4 What Drives Distraction? Distraction as a Breakdown of Multilevel Control

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CONTENTS

Chapter 3 offered a definition of distraction and pointed toward some of the challenges in identifying distraction as a cause of motor vehicle crashes. As with most safety-related mishaps, distraction-related incidents and crashes are complex events with multiple causes. Definitions of distraction, related models of performance, and crash analyses can pursue an arbitrarily long causal sequence in explaining the situation.[1] Chapter 3 also characterized distraction as a failure to maintain an appropriate distribution of attention relative to the demands of activities critical for safe driving. This chapter considers the processes that underlie distraction in an effort to provide a useful causal explanation of distraction-related crashes and to describe why drivers fail to maintain an appropriate distribution of attention. This explanation of how attention is diverted away from activities critical for safe driving describes distraction as a breakdown in a multilevel control process, with a different timescale characterizing each level.

4.1 DISTRACTION AS A BREAKDOWN OF MULTILEVEL CONTROL

A common perspective regarding distraction is that drivers passively respond to the demands of driving and competing activities and that doing two things at once compromises performance of one or both of the activities (i.e., dual-task interference). This perspective captures important cognitive constraints regarding the degree of interference between concurrent tasks, but it does not account for how drivers distribute their attention between such tasks, distribute tasks over time, or choose to engage in tasks. Considering drivers as active controllers provides a useful perspective on distraction.

Driving, as a control process, has been described in terms of three levels: operational, tactical, and strategic.[2–5] The operational level concerns the lateral and longitudinal control of the vehicle and occurs at a timescale of milliseconds to seconds. Tactical control concerns the choice of lanes and speeds and occurs at a timescale of seconds to minutes. Strategic control concerns decisions regarding routes and travel patterns and occurs at a timescale of minutes to weeks. Each of these three levels of control applies to activities critical to safe driving and to competing activities.[6]

These three levels can also be used to describe the control of attention to competing activities. At the operational level, drivers control resource investment; at the tactical level, they control task timing; and at the strategic level, they control exposure to potentially demanding situations. Distraction-related mishaps result from a breakdown of control at any one level, and from the accumulation of control problems that compound as they propagate across levels. A consequence of this perspective is that distraction-related crashes result not only from dual-task interference but from drivers' inability to control potentially distracting interactions.[7]

The following definition of distraction guides this discussion: *Driver distraction is a diversion of attention away from activities critical for safe driving toward a competing activity.* Specifically, "competing activity" refers to interactions with in-vehicle technology, passengers, food, thoughts, and noncritical driving activities. These noncritical driving activities can involve in-vehicle technology, as with distraction associated with a navigation system, or a conversation with a passenger regarding the choice of speed. For the purposes of this chapter, the discussion of distraction and distribution of attention is grounded in a concrete scenario involving in-vehicle technology, but the general process applies to other competing activities.

Consider the following scenario. Anticipating a long drive, Sam decides to insert an MP3 player into his car's audio system and select a playlist as he begins to drive out of the city. After inserting the player, he glances down to view the catalog of playlists and begins to scroll through the list. Meanwhile, a car abruptly merges in front of Sam's car to exit the freeway, suddenly shrinking the gap between his car and the car ahead. Sam begins to slow to widen the gap, then looks back to the playlist to continue scrolling down the list. Overshooting the desired playlist, Sam continues to look at the MP3 player as the car ahead brakes suddenly to accommodate other vehicles entering the highway. Sam looks up to find himself crashing into the vehicle ahead.

Figure 4.1 shows some causes of distraction-related mishaps in terms of a multilevel control framework and highlights several contributors to the distraction-related

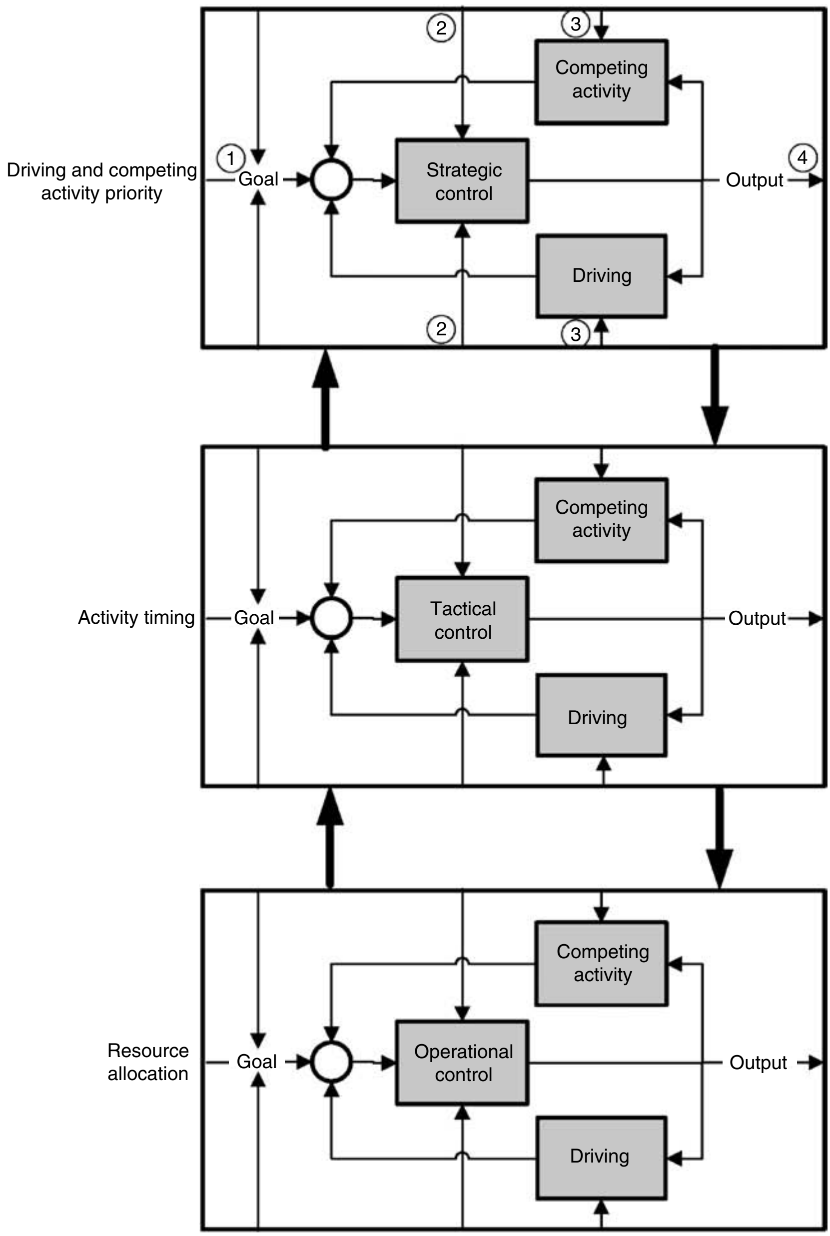

FIGURE 4.1 Distraction as a breakdown in multilevel control in activities critical for safe driving and competing activities. Numerals indicate interactions between levels: (1) adaptive control, in which the output of one level affects the goal of another level; (2) feedforward control, in which the output of one level affects expectations and appropriate response schema at another level; (3) cascade effects, in which the output of one level influences the control dynamics of another level; (4) the output supports feedback control for a given level and adaptive control for other levels. The numerals at the strategic level apply to the tactical and operational levels. The heavy lines between levels encapsulate these interactions.

crash in this scenario. One contributing factor is the breakdown of control at the operational level, where the visual and cognitive demands of selecting the playlist interfered with Sam's attention to the road. Another contributor was the cascade effect set in motion when Sam overshot the playlist at the operational level, which led to a longer-than-expected task duration. This overshoot compelled continued interaction and undermined control at the tactical level by inhibiting Sam from adapting his speed and headway to the changing traffic conditions. At the strategic level, the decision to interact with the playlist in a relatively demanding roadway environment also contributed to the crash. Each of these causes represents equally valid explanations of the crash, and each demands a different set of theoretical considerations. Importantly, each also points to different design and policy strategies to prevent distraction-related crashes.

Three types of control are active in each level in Figure 4.1. Breakdowns in any one of these three types contribute to driver distraction. Each type of control has important limits, as shown by the columns on the right of Table 4.1. Feedback control uses the difference between a goal state and the current state to guide behavior. To be successful, feedback control depends on timely, precise information regarding the difference between the current state of affairs and the goal state. In driving, such feedback is often delayed and noisy. Furthermore, for feedback control to be effective, the time constant of drivers' response to the error signal must be fast relative to the system needing to be controlled so that responses can be made before the system diverges by an unacceptable degree from the desired state.

The second type of control, feedforward control, uses the anticipated future state of the system to guide behavior. Feedforward control is critical for safe

TABLE 4.1
Challenges for Each Type of Control for Each Time Horizon

Control Type	Operational: Control Attention to Tasks (milliseconds to seconds)	Tactical: Control Task Timing (seconds to minutes)	Strategic: Control Exposure to Tasks (minutes to days)
Feedback—reactive control based on past outcomes	Time constant of driver response is slower than that of driving demands	Feedback is too delayed or noisy to guide behavior	Poor choices might not affect performance
Feedforward—proactive control based on anticipated situation	Task demands are unpredictable or unknown	Task timing is unpredictable or unknown	Potential demands are unpredictable or unknown
Adaptive—metacontrol based on adjusting expectations, goal state, and task characteristics	Tasks that lack a graded effort/accuracy trade-off	Biological and social imperatives not calibrated to task importance	Poor calibration regarding interaction between driving and IVIS goals

driving, enabling experienced drivers to anticipate, detect, and respond to hazards in a proactive manner.[8,9] Expectations associated with feedforward control have a powerful effect on drivers' reaction time to events, reducing reaction time by 750 ms compared with unexpected events.[10] Feedforward control can compensate for the limits of feedback control, but it suffers from other problems. Feedforward control requires an accurate internal model of the future state of the system and an absence of any major unanticipated disturbances. The uncertainty associated with poor mental models of driving situations and competing activities, coupled with the inherent variability of driving demands, limits the effectiveness of feedforward control.

The third type of control, adaptive control, reduces the difference between the goal state and the current state by redefining the goal state.[11] As such, adaptive control represents a type of metacontrol that is critical for accommodating change in the operating environment. While the traditional focus has been on feedback and feedforward control, adaptive control represents an important option for drivers. With adaptive control, drivers adjust their response to task demands according to their performance criteria and capacity. For example, drivers adjust their tolerance for errors in lateral control and tolerate the occasional lane deviation as they focus on an in-vehicle interaction. The success of adaptive control depends on task flexibility over time, and task performance depends on the effort invested. If a task cannot be delayed, or if task performance declines abruptly with diminished effort, then adaptive control may be ineffective. Another challenge for adaptive control is potentially poor calibration regarding the expected driving performance achievement and engagement in a competing activity, such as using an in-vehicle information system (IVIS). Drivers may not realize the consequences of adopting less ambitious goals for performing the driving task. Table 4.1 summarizes some of the reasons why each control type might fail at each time horizon.

In addition to the control challenges outlined in Table 4.1, control can suffer from interactions across the three time horizons. Cascade effects occur when the outcome at one level of control affects control at another level or when control breakdowns at one time horizon undermine control at the others. Such effects are often nonlinear in that small perturbations at one level can lead to catastrophic effects at another. Poor choices at the strategic level can propagate downward and make control at the tactical and operational levels more difficult. In the previous example, the choice to start using the MP3 player in an urban environment imposed greater demands on the tactical control of task timing. Likewise, errors at the operational level can propagate upward to tactical control, as when overshooting in selecting a playlist compelled an unexpectedly long interaction. Control at the longer time horizons constrains that of the shorter time horizons by specifying the goals and tasks at shorter time horizons. Control at the shorter time horizons creates disturbances that undermine control at the longer time horizons. Distraction-related incidents occur when the demands of driving and competing activities combine to undermine control at any one time horizon or initiate cascade effects across the horizons.

Beyond cascade effects, saturation effects represent another important factor that can undermine control.[12] Saturation effects occur when control limits and safety margins are reduced, making effective control vulnerable to small perturbations. At the operational level saturation can be defined in terms of spare capacity, and at the tactical level it reflects the utilization rate, which is the percentage of time the driver is busy responding to the IVIS or driving demands. At the strategic level, saturation reflects the overlap of the demand distributions discussed in Chapter 3—the probability that a driving situation will occur in which the demands will exceed the attention devoted to the roadway. As saturation increases, the potential for breakdown at a given level increases. Such a breakdown might then lead to cascade effects across levels. If the other levels are also highly saturated, they may have little capacity to accommodate these perturbations, prompting further cascade effects that undermine driving safety.

In summary, contrary to many views of distraction, drivers are not the passive recipients of IVIS and other competing demands, as well as driving demands. Instead, it is argued here that drivers actively control the mechanisms that give rise to the distraction they experience. This control occurs at three interacting time horizons (operational, tactical, and strategic) and is achieved by three types of control (feedback, feedforward, and adaptive). The limits of control at each time horizon, and the cascade effects across levels, cause distraction-related mishaps. Saturation effects exacerbate cascade effects because a highly saturated controller is vulnerable, so that small perturbations can cause catastrophic failures. Labeling distraction as simply a problem of information overload neglects the failures that lead to temporally constrained driving and competing demands that overwhelm the driver's capacity. Defining distraction as dual-task interference neglects the failures that occur at the tactical and strategic levels and how these failures interact.

The following sections describe control at the three time horizons. Each of these descriptions provides a different vocabulary for discussing distraction, different tools for assessing it, and different approaches to reducing it. The discussion begins at the operational level, with a description of resource competition between IVIS and driving demands. Following that, the tactical level is considered, with a description of task timing of IVIS and driving demands. The section finishes at the strategic level, with a description of exposure to IVIS and driving demands.

4.2 OPERATIONAL CONTROL: DISTRACTION AS RESOURCE COMPETITION

In the scenario involving selecting an MP3 playlist, distraction arises from resource competition associated with the task of playlist selection and the demands of event detection and vehicle control. Distraction is most likely to occur when the resource demands of the driving task overlap with those of the competing task.[13]

Multiple resource theory provides a useful theoretical perspective for describing driving and IVIS task demands.[14] This approach describes attentional resources in terms of modes, codes, and stages (see Chapter 5 of this book for more detail). When both driving and IVIS tasks demand the same type of resources, performance on one or both tasks suffers. To the extent that the tasks involve different resources, performance will be relatively unaffected. The task of dialing a cell phone with a voice recognition system while negotiating a curve, compared with dialing using a standard keypad, illustrates the benefit. Voice dialing demands resources associated with the oral/auditory mode of interaction, whereas the standard keypad involves resources associated with visual/manual mode of interaction. The stage (perception, cognition, and response selection) seems to be a particularly important consideration. Both basic and applied research has shown a processing bottleneck with response selection.[15,16] Two concurrent tasks involving response selection causes performance to suffer, even when they require different modes and codes of processing.[17]

Not surprisingly, drivers' ability to keep the car in the lane and respond to braking lead vehicles diminishes when they look away from the road.[18,19] Substantial research shows that even when two tasks engage separate resources, as when driving while holding a conversation with a hands-free cell phone, they increase the reaction time to events such as a braking lead vehicle by approximately 300 ms[20–22] and even degrade perceptual judgments.[23] Performance suffers because both tasks require a certain degree of central processing resources, but these effects are less than for tasks that compete for visual/manual resources.[24–26] The recent Crash Avoidance Metrics Partnership (CAMP) Driver Workload metrics project, for example, revealed that although auditory-vocal tasks degraded driving performance, their effects were not as pronounced as those of the visual-manual tasks.[24]

Multiple resource theory can be operationalized using a demand vector associated with driving and IVIS tasks. The degree to which resource requirements overlap defines the decrement of performance in the two tasks (see Chapters 5 and 15 for details). Drivers use adaptive control to modulate this performance decrement by choosing an allocation policy that distributes resources between the competing tasks. The performance of one task could be preserved by preferentially allocating resources to that task.

Several factors undermine drivers' control of distraction at the operational level. Feedback control is problematic because drivers receive misleading feedback regarding the success of their allocation policy. The capacity of ambient (or peripheral) vision to support lane position makes it possible for drivers to look away from the road and receive positive feedback regarding their ability to drive safely. Because hard-braking events are rare, drivers fail to receive regular feedback regarding their impaired performance on event detection, which requires focal vision. Feedforward control is also compromised by a limited ability to anticipate the confluence of IVIS and driving demands. The effectiveness of adaptive control depends on the degree to which performance of the IVIS task declines as resources are allocated toward driving tasks. If IVIS performance declines abruptly with a small decline in resource allocation, then drivers may be unable to adopt an allocation policy in which they modulate their IVIS performance goals to accommodate driving demands. When it is impossible for the driver to change the demand associated with the performance of a task, the task is said to be *unadjustable* (see Chapter 15 for more detail).

Considering distraction as resource competition at the level of operational control leads to three general design considerations. Most obviously, minimizing the overall demands associated with IVIS interactions or the demands of driving will tend to diminish distraction. Advanced driver support systems, such as collision warning systems and intelligent speed adaptation, can reduce driving demands and diminish distraction. More subtly, creating IVIS interactions that avoid direct competition for common resources associated with driving tasks will also diminish distraction. This suggests that IVIS designs that rely on verbal/auditory interactions, such as voice-based control, rather than visual/manual interactions will reduce distraction. However, this approach may not always be effective because reducing resource competition does not eliminate dual-task decrements, and voice control of some tasks may involve more effort than their visual/manual counterparts. For example, a continuous control task, such as raising a window, may be more difficult and time consuming with voice control. A third consideration of this approach has not been widely discussed: that is, to support a graded rather than "brittle" resource allocation and performance trade-off for IVIS interactions.[27] For example, analog displays make it possible for drivers to extract approximate information with little effort and more precise information with greater effort. In contrast, digital displays provide only highly precise information, but only with focused effort. Analog displays tend to support adaptive control, so that drivers can easily modulate their attention to the device, extracting approximate information with a single brief glance and more precise information with a longer glance. This helps drivers succeed with their interactions even if they devote most of their attention to the road.

4.3 TACTICAL CONTROL: DISTRACTION AS FAILURE OF TASK TIMING

In the scenario of searching for an MP3 playlist, distraction depends as much on the timing of the interaction as on the resource demand of the interaction. It is the timing of the scrolling activity relative to the lead vehicle braking that is particularly problematic. In this example, the IVIS interaction associated with overshooting the playlist provides a particularly compelling incentive for the driver to extend the interaction, increasing the delay in responding to roadway events. Distraction is likely when a breakdown of tactical control leads to a situation where multiple tasks must be performed at the same time.

Queuing theory provides a useful theoretical perspective to consider distraction at the tactical level. According to a queuing theory representation of driving, drivers act as a server, processing tasks sequentially and causing tasks to wait if the server is occupied processing another task. Tasks awaiting the server accumulate in a queue. Such a representation has a long history in human performance modeling and offers a perspective for addressing distraction that focuses on task timing rather than competition for multiple resources.[28–31]

In contrast to the multiple resource perspective of distraction, a queuing theory perspective describes the demands on the driver in terms of the policy for queuing tasks, task timing, and how easily the tasks can be interrupted. As such, it provides a framework for considering how drivers plan and manage their interactions with critical driving tasks and competing activities.

A common measure in queuing theory is the utilization rate of the server, which corresponds to the time spent in processing tasks divided by the total time available to process tasks. In terms of distraction, utilization rate can be considered as the time spent responding to critical driving tasks and competing activities. An important insight from queuing theory concerning distraction is that any nonzero utilization rate will delay some percentage of incoming tasks. This means that even an IVIS that requires drivers to respond to relatively infrequent, short tasks will delay response to driving demands. Specifically, the expected delay increases with the utilization rate (ρ) and decreases with the rate at which tasks are processed (μ). Assuming new tasks arrive according to a Poisson distribution, Equation 4.1 predicts the delay.

$$\text{Delay} = \frac{\rho}{\mu(1-\rho)} \tag{4.1}$$

Although Equation 4.1 and queuing theory provide an elegant description of how a driver might process driving and competing tasks, it fails to consider the active role drivers play in determining the timing of activities. Drivers are not passive servers who respond to tasks as they appear. Drivers can reduce delays if task demands can be predicted and if tasks can be interrupted. Characteristics of the driving situation and the IVIS interact to determine how successfully drivers time tasks to avoid the delays predicted by Equation 4.1. Three characteristics of competing tasks can undermine control at the tactical level (see also Chapters 15 and 19):

- A task is said to be *unignorable* when it is so compelling or demanding that the driver cannot delay engagement.
- A task is *unpredictable* when its onset is unexpected or its duration and demand cannot be foreseen by the driver.
- A task is *uninterruptible* when it cannot be easily disengaged or cannot be resumed after interruption.

Some tasks are not easily ignored. The characteristics that make it difficult for drivers to ignore competing activities include a combination of internal and external forces that determine when the driver initiates or delays a task. Biological and social imperatives affect the degree to which driving and competing activities demand attention to initiate or continue an interaction. In the case of initiating a cell phone conversation, these factors might range from a general need to call or a need to call at a specific time, to an external reminder to call (e.g., a PDA reminder) or a cell phone ring. Preliminary research suggests that drivers tend to neglect future driving demands and focus on the current demands of competing activities. As an example, drivers tend to answer ringing cell phones independent of the upcoming driving demands.[32] The social imperatives that induce drivers to respond to these demands are exacerbated by a tendency for drivers, particularly young drivers, to fail to anticipate hazardous situations.[33] The tendency to neglect upcoming driving demands and respond to social and biological imperatives regarding competing interactions may play an important role in driver distraction. As mentioned in Chapter 2 of this book, in responding to some categories of distraction (e.g., children), drivers assume different social roles (e.g., parent), which make it difficult for them to ignore the competing activity.

Drivers can also avoid delays in responding to the road by interrupting competing activities and returning their attention to the activities critical for safe driving. Interruptions that prevent goal rehearsal or that occur in the middle of the task result in longer resumption times.[34] These results are consistent with the goal activation model[35] and suggest that increasing the duration of a competing task may make drivers less able to interrupt that task and return to driving tasks. The goal activation model also predicts that the distraction posed by a competing activity may persist even after it has ended, because drivers continue to think about certain aspects of the competing activity.

Going beyond the ability to manage task timing through their decision to initiate or interrupt tasks, drivers can also actively negotiate the timing and nature of the tasks. Drivers actively negotiate with other drivers on the road to widen their safety margins. Likewise, a driver might adjust the pace of a conversation or delay an interaction based on road demands. In these situations, drivers actively adapt demands of driving and competing activities to arrive at an acceptable combination.[36]

Human–human communication provides a useful metaphor for how drivers adapt the demands of the competing tasks.[37] Human communication is a collaborative process supported by back-channel communication.[38–40] Back-channel responses[38,41] refer to the hearer's use of peripheral utterances, such as "uh-huh" or "yeah," to provide feedback that the utterance is being understood and to coordinate turn taking.[42] Back-channel utterances represent a large proportion of conversations—19% by one estimate.[43] Although many speech theorists focus on back-channel communication as speech acts (e.g., "uh-huh" or "hm"), back-channel communication can also take the form of pauses, intonation, gestures, and facial expressions. Back-channel responses support grounding. Grounding is the development of a shared context that supports joint understanding and the timing of interactions. Without back-channel communication and the grounding that it supports, the goals of communication are unlikely to be met and direct communication will likely fail.

As with conversation, back-channel cues support drivers' understanding of the driving context, help coordinate the timing of interactions, and guide the adaptation of demands. Back-channel communication is already a critical component in driving. For example, drivers respond to the slippery feel of tires on an icy road to moderate their driving behavior—not just relying on the information provided by weather reports or even on focused observation of the roadway. For those who drive manual cars, it is not necessarily the position of the tachometer that lets the driver know when to shift. The sound and vibration of the motor are also essential, even though few people focus their attention on these cues. Drivers would lose a critical component of how they sense and perceive the driving environment if they did not have such back-channel cues. Although the ideas of back-channel communication were initially developed to describe communication between people, the concepts seem relevant to any situation that demands dynamic coordination between multiple entities.[44] For example, an IVIS might use the pauses between voice commands of the driver to identify situations where the driver might be engaged in a demanding driving situation.

Feedforward control is difficult because driving and some competing activities, such as IVIS demands, are unpredictable. Another challenge to effective feedforward control is that breakdowns in control at the operational level can lead to unexpected demands and poor management of the IVIS and driving demands at the tactical level. Speech recognition systems, particularly in the context of a noisy car, will likely induce errors. Such errors can lead to an unanticipated and increasing spiral of demand. Inexperience also undermines feedforward control in a way that can be particularly devastating.[45] Interaction with IVIS will likely exacerbate problems of feedforward control and the difficulty drivers have in anticipating and responding to upcoming demands. Concerning adaptive control, face-to-face conversations allow participants to accommodate some of the demands on the speaker by adjusting their engagement on the basis of back-channel cues that support common ground and efficient turn taking—passengers will suspend a conversation when drivers encounter high-demand situations. This also occurs at a much more limited level for drivers talking on a cell phone. Interactions with IVIS devices currently lack this ability to establish common ground, making adaptive control somewhat difficult, particularly if IVIS interactions are not ignorable or interruptible.

Considering the driver in terms of queuing theory leads to several important design considerations. Queuing theory suggests that minimizing distraction should focus on reducing the likelihood that tasks will simultaneously demand the driver's attention. This implies that, first, to the extent possible, IVIS demands placed on the driver should be timed to avoid conflict with upcoming traffic demands—for example, notifications of low-priority information concerning an upcoming restaurant could be delayed if the driver is approaching an intersection.[46] Workload managers work on this principle by prioritizing, delaying, or canceling IVIS interactions and system information if the concurrent demands of driving and the IVIS are too high (see Chapters 26 and 28 of this book). Second, IVIS devices should avoid interactions that are hard to ignore, interrupt, or resume. Finally, future systems could benefit by considering the benefits of back-channel communication to make the behavior of the IVIS more predictable to the driver and facilitate adaptive control. These design considerations and those associated with multiple resource theory at the level of operational control are not mutually exclusive. Multiple resource theory can define the degree to which a performance declines if tasks are performed simultaneously and queuing theory defines how likely tasks are to be performed simultaneously.

4.4 STRATEGIC CONTROL: DISTRACTION AS INAPPROPRIATE PRIORITY CALIBRATION

In the scenario of Sam searching for an MP3 playlist, distraction depends as much on the decision to use the device in a challenging driving environment as the specific timing of the interaction or the resource demand of the interaction. The decision to use a device in a challenging driving environment can depend on many factors:

- Drivers' awareness of the demands associated with using the device in that environment
- Drivers' appreciation for own ability to handle the demands associated with using the device in that situation
- Propensity of the individual to take risks
- Existence or absence of laws that permit its use in this context
- Productivity and other pressures
- Driving culture and societal norms

Had Sam delayed the interaction, initiating the search in a less demanding driving situation, the crash would not have occurred. Distraction is likely when drivers engage in demanding competing activities in situations in which the critical driving task is also likely to be demanding. Queuing theory describes the delays associated with a particular utilization rate and how these delays can be mitigated by supporting the driver in managing task timing. Control at the strategic level concerns how drivers select a target utilization rate and determines an acceptable demand profile of driving and competing activities.

The concepts underlying diffusion may provide a useful theoretical perspective to consider distraction at the strategic level. According to this perspective, drivers' choice of behaviors follows a random walk process that is influenced by productivity pressures and safety concerns. Drivers do not seek risky situations and rarely consciously balance risk and productivity. Instead drivers engage in different behaviors in a somewhat random fashion, with productivity pressures pushing this random process toward behaviors that involve increasing attention to tasks that are not critical to safe driving. In this situation, productivity pressures can push behavior toward and over safety boundaries. Such a representation has been developed to describe how safety practices erode in other complex sociotechnical systems.[47]

In controlling the distribution of attention at the strategic level, a fundamental challenge is that in driving, the safety boundaries are not very salient and the production pressures will gradually influence driver behavior to migrate into increasingly unsafe situations. The drift toward safety boundaries reflects a breakdown in feedback control. One reason for such behavior is that driving provides poor feedback, particularly concerning the inappropriate engagement in competing tasks. Because driving is often forgiving, drivers can neglect the driving task to a dangerous degree and suffer no immediate consequences. Even when drivers receive feedback in the form of a crash, it seldom results in a lasting change in behavior.[48] This poor feedback also causes drivers to overestimate their driving ability. In one study, half the drivers judged themselves to be among the safest 20%, and 88% believed themselves to be safer than the median driver.[49] Providing better feedback might lead drivers to adopt safer behavior.[50–52] Similarly, a well-designed device that reduces distraction at the operational level may actually undermine driving safety if it encourages drivers to use the device more frequently while driving. This *usability paradox* occurs when increased ease of use reduces the risk of any particular interaction, but increases overall risk by encouraging drivers to use the device more frequently. This tendency for drivers to adapt to improvements and undermine the expected safety benefit is a common phenomenon. For example, when roadway improvements are made (lanes widened, shoulders added, lighting improved), speeds often increase and undermine the potential safety benefit.[53]

Feedforward control at the strategic level suffers from the inherent variability of the driving environment. Even relatively demanding situations, such as driving on congested freeways, do not always pose a critical demand for the driver. Likewise, even situations that are typically not demanding can occasionally require drivers' full attention. The inherent variability of driving demands and the challenge of estimating the typical demand of a driving situation undermine the effectiveness of feedforward control, particularly for novice drivers who have not developed an appreciation for the demands associated with various driving environments and the demands of various competing tasks. Not only have novice drivers not developed an appreciation of the demands associated with driving and of competing activities, but they have not developed an appreciation of their own capacity to meet those demands.[54]

At the strategic level, adaptive control depends to some extent on a societal judgment of what constitutes acceptable risk and safe driving. The strategic decision to carry a cell phone into a car and generally intend to answer incoming calls depends on the driving culture and associated social norms concerning acceptable driving behavior. Such social norms may be the most powerful factors governing distraction, but may be the most difficult to quantify and shape. Subtle design modifications that reduce distraction at the operational level of behavior may have a much smaller effect on driving safety compared with changes in societal norms that influence the strategic level and make the use of a device while driving taboo. Societal response to traffic deaths illustrates this tendency. Recent high-profile catastrophes (e.g., the Oklahoma City bombing, shootings at Columbine High School, terrorist attacks on September 11, 2001, and Hurricane Katrina) caused less than 5,000 fatalities. In contrast, 42,636 lives were lost in 2004 alone as a result of vehicle crashes in the United States. Compared with motor vehicle fatalities, fatalities associated with disasters have had a much greater influence on American public policy and individuals' behavior. The American public seems to consider the loss of an average of 116 lives each day in crashes as an acceptable risk of transportation. Calibrating the public to the human toll of attending to competing tasks could lead to cultural changes that promote substantially safer driving.[55]

4.5 CONCLUSIONS

Defining distraction as a diversion of attention away from activities critical for safe driving toward a competing activity implies a breakdown in the control of attention. Considering distraction as a problem of control at three different timescales describes the causes of distraction differently than many other accounts of distraction. These differences lead to a range of design considerations that may help reduce distraction-related crashes. At the operational level, cognitive and motor constraints that govern driver performance tend to influence distraction. At the tactical level, attitudes and intentions that govern driver behavior tend to influence distraction. At the strategic level, societal norms and culture influence the roles that drivers adopt and these roles, in turn, govern the likelihood of distraction. These distinctions point toward fundamentally different and complementary contributions to distractions, which each require different design and policy strategies to mitigate. At each of these levels, a control-theoretic approach that considers the limits of feedback, feedforward, and adaptive control leads to novel design considerations. These considerations focus on improving feedback regarding the effects of neglecting the driving task, supporting more accurate expectations regarding the demands that compete for drivers' attention, and promoting more appropriate safety boundaries and performance criteria that guide control.

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