fully, some driving-related functions and tasks (e.g., forward collision warning (FCW), lane departure warning, intelligent speed adaptation (ISA), in-vehicle navigation systems) provide another mechanism by which driver workload and distraction can be reduced—provided, of course, the systems are well-designed and evaluated. Unfortunately, very few guidelines and standards currently exist for the ergonomic design and evaluation of such systems (but see Campbell et al.[12]).

ISA, for example, is a system for which there currently exists no human factors design and evaluation guidelines or standards. This system has been shown, in numerous studies, to be highly successful in reducing speed and in conferring a range of other safety benefits,[13–15] is available in several countries as a commercial aftermarket product, and is being strongly promoted by many governments around the world. Little is known, however, about the extent to which this system moderates driver workload and distraction and to what extent this varies among different interface design configurations. It is possible that such systems, even though they could reduce crash risk, might increase driver workload and distraction if poorly designed. Is it better, for example, to provide the driver inside the vehicle with a continuous display of the posted speed limit along the road network, or to warn the driver only when the posted speed limit has been exceeded? The first design strategy is more likely than the second to divert drivers' attention away from activities critical for safe driving (assuming the ISA display is visual), but in doing so may make drivers less likely to want to continue to monitor redundant information from the speedometer and external speed signs (everyday driving activities which, in themselves, could divert drivers' attention away from activities critical for safe driving). The second design strategy is less likely than the first to divert drivers' attention away from activities critical for safe driving, but it may encourage drivers to continue to look at the speedometer and at external speed signs, activities which, as noted, could divert their attention away from activities critical for safe driving. Although existing guidelines, reviewed in Part 7 of this book, provide some general guidance relevant to the design of interfaces for ADAS, the focus of these, as previously noted, is on information and communication systems. Clearly, more suitably tailored guidelines and standards are needed for the design of ADAS technologies, which are derived from a proper understanding of the manner and contexts in which they are used.

More generally, as noted in Chapter 3 (see also Refs. 2 and 3), technological developments are making it possible to display to the driver, inside the vehicle, driving-related information currently displayed on signs and other media outside the vehicle. ISA, noted earlier, is capable, for example, of displaying to the driver inside the vehicle the posted speed limit along all segments of the roadway. Systems also exist, which are capable of displaying inside the vehicle a host of other information currently found on guide, warning and regulatory signs outside the vehicle. The information can be displayed to the driver any time, in any sensory modality, and in any design configuration. This is an interesting development. If the display of information from outside the vehicle is well designed and integrated with information already inside the vehicle, it has potential to reduce overall driver workload and, in turn, vulnerability to distraction. If not, drivers may find themselves overwhelmed by spatially and temporally overlapping and redundant information from within and outside the vehicle, which has potential to distract, overload, and confuse them. Little, however, is known about the impact on driver workload and distraction of the in-vehicle echoing of external information, and very little guidance exists to inform design efforts (one exception being Saad and Dionisio[15]). Clearly there is a need for further research in this area to support guideline and standards development efforts.

32.2.2.3 Human-Centered Design Process as a Countermeasure

An important, overarching countermeasure for distraction is use of a human-centered design process. The ISO standard for the UCD process (ISO 13407)[17] aims to help those responsible for managing hardware and software design processes to identify and plan effective and timely UCD activities. It defines a general process for including human-centered activities throughout a development life cycle, but does not specify exact methods. The methods for human-centered design and evaluation of potentially distracting in-vehicle systems and functions must therefore be defined to fit with this more general process.

A critical part of the UCD process is evaluation, ideally through testing with actual users. Any development process, which claims to have met the recommendations in ISO 13407 shall specify (a) the procedures used, (b) the information collected, and (c) the use made of the results. Within the automotive domain, there has been a proliferation of methods and metrics, which have been used at different stages of the UCD process to inform and refine the design of systems and functions to limit the impact of distraction on driving performance (see Part 3 of this book). However, there is currently little consensus regarding which assessment methods and metrics should be used for the evaluation of particular activities with potential to distract (see Chapter 7), and at which stages of the UCD process particular methods are most appropriate to use.

The outputs of projects such as Human Machine Interface and the Safety of Traffic in Europe (HASTE),[13] Adaptive Integrated Driver-vehicle Interface (AIDE),[18] and Crash Avoidance Metric Partnership (CAMP)[19] provide some initial guidance in assessment. Rapid evaluation procedures are needed that are cost-effective, easy to use by designers, and do not require sophisticated equipment and months of time. The lane change test is such a procedure although, as is noted in Chapter 25, the notion that a single, low-cost, test can assess the interference with driving of a competing task, regardless of its visual, auditory, cognitive, and psychomotor demands, may be unrealistic. Table 15.5 in Chapter 15 of this book, identifies mechanisms that moderate the effects of distraction that might be considered in refining the sensitivity and scope of existing assessment procedures, including checklists. In future, rapid evaluation procedures might include computational models of driver performance such that preliminary design concepts can be evaluated more quickly and earlier in the design and development cycle. Some models of this kind already exist (see Chapter 25). There also remains a need to develop reference tasks that provide benchmarks against which the impact on driving performance of distracting activities (driving related and nondriving related) can be established. These must be unambiguously defined, repeatable across different test environments, and induce mechanisms of distraction identical to those induced by the distracting activity under investigation.

32.2.2.4 HMI Integration as a Countermeasure

As the number of systems and functions that interact with the driver increases, so to do the number and complexity of input/output (I/O) devices and associated driver behaviors. HMI integration needs to be achieved to realize the full potential of intelligent vehicle technologies and is now the subject of some major research initiatives, for example the AIDE project,[20] the Integrated Vehicle-Based Safety Systems (IVBSS) project,[21] and the Integrated Safety System (INSAFES) project.[22] HMI Integration leads to many technological challenges. For example, packaging problems, a many-to-many mapping between applications, I/O devices, reconfigurability, and scalability. There are many human factors-related reasons for integration. For example, for solving problems associated with presentation of multiple simultaneous warnings[21,22] and problems of driver interaction with multiple different systems. Perhaps the main benefit from integration is achieved by using real-time centralized HMI management to resolve presentation conflicts between applications, for example, conflict between a telephone call and a navigation message presented simultaneously.

32.2.2.5 Safe Integration of Nomadic (Portable) Devices as a Countermeasure

A special case of integration that needs specific attention because of the distraction problem is that of the safe integration of nomadic (portable) devices; that is, mobile devices such as smartphones, navigation systems, and music players. The safety problems associated with nomadic devices are well recognized (see, e.g., Part 5 of this book), and integration of cell phones is in part even regulated through legislation (see Chapters 11 and 30). However, the benefits of different integration implementations need to be better understood. The assumption that integrated systems are necessarily better than non-integrated systems may not always be true and warrants more research. For example, Transport Canada[11] has called for a limit to the implementation of open architectures for portable devices brought into the vehicle. It is important to note that nomadic device integration can be achieved at different levels of integration, ranging from partial to full integration: physical integration (crashworthiness, power), synchronization of information (e.g., using Bluetooth technology), integration with driver–vehicle-environment (DVE) state (see, e.g., Ref. 20), audio integration, text/menu integration, vehicle integration (e.g., car-area-network [CAN]), visual information integration of nondynamic images, and visual information integration of dynamic/moving images.

One main research initiative within this area is taking place within the European AIDE project.[20] Work in AIDE on nomadic device integration involves both the technical development of possible solutions for nomadic device integration as well as the establishment of the nomadic device forum (that brings together vehicle manufactures, electronic device manufacturers, telecom industries, public authorities, and other stakeholders). To date, technical results include the identification of key integration "use cases" and basic architectural requirements. Moreover, a potential integration solution, based on a Bluetooth protocol, has been identified. One current on-market example of nomadic device integration is Ford Sync.

32.2.2.6 Incentive Schemes as Countermeasures

Under a voluntary regime, even the most ergonomically designed vehicle cockpits and technologies will be ineffective in limiting the effects of distraction if there is no demand for them by consumers. There exist, however, many mechanisms for stimulating voluntary demand by consumers for vehicles and technologies that optimize safety.[23,24] One option, suggested by Hedlund et al.,[1] that is likely to be effective, is to make bonus safety points available to vehicle manufacturers for electronic systems that have been assessed as meeting minimum requirements for limiting distraction. Such incentive schemes already exist for other technologies (e.g., seatbelt reminders, air bags) under the European new car assessment program (EuroNCAP) and similar programs operating in other jurisdictions.

32.2.3 Real-Time Distraction Countermeasures—Preventing and Mitigating Distraction While Driving

This section focuses on distraction countermeasures that actively operate in *real-time* while driving, so-called "real-time distraction countermeasures" (RDC). Engström and Victor (Chapter 26) define two main classes of existing RDC functions—real-time distraction *prevention* (with the focus on workload management) and real-time distraction *mitigation* (with the focus on distraction warning/feedback).

32.2.3.1 Real-Time Distraction Prevention

Real-time distraction prevention countermeasures, also commonly known as *workload managers*, include functions that serve the main purpose of preventing mental overload and distraction from occurring in the first place; for example, by prioritizing and scheduling system-initiated information according to the current driving situation or driver state (see Chapters 26 and 27 for details). The most common real-time distraction prevention functions include the following:

- *Information scheduling*, with the general purpose of ensuring that the driver receives information only when it is needed and when the driver is available to receive it (Chapters 26 and 27)
- *Demand-based advisories*, which are issued to discourage the use of functions such as MP3 music players, manually dialing 7- or 10-digit phone numbers, reading navigation maps, and using turn-by-turn navigation systems (Chapter 27)
- *Function lockout*, which involves the entire disabling of a function or subfunction in certain conditions (Chapters 26 and 27)
- *Adaptation of information format*, which involves altering the way the information is presented (not just the timing) to the current context (i.e., the driving situation or the presence of concurrent messages) (Chapter 26)

Although the majority of work within this area has been on embedded in-vehicle systems, such as the on-market systems in Volvo and SAAB Cars, it is important to note that nomadic-device-based solutions can also implement distraction prevention functions. For example, a cell phone service provider can take messages for the driver when they detect the phone is being driven, or require the person to confirm they are not driving before they answer or make a call. Further, shared solutions, which involve embedded-in-vehicle and nomadic-device-based solutions, are also possible. Currently, the area of context-aware, vehicle-integrated nomadic devices is attracting considerable research interest.

32.2.3.2 Real-Time Distraction Mitigation

Real-time distraction mitigation countermeasures are functions that serve the main purpose of mitigating distraction once it occurs. For example, by redirecting drivers' attention to the relevant aspects of the driving task (see Chapter 26). These functions provide feedback to help the driver shift attention back to driving when she/he is judged as being "too distracted" according to predetermined criteria set by the system, the driver, or the owner. The idea is to help the driver realize that he or she is being "tricked" into a distractive behavior. Two main functions are under development (e.g., in Volvo, SAAB, and in the AIDE and Safety Vehicles using Adaptive Interface Technology [SAVE-IT; see Chapters 27 and 28] projects) as follows:

- The *visual distraction alert.* The basic idea here is to help the driver to realize that she/he is glancing away from the road for too long or too often, and to "train" the driver to recognize a limit. As such, it alerts the driver to inappropriate behavior, and does not necessarily have a direct coupling to driving performance deterioration.
- The *cognitive distraction alert.* Feedback is given to the driver in situations where the driver is cognitively distracted, that is, when excessive attention is directed to internal thoughts or auditory content. The feedback can be given to wake the driver up, giving a reminder to increase scanning behavior.

Although research into real-time distraction mitigation functions is quite active, the field is still rather immature. In general, more research is needed to determine the effectiveness of distraction mitigation functions in improving performance and safety, in the short and long term.

32.2.3.3 Driver–Vehicle-Environment Adaptive Collision Warning Functions as Distraction Countermeasures

Driver-vehicle-environment (DVE) adaptive collision warning functions adapt warnings to certain states of the driver, vehicle, or environment (see Chapters 26 and 28). By doing so, they primarily improve the warning functionality with regard to effectiveness and acceptance. DVE states that warrant adaptation of warnings include eyes-off-road, visual time-sharing, cognitive distraction, high driving demand, driver impairment, driver intent of maneuvering, high traffic risk, and driver characteristics. Possible types of adaptation include altering the timing, intensity, duration, complexity, and modality of warnings. The primary role of the warning adaptivity is not to counteract distraction *per se*, but rather to optimize collision warning functionality. For example, a static warning will likely warn a driver too late of an unexpected event that occurs when the driver is distracted because of the increased RT associated with unexpected events.

Most research has been performed on distraction-adaptive (DA) forward collision warning (FCW) (see Chapters 26 and 28). Such FCW systems generally adjust the warning timing based on where attention is allocated, although other types of adaptation (e.g., of warning intensity) are possible as well. Other DA functions have also been tested: DA lane departure warnings either cancel a warning when the driver is attentive or provide an earlier lane departure warning if distraction is detected; DA curve speed warnings involve issuing an earlier warning when distraction is detected; and DA adaptive cruise control involves automatically and gradually increasing the headway to the vehicle in front or changing the set speed if distraction is detected to allow for longer reaction time.

In summary, the RDC research field is very active, with some first-generation products already available on the market. However, the field is immature and to a large extent technology-driven. There is still little consensus regarding which RDC functions are the most efficient and useful. The full benefits of adaptive functions are not yet clear.

32.2.4 Summary—Vehicle and Technology Design Countermeasures

Tingvall's "integrated safety chain" (see Figure 33.1 in Chapter 33) provides a perspective on how best to proceed in addressing the distraction problem as it relates to the use of technology in vehicles. Tingvall differentiates in Chapter 33 between five stages in the sequence of events leading up to a crash: "normal driving," "deviation from normal driving," "emerging situation," "critical situation," and "crash unavoidable." The distraction countermeasures outlined here can be placed within each of these stages to provide a holistic view.

With regard to the material reviewed in this book, distraction countermeasures in the "normal driving" stage are achieved by the following:

- *Design-phase distraction countermeasures*, such as the use of guidelines and standards, to reduce distraction and workload from interactions with in-vehicle, aftermarket, and nomadic devices
- *HMI integration*, including nomadic device integration
- *Real-time distraction prevention functions* that serve the main purpose of preventing mental overload and distraction from occurring in the first place; for example, by prioritizing and scheduling system-initiated information according to the current driving situation or driver state

Various systems have been developed to support drivers who momentarily deviate from normal driving, which may occur because drivers are inattentive, distracted, or in some other state. Some systems were not originally designed *per se* as distraction mitigation systems (e.g., forward collision warning, lane departure warning, intelligent speed adaptation), but have the potential to mitigate the effects of distraction by warning drivers when they fail to self-regulate in response to distraction (e.g., if they exceed the speed limit; if they get too close to the vehicle ahead). Others, such as the real-time distraction mitigation functions (the visual distraction alert and the cognitive distraction alert; see Chapters 26 and 28) have been designed specifically to warn drivers when they are driving in a distracted state that warrants intervention.

Tingvall describes an "emerging situation" as one that is less transient than a deviation from normal driving. Here the driver may not be aware of a sudden event that has potential to threaten safety—the driver may be drifting off the road or may be rapidly approaching a vehicle ahead. As discussed in Chapter 26, more aggressive real-time distraction warnings could be issued at this point. However, DA collision warning functions can alter the timing, intensity, duration, complexity, and modality of warnings. For example, an FCW is delivered earlier if the driver is distracted.

A "critical situation" is one where, for whatever reason, previous defenses in the integrated safety chain have failed and, in response to an impending crash, there is loss of control of the vehicle by the driver. Here immediate correction is required. Active safety systems, such as electronic stability control, lane-keeping assistance with active steering, and emergency braking assist, are available to support the driver to regain control of the vehicle and avoid a crash that might be attributable fully, or in part, to distraction. The sensors that comprise these systems can also be used to prime the early activation of passive safety systems.

At the tail end of the integrated safety chain, when a "crash is unavoidable," the distracted driver can benefit from the crash mitigation effects (e.g., lower impact speed) of previous countermeasures such as electronic stability control, lane-keeping assistance with active steering, and emergency braking assist. At impact, the driver still has many passive vehicle safety features to rely on for protection. A forgiving road infrastructure can also provide additional occupant protection at this stage of a crash.

The integrated safety chain (and other similar models) is useful not only in helping to identify where and how in the crash sequence existing and emerging driver distraction countermeasure technologies can be effective in protecting the driver. It is also useful in creating conceptual links between the operation of these technologies and other vehicle active and passive safety technologies that exist to protect the driver at successive stages in the chain and in creating conceptual links at each stage of the chain between driver, vehicle, and road infrastructure-related countermeasures.

In summary, the automotive industry has been proactive in developing a wide range of countermeasures to prevent and mitigate the effects of distraction. However, as an industry, it cannot be expected to shoulder the burden of good design in limiting distraction. Driving is a complex, multitask activity, and elements of the driving task itself (relating to both vehicle control and roadway monitoring) have the potential to divert the attention of the driver away from activities critical for safe driving. Responsibility for mitigating, through driver-centered design, the propensity for competing tasks to divert attention away from activities critical to safe driving is therefore a joint responsibility shared by multiple stakeholders: vehicle manufacturers, aftermarket suppliers, nomadic device suppliers, and road authorities. In the final section of this chapter, we consider what can be done to design the road environment to limit distraction.

32.3 ROAD DESIGN COUNTERMEASURES

32.3.1 Background

Data from crash studies, reviewed in Chapter 16, suggest that ~30% of distraction-related crashes derive from the driver being distracted by sources outside the vehicle. Known sources of distraction external to the vehicle that have been identified as contributing factors in crashes were identified and categorized in Chapter 15. These include animals, architecture, advertising billboards, construction zones/equipment, crash scenes, incidents (e.g., road rage, near-misses), insects, landmarks, road signs, road users, scenery, vehicles, and weather (e.g., lightning). The potential impact of these sources of distraction on driving performance and safety can be moderated, to varying degrees, through road design.

Relative to the amount of research on sources of distraction deriving from inside the vehicle, far less has been done in relation to external sources of distraction. Most of the relevant work, reviewed in Chapter 13, has focused on billboards, advertising signs, and, to a lesser extent, traffic signs.

32.3.2 Options for Road-Design-Based Countermeasure Development

As noted in Chapter 13, there is currently a lack of research evidence on which to form guidelines or standards about how much distraction from outside the vehicle is "safe." There are, however, some general recommendations for countermeasure development that can be made at this point in time.

Methods are needed for identifying sources of distraction on or near roads that adversely affect driving performance and safety, or have the potential to do so. General approaches for identifying sources of distraction with potential to compromise safety were described in Chapters 15 through 17. More specific guidance, relating to sources deriving from outside the vehicle, is provided in Chapter 13. Road safety audits, for example, which are routinely undertaken in Australia and other parts of the world, could include criteria for the identification and assessment of roadway-related activities, objects, and events that could distract drivers and degrade driving performance and safety.

There is a need to develop a taxonomy of those objects, events, and activities on or near road reserves that have the potential to distract. The taxonomy proposed in Chapter 15 provides an initial attempt at categorizing sources of distraction outside the vehicle currently known to be contributing factors in crashes and near-crashes, including those on or near the road reserve.

Needed are methods and metrics for assessing how sources of distraction from outside the vehicle impact driving performance. Work in this area is still in its infancy relative to that undertaken in relation to distractions deriving from inside the vehicle. As for the assessment of in-vehicle distraction, there is a need to develop reference tasks, which induce "acceptable" levels of distraction against which the impact of external distractions on driving performance can be assessed. Some initial thoughts on this issue are contained in Chapter 13.

Data are needed on the effects on driving performance and safety of external sources of distraction, individually and in combination. Although limited data exists on the impact of static and dynamic advertising billboards on driving performance, the data is inconclusive (at least for static billboards) and there is a scarcity of published research on the impact on driving performance and safety of other sources of distraction external to the vehicle. Even for advertising billboards, the focus has been on those erected as dedicated structures at specific locations. Nothing is known about those that are placed on the sides of buildings and on the backs of buses, taxis, and other moving objects.

There is some limited evidence, reviewed in Chapter 13, that both younger and older drivers are more vulnerable to the effects of distractions deriving from outside the vehicle. Given that distraction is a joint property of the demands of driving and competing tasks (see Chapter 4), UCD of the road environment to support the driving task has potential to reduce driver workload and, in turn, reduce driver vulnerability to distraction—not just for young and elderly drivers, but for all road users. Reducing the demands of the roadway, however, may not be sufficient. The roadway needs to be designed in such a way that the demands can be anticipated so that drivers can devote attention to the road when needed. Although some guidelines for UCD of roadways for the elderly have been developed,[25] no known guidelines exist in relation to young novice drivers.

Little specific guidance exists for the UCD of the traffic management system to minimize driver workload for the population at large, although some general guidance on human factors issues relevant to the design, operation, and evaluation of the road environment can be found in the literature.[26–30] Self-explaining roads are a promising development.[30,31] These are designed to increase the likelihood that a driver will automatically adopt appropriate speed and steering profiles without depending on road signs. "The geometric features of the road encourage the desired driver behavior, and do not rely on the driver's ability or willingness to read and obey road signs. A perfect self-explaining road would not require speed limit signs and curve advisory signs" (p. xii).[30] Burns[32] suggests that self-explaining roads, although used mainly as a tool for speed management, may also play a role in managing distraction. Road traffic environments that are more or less tolerant of driver distraction could be designed to make this tolerance self-evident, although drivers may compensate for greater levels of tolerance by engaging more in distracting activities. Alternatively, roadways could be designed to convey an illusion to drivers that they must be vigilant, making the road look intolerant to distraction, when in reality it is very tolerant to frequent inattention. Such an illusion might make drivers generally attentive to the road.

The degree to which the traffic engineer can prevent and mitigate the effects of specific distractions deriving from outside the vehicle, which are known to contribute to crashes and near-misses (see Chapter 15), varies according to the source. There are, however, some sources of distraction known to be contributing factors in crashes that would appear to be amenable to intervention by traffic engineers.

Animals. On or near stretches of road where it is known that roadway incursions by animals are problematic, warning signs (e.g., "Kangaroos next 5 km") and even barriers could be used to minimize the likelihood of an interaction between drivers and animals that leads to distraction. Such countermeasures have already been implemented in many countries, to prevent physical contact between vehicles and animals.

Architecture. It is possible to visually mask (e.g., with trees) prominent architectural structures likely to distract drivers or to reroute traffic away from them, although such countermeasures may not always be practical to implement. Scenic routes are, by definition, set up to distract drivers. Not only do they contain architecture, prominent landmarks, and other things attractive to drivers; but they are often located in rural environments, with narrow, winding, roads that increase workload and hence increase driver vulnerability to distraction. If such routes are to be promoted, it is incumbent upon relevant stakeholders to ensure, as a duty of care to drivers, that drivers are aware of the risk of distraction and that road design measures are put in place to minimize distraction and its effects on driving performance and safety. Basic measures, such as reducing the speed limit along scenic routes, would reduce driver workload, provide drivers with more time to recover from the effects of distraction, and reduce impact forces in the event of a distraction-related crash.

Advertising billboards. Some guidelines and checklists assess whether a proposed advertising sign or billboard is likely to pose an unacceptable risk to drivers. A checklist developed for this purpose by the roads and traffic authority in the Australian state of Victoria (VicRoads), is presented as an example in the appendix to this chapter, along with their operational requirements for installing variable message signs, used for displaying advertisements. Other examples can be found in a report on the findings of an Australian parliamentary inquiry into driver distraction.[10] Given the paucity of research data on the effects of advertising signage (with respect to both design and location), on driving performance and safety (and during and after driver exposure to the advertising material), such checklists and guidelines are generally based on accumulated wisdom and past traffic engineering practice. Clearly, there is a need for more prescriptive guidelines, checklists, and regulations controlling the location, size, and content of advertising on or near road reserves. Further research is needed to inform and support the development of these.[33]

Crash scenes. So-called rubber necking is a commonly observed behavior in the vicinity of crashes. It is possible to route traffic away from crash scenes or to visually mask the scene in some way, although these countermeasures may not always be practical or easy to implement. Reducing traffic speed in the vicinity of crash scenes would reduce driver workload, provide drivers with more time to recover from the effects of distraction, and reduce impact forces in the event of a crash.

Landmarks. It is possible to visually mask (e.g., with trees) prominent landmarks most likely to distract drivers or to route traffic away from them; but, again, such countermeasures may not always be practical to implement. Indeed, it may be counterproductive to do so if certain landmarks are critical for route finding. Masking them may lead drivers to invest more effort in trying to locate the landmarks, or in choosing new ones, which may lead to greater distraction.

Road signs. Most jurisdictions have in place specific guidelines and standards for the location, design, and use of traffic signs on roads. Traffic signs, even though they directly support the driving task, can be sources of distraction. If poorly designed or located, traffic signs may prolong the diversion of attention away from activities critical for safe driving. If absent in locations where they should be (e.g., in the case of missing street signs and numbers), they may encourage drivers to adopt compensatory search strategies which divert attention away from activities critical for safe driving; and if poorly colocated, they may induce visual search competition or clutter, impairing visual search and diverting attention away from activities critical for safe driving. It is important that existing guidelines and standards, which regulate the location and design of road signs on road reserves are revised to minimize the potential for distraction from signs—together, and in combination. While there is very little specific research available on traffic signs and distraction to support this activity, there is available general guidance in the literature on USD of traffic signs[34] (Chapter 13).

Road users. Road users can distract drivers in different ways: by behaving unpredictably, erratically, or irresponsibly as pedestrians, riders, or drivers; by attracting attention by virtue of their appearance, size, or other defining feature; by attracting attention by virtue of the vehicle they are riding or driving; and by other means. Given that distraction is a property of the joint demands of driving and competing tasks, the road engineer basically has two options for limiting driver distraction deriving from other road users. First, as discussed earlier, UCD of the road traffic system has the potential to reduce driver workload and, hence, vulnerability to distraction from other road users. Another option is to prevent or minimize, where possible, driver interaction with other road users, especially in traffic situations in which drivers are known to be most vulnerable to the effects of distraction. The extant data suggests that distraction is largely associated with rear-end crashes, same travel-way/same direction crashes, single-vehicle crashes, and crashes occurring at night (see Chapter 16). High friction road surfaces (for rear-end crashes), median barriers (for same travel-way/same direction crashes), sealed road shoulders (for single-vehicle crashes), and improved lighting and delineation of roads at night (for crashes occurring at night) are examples of traditional traffic engineering countermeasures that are likely to mitigate the effects of distraction deriving from interaction between road users.

Weather. There is little the traffic engineer can do to prevent or reduce the distracting effects of weather phenomena. Minimizing sun glare is perhaps one exception. Appropriate routing of roads to minimize driver exposure to sun glare is a countermeasure that is likely to be effective, given that sun glare has been shown to be a contributing factor in distraction-related crashes (see Chapter 16).

32.3.3 A Distraction-Tolerant Road System

Ultimately, as underscored by Tingvall in Chapter 33, the aim should be to create a distraction-tolerant road system, at all stages of the "injury safety chain" (see Figure 33.1, Chapter 33), such that, in the event of a distraction-related crash (or, indeed, any other crash), no road user is killed or seriously injured. In the context of Figure 33.1, the countermeasures already described can be regarded as ones that aim to prevent or reduce the potential for distraction and, hence, promote "normal driving." At later stages of the crash sequence, however, the traffic engineer, like the vehicle engineer, has other countermeasures at his or her disposal to mitigate the effects of distraction. Tactile edge linings and real-time over-speed feedback warning signs, for example, can be used to provide feedback to distracted drivers who "deviate from normal driving," who are unaware that they are speeding or veering off the road. In "critical situations," if a crash is still avoidable, high friction road surfaces and sealed road shoulders can support the driver in avoiding a crash. At the terminal stage of the crash sequence (i.e., "crash unavoidable"), wire rope barriers and other road treatments can be used to minimize crash impact. As noted earlier, further research is needed to identify common crash and near-crash configurations and environmental conditions in which distraction is a contributing factor to enable the development of more targeted countermeasures at each stage of the integrated safety chain.

As noted in the previous section, technological developments are making it possible to display to the driver, inside the vehicle, traffic-related and nontraffic-related information currently displayed on signs and other media outside the vehicle. Little is known about the impact on driving performance and safety of this in-vehicle echoing of external information. Does the driver continue, for example, to search for speed limit signs outside the vehicle even though there is no longer any need to? Clearly there is a need for further research in this area.

Finally, there is a need for vehicle manufacturers to enter into a direct diallog with traffic engineers—to ensure that there are no incompatibilities in the spatial and temporal design of traffic messages and signals impinging on the driver from within and outside the vehicle that could increase the potential for distraction. Future roadways may even include infrastructure that communicates with the car, such that it can tell when a driver is distracted. If information regarding driver state can be communicated to the roadside, then road signs and traffic control devices could adapt to draw drivers' attention back to the road. As for vehicle cockpit design, there is a critical need for institutional arrangements and process-oriented design standards, which ensure that, at a macro level, there is mutual cooperation and cross-talk between the automotive industry, road authorities, local councils, suppliers, the aftermarket industry, and other relevant stakeholders to ensure that, through coordinated design, driver interaction with competing tasks deriving from inside and outside the vehicle (driving and nondriving related) does not lead to a breakdown in multilevel control processes at one or more levels of control (tactical, strategic, and operational).

32.4 DISCUSSION AND CONCLUSIONS

This chapter has provided an overview and discussion of numerous countermeasures that relate to the vehicle itself, the technology brought into, or added to, the vehicle, and the road environment in which the vehicle is traveling. The first section dealt with what designers of systems and functions can do to prevent distraction in the design-phase before manufacturing and during driving (in real time). The second section dealt with what designers of the road environment can do to counteract distraction.

Several developments in vehicle and technology design are likely to be effective as countermeasures in preventing and mitigating the effects of distraction:

1. Further development and refinement of distraction assessment methods and of design, performance, and process guidelines and standards
2. Increased commitment to the UCD process
3. Increased integration of the human-machine interface, including nomadic devices

4. Continued development and validation of RDC:
   - Real-time distraction prevention (workload management) functions such as information scheduling, demand-based advisories, function lockout, and adaptation for information format
   - Real-time distraction mitigation functions such as visual distraction alert and cognitive distraction alert
5. Continued development and validation of DA collision warning functions such as FCW, lane departure warning, curve speed warning, and adaptive cruise control

In this chapter we have also provided specific guidance for preventing and mitigating the effects of some specific distractions deriving from outside the vehicle that are known to contribute to crashes and which appear to be amenable to intervention by traffic engineers. There are, however, further countermeasures that are needed in this area: methods are needed for identifying sources of distraction external to the vehicle that do, or have the potential to, distract; a taxonomy of objects, events and activities that could distract must be developed (the taxonomy in Chapter 15 is only a starting point); methods and metrics for measuring the impact on driving performance and safety of external sources of distraction are needed; and traffic engineers need guidance on how to design, from a user-centered perspective, the traffic management system to reduce driver workload and limit distraction.

Effective USD of vehicles and technology is fundamental to the prevention and mitigation of distraction. There are, however, some possible downsides of improved design that must be considered. Ergonomically designed interfaces can, for example, encourage drivers to use them more often, thus increasing their exposure to risk (the so-called "usability paradox"; see Chapter 4); and the more automated is the driving task, the more "satisficing" (see Chapter 2) it will be, freeing up driver attention that can be used by drivers to take on other roles within the vehicle that may distract them. Effective USD requires continuous evaluation and feedback to identify and rectify such unintended side effects.

Vehicle cockpits are evolving rapidly, and the role of the driver, like that of the pilot, will change over time—from being the active controller of the vehicle to being more of a systems monitor.[27] Already there exist intelligent transport systems, which are capable of automating, partly or fully, all of the key components of driving: finding one's way; following the road; monitoring speed; avoiding collisions; following traffic rules; and controlling the vehicle.[35] These technologies will create new styles and modes of human-machine interaction. At the same time, they will make it possible to display inside the vehicle information currently displayed outside it; and in doing so, blur the distinction between what the driver sees and responds to inside and outside the vehicle. The implications of these developments from a distraction perspective are many and varied. Ultimately, they will provide an impetus for closer cooperation and shared responsibility between vehicle and road designers for ensuring that the design of the driving task to limit distraction is an integrated activity. Tingvall's integrated safety chain provides a conceptual roadmap for how that integration might proceed. Designing vehicles and technologies to limit the effects of distraction will remain a challenging area for countermeasure development.

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APPENDIX 1: VICROADS' TEN-POINT ROAD SAFETY CHECKLIST TO ASSIST IN THE LOCATION OF NEW ADVERTISING SIGNS

An advertisement, or any structure, device, or hoarding for the exhibition of an advertisement, is considered to be a road safety hazard if it

1. Obstructs a driver's line of sight at an intersection, curve or point of egress from an adjacent property; or
2. Obstructs a driver's view of a traffic control device, or is likely to create a confusing or dominating background which might reduce the clarity or effectiveness of a traffic control device; or
3. Could dazzle or distract drivers because of its size, design, or coloring, or it being illuminated, reflective, animated or flashing; or
4. Is at a location where particular concentration is required (e.g., high pedestrian volume intersection); or
5. Is likely to be mistaken for a traffic control device, for example, because it contains red, green, or yellow lighting, or has red circles, octagons, crosses or triangles, or arrows; or
6. Requires close study from a moving or stationary vehicle in a location where the vehicle would be unprotected from passing traffic; or
7. Invites drivers to turn where there is fast moving traffic or the sign is so close to the turning point that there is no time to signal and turn safely; or
8. Is within 100 meters of a rural railway crossing; or
9. Has insufficient clearance from vehicles on the carriageway; or
10. Could mislead drivers or be mistaken as an instruction to drivers

VicRoads operational requirements for the installation of variable advertising message signs are that the sign

- Not display animated or moving images, or flashing or intermittent lights
- Not be brighter than 0.25 candella/m^2
- Remain unchanged for a minimum of 30 s
- Not be visible from a freeway
- Satisfy the ten point checklist

Source: From Parliament of Victoria, *Inquiry into Driver Distraction—Report of the Road Safety Committee on the Inquiry into Driver Distraction*, Report No. Parliamentary Paper No. 209 Session 2003–2006, Parliament of Victoria, Melbourne, Australia, 2006. With permission.

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