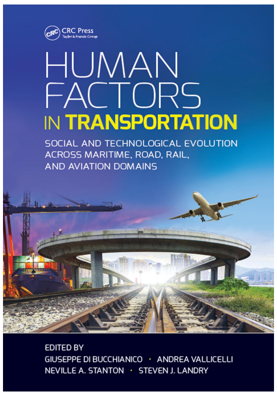

Human Factors in Transportation
Social and Technological Evolution Across Maritime, Road, Rail, and Aviation Domains

Giuseppe Di Bucchianico, Andrea Vallicelli, Neville A. Stanton, Steven J. Landry

Analyzing Eco-Driving with the Decision Ladder: The First Step to Fuel-Efficient Driving for All

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Section III

Road Domain

Introduction

The rail and road domain is by far the largest subsector of transportation, employing about nine out of 10 transport workers and also representing a significant percentage of the GNP (gross national product) of the entire world economy. Given its size, it is, however, also responsible for the most important problems connected with the entire transport sector: from environmental problems caused by harmful emissions to strictly ergonomic issues, and to the psychosocial stress induced on whole populations, groups, or individuals users of transport systems.

The 10 chapters within Sections II and III of the book are divided into two groups, respectively, related to the road transportation (Chapters 10 through 14) and rail transportation (Chapters 15 through 19). You will notice how, starting from fields of application that are often very specific, but which have references to wider issues, it is possible to face the broader issue of the pervasiveness of new technologies and its impact on the evolution of social and cultural aspects of contemporary society.

In particular, the research and experiences described in these chapters relate largely to the behavior of drivers, cyclists, pedestrians, users, and to the relationships established between them, and with respect to the means of transport, infrastructure design and driving assistance systems that are increasingly advanced and complex.

Neville Stanton

15

Analyzing Eco-Driving with the Decision Ladder: The First Step to Fuel-Efficient Driving for All

Rich C. McIlroy and Neville A. Stanton

CONTENTS

15.1 Introduction

Many modern vehicles come with a means for providing feedback and advice to the driver about fuel efficiency, be they traditionally powered (i.e., by internal combustion engine [ICE]) or powered by more novel means (e.g., hybrid, electric, hydrogen). A fairly well-established finding is that the way in which a car is driven significantly affects the amount of fuel used—a difference that varies from around 15% in ICE vehicles (Evans, 1979; Waters and Laker, 1980) to as much as 30% in electric vehicles (Bingham et al., 2012). To support such fuel-efficient driving styles would clearly be a worthwhile activity; however, there exists great variance in the ways different vehicle manufacturers go about this, in terms of the actual type of information presented, and in the way it is presented.

This chapter therefore presents the first step toward the design of a fuel-efficiency support system that does not provide feedback about current efficiency levels, but aims to support the very behaviors that characterize fuel-efficient driving. To achieve this goal it is first necessary to understand those behaviors, hence the focus of the current research is the analysis of the decision-making processes made when driving in an economical fashion.

Following a review of both the academic literature and of publicly available web-based eco-driving resources, four specific driving activities that can each have a significant effect on fuel efficiency were identified. These activities were modeled using Rasmussen's decision ladders (Rasmussen, 1974), an analysis technique that models activities in decision-making terms. Then followed a number of interviews with experienced "eco-drivers" (i.e., subject matter experts) with the resulting information serving to amend, supplement, and validate these decision ladder models. One of the completed models is then discussed, largely in terms of the skills, rules, and knowledge (SRK; Rasmussen, 1983) theoretical framework, and in terms of its contribution to the design of a new, in-vehicle information system. A more detailed report of this research has also been published as a journal article (McIlroy and Stanton, 2015); this includes a discussion of all of the completed decision-ladder models.

15.2 SRK and Decision Ladders

15.2.1 The SRK Taxonomy

The SRK taxonomy theoretical framework (Figure 15.1) describes three different levels of cognitive control with which actors interact with their environment (Rasmussen, 1983). Skill-based behavior (SBB) involves automatic, direct interaction with the environment; rule-based behavior (RBB) involves associating familiar perceptual cues in the environment with stored rules for action and intent; knowledge-based behavior (KBB) involves

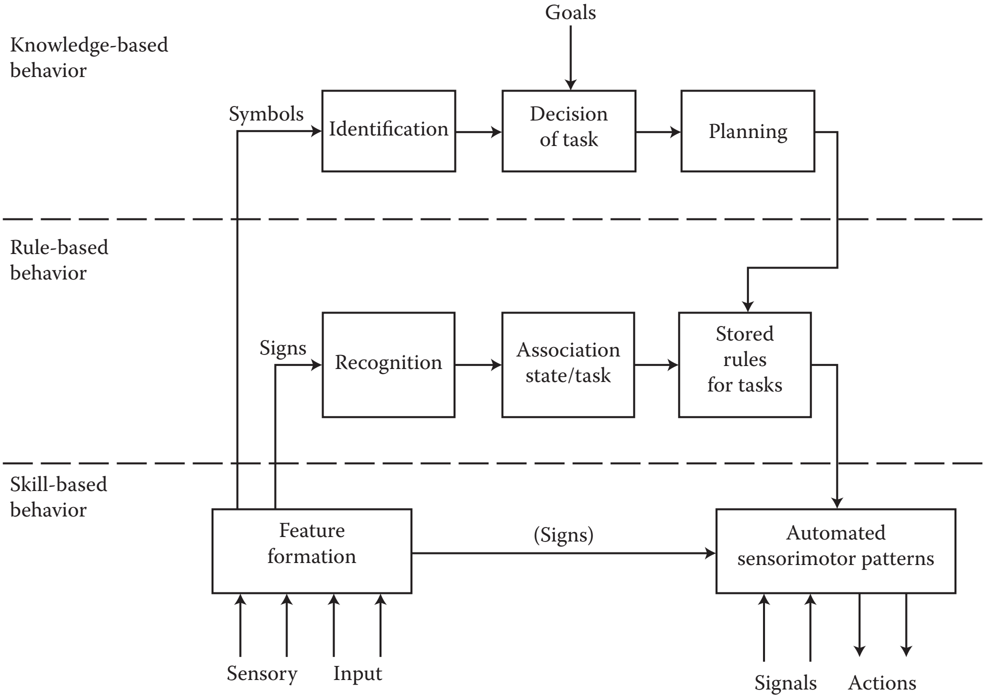

FIGURE 15.1
Graphical representation of the SRK taxonomy. (Adapted from Rasmussen, J. 1983. *IEEE Transactions on Systems, Man, and Cybernetics*, 13(3), 257–266.)

analytical problem solving based on symbolic reasoning and stored mental models (Vicente, 2002). Typically, interaction in unfamiliar or unanticipated events, and novice interaction (akin to interaction in unfamiliar events) will proceed using KBB, whereas expert interaction, and interaction in highly routine and familiar situations will more often proceed with SBB. The theory can also be applied to the process of learning, insofar as an individual, starting as a novice, will usually interact with a task at the KBB level. As experience grows, behavior will progress through RBB to SBB, whereby actions become routine and automatic. In this sense the theoretical framework bears resemblance to earlier descriptions of learning from the field of psychology, such as the conversion of declarative to procedural knowledge (Anderson, 1976, 1983).

Declarative knowledge refers to information in individual fragments that are stored separately, for example, knowledge of facts, events, and relationships, while procedural knowledge represents knowledge of how to do things, for example, complex motor skills, cognitive skills, and strategies. Behavior based on declarative knowledge requires effortful and time-consuming integration of knowledge fragments (Anderson, 1993). With procedural knowledge, on the other hand, the retrieval of information required to guide behavior is said to be fast and automatic (Pirolli and Recker, 1994). As Anderson (1993) explains, it is the conversion of declarative knowledge to procedural knowledge, through the amalgamation (or aggregation, in Rasmussen's words) of individual pieces of information into coherent concepts, or higher-level chunks that guide action, that characterizes skill development. These distinctions clearly resonate with the SRK philosophy; where KBB requires the operator to perform complex reasoning, reflecting on and interpreting information displayed in the interface (using declarative knowledge), perceptual-motor reasoning (skill- and rule-based) needs only recognition of familiar aspects of the task or problem to guide behavior (Glaser, 1984). Such similarities between the SRK and earlier descriptions of human cognition are by no means accidental; Rasmussen et al. (1990) expressly state that the SRK taxonomy "is compatible with the main-line of conceptualization within cognitive science and psychology (declarative vs. procedural knowledge …)" (Rasmussen et al., 1990, p. 106).

15.2.2 Decision Ladders

The decision ladder, first described in detail by Jens Rasmussen in 1974, aims to provide a model of human data-processing that can be used "to facilitate the matching of the formatting and encoding of data displays to the different modes of perception and processing used by human process controllers" (Rasmussen, 1974, p. 26). The diagrams depict the decisions that actors are required to make at different stages of a particular decision-making process (see Figure 15.2) and contain two different types of nodes; the rectangular boxes represent information-processing activities, the circles represent the resultant state of knowledge. For example, the information-processing activity labeled as diagnose state leads to knowledge of the current system state. The left portion of the diagram is concerned with an analysis of the situation and diagnosis of the current state of affairs, while the right side deals with the definition, planning, and execution of an action. The top of the diagram represents the evaluation of options and the consideration of specific goals pertaining to the task at hand.

The sequential arrangement of the rectangles (information-processing activities) and circles (states of knowledge) characterizes both the process of decision making through which a novice operator would progress, and the decision-making steps required during unanticipated and novel situations (i.e., at the knowledge-based level of cognitive control).

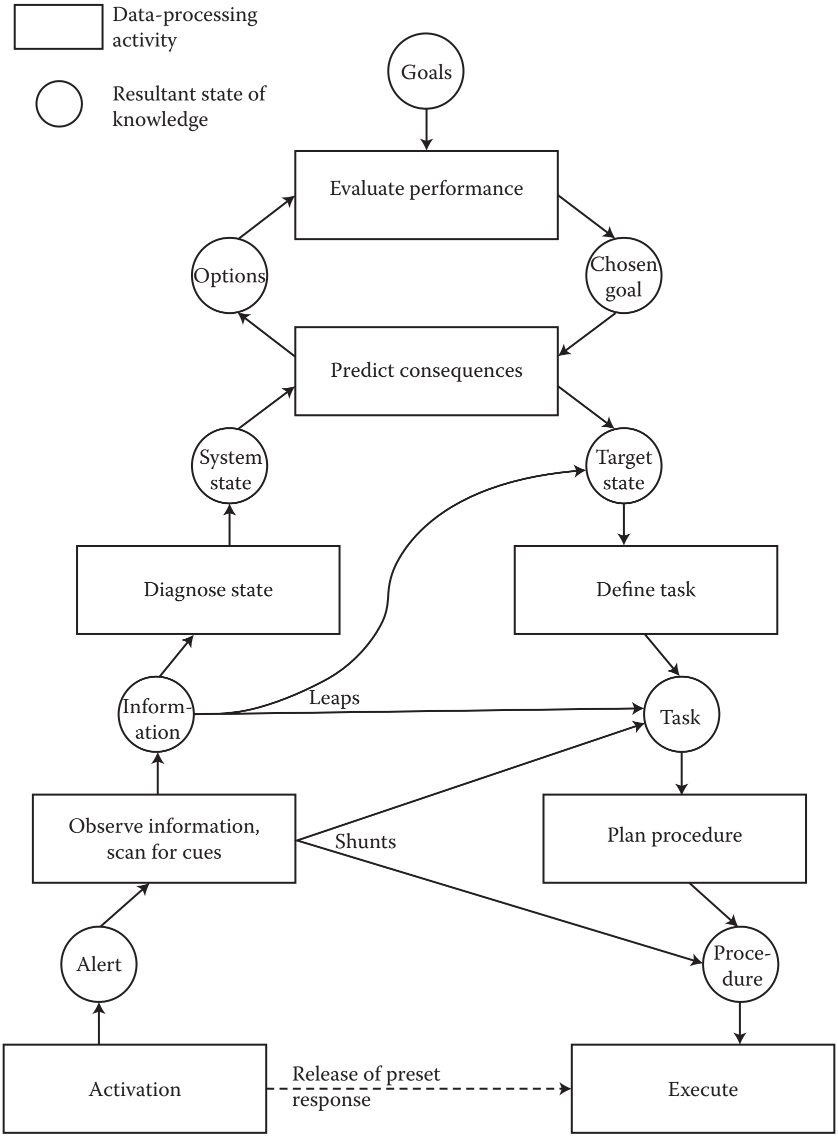

FIGURE 15.2
Decision ladder. (Adapted from McIlroy, R. C., and Stanton, N. A. 2015. *Ergonomics*, 58(6), 1–17. Doi: 10.1080/00140139.2014.997807.)

In these situations, and with novice actors, the top part of the diagram may be circulated around more than once. In these instances the decision maker may have to consider the various options available to him or her, and what affect each of these options will have on the chosen goal of the activity. Furthermore, there may be multiple, conflicting goals present in the decision-making task; each will require consideration.

Experienced actors rarely follow the linear sequence depicted in the decision ladder unless an unexpected situation or event is encountered; they are likely to take shortcuts. There are two types of shortcut defined in the literature (Jenkins et al., 2009; Vicente, 1999): shunts and leaps. Shunts connect data-processing activities to nonsequential states of knowledge while leaps connect two states of knowledge. The arrows in the center of Figure 15.1 represent these shortcuts. For example, in certain situations the process of diagnosing the system state may lead directly to the knowledge that a set procedure is required; such a shortcut is an example of a shunt. An example of a leap would be the association of knowledge of the current system state with the knowledge of a task that needs to be performed in order to, for example, get the system back to normal system operations. These shortcuts are often driven by rules and heuristics, learned through, for example, formal training and informal experience. Experienced actors may also enter the decision ladder at different nodes; they do not necessarily have to enter at activation and exit at execute. For example, an experienced actor may enter the decision ladder with an understanding of the current system state. From this they may infer, from past experience, the action required to achieve his or her given goal. Similarly, the activity may not necessarily flow from left to right, but can occur from right to left. For example, knowledge of the desired target state may lead an actor to observe for more information and cues to understand how this state may be achieved.

These shortcuts are indicative of rule-based behaviors (RBBs); they represent instances in which familiar perceptual cues in the environment are associated with stored rules for action and intent. SBB, the fast, automatic response to stimuli in the environment, is represented on the decision ladder by the arrow connecting activation with execute. Here, upon activation of the decision-making process, a preset response is released, resulting in the execution of a particular activity.

As previously described, the full decision ladder, when annotated for a given decision-making process, will represent the way in which an actor analyzes the situation, evaluates and selects goals, and plans and executes a task when using knowledge-based reasoning (i.e., follows the sequential path in its entirety), with all possible information inputs and options; this represents a prototypical model of activity (Jenkins et al., 2010). Rather than representing any one particular instance of an activity and the decisions therein (this would be a typical model of activity), the prototypical model aims to capture all possible elements that may affect the decision-making process (though not all will be used in any given situation). For example, Jenkins et al. (2010) describe the process of developing a decision ladder by means of asking a subject matter expert about a specific instance in which the activity of interest was performed. This supported development of a model of typical activity, that is, a particular example of an event that, in the case of Jenkins et al. (2010) has happened in the past. This typical model was then supplemented with all the additional and alternative information that may have been used, and the information that could be used in similar situations. This converts the typical model into the prototypical model.

According to Elix and Naikar (2008), the decision ladder approach can be used to inform the design of an interface; they do not, however, go into great detail on how this is to be achieved. Jenkins et al. (2010) go further in explaining how the generated prototypical models support an understanding of the relationships between the elements in the decision-making process. It is suggested that understanding the decisions to be made and the information sources that guide these decisions will help a designer to design an interface that more fully supports the operator in their task. Rasmussen et al. (1994) also make this point, stating that a designer must have a satisfactory understanding of the decision-making process of the potential user if they are to provide the correct information in the correct volumes in the interface. The process of developing the decision ladder supports such an understanding.

15.3 Modeling Fuel-Efficient Driving

For the analysis of the decision-making processes when driving in an economical fashion, it is necessary to first select specific situations, and in turn decision-making events, that have the most significant effect on fuel economy. This selection process serves to constrain, and give focus to the analysis. Hence a review of the available information on eco-driving was undertaken.

15.3.1 Activity Identification

Information on the driving styles that characterize a more economical use of fuel in the road vehicle is widely available, both in the academic literature, and across a plethora of more publicly available websites. Hooker (1988) offered one of the first descriptions of the specific driving styles that characterize economical driving. His research revealed that it is the style of acceleration and the timings of gear selections that have the greatest effect on fuel use in the vehicle. This is still the case in modern vehicles; Barkenbus (2010) states that eco-driving is characterized by (among other things) smooth acceleration, shifting up to the highest gear possible as early as possible (within the boundaries of safety), and anticipating the traffic flow and road layout ahead so as to avoid sudden starts and stops (i.e., to drive as smoothly as possible).

The concept of anticipation for eco-driving also features heavily in the more publicly available media, including specific eco-driving websites (e.g., ecodrive.org, 2013; Travelfootprint.org, 2013), motoring organizations (e.g., The AA, 2013), car manufacturers (e.g., Ford, 2013; Renault, 2013), local government (e.g., Devon County Council, 2013), and national and international nongovernmental organizations (e.g., Energy Saving Trust, 2013; United Nations, 2013). These resources offer advice not only on the style of driving that characterizes lower fuel consumption, but on the general maintenance of the vehicle as well. For example, removing unnecessary weight from the vehicle (e.g., not keeping the golf clubs in the car when they are not to be used), avoiding the use of air conditioning, and maintaining the recommended tyre pressures will all have a beneficial effect on fuel economy. This research is, however, only concerned with the types of driving styles and behaviors that characterize fuel-efficient use of the vehicle, that is, the driving task itself, hence these maintenance and peripheral use-related considerations were not included in our research.

This leaves us with two primary classes of driving behavior that significantly affect fuel economy. Behaviors related to use of the vehicle's gears, and behaviors related to use of the vehicle's accelerator and brakes. The second point can be further simplified to only use of the accelerator pedal; to minimize use of the vehicle's hydraulic brakes the driver must anticipate the road scene ahead in order to remove his foot from the accelerator pedal such that coasting down to a required speed can be achieved. This allows for smoother driving and, over the course of a route, reduces the amount of accelerator pedal usage (and therefore fuel usage).

Though the issue of gear choice behaviors is an important one in terms of the use of fuel in a manual transmission, ICE vehicle, we did not include this class of behavior in our analyses for two main reasons; first, the aim is to develop a system that is equally useful in both ICE vehicles and electric vehicles (which do not have gears in the same way ICE vehicles do); second, to reduce complexity and maintain focus. Hence only those behaviors associated with use of the accelerator pedal were considered.

TABLE 15.1

Eco-Driving Activities Selected for Analysis

Driving Activity	Description
Acceleration	Either from a standstill or from a lower speed to a higher speed. Though advice on fuel-efficient acceleration varies across information sources, there is a consensus that harsh, abrupt acceleration should be avoided
Deceleration (full stop more likely)	For example, when approaching a stop sign or traffic light at red. Early release of the accelerator pedal to take advantage of the vehicle's momentum to carry it to the stopping event is advised, that is, to minimize use of the brake pedal
Deceleration (full stop less likely)	For example, when approaching a bend in the road or going from a higher speed limit to a lower one. Again, early release of the accelerator pedal is advised in order to take advantage of the vehicle's momentum to carry it down to the required speed. Again, to minimize use of the brake pedal
Headway maintenance	Though this does not have a direct effect on fuel economy, the indirect effect of maintaining a sufficient distance to the lead vehicle allows for early responses to upcoming events and affords the driver a better view of the road ahead (i.e., it is less blocked by the lead vehicle) therefore again supporting early responses to upcoming road events. This is also largely about minimizing the need for brake pedal depression

Source: Adapted from McIlroy, R. C., and Stanton, N. A. 2015. *Ergonomics*, 58(6), 1–17. Doi: 10.1080/00140139.2014.997807.

Based on the information provided in the academic and public literature, and on the aforementioned criteria, four specific activities were identified for modeling; these are presented in Table 15.1 alongside a brief description of why each is important in terms of fuel efficiency.

15.3.2 Eco-Driving Decision Ladder Validation

A decision ladder model was developed for each of the four activities listed in Table 15.1. The first iteration of the analysis was based on information gathered from web resources (e.g., specific eco-driving websites) and from the academic literature on eco-driving. A focus group was held at the University of Southampton's Transportation Research Group, the participants of which were four researchers, including the two authors of this chapter, each of whom possessed a working knowledge of human factors in road transport. Note, however, that none of the members of the focus group was an expert in eco-driving specifically. The group served both to validate the choice of activities, and to discuss the resultant models. It provided a platform for the discussion of the first iteration of the analysis. Table 15.2 provides a summary of the four participants' relevant information.

TABLE 15.2

Focus Group Participant Information

Participant	Gender	Age	Years Driving	Years Involved in Road Transport Research
1	Male	53	37	20
2	Male	27	4	2
3	Female	28	11	6
4	Female	25	8	2

Source: Adapted from McIlroy, R. C., and Stanton, N. A. 2015. *Ergonomics*, 58(6), 1–17. Doi: 10.1080/00140139.2014.997807.

Though the focus group discussions were useful for an initial attempt at model validation, the participants were not subject matter experts (i.e., they did not have specific eco-driving experience). As such, a number of interviews with experienced "eco-drivers" were arranged to further validate the models.

Participants were initially sought from two eco-driving websites: ecomodder.com and hypermiler.co.uk. These websites provide a platform for those interested in both the technologies and behaviors associated with fuel-efficient driving, offering news of new technologies, advice on saving fuel when driving, and providing a space for the community to discuss experiences and practices. A request for participation was posted to the forums hosted on each website. From this, two individuals contacted the current authors; one was a member of the forums on ecomodder.com, the other on hypermiler.co.uk. Two more participants were contacted through the ECOWILL project, details of which can be found from www.ecodrive.org. This European-wide project aims at providing information on eco-driving to the general public, as well as undertaking formal, academic research into various eco-driving aspects, including research involving driving instructors trained and experienced in teaching eco-driving techniques to individuals.

In all cases, participation was entirely voluntary, without any payment (monetary or otherwise). Due to the geographically dispersed nature of the participants (one each in the United States, Germany, Scotland, and England), face-to-face interviews were not possible; hence three interviews were conducted using Skype™, with the other conducted over the telephone (as per this participant's preference). Each interview lasted approximately 1 h. Relevant participant information is provided in Table 15.3.

To elicit information regarding each specific driving situation, a procedure similar to that described in Jenkins et al. (2010) was followed. Each expert was introduced to the decision ladder model and asked about his goals for each activity. The left-hand side of the diagram was then populated with information regarding the cue or cues responsible for bringing to attention the need for some action. Then the expert was asked to list the sources of information he uses to build an understanding of the current state of the system, that is, what cues in the environment will later go on to affect his decision-making process. The top section of the diagram was populated through a discussion of the options available to the driver and how these impact on the chosen goal, be it efficiency or otherwise. Then the target state was discussed; this largely related to the selection of accelerator pedal position at particularly points along the roadway. Finally, the task required to achieve this target state and the necessary procedure were discussed.

TABLE 15.3

Interviewee Information

Participant	Gender	Age	Years Driving	Years Eco-Driving	Motivation	Primary Car Driven
1	Male	45	30	27	Financial and environmental	2003 Honda Civic Hybrid
2	Male	72	>50	30	Financial and "as a game"	Kia C'eed 1.6 diesel (year unknown)
3	Male	45	27	7	Environmental and through work	2004 Ford c-max
4	Female	42	25	9	Environmental and through work	2005 Audi A3

Source: Adapted from McIlroy, R. C., and Stanton, N. A. 2015. *Ergonomics*, 58(6), 1–17. Doi: 10.1080/00140139.2014.997807.

Following the discussions it became clear that "deceleration (full stop less likely)" was too broad a category, insofar as the information used to guide performance when approaching a road curvature was sufficiently different to the information used in other slowing events to warrant its own decision ladder. As such, this model was broken down into two separate models: "deceleration for road curvature" and "deceleration for other slowing event." For the purposes of brevity, only the "deceleration for road curvature" decision ladder will be discussed in detail here (Figure 15.3; see McIlroy and Stanton (2015) for descriptions of the remaining models).

15.4 Interpreting the Model

As this research is interested in the decision-making processes specific to eco-driving in particular situations, the goal of the activity being modeled was identified as "to decelerate from a higher speed to a lower speed in order to negotiate a road curvature whilst maintaining safety and minimizing overall fuel consumption for the journey."

The first annotated step on the left-hand side of Figure 15.3 is the alert; this indicates that the driver has been alerted to the curvature in the road ahead (i.e., it has been seen). The driver then scans for cues, from both within and outside of the vehicle. In terms of useful information, the driver may attend to, for example, the speedometer and tachometer, other road users, the road layout, markings, and signage both before and (if possible) after the road curvature, as well as physical movement (i.e., vestibular cues), visual momentum (i.e., the passing of the road scene outside the vehicle), the sounds of the engine, and car–road interactions (e.g., tyre noise at moderate-to-high speeds). These information sources allow the driver to establish an understanding of the road environment, the state of the driver's own vehicle (e.g., speed, acceleration, weight characteristics), the weather conditions, and the behavior of other road users.

In the top part of the diagram the driver may cycle through the potential options for action, and consider the effect that the current system state will have on these possibilities. For example, based on an understanding of the system state, the driver can estimate the effect of engine braking and different levels of hydraulic (i.e., traditional, brake–pedal initiated braking), and regenerative braking (where this is applicable) on the state of the system as a whole. For the purposes of this analysis, a primary goal is to be able to decelerate, in the most fuel-efficient manner, down to a speed that is appropriate to safely negotiate the road curvature. This is achieved by minimizing the use of the hydraulic brake pedal, or conversely, maximizing the use of the vehicle's momentum to carry it to the corner. Of course, safety will always be paramount in an on-road situation. The state of the system may therefore impact on the ability to turn the corner efficiently, for example in icy conditions or in conditions of heavy traffic flow.

The right-hand side of this upper section also has two other, potentially conflicting goals, namely to conform to social pressure and to reach the destination as quickly as possible. Each one of the subject matter experts raised both of these issues. One can imagine various situations in which speed is critical, from the emergency (e.g., a pregnant woman, going into labor, being rushed to hospital) to the relatively mundane (e.g., rushing home from work in order to get back before the plumber arrives). In terms of social pressure, this can come from both within and outside the vehicle. For those pressures coming from within the vehicle, one can imagine, for example, a situation in which a young driver succumbs to peer pressure to drive more aggressively (an established finding, particularly for

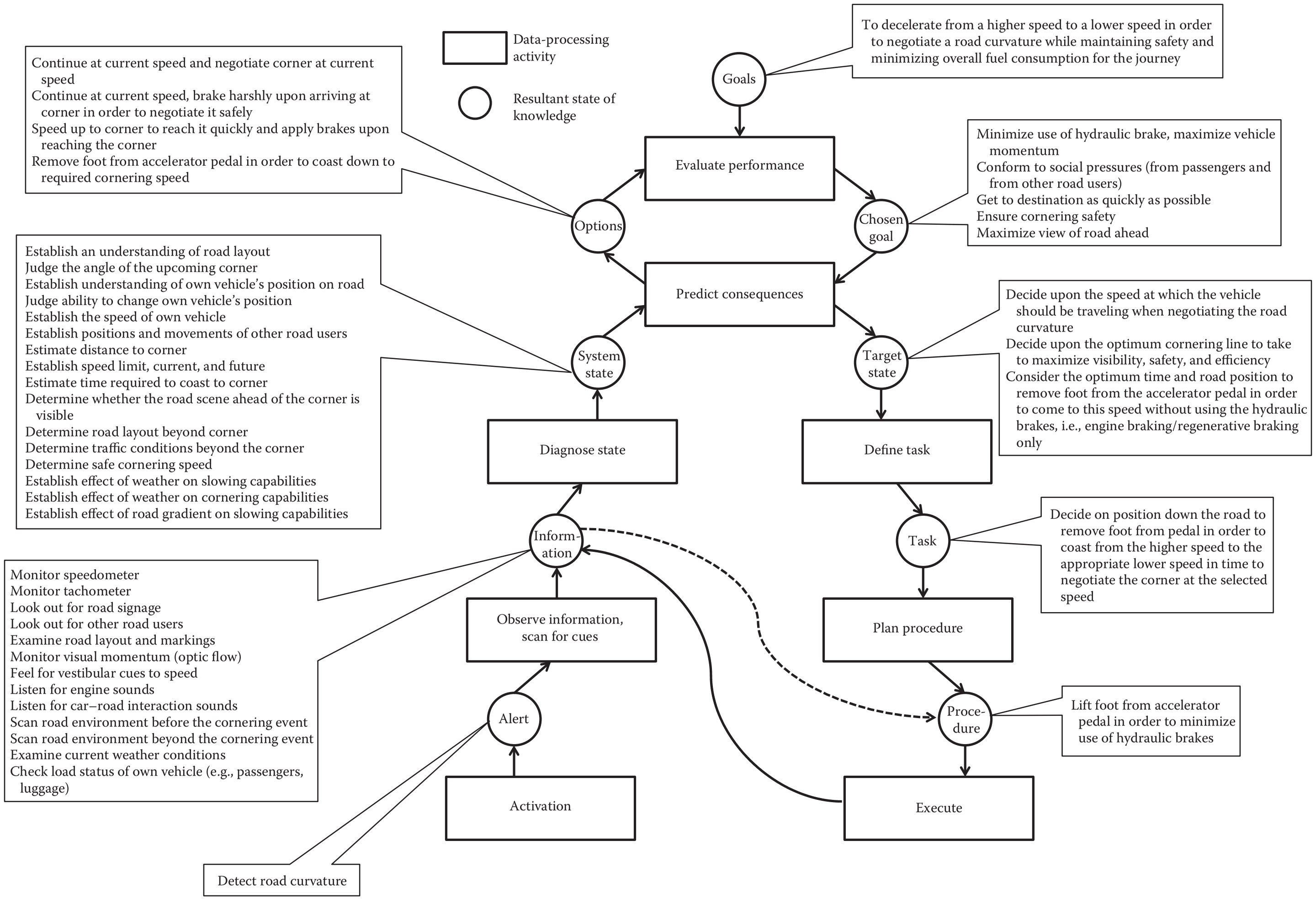

FIGURE 15.3
Decision Ladder for “deceleration for road curvature.” (Adapted from McIlroy, R. C., and Stanton, N. A. 2015. *Ergonomics*, 58(6), 1–17. Doi: 10.1080/00140139.2014.997807.)

young men, e.g., Conner et al., 2003). Pressures coming from outside the vehicle relate to the behavior of other road users, for example, other drivers' use of their horns to influence the driver's behavior, or the act of driving very close to the rear of the driver's vehicle to encourage the driver to go faster (see, e.g., Åberg et al., 1997 for a discussion on the effect of the social environment on driver behavior and perceptions).

Moving down the right hand side of the diagram, the target state (assuming the goal of fuel-efficient negotiation of the corner) can be understood in terms of the use of the accelerator pedal, or more specifically, the time and road position (dependent on current speed) at which the foot should be removed from the accelerator pedal in order to coast, from the current speed, down to the required cornering speed. This involves an understanding of the current speed, the ideal speed for cornering, and the deceleration characteristics of the vehicle when using only engine braking (i.e., without the use of the hydraulic brake). This knowledge of the target state necessarily leads on to an understanding of the task, that is, when to remove the foot from the accelerator pedal, and the procedure, that is, remove the foot and minimize hydraulic brake use.

15.5 Discussion

The way in which an individual will progress from the alert stage to the execute stage will depend on a number of factors, for example, the characteristics of the driver (e.g., novice or expert) or the information available at a specific location (e.g., signage may differ, visibility may be different depending on time of day or weather). These shortcuts (i.e., the shunts and leaps) are often associated with actors of different experience; novices unfamiliar with a situation are usually expected to progress linearly through the diagram in its entirety (with notable effort), whereas experts may use a particular cue in the environment on which to base immediate action. Though it is experience that most commonly guides the shortcuts through the model, it may be possible to encourage them through the careful design of information presented to the driver in the vehicle. A primary aim of doing so would be to transform a cognitive task into a perceptual task. The question is, therefore, how do we support skill-based control in the novice eco-driver?

For some guiding principles we can turn to theory of direct manipulation interfaces (DMI) (e.g., Hutchins et al., 1986). This approach emphasizes the need to represent objects of interest and to allow the users to act directly on what they can see in the display; it both provides an "attempt to display the domain objects of interest and allow the operator to act directly on those objects" (Rasmussen and Vicente, 1989, p. 527) and allows the operator "to rely on the perceptual cues provided by the interface to control the system" (ibid, p. 525). Note that these quotes come not from DMI proponents, but from the creators of ecological interface design (EID; Rasmussen and Vicente, 1989; Vicente and Rasmussen, 1992), a design approach intimately linked with the SRK taxonomy. Both design approaches argue for the benefits of taking advantage of the human sensorimotor system, that is, to encourage behavior at the skill-based level. In terms of the task under analysis here, the fuel-efficient cornering of the road vehicle, one could imagine a system that informs the driver, through some salient stimulus, of the particular behavior required as well as the time at which that particular behavior should be performed (given the goal of fuel efficiency). When one considers that the task in question is largely related to use of the accelerator pedal (note that the "task" box on the right-hand side of Figure 15.3 talks of removing the foot from the pedal at a given road position), the possibility of providing tactile or haptic feedback through the accelerator pedal becomes one that satisfies both the tenets of EID (and, in turn, the SRK taxonomy) and those of the DMI approach.

In order to support SBB, an information system should provide information that encourages the driver to take a shortcut through the decision ladder as low down in the diagram as reasonably possible; in this case, this would likely support a "leap" from the alert that a corner ahead has been detected, to the knowledge of the task, namely to lift the foot from the accelerator pedal. This would support interaction via time–space signals, a necessary means for encouraging SBB, as the stimulus could come at a particular point on the road; this would be determined by a combination of spatial data and speed data (i.e., the faster a car is traveling, the earlier the signal should come to support a full coasting phase) and calculated using already-present information from car radar systems and satellite navigation information. Furthermore, following the suggestion that the operator should be able to act directly on the display, this time–space signal could be presented through the accelerator pedal, as a vibration (e.g., Birrell et al., 2013), or as an additional counterforce applied to the pedal (e.g., Mulder et al., 2010). This type of system, one that combines the action and control surfaces (i.e., the area onto which an action is performed is one and the same as the area from which information is garnered), would satisfy the theoretical arguments of both the SRK taxonomy and the DMI approach and should, in theory, support SBB in the driver.

15.6 Conclusions

This chapter has discussed the first step toward the design of an in-vehicle, eco-driving information system: the preceding analysis phase. The most influential in-vehicle activities or behaviors for fuel consumption, identified through a review of the academic literature and of more publicly available web-based resources, were modeled using Rasmussen's (1974) decision ladders. One of these, the "deceleration for road curvature" decision ladder, was presented and discussed in terms of the possibility for designing an in-vehicle information system that will support drivers, particularly those currently lacking in eco-driving expertise, to perform the eco-driving activities at the skill-based level of cognitive control. The model was also discussed in terms of the tenets of DMI, with the concept of combining action and control surfaces with accelerator–pedal-based haptic feedback offering a potential avenue for future research. While there are already examples of these kinds of systems in the extant literature (e.g., Birrell et al., 2013; Hajek et al., 2011; Mulder et al., 2011), the current research provides the first attempt to theoretically ground these efforts in existing descriptions of human control behavior and approaches to system design (see McIlroy and Stanton, 2015).

Acknowledgment

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References

Åberg, L., Larsen, L., and Beilinsson, L. 1997. Observed vehicle speed and drivers' perceived speed of others. *Applied Psychology*, 46(3), 287–302.

Anderson, J. R. 1976. *Language, Memory, and Thought*. Hillsdale, New Jersey: Erlbaum.

Anderson, J. R. 1983. *The Architecture of Cognition*. Cambridge, Massachusetts: Harvard University Press.

Anderson, J. R. 1993. *Rules of the Mind*. Hillsdale, New Jersey: Erlbaum.

Barkenbus, J. N. 2010. Eco-driving: An overlooked climate change initiative. *Energy Policy*, 38(2), 762–769.

Bingham, C., Walsh, C., and Carroll, S. 2012. Impact of driving characteristics on electric vehicle energy consumption and range. *IET Intelligent Transport Systems*, 6(1), 29–35.

Birrell, S. A., Young, M. S., and Weldon, A. M. 2013. Vibrotactile pedals: Provision of haptic feedback to support economical driving. *Ergonomics*, 56(2), 282–292.

Conner, M., Smith, N., and McMillan, B. 2003. Examining normative pressure in the theory of planned behavior: Impact of gender and passengers on intentions to break the speed limit. *Current Psychology*, 22(3), 252–263.

Devon County Council. 2013. Eco-driving film. Retrieved from http://www.devon.gov.uk/index/video/videotransport/ecodrivingvid.htm

ecodrive.org. 2013. The golden rules of eco-driving. Retrieved from http://www.ecodrive.org/en/what_is_ecodriving-/the_golden_rules_of_ecodriving/

Elix, B., and Naikar, N. 2008. Designing safe and effective future systems: A new approach for modelling decisions in future systems with cognitive work analysis. In *Proceedings of the 8th International Symposium of the Australian Aviation Psychology Association*. Sydney, Australia: Australian Aviation Psychology Association.

Energy Saving Trust. 2013. Driving. Retrieved from http://www.energysavingtrust.org.uk/Travel/Driving

Evans, L. 1979. Driver behavior effects on fuel consumption in urban driving. *Human Factors*, 21, 389–398.

Ford. 2013. Driving to lower fuel consumption and emissions. Retrieved from http://www.ford.co.uk/OwnerServices/FuelEconomyandEnvironmentalProtection/FuelEfficientEcoDrivingTips

Glaser, R. 1984. Education and thinking: The role of knowledge. *American Psychologist*, 39, 93–104.

Hajek, H., Popiv, D., Just, M., and Bengler, K. 2011. Influence of a multimodal assistance supporting anticipatory driving on the driving behavior and driver's acceptance. In M. Kurosu (Ed.), *Human Centered Design, HCII 2011, LNCS 6776* (pp. 217–226). Berlin: Springer-Verlag.

Hooker, J. N. 1988. Optimal driving for single-vehicle fuel economy. *Transportation Research Part A: Policy and Practice*, *22*(3), 183–201.

Hutchins, E. L., Hollan, J. D., and Norman, D. A. 1986. Direct manipulation interfaces. In D. A. Norman and S. W. Draper (Eds.), *User Centered System Design: New Perspectives on Human-Computer Interaction* (pp. 87–124). Hillsdale, New Jersey: LEA.

Jenkins, D. P., Stanton, N. A., Salmon, P. M., and Walker, G. H. 2009. *Cognitive Work Analysis: Coping With Complexity*. Farnham, England: Ashgate Publishing Limited.

Jenkins, D. P., Stanton, N. A., Salmon, P. M., Walker, G. H., and Rafferty, L. 2010. Using the decision ladder to add a formative element to naturalistic decision-making research. *International Journal of Human-Computer Interaction*, 26(2–3), 132–146.

McIlroy, R. C., and Stanton, N. A. 2015. A decision ladder analysis of eco-driving: The first step towards fuel-efficient driving behavior. *Ergonomics*, 58(6), 1–17. Doi: 10.1080/00140139.2014.997807.

Mulder, M., Abbink, D. A., van Paassen, M. M., and Mulder, M. 2011. Design of a haptic gas pedal for active car-following support. *IEEE Transactions on Intelligent Transportation Systems*, 12(1), 268–279.

Mulder, M., Pauwelussen, J. J. A., van Paassen, M. M., and Abbink, D. A. 2010. Active deceleration support in car following. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, 40(6), 1271–1284.

Pirolli, P., and Recker, M. 1994. Learning strategies and transfer in the domain of programming. *Cognition and Instruction*, 12, 235–275.

Rasmussen, J. 1974. The human data processor as a system component. Bits and pieces of a model. Riso-M-1722. Roskilde, Denmark.

Rasmussen, J. 1983. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, 13(3), 257–266.

Rasmussen, J., Pejtersen, A., and Goodstein, L. P. 1994. *Cognitive Systems Engineering*. New York: Wiley.

Rasmussen, J., Pejtersen, A. M., and Schmidt, K. 1990. *Taxonomy for Cognitive Work Analysis*. Roskilde, Denmark: Risø National Laboratory.

Rasmussen, J., and Vicente, K. J. 1989. Coping with human errors through system design: Implications for ecological interface design. *International Journal of Man-Machine Studies*, 31(5), 517–534.

Renault. 2013. Eco Driving Tips. Retrieved from https://www.renault.co.uk/discover-renault/environment.html

The AA. 2013. Eco-driving advice. Retrieved from http://www.theaa.com/motoring_advice/fuels-and-environment/drive-smart.html

Travelfootprint.org. 2013. Reduce your Travel foot print—Eco-driving. Retrieved from http://www.ecolane.co.uk/

United Nations. 2013. United Nations Environment Programme: Ecodriving. Retrieved from http://www.unep.org/transport/Programmes/Ecodriving/

Vicente, K. J. 1999. *Cognitive Work Analysis: Towards Safe, Productive and Healthy Computer-Based Work*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Vicente, K. J. 2002. Ecological interface design: Progress and challenges. *Human Factors*, 44, 62–78.

Vicente, K. J., and Rasmussen, J. 1992. Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics*, 22, 589–600.

Waters, M. H. L., and Laker, I. B. 1980. Research on fuel conservation for cars. Report No. 921. Crowthorne, England.