A SYSTEMIC MODEL FOR DRIVER-IN-CONTROL

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Summary: Models of driving have traditionally been couched either in terms of guidance and control or in terms of human factors. There is, however, a need for more powerful models that can match the rapidly growing complexity and sophistication of modern cars. Such models must provide coherent and consistent ways of describing driver performance to help engineers develop and validate technical concepts for semi- and fully automated systems in cars. This paper presents a qualitative model for Driver-in-Control (DiC) based on the principles of cognitive systems engineering. The model describes driving in terms of multiple, simultaneous control loops with the joint driver-vehicle system (JVDS) as a unit. This provides the capability to explain how disturbances may propagate between control levels. The model also enables new functions to be evaluated at the specific level at which they are aimed, rather than by their effects on global driving performance.

INTRODUCTION

The study of driving has traditionally been viewed either as a problem of guidance and control or as a human factors problem. The former view came from the need to develop parametric models to evaluate and predict driver-car handling. The latter view arose from the increasing capabilities and complexities of cars—and of technology in general—which created performance potentialities and control demands that often exceeded human abilities. While both views are valuable, neither is fully adequate to face the challenges of modern and future cars. One reason is that the development of advanced driver support systems and active safety functions significantly changes the nature of driving. Rather than directly controlling the direction and speed of the car, the driver must now co-operate—and sometimes compete—with several automated systems.

Another reason is that changes to traffic patterns and driving purposes means that drivers must attend to several goals at the same time. Together this creates a need for models of driving that go well beyond what the traditional approaches can provide. Many authors have emphasised that driving is not a unitary activity but that it involves a combination or hierarchy of tasks (e.g., Gibson & Crooks, 1938; McRuer et al., 1977; Michon, 1985). Descriptions of driving typically comprise planning the drive, monitoring both one's own car and other traffic, and controlling speed and direction (comprising steering, accelerating, braking). Task analyses of driving have produced lists of up to 1,700 subtasks (McKnight & Adams, 1970), although most researchers usually settle for more modest numbers. Driving obviously cannot be described as a combination of tasks without providing a principle by which the tasks can be organised, usually in the form of some kind of hierarchy of tasks or actions. Michon (1985), for instance, proposed three levels of tasks called strategic (planning), tactical (manoeuvring) and operational (control).

Since driving is a dynamic activity, models must be able explicitly to account for the dynamics, and hence be functional rather than structural. Driving takes place in time, and models that cannot represent time are ill suited as research tools. This requirement immediately rules out all structural/taxonomic models as well as all models based on traditional task analyses. Hierarchical models further imply that there are different levels of performance or control, such as the three levels that Michon, and others, have proposed. But as soon as two or more levels are used the problem arises of how control or performance can change from one level to another. Michon (1985) describes this as follows:

> "A comprehensive model of driver behavior should not only take the various levels into account, but should also provide an information flow control structure that enables control to switch from one level to the other at the appropriate points in time."

The implication of this view is that control resides on one level only at a time. This limitation is also present in other types of operator models, particularly in the distinction between skill-based, rule-based, and knowledge-based behaviour (Rasmussen, 1986). Most models furthermore describe the driver separately from the car, following the long tradition of human-machine studies. In order to be of practical value a model of driving must, however, meet two criteria: (1) allow control to exist on several levels simultaneously, and (2) describe the driver and the car as a joint system, rather than as two separate systems. The first criterion simply reflects the fact that both humans and machines routinely pursue several goals at the same time. A driver may, for instance, be involved in maintaining the lateral position of the car, carrying out an overtake manoeuvre, and keeping a "mental" eye on the fuel level and the expected time of arrival. The second criterion recognises that modern cars contain a number of automated functions that in some conditions can take control of the car, while other functions run in the background and thus exist side-by-side with the driver's actions. The couplings and dependencies among these functions determine how easy it is to control the car, and hence, how well the Joint Driver-Vehicle System (JDVS) performs.

DRIVER-IN-CONTROL

In order to capture this complexity, a project carried out by Saab Automobile has developed a model for Driver-in-Control (DiC), as a descriptive model of the JDVS rather than as a parametric model of the driver. To define the meaning of "driver in control," it is useful to start by noting that being out of control is generally associated with the occurrence of unwanted conditions. Being in control means having the power or ability to direct and manage the development of events, while not having control means that this ability is temporarily or permanently lost. Thus, if a JDVS is out of control, it is unlikely that it will achieve the intended outcomes and likely that unexpected and unintended outcomes occur instead. We can therefore propose the following definition: A JDVS is in control of a situation either if unexpected conditions do not arise, or if it is possible to avoid unwanted outcomes of such conditions. The former means that the JDVS is able to prevent unexpected conditions from occurring; the latter means that the JDVS is able effectively to recover from such conditions, should they occur.

The JDVS model further makes a distinction between act-of-driving (to drive well) and purpose-of-driving (to achieve a goal). The control that is needed for act-of-driving is clearly different from the control needed for purpose-of-driving, the former being focused on safety issues and the latter on efficiency issues. Referring to the first model criterion described above—that control can exist on several levels simultaneously—DiC models answer this by describing driving in terms of multiple, simultaneous control loops. Some of these are of a closed-loop (reactive) type, some are of an open-loop (proactive) type, and some are mixed. As a starting point, it is useful to distinguish between four different modes or levels of control in driving performance, which have been called tracking, regulating, monitoring, and targeting (goal-setting) respectively.

The DiC Model

The starting point is a functional model of control described as a cycle that links intentions / objectives, actions, and outcomes (Hollnagel, 2002). This basic cycle is used on every level of the DiC model, but with different characteristics in terms of, for example, the type of control (feedback, feedforward) and temporal dynamics (Figure 1). The tracking loop describes the low-level driving activities required to maintain speed, distance from the car in front/behind, relative or absolute lateral position, etc. Tracking activities are basically closed-loop control, which skilled drivers can accomplish with little effort and without paying much attention to them.

The regulating loop provides the goals and criteria for the tracking level. Regulating is mostly closed loop, although some anticipatory control may occur. It is concerned with aspects such as target speed, specific position and movement relative to other traffic elements, etc., and may therefore involve a number of tracking sub-loops. Regulating also requires that the driver attend to what s/he is doing. The monitoring loop is concerned with the state of the joint driver-car system relative to the driving environment (traffic flow, hazards) and generates the plans and objectives used by the regulating and tracking loops.

The status of the JDVS is monitored on this level—for instance the car's condition, location, available and used resources, etc. Monitoring further keeps track of traffic signs and signals such as indications of direction (locations and distances), warnings (e.g. road conditions or curves),

and restrictions (e.g., one-way traffic or speed limits). Monitoring is therefore a mixture of closed-loop and open-loop control. The targeting loop (goal setting) is where the destination and driving criteria are generated. Targeting is distinctly an open-loop activity, which is implemented by a non-trivial set of actions and often covers an extended period of time. Assessing the change relative to the goal is not based on simple feedback, but rather on a loose assessment of the situation—for instance, the estimated distance to the goal. When it is done regularly, it may be considered a part of monitoring. When it is done irregularly, the trigger can be one of several factors such as time, a pre-defined cue or landmark (physical or symbolic), the user's background "simulation" or estimation of the general progress (like suddenly feeling uneasy about where one is).
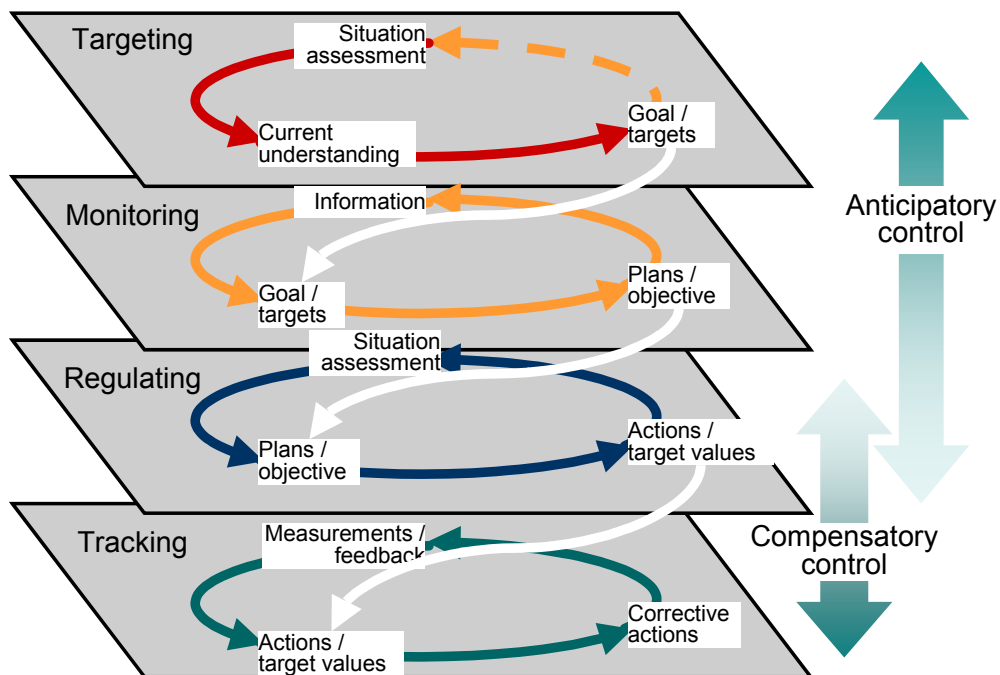

Figure 1. Principles of the DiC model

Effective control means that the JDVS must be in control on all levels at the same time. Ineffective control happens when control is lost of one or more of the loops. The coupling between the four loops illustrates how they are functionally connected. The levels are generally linked by goals or objectives (from higher to lower levels) and feedback (usually from lower to higher levels). To avoid cluttering, Figure 1 does not show how feedback links or unexpected events may impinge on the loops, although this obviously is part of the more detailed model description.

A major advantage of the DiC model is that it explicitly describes how disturbances can propagate between control levels. A change in goals on the targeting level, such as an altered destination or a new arrival time, will affect plans and actions possibly leading to, for example, more risky manoeuvres. Similarly, a disturbance at the tracking level, such as an active safety system kicking in, will affect regulating, and a large disturbance may even affect monitoring.

The DiC model makes it possible to account for the dynamics of such changes in a way that is unattainable by structural models. The description can be complemented by parametric models for specific subfunctions on, for example, the tracking or regulating levels, using the DiC model as the overall framework.

APPLICATIONS

One application of the DiC model has been to propose operational measures of loss of control in order to evaluate the quality of driving and the effects of specific support functions. The model provided the basis for defining performance requirements for a JDVS. This was combined with a systematic classification of potential performance deviations taken from established risk analysis methods, to propose operational criteria and observable indicators for performance deviations. These were classified as mild, serious, or severe and related to specific types of performance measurements and failure modes. Other applications of the DiC model will be used as the basis for design and as the starting point for dynamic simulations of JDVS performance.

Another use is to evaluate the impact of new technologies and support functions. New features can be assessed at the specific level at which they are aimed, whether it is navigation support or a new type of ACC. The possible effects on other levels can then be considered (cf. above), leading to a global assessment that is more detailed than a wholesale evaluation. An indication of how this may be done is provided by Table 1, which describes the main functional characteristics of each level of control.

Table 1. Functional characteristics of DiC levels

	Types of control involved	**Demands to attention**	**Frequency of occurrence**	**Typical duration**	**Level/scope of automation**
Targeting	Goal setting (feed forward)	High, concentrated	Low (mostly pre-journey)	Short (minutes)	**Low**
Monitoring	Condition monitoring (feedback + feedforward)	Low (car) High (traffic, hazards)	Intermittent but regular (car) Continuous (traffic, hazards)	10 minutes to duration of voyage	Low
Regulating	Anticipatory (feedback + feedforward)	High (uncommon manoeuvres)	Very high (town) Medium (country)	1 second-1 minute	Medium
Tracking	Compensatory (feedback)	None (pre-attentive)	Continuous	<1 second	High

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