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"THE DETECTION AND CATEGORIZATION OF ALTERCONTROL"

PHASE II REPORT TO BMW ON A METHODICAL APPROACH FOR THE ENGINEERING OF DRIVER ASSISTANCE SYSTEMS

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16. Abstract

A concept is developed and demonstrated for measuring normal driving behavior in a specialized way that reveals the contrast between human preferences in vehicle control and the functionality of any given driver assistance system (DAS). The concept basically distinguishes the DAS-controlled domain from all other portions of the driving task which concern the driver. The term "Altercontrol" has been coined to define the other, alter, control agenda that is deemed appropriate by the driver. Using the example case of Stop & Go Adaptive Cruise Control (ACC) as the DAS function in question, the method of Altercontrol detection was applied over approximately 400 km of manual driving on a mixed route of motorways and surface streets. The reference model of a simple headway controller ran in the background while the instrumented vehicle was driven normally by a layperson. The test results showed 130 distinct incidents of Altercontrol (as opposed to ACC-like headway control) that were employed during the test drives. Each incident was characterized by the range/range-rate zone of its occurrence, the apparent control tactic employed by the driver, and the time duration over which the Altercontrol state prevailed. A categorization scheme is presented by which all Altercontrol of this kind falls into one of five cells of a matrix relating the type of prevailing "conflict" to the polarity of the headway-keeping "error" that was seen as a difference relative to strict headway-control rules. The conflicts range from benign discretionary controls to safety-critical action.

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1.0 INTRODUCTION

This document constitutes the final report from Phase II of a research study sponsored by Bayerische Motoren Werke AG (BMW) at the University of Michigan Transportation Research Institute (UMTRI). The overarching goal of this research program has been to create a methodical approach for guiding the development and evaluation of driver assistance systems (DAS). It is intended that such an approach will help reduce the time for developing products which, as a class, must be made profoundly complementary to the human reality that governs normal driving. Where such products offer a control-assistance function, the most important realities include the driver's intent and expectations for controlling the vehicle motion.

Noting that any practicable system will address some, but not all of the driver's control activity, Phase I of the research program identified an evaluative concept that would distinguish the DAS-controlled domain from all other portions of the driving task which concern the driver. The domain of "other" concerns was termed "Altercontrol". The altercontrol concept thus addresses—at every moment in time—the other, or alter, control agenda that the driver would otherwise have deemed appropriate, if no assistance function were provided. When driving with a DAS function engaged, the driving needs that elicit altercontrol by the driver, either:

- prompt human intervention on the DAS function,
- provoke customer dissatisfaction,
- pose a possible safety risk, and/or,
- induce submission of driver preference to the DAS function, over time, if the driver's altercontrol judgments turned out to be discretionary and, thus, negotiable.

The Phase II project has developed a working method for detecting altercontrol during normal manual driving with an instrumented vehicle. This method has been applied over approximately 400 km of driving on mixed routes of motorways and surface streets. The report presents the elements of the method, itself, as well as the results obtained from testing. In section 2.0, the concept for detecting altercontrol driving activity is presented, followed by a presentation in section 3.0 of the specific formulation used for making altercontrol observations in the field. In section 4.0, the adaptation of a BMW test vehicle as an altercontrol observation platform is described, together with the test protocol. Section 5.0 presents and discusses the test results. Although the scope of testing was modest, the results do show an interesting distribution of events across some eighteen categories of altercontrol. Noting that the distribution of these results was significantly determined by the model structure used for altercontrol observation, section 6.0 discusses the current state of the model and the outlook for further improvements. Sections 7.0 serves to place the altercontrol observations in perspective with the "methodical approach" which BMW seeks to develop, while section 8 provides conclusions and makes recommendations for the next steps, respectively.

2.0 RESEARCH CONCEPT

Since all of the UMTRI's work for BMW has so far restricted itself to the longitudinal domain of DAS functionality—principally to that of Stop & Go ACC—the concept of altercontrol has first been developed for application to this domain [2]. Nevertheless, it should be noted that one could consider applying the altercontrol concept to the study of any DAS function.

In developing this concept with the intent of ACC evaluation, we observe firstly that the driver's actions in longitudinal control are governed both by the immediate headway constraint, such as an ACC function addresses, and by a host of other considerations that may be quite unrelated to the prevailing headway. Thus, we might say that all longitudinal control can be divided into operational zones covered either by Headway-only terms of control or by the sum of all other, or alter, terms for control. If the immediate range and range-rate to the preceding vehicle were the only reality that governed the driving process, the other terms for control would always be nil. However, driving style preferences, safety demands, navigational tactics, etc. arise from the much richer realm of roadway operations in which human drivers actually operate, suggesting that Headway-only control may be substantially less than all control actions that drivers would elect to employ. These other actions constitute the altercontrol domain corresponding to the ACC function.

Clearly, the scope of concern of a Headway-only controller is confined to the immediate headway space and essentially represents that which an ACC controller is tasked to manage (even though a sophisticated ACC algorithm might have various features that anticipate curved paths, cut-ins, and so forth.) Whatever is the full scope of the system function, however, altercontrol by definition addresses everything else. Altercontrol includes, for example, all circumstances in which throttle and/or brake are modulated to enable passing maneuvers, to respond to traffic signals and signs, to interpret adjacent-lane movements and signaling which foretell cut-in or the converse case in which a preceding vehicle is anticipated to vacate its currently-impeding position by turning right or left when traffic clears. Altercontrol also includes a host of other cautionary tactics such as arise when the driver is uncertain about another vehicle's movements, when downrange vision is occluded by nearby vehicles, when construction zones deviate from lane-marking conventions, etc. etc.

Shown in Figure 1, the initial concept of altercontrol detection from [2] is illustrated. One begins with the longitudinal acceleration response, Ax_m (or Ax_{manual}), that was measured during actual operation of a radar-equipped test vehicle by a human driver. Then, a model of Headway-only control is run on the associated range, range-rate, and velocity data, yielding the continuous variable, Ax(H), that the Headway-only controller would have applied. The running difference between these two variables is plotted in the figure as the basis for detecting, along the time line, those incidents in which an altercontrol driving tactic was employed by the human driver.

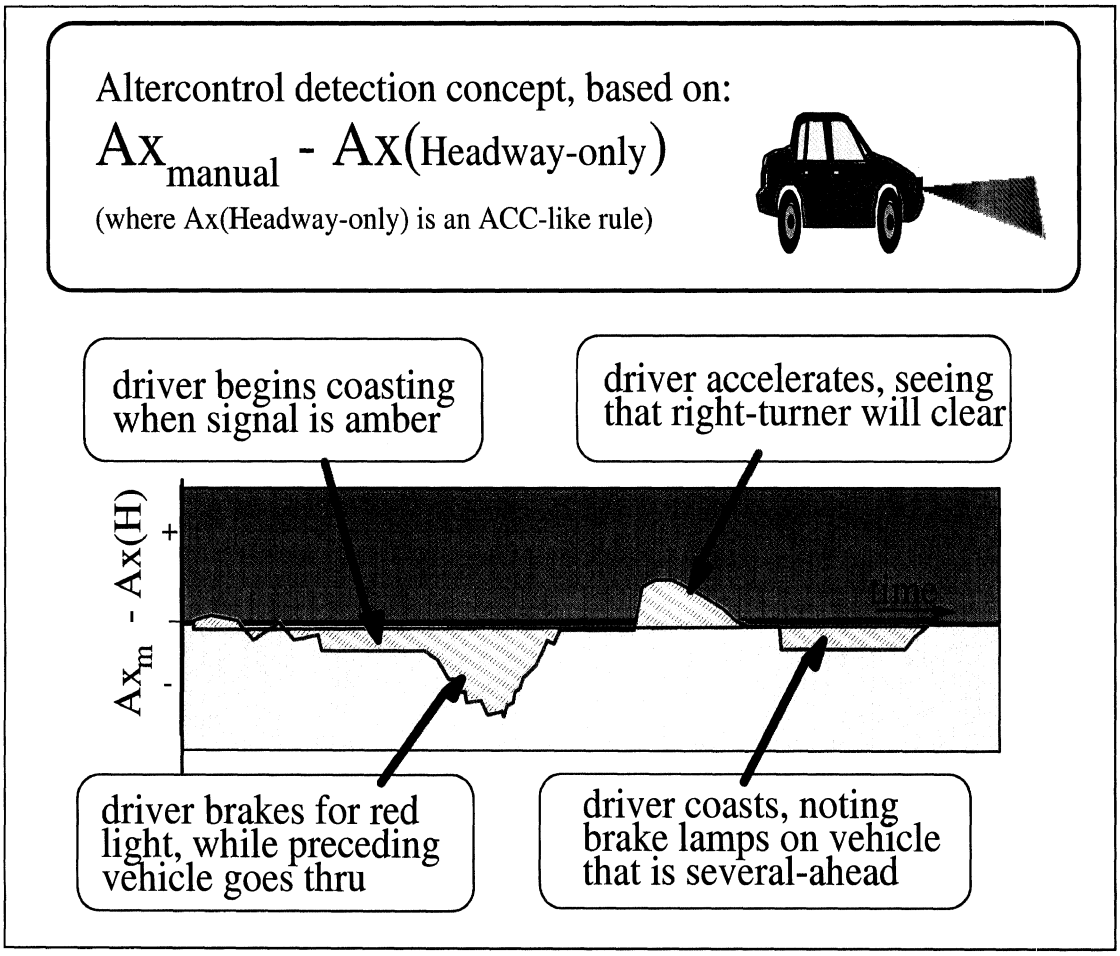


Figure 1. Detecting Altercontrol by the difference, model vs. manual

The figure illustrates a few example scenarios in which either positive or negative differences between the respective acceleration variables arise due to driver actions that address non-headway phenomena. Clearly, some of the example altercontrol situations would be distinctly related to driving safety while others are simply stylistic and discretionary to the individual. For example, the figure shows the following altercontrol scenarios, beginning at the left:

- The Ax_m value becomes more negative than is the acceleration level of the headway-only controller, since the actual driver elects to coast after observing a traffic signal light turning amber. Clearly, the driver's altercontrol tactic is to begin managing speed in response to the traffic control device to which, of course, the (H_{only}) controller is oblivious.
- The difference value grows abruptly more negative as the driver begins to brake for a red light, even though the preceding vehicle goes through the intersection. A rather crucial phase of altercontrol has set in, by which the driver's altercontrol response is critical to safety.
- The difference value goes positive as the driver proceeds toward a vehicle that is about to vacate the lane ahead by turning off of the roadway. Failure of a simple ACC controller to provide a comparable response may tend to frustrate some drivers and thereby discourage utilization. (The deliberate shortening of headway gaps by the driver in order to discourage cut-in behavior is another classical context in which positive differences in $[Ax_m - Ax(H_{only})]$ would arise.)
- Finally, at the far right, the driver releases the throttle and coasts, upon observing brake lamps illuminated on the vehicle ahead of the preceding vehicle. In this case, the driver exercises anticipatory manual control, using sensory information which a headway controller generally lacks.

The desire to experimentally detect moments of transition from H_{only} to altercontrol using data from a manual driving sequence has led, in this project, to a synchronized video means of observing altercontrol. Each observed event is then classified by type and graded to interpret its significance for customer satisfaction, safety, etc. The accumulation of a large quantity of altercontrol observations thereby reveals the relative frequency of occurrence with events of differing type.

In the Phase II project being reported here, altercontrol observations were implemented using an approach that differs computationally from that shown above in Figure 1, although the conceptual basis is the same. Whatever the mechanics of implementation, the intent is to obtain an orderly cataloguing of all driving activity, segregated according to that which a Headway-only controller would have done and that which a human driver actually did when driving manually. Clearly, the human actions reflect, among other things, constraints in human capability such as resolution in human visual perception, psychological judgment of headway risks, the primal reaction of the visual system to looming objects, and the psychomotor consistency/reliability of the human actor as a headway servomechanism. There are also intentional factors. For example, satisficing theory [3], [4] suggests that a substantial degree of control impression simply shows the person's sense of disutility in doing it better. The stylistic preferences of the individual also become directly expressed in one's altercontrol activity.

With the help of rigorous cataloguing and compilation of data of this kind, the possibility arises that in the future, cognitive modeling would seek to represent the decision patterns and control behavior observed when driving with ACC engaged. Insights from cognitive modeling may then stimulate innovative approaches in ACC system design that make its usage in Stop & Go driving more satisfying and less risky for the customer.

3.0 MODEL AND ALGORITHM

The objective of the model developed in this work was to identify the transition to altercontrol in a real-time driving process. The model does this by comparing driver pedal actions and acceleration/deceleration levels with a set of expected actions and accelerations that are assumed to be consistent with headway keeping. The intent was to discover as many altercontrol instances as possible. Given the developmental stage of the altercontrol concept and the relatively limited scope of sensory inputs, it was clear that not all altercontrol instances could be captured.

3.1 Basic System Structure

During the first phase of this study [2], a driver model for representing the task of forward-gap management in stop-and-go traffic was developed. The driver model from the first phase was based on perceptual boundaries drawn in the range versus range rate phase space, thus dividing it into zones. Each of these zones was associated with an expression that computed a commanded longitudinal acceleration. In conjunction with this driver model, a simplified model of longitudinal vehicle dynamics was devised, with the acceleration command as computed by the driver model used as its input. The longitudinal dynamic response was then computed to determine the vehicle's motion. Since the speed of the preceding vehicle was known as a function of time, range was a result of double integration. Such an integration scheme was (1) very sensitive to parameter settings, and (2) generated a cumulative error that built over time. When evaluated in the context of the planned testing (driving for 1.5 hours in regular traffic), these drawbacks demonstrated a significant hindrance on the ability to accurately identify altercontrol events in a timely manner.

In the previous study the motion predicted by the model was compared with actual driving data, demonstrating a good match with the measured results. This approach, however, was found to be insufficient for the purpose of detecting and flagging altercontrol events on-the-fly while driving an instrumented test vehicle in real-world traffic. A new approach, which employed an improved version of the driver model, was developed and adopted during this phase of the study.

3.2 Description of the Model-Based Scheme for Detecting Transitions

Manual driving is a highly complex process in the sense that it is very inconsistent. The driver's preferences regarding separation from the surrounding traffic and maneuvering within that traffic is rather fluid. The individual's attention and vigilance can change by the minute since driver actions are determined by a variety of possible inputs (e.g., traffic lights, navigation considerations, etc.). However, when it comes to the control of headway and of the longitudinal motion of the vehicle, existing driver models and empirical observations suggest that certain driving behavior can be assumed universal – unless special circumstances prevail. For example, drivers are expected to slow down as they get closer to another vehicle in their lane – unless they intend to pass. The underlying approach that was adapted for detection of altercontrol focuses on these universal-driving rules. If the driver deviates from these rules–that is, if the driver does not act according to what is assumed to be universal behavior for speed and headway keeping–he is then said to be motivated by altercontrol.

The model that was developed and implemented in this phase of the study is similar to its phase-1 predecessor, insofar as it divides the range versus range rate phase space into zones. However, in contrast to the earlier model, this version does not compute commanded acceleration values for each zone. Rather, it employs sets of expectations in these zones. Given the headway situation in terms of the location within the range versus range rate space, drivers are expected to act in a certain way (or conversely, there are certain actions that they are *not* expected to take). For example, when approaching another vehicle at a high closure rate, drivers are expected to slow down, not to accelerate.

For illustrative purposes, the difference between the models is depicted in Figure 2. This new model is discussed in detail in the next section.

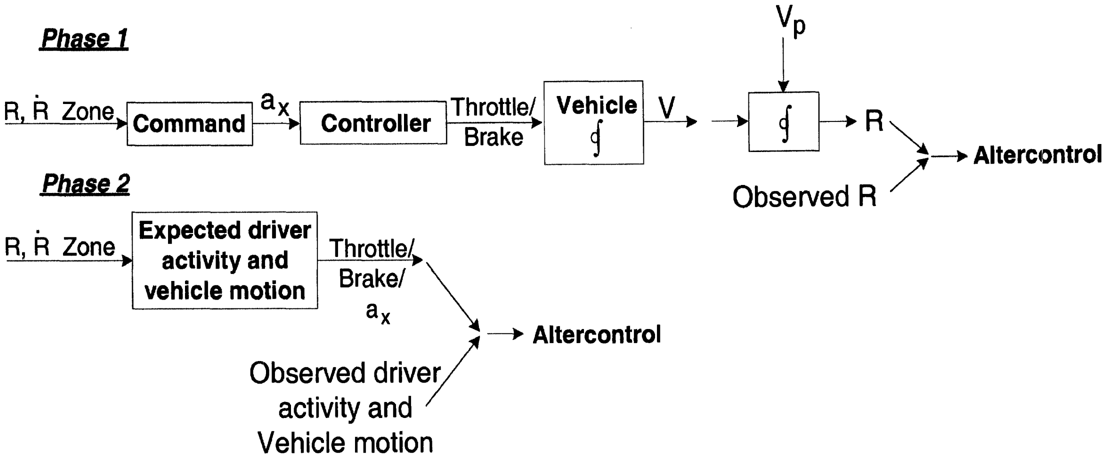


Figure 2. Difference between Phase 1 and Phase 2 models to detect altercontrol

The driver model for headway control that is used in this study is based on aspects pertaining to recognizing the driving situation. The range versus range rate phase space is a useful construct for purposes of depicting and analyzing these aspects. Perceptual boundaries that are drawn in that space define zones for which the universal control rules are applied. These zones and boundaries are depicted in Figure 3.

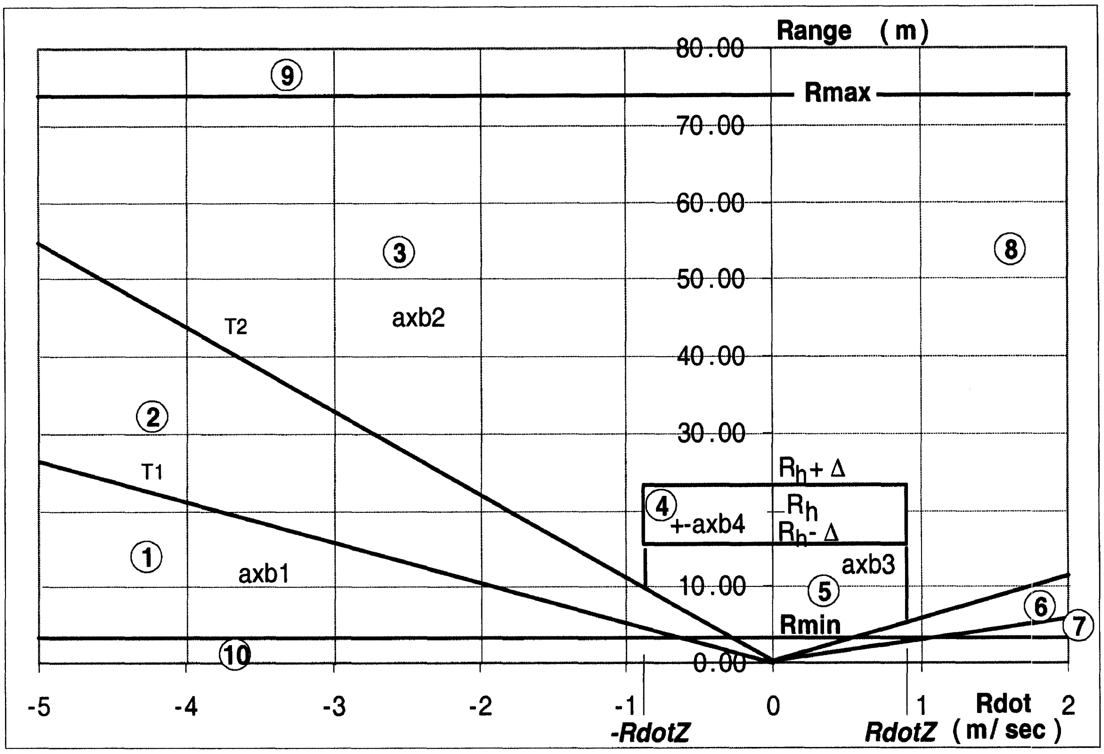


Figure 3. Zones in the range versus range rate space

This figure may be considered as a generic representation of the headway-control space: No matter what the conditions are, the range and range-rate to the target can be mapped into Figure 3 at any time that a preceding "target" vehicle exists.

The various zones numbered 1 through 10 in Figure 3 are defined in Table 1 below. These definitions are based on parametric values that are provided in Table 2. At each point in time, the range and range rate to the preceding vehicle is identified with a specific zone, thus determining (1) if a headway-control action in response to the observed target is expected and (2) the expected nature of such a control action. These expectations can be compared to an action that is actually taken by the driver to determine whether it conforms with such headway-control considerations, or whether the driver is more likely to be motivated by altercontrol considerations.

Table 1. Zone definitions and corresponding driver actions expected in headway control

Zone	Name and Description	Expected driver actions in headway control
1	***Potential danger zone***. This zone involves short headways that are combined with high closure rates (high negative values of $\dot{R}$). It is bounded from below by a minimum range value ($R_{\min}$), and from above by the sloped line T1. The slope of the upper line represents a constant value of time to collision (or time to impact – Tti).	(a) No displacement of the accelerator pedal. (b) Should brake if natural retardation is not decelerating the vehicle at least at the $axb1$ level.
2	***Rapid closing***. The following vehicle closes the gap on the lead vehicle at a rate that is considered too high to be consistent with headway control. Zone 2 is bounded from below by the sloped line T1, and from above by another sloped line, T2, whose associated value of Tti is greater than that corresponding to the line below.	No positive displacement of the accelerator pedal should be observed.
3	***Closing***. The gap between the vehicles is decreasing, typically at moderate closure rates (moderate negative values of $\dot{R}$), and the range is relatively long. This zone is bounded from above by some maximum range value ($R_{\max}$), and it covers the rest of the negative $\dot{R}$ region that is not covered by zones 1 and 2 (with the exception of a portion of zone 4, as depicted in Figure 3)	Acceleration should not exceed the defined positive value, $axb2$.
4	***Following***. The driver maintains a more-or-less constant headway time to the car ahead. In the typical case this state of following will also involve an approximately constant speed. The rectangular shape of this zone spans symmetrically about the estimated value of the driver's desired range (R_h): $\pm \Delta$ % of R_h vertically (along the range axis), and $\pm RdotZ$ m/sec horizontally (along the $\dot{R}$ axis).	(a) Should not use the accelerator pedal to accelerate at more than $axb4$. (b) Should not depress the brake pedal to decelerate at more than $-axb4$.

Zone	Name and Description	Expected driver actions in headway control
5	***Following too close***. The vehicle is traveling with a short range value, but without a significant level of range rate—that is $\|\dot{R}\|$ values are in the vicinity of zero ($\pm RdotZ$).	Acceleration should not exceed the small positive value, $axb3$.
6,7,8	***Separating***. The gap between the vehicles is opening ($\dot{R} > 0$). These zones are bounded by a minimum range value ($R_{\min}$), and a maximum range value ($R_{\max}$). The algorithm design provides for breaking down the separating region into three "sub-zones" – discriminating between separating under three proximity conditions. From the data obtained in this study, however, it was found that these sub-zones do not provide a significant contribution. The entire separating zone, therefore, is referred to hereafter as zone 8.	Should not be braking.
9	***Too close***. The range is below some minimum range value ($R_{\min}$), regardless of the range rate. It can be argued that any situation involving such short range values denotes altercontrol. Nevertheless, given the structure of this algorithm, no expectations or rules were established which pertain to this zone. In this study, test results did not include altercontrol observations in zone 9.	(—)
10	***Too far***. The reported target is beyond some maximum range value ($R_{\max}$), regardless of the range rate. It was assumed that altercontrol is generally not an issue when operating at long range.	(—)

As mentioned earlier, the boundaries in Figure 3 serve to delineate the respective zones according to a set of parametric values. In addition, the expectations listed in Table 1 are defined in terms of additional parameters. Thus, the algorithm design allows for great flexibility in setting up rules, zones, and expectations, serving the methodical approach for defining, detecting, and classifying altercontrol episodes. Following a pilot stage of study, the parametric values listed below in Table 2 were selected for use in testing. (Note that a_x is longitudinal acceleration of the host vehicle, and R_h is the assumed desired headway distance, as discussed later.)

Table 2. Parametric values used in the model

Symbol	Definition	Value
$axb1$	Minimum deceleration expected in zone 1	– 0.1 g
$axb2$	Maximum acceleration expected in zone 3	0.07 g
$axb3$	Minimum deceleration expected in zone 5	– 0.075 g
$axb4$	Maximum acceleration/deceleration expected in zone 4 (i.e., a_x is expected to be within $\pm axb4$)	0.1 g
AxZ	Tolerance on a_x defining an effectively constant speed motion	0.001 g
$R_{\min}$	Minimum range for considering altercontrol	4 m
$R_{\max}$	Maximum range for considering altercontrol	$\min(75\text{m}; 3R_h)$
$RdotZ$	$\dot{R}$ tolerance for bounding zones 4 and 5	±0.9 m/sec
Tti_1	Time to impact boundary between zones 1 and 2 (slope)	6 sec
Tti_2	Time to impact boundary between zones 2 and 3 (slope)	12 sec
Δ	R tolerance for bounding zone 4	±10% of R_h

The parameter $R_{\max}$ in Table 2 may deserve special attention, since it is the only one that is not either fixed or based on a linear relationship. Initially, $R_{\max}$ (which delineates zone 9 in Figure 3) was set to be fixed at 75 m. Pilot testing showed, however, that under low-speed conditions, a vehicle at a range of as little as 40 m ahead may be well beyond the headway-control considerations of the driver. Applying the altercontrol algorithm out to the 75 m range under such low-speed circumstances often generates “false detection” of altercontrol events. The two-valued definition of $R_{\max}$ as listed in Table 2 appeared to resolve this low-speed issue.

The rules by which the altercontrol algorithm evaluates how well the driver complies with the expectations at any given zone are listed in Table 3. Each of these rules is assigned a number, called *Control Indicator*, for convenient reference in the conduct of test driving and in the cataloging of data. Note that the names as they appear in Table 3 incorporate the parametric values of *axb*1 through *axb*4 from Table 2.

Table 3. Algorithmic control indicators to trigger altercontrol alert

Control Indicator	The Condition Indicating Altercontrol
0	Headway-control domain (i.e., altercontrol is not indicated)
1	Accelerator pedal applied, Zone 1
2	a_x>-0.1g & no brakes, Zone 1
3	a_x>0, Zone 2
4	a_x>0.07g, Zone 3
5	Accelerator pedal applied, a_x>0.1g, Zone 4
6	Brake pedal applied, a_x<-0.1g Zone 4
7	a_x>0.075g, Zone 5
8	Brake pedal applied in Zone 6
9	a_x<-0.2g, Zone 7
10	Brake pedal applied, Zone 8

Headway time is a critical variable for the evaluation of altercontrol. The desired range shown in Figure 3 is determined by $R_h = T_h \cdot V_p$, where T_h is the headway time, and V_p is the speed of the preceding vehicle. The detection of altercontrol in Zones 4, 3, and 5 is directly affected by the driver's choice of a preferred headway. Furthermore, under manual driving conditions, the preferred headway time is not a constant but depends on the traffic conditions, the driver's urgency to arrive at the destination, the driver's emotional state, etc. Therefore the concept of determining one useful value for T_h that could be used throughout a natural-driving test, while seeking to capture altercontrol activity, seems unreasonable. Accordingly, an adaptive scheme for continuous determination of T_h was developed as outlined below.

Algorithm for T_h: A special algorithm whose objective is to estimate the driver's current preference of headway-time setting was developed. This algorithm constantly operated in the background as the vehicle was driven, determining on-the-fly, the T_h value that would be used in the altercontrol algorithm. For this adaptive-T_h strategy, a two-second data buffer was kept in memory and it was constantly updated at a 10-Hz rate. At each computational cycle, the following criteria applied for gathering R and V_p data into the buffer (see definitions of parametric values in Table 2):

- the data pertains to a consistent target (no new target appeared, as described below)
- all speed (V) data is above the minimum speed ($V_{\min}$) of 5 kph
- all speed (V) data is less than an estimate of the driver's preferred speed, V_{set}, as is described below
- all $\dot{R}$ data is between $\pm RdotZ$, and it includes both $\dot{R} > 0$ and $\dot{R} < 0$ values
- all R data is less than $R_{\max}$
- the average acceleration, $\overline{a}_x$, that prevailed over the 2-second buffer window falls between $\pm AxZ$
- the brake pedal is not applied

When all of the above conditions are satisfied, the algorithm computes the average T_h value based upon the buffer data (R / V_p), and the resultant value is used in the altercontrol algorithm. Each time a new T_h is updated, the data buffer is emptied (reset). A default value of T_h equal to 1.4 sec., was used from the time that the car was started up until a new T_h was established by the algorithm for the first time.

The adaptive headway algorithm described above makes reference to two operative variables that must also be established before T_h can be determined: i.e., New-target, and V_{set}. Both of these variables are also evaluated in a continuous manner, as described below.

New-target algorithm: "New-target," as the name implies, is an indicator that the radar has switched to operate on a new target. This is the case when a vehicle cuts-in in front of the host, or when the host changes lanes and follows another vehicle. The altercontrol algorithm uses this indicator to reset certain evaluation processes that are relatively long-term (e.g., T_h adaptation), each time a new target appears. Also, the New-target indicator allows the altercontrol algorithm to bridge across abrupt transitional dynamics, as well as to filter out momentary targets that might be false detections.

The New-target algorithm considers the three most recent range readings of the current target. It then applies an rms linear-fit algorithm to the three points and evaluates the actual deviation of the last range reading from this linear fit. If the deviation of the current range is beyond ±0.5 m of the linear fit, the new-target indicator is set to "1", and the process repeats itself. Obviously, the first two data points following a new target are always zero.

Algorithm for V_{set}: Open-road speed, or V_{set}, represents the speed that the driver appears to prefer, given no impeding vehicle ahead. In an ACC operation, or even with conventional cruise control, when the driver hits the "set" button the open-road speed is set. Under manual-driving conditions, however, some automated procedure is needed if the altercontrol algorithm is to determine a manual equivalent to V_{set}.

Similar to the T_h algorithm, the V_{set} algorithm was constantly computed in the background as the vehicle was driven. The computation yields a continuous 'on-the-fly' value of V_{set} for use in the altercontrol algorithm. Basically, a four-second data buffer of the host velocity signal, V, is updated at each (0.1 sec.) computational cycle whenever the following conditions are satisfied:

- the velocity value, V, is above the minimum speed of 5 kph
- the range value, R, represents either no target in view or $R > R_{\max}$
- the average acceleration value, $\overline{a}_x$, in the buffer is within $\pm AxZ$
- the brake pedal is not applied

When all the above conditions are satisfied, the algorithm computes the average speed, V, across the four seconds of buffer data, and the resultant value is then used in the altercontrol algorithm as V_{set}. There is a special case in which V_{set} is determined by an alternative process. That is, regardless of the above conditions, at any given time that the vehicle's speed, V, exceeds the current value of V_{set}, the open-road speed gets updated instantaneously. For example, if V_{set} was determined to be 32 mph and the driver accelerates above that level, the value of V_{set} is "latched" to the current speed, V, and rises with it.

As a summary of the model description, Figure 4 provides an overall view of the altercontrol algorithm flow. The box labeled "data" in the figure represents a signal-conditioning process that was performed at each time step:

- a fixed offset correction is applied to the longitudinal acceleration data
- the range data are calibrated by a given linear function (the Radar provided data in reference to the vehicle's CG rather than to the front bumper)
- the Radar data contained the speed of the preceding vehicle (V_p) rather than the range rate to the target ($\dot{R}$).

After processing the input data and evaluating the operative variables (New-target, T_h, and V_{set}), the algorithm maps the target position as defined by its range and range-rate coordinates, into a specific zone (according to Figure 3). The driver's momentary control actions are then evaluated per the expectations outlined in Table 1, followed by a determination of whether these actions constituted altercontrol or headway control.

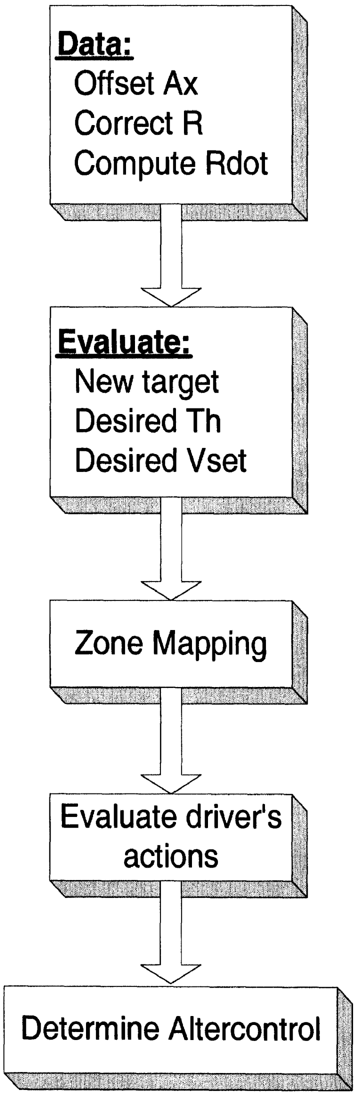


Figure 4. Altercontrol algorithm flow

4.0 TEST METHOD

The basic approach used to study altercontrol was to gather data on natural driving behavior in as unobtrusive a fashion as possible under conditions in which altercontrol was most likely to be observed. The data were then examined to determine if episodes of altercontrol exhibited common patterns within and across drivers that could be associated with either driver strategies or driving scenario. In particular, we were interested in determining *what* information, apart from lead vehicle range, drivers routinely use in driving, and *how* they use it. The approach is similar, in some respects, to other work comparing ACC simulation to naturalistic driving [1], but differs in its specific examination of episodic deviations from range-based headway control.

Data were gathered using an instrumented vehicle that recorded vehicle parameters synchronized with video recording of the forward roadway scene along with "on-the-fly" detection of instances of altercontrol while the car was driven. The system enabled close examination of both video records and vehicle characteristics for each detected altercontrol event. At the discretion of the accompanying experimenter, supplemental observations could also be added to the data stream to clarify altercontrol situations that might be ambiguous. The experimenter marked such annotations in the data stream with the use of a *mark-data* button that set a flag in the data so that his comments could be retrieved and associated with the proximate event.

To illustrate the practical use of such annotation, we offer an example. Suppose another vehicle approaches in an adjacent traffic lane into which the host driver is considering moving. The approaching vehicle could influence the host driver's lane change behavior by imposing a deadline or gap-constraint on the timing of the lane-change maneuver. The present instrumentation system, blind to rearward approaches, would fail to note this condition without the observational assistance provided by the experimental observer. Thus a key role played by the experimenter in the test method was to provide additional support in identifying the relevant factors precipitating an altercontrol incident.

Route constraints. To investigate the circumstances in which a driver departs from conventional range-based headway control, we selected a route whose traffic conditions would likely provide useful data. Altercontrol, by definition, is the use of alternative vehicle control strategies in situations where range management is an existing issue. Consequently, to maximize car-following opportunities, we targeted dense traffic conditions.

We preferred, as well, to control the number of potential altercontrol scenarios that might be observed in order to improve our chance of observing different drivers in similar situations. Stop and go traffic conditions were also targeted on both limited access highways and on arterial roadways in keeping with prior research. In general, the roadways investigated here offered a limited range of maneuvering opportunity—most maneuvers were prompted by lane changes—while ensuring there would be ample opportunity to engage in car-following.

4.1 Adaptation of the Test Vehicle

The vehicle that was used as the test platform in this study was a 1998 BMW model 750iL. This vehicle (see Figure 5) was provided by the BMW R&D Center of North America already instrumented and equipped to operate with a prototype adaptive-cruise-control system. The system employed a Bosch radar sensor that was installed under the right-hand side of the front bumper (shown in the insert in Figure 5). Though the ACC system by itself was not a feature that was needed for the purpose of this study, it provided the supporting infrastructure for data measurements and communication. That is, signals such as speed, brake, throttle, and the radar information required for ACC were thereby available on a CAN bus for application to the detection of altercontrol in this study.

Figure 5. The test vehicle

For video equipment, BMW had already installed a forward-looking video camera (model Watec WAT-202B auto iris, with a COSMICAR/Pentax TV lens series GX with a fixed focal length of 6mm). It was mounted behind the windshield, by the rear-view mirror (see Figure 6).

Figure 6. Forward-looking video camera

The experimental nature of the already-installed instrumentation was clearly not as robust as a production system and the availability of technical support was rather limited. As will be discussed later, the system quit operating during an advanced stage of the testing, resulting in less data collection than had been planned.

This section describes three aspects of the vehicle adaptation: (1) the data acquisition system (DASys) installed by UMTRI, (2) mechanization of the altercontrol algorithm, including details of the altercontrol observation system, and how it was integrated into the DASys, and (3) the observer's interface.

4.1.1 UMTRI Data Acquisition System

An interactive DASys package was constructed and installed in the test vehicle by UMTRI. Data were collected from three sources: (1) BMW's instrumentation computer, (2) digital video recorder, and (3) experimenter's input. The investigator was able to log and provide audio annotations during the test runs. After a test drive, the collected data was transferred via ethernet to a database server for analysis.

Figure 7 provides an overview of the data acquisition system design. The items in the figure that are particular to the mechanization of the altercontrol algorithm and to the observer's interface will be discussed in details in sections 4.1.2 and 4.1.3.

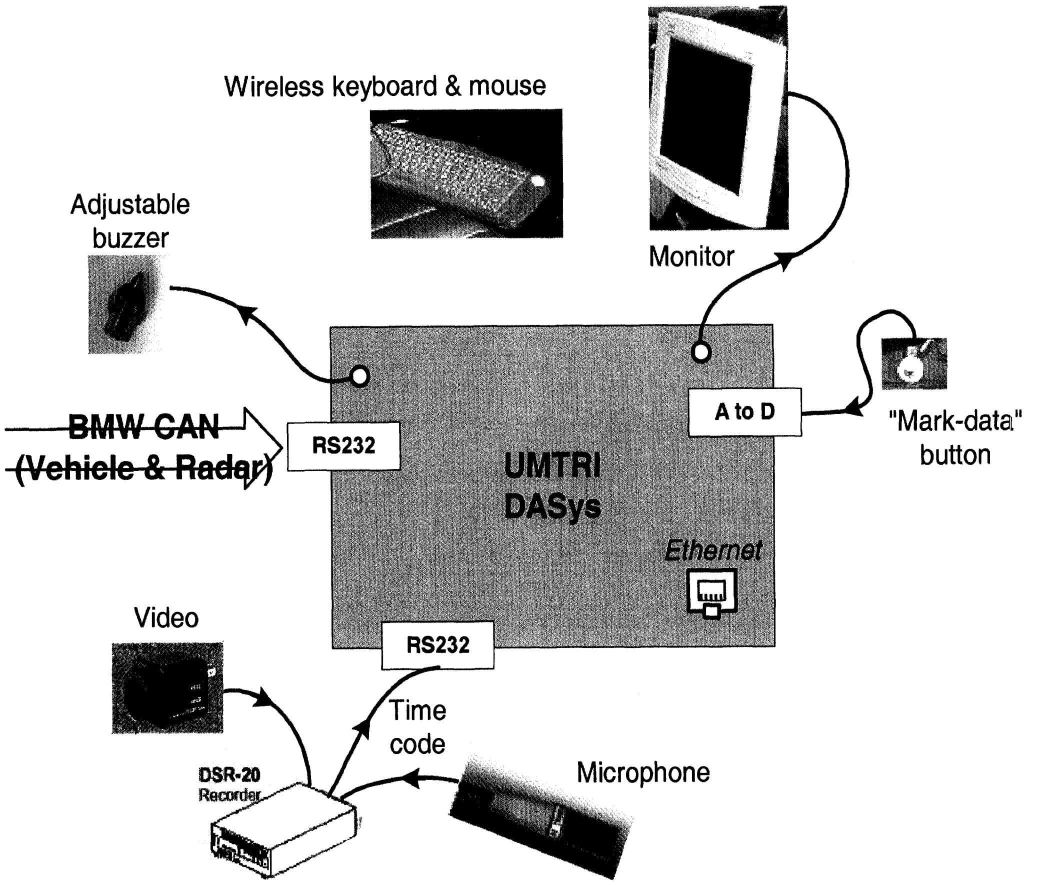


Figure 7. Data acquisition system overview

The DASys package handles data collection and logging tasks while also serving as the computer host for UMTRI's implementation of the altercontrol algorithm (see next section). The DASys computer is an EBX Form-Factor CPU with a Celeron processor and PC104 expansions for a CAN controller card and a D/A converter. The DASys package size is approximately 10" x 8" x 8" and was mounted on top of BMW's instrumentation computer in the trunk (see Figure 8). A monitor and keyboard were installed in the front-seat area for use by a researcher driving the vehicle during the development stages. During the actual testing, the monitor and keyboard were mounted in the area of the rear seat—the position taken by the researcher during actual data collection (see section 4.1.3).

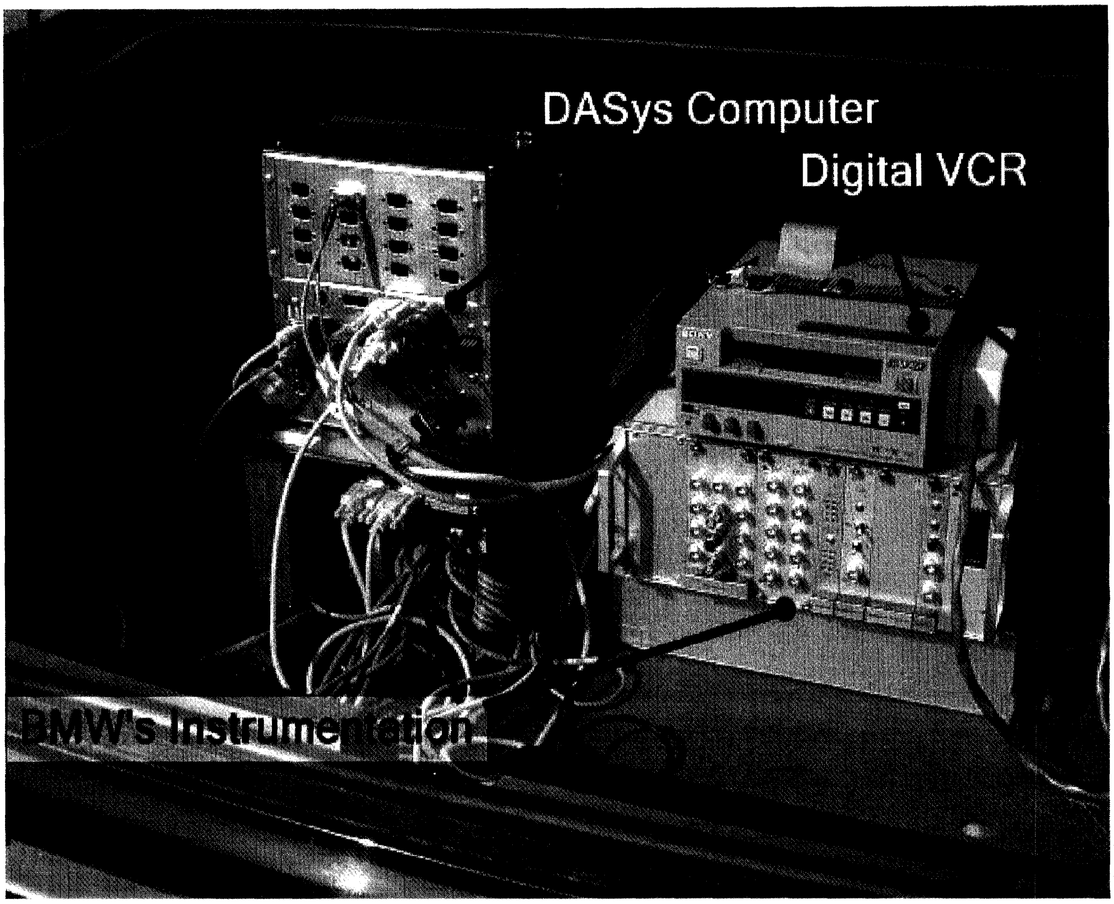


Figure 8. DASys and instrumentation in the trunk

The forward-scene video signal was recorded on a digital VCR (model Sony DSR-20) that was mounted in the trunk. Audio recording of the experimenter's comments employed the same recorder via an amplified microphone. The time-code signal from the digital VCR was recorded by the DASys computer, which allowed an accurate cross-reference between the data and the video during the analysis.

The DASys received data messages from BMW's instrumentation computer at 10 Hz. This includes 8 variables that are available from the CAN bus and 3 from the radar (see Table 4). In addition, 11 variables associated with UMTRI's implementation of the altercontrol algorithm were recorded (see Table 5). Only the ACC-operable radar track was selected for use in this study, from among all the available radar information. When conducting the altercontrol testing, the data were logged onboard as two binary files. Upon return to the lab, the files were uploaded into a *Microsoft*® Access database for later analysis.

Table 4. Signals from the BMW computer

No.	Signal	Scale/Units
1	Brake pressure	0 – 1
2	Velocity	m/sec
3	Steering angle	deg
4	Throttle position (Engine)	0 – 1
5	Accelerator pedal position	0 – 1
6	Longitudinal acceleration	m/sec^2
7	Yaw rate	rad/sec
8	Turn signal	0 – inactive, 2 – left, 4 – right
	Target data from radar (one target):	
9	Range	m
10	Velocity of target	m/sec
11	Azimuth	rad

Table 5. Signals from UMTRI's altercontrol algorithm

No.	Signal	Scale/Units
1	Test time	1,2,3,... (count, each represents 0.1 sec increments)
2	Free-lane velocity setting (V_{set})	m/sec
3	Longitudinal acceleration (corrected)	m/sec^2
4	Range rate	m/sec
5	Range (corrected)	m
6	New-target	0 or 1
7	Headway time setting (T_h)	sec
8	Zone	an integer between 1 and 10
9	Buzzer	0 or 1
10	Reason	an integer between 1 and 10 (the control indicator from Table 3)
11	Frame counter	an integer representing the time code from the VCR

4.1.2 Mechanization of an Altercontrol Observation System

Identifying altercontrol events, as defined earlier, is based on observing deviations from a set of assumptions regarding what the driver will do under various conditions to maintain headway. In concept, altercontrol is *any* action taken by a driver where the headway to the immediately-preceding vehicle is not the sole consideration. Given the exploratory nature of this research, any algorithm that is aimed at automatically detecting such altercontrol behavior by the driver is likely to incorrectly label some events as altercontrol, as well as to miss the detection of other true-altercontrol events. To maximize the capture of true events and to supplement the data processing following the test drive, the experimental design involved an observing researcher as a passenger during the drive. The interactive altercontrol observation system provided the researcher with feedback regarding altercontrol events it detected, and allowed the researcher to provide additional input. The interactive elements of this system are depicted in Figure 7.

The altercontrol algorithm described in section 3 was programmed and integrated into the data acquisition software. The program flow (see Figure 4) flags an event thought to likely be altercontrol. If the algorithm determines that the driver's control action falls outside of the domain of strict headway control, then the altercontrol notification is activated, alerting the researcher via a short buzzer tone that was inaudible to the driver. In addition, the state of several other variables, operative parameters, and settings (e.g., range, T_h, etc.) was displayed for the researcher to see.

In support of altercontrol documentation, special provisions were made to allow the researcher to provide his/her own supplemental observations and annotations during the drive. A microphone continuously recorded comments made by either the driver or the experimenter, and a *mark-data* button made it possible for the observer to set a flag in the data at any arbitrary moment. This flag facilitated immediate access to the pertinent data (time history, video, or voice) during data analysis activities.

4.1.3 Observer's Interface

Figure 7 shows the five elements that comprise the observer's interface: (1) a wireless keyboard/mouse, (2) a monitor, (3) a microphone, (4) a *mark-data* button, and (5) a buzzer. These elements were installed in the area of the rear seat, so that the researcher could monitor the driver, the driving process, the altercontrol monitoring system, and record audio comments in a way that was transparent to the driver.

A general view of the experimenter's station in the rear seat is provided in Figure 9. In addition to the microphone and the *mark-data* button that are highlighted, the figure shows the wireless keyboard/mouse, and the LCD computer monitor as it was mounted to the back of the front passenger seat. The buzzer with its adjustable volume control was mounted by the experimenter's headrest (see Figure 10). With this arrangement, the buzzer was audible to the researcher but not to the driver.

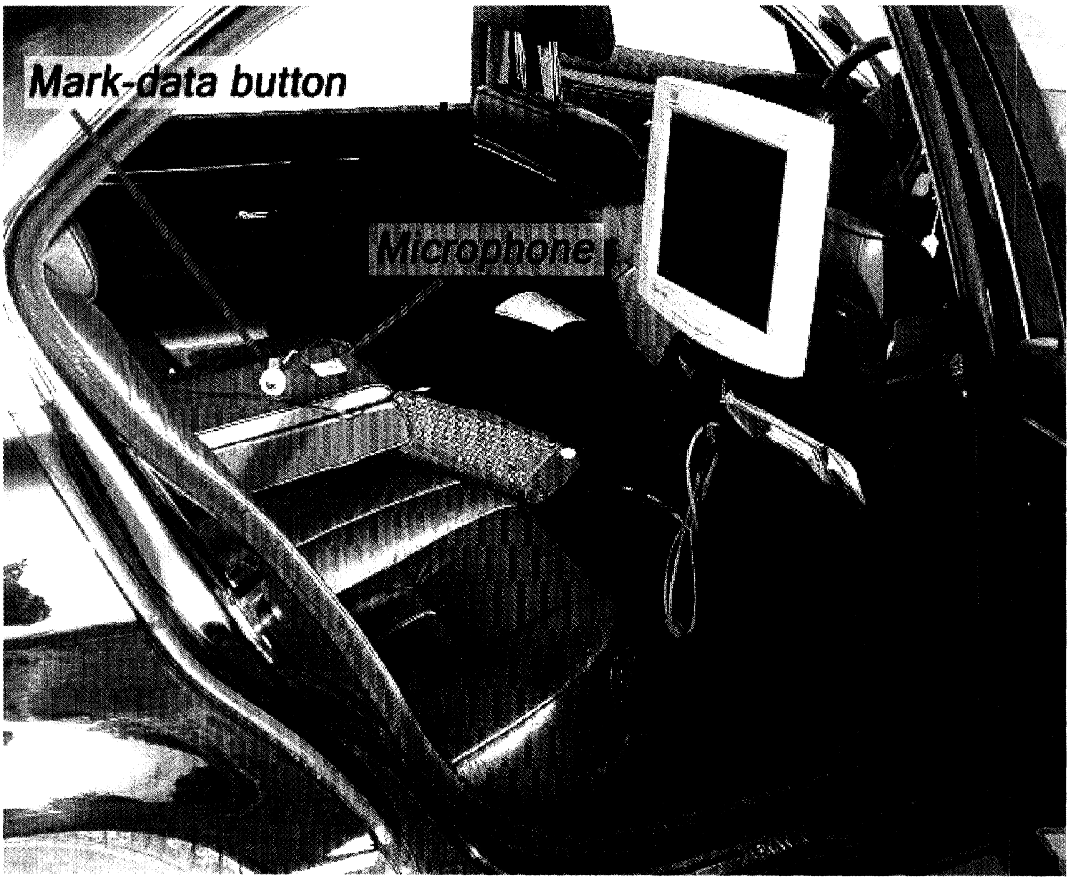


Figure 9. Experimenter's station

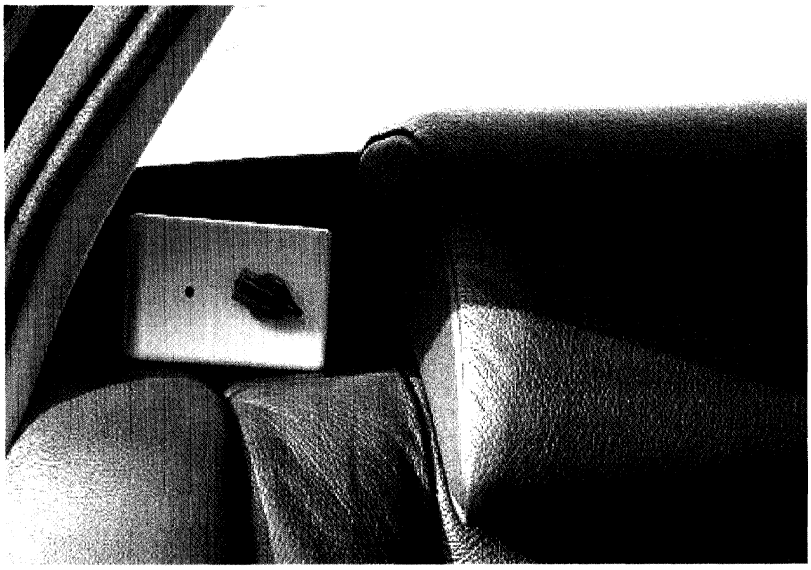
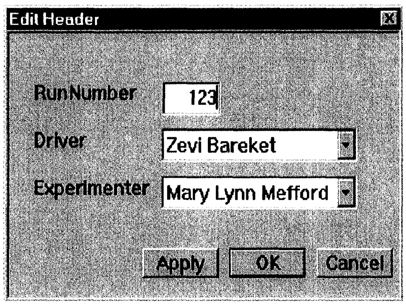


Figure 10. Adjustable buzzer installation

At the beginning of each test, the test-control software wrote a test header. This header included basic information regarding the driver, experimenter, and an identifying sequential number of the test, as provided by the experimenter via a dialog box with pull-down menus (e.g., Figure 11). Once the test started and the DASys was actually saving the data, the time history data were written to a file identified by the run number.



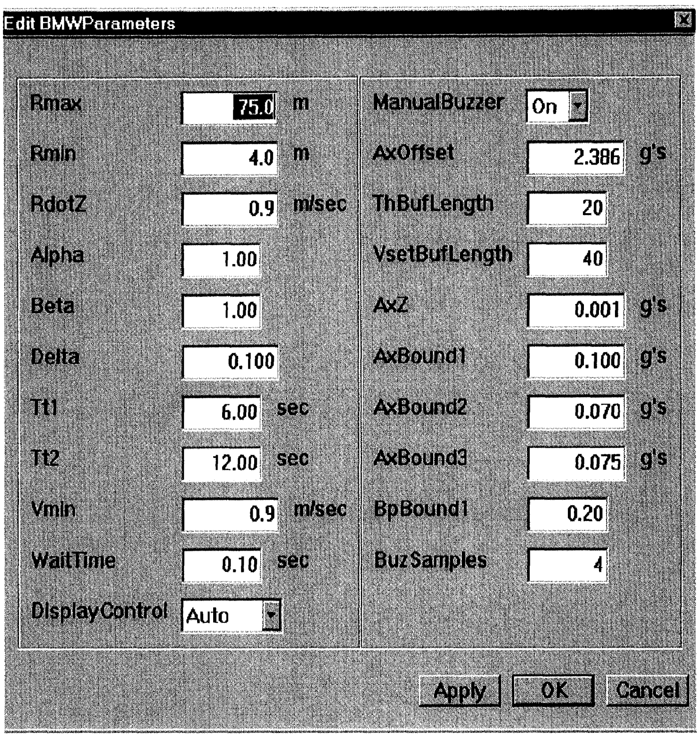
RunNumber 123

Driver Zevi Bareket

Experimenter Mary Lynn Mefford

Figure 11. Test header information

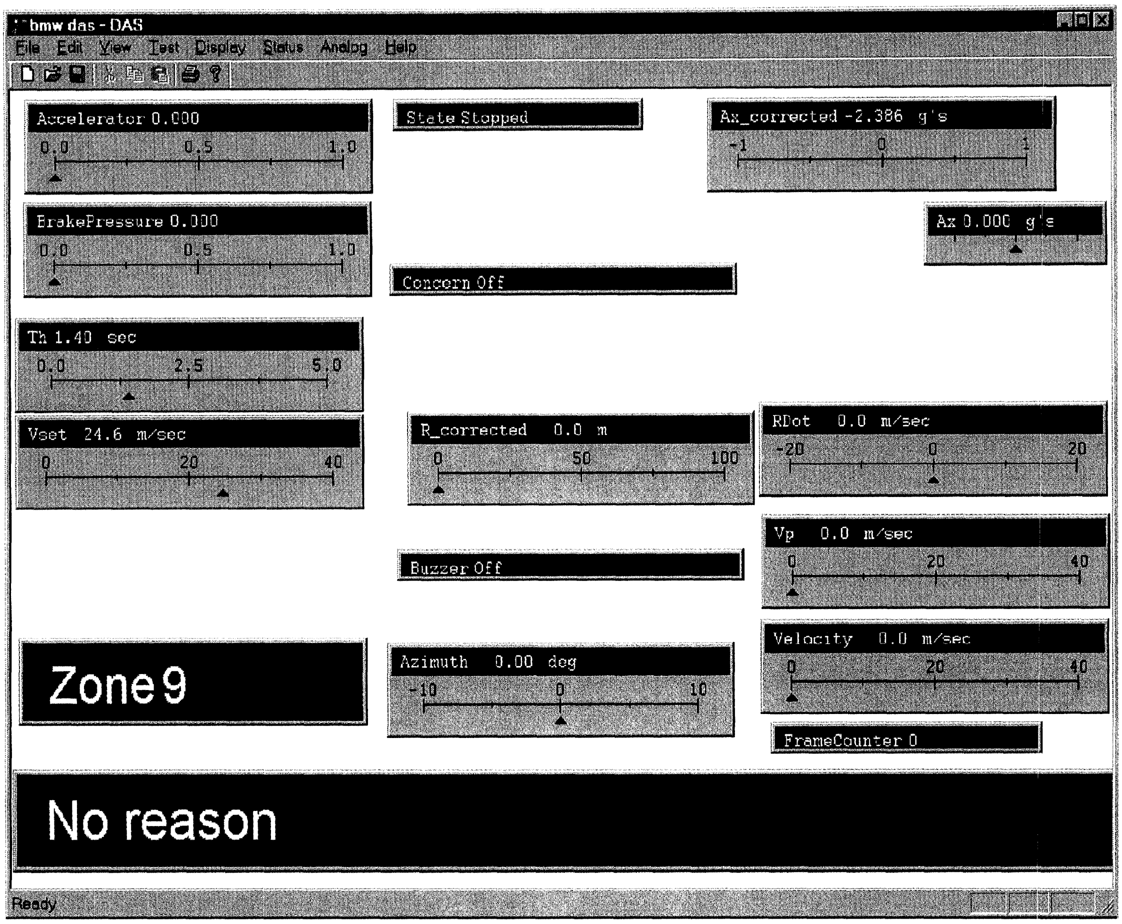
The altercontrol algorithm employed an array of parameters during its operation (see section 3.2). At any given moment during the test, it was possible to change the value of any of these parameters. However, unlike the procedure requiring the setting of run number, driver, and experimenter identifications, the researcher did not *have* to set these parameters each time. Instead, the program retained the most-recent values of its settings, and it defaulted to them until they were modified. The dialog box interface for setting the parameters of the altercontrol algorithm is shown in Figure 12.



Rmax	75.0	m	ManualBuzzer	On	
Rmin	4.0	m	AxOffset	2.386	g's
RdotZ	0.9	m/sec	ThBufLength	20	
Alpha	1.00		VsetBufLength	40	
Beta	1.00		AxZ	0.001	g's
Delta	0.100		AxBound1	0.100	g's
Tt1	6.00	sec	AxBound2	0.070	g's
Tt2	12.00	sec	AxBound3	0.075	g's
Vmin	0.9	m/sec	BpBound1	0.20	
WaitTime	0.10	sec	BuzSamples	4	
DisplayControl	Auto				

Figure 12. Parameters setting dialog box

During the test drive, the experimenter could observe the state of the data acquisition system, a selected suite of variables, operative parameters, and the explicit output of the altercontrol algorithm on the monitor. Figure 13 provides a snapshot of the computer screen as viewed by the researcher. The information content of the display could be modified at any time by removing some of the gauges, or alternatively, by selecting other gauges or information for display. After the pilot testing, the display configuration shown in Figure 13 served as the altercontrol observation system.



Accelerator 0.000

BrakePressure 0.000

Th 1.40 sec

Vset 24.6 m/sec

State Stopped

Concern Off

R_corrected 0.0 m

Buzzer Off

Azimuth 0.00 deg

Ax_corrected -2.386 g's

Ax 0.000 g's

RDot 0.0 m/sec

Vp 0.0 m/sec

Velocity 0.0 m/sec

FrameCounter 0

Zone 9

No reason

Figure 13. Data acquisition system display

4.2 Protocol for Concurrent Observation During Manual Driving

The method and procedure described below was devised to meet an exploratory agenda with a principle goal of determining the feasibility of a method for detecting normal examples of drivers engaged in *altercontrol* maneuvers. To accomplish this, a decision was made to impose no constraints on the participating drivers apart from the selected route, the vehicle, and the departure time. Although an experimenter was present throughout the drive, he or she merely acted to supplement the data record.

4.2.1 Basic Test Procedure

Subjects. Five drivers, between the ages of 23 and 56 (average age, 42.8) were asked to drive a predefined route through the Detroit metropolitan area and environs. There were three female and two male drivers. All were licensed drivers with at least 5 years driving experience. None of the drivers had specific knowledge of the objectives of the research project. The number of subjects was fewer than intended due to hardware failure during testing.

Procedure. Drivers were advised that they were participating in a study to investigate normal driving behavior during rush-hour traffic conditions. Drives were initiated during the morning rush hour for three of the drivers (7:00 to 9:00 am) and during the evening rush hour (4:00 to 6:00 pm) for the other two drivers. Drivers were briefed by the experimenter on the route and advised that they would be alerted to upcoming exit and entrance ramps.

An experimenter accompanied each subject throughout the 1.5-hour drive, seated in the rear, behind the front passenger seat. When an altercontrol episode was detected by the instrumentation, a quiet high-pitched beep was sounded near the experimenter's ear. To mask this audible cue from the driver, recordings of light piano music were played continuously in the front of the car. The music was also used to discourage verbal communication between the driver and experimenter to minimize potential distraction to the drivers.

4.2.2 Driving Route and its Traffic Characteristics

The constraints that the driving route include stop-and-go traffic and that the drive not last more than 2 hours dominated the route selection. Weekday Detroit metropolitan traffic conditions were monitored for two weeks prior to the start of the study during the morning and evening rush hour to find highways which routinely exhibited high-density traffic. These observations were confirmed by the Michigan Department of Transportation. From these candidate roadways, we selected the nearest one, the Southfield Freeway (M-39).

Distinct morning and evening routes were devised which included four freeways (M-14, I-96, M-39/Southfield, and I-94) and one divided arterial roadway (US-24/Telegraph road) in the Detroit metropolitan area (see Figure 14 and Figure 15). The morning route was 75 miles (120 km) long and typically started at 7:00am in order to meet the regular congestion period on the Southfield Freeway at approximately 7:45 am. The evening route was 83 miles (133 km) long and typically started at 4:00 pm to meet the Southfield congestion at approximately 4:45 pm. Table 6 and Table 7 detail the annual average 24-hour traffic volumes for the various road sections of the selected routes.

The routes contain three basic kinds of traffic: dense freeway traffic moving at posted speeds (I-94, M-14, I-96), dense freeway traffic either exhibiting stop and go traffic or traffic below posted speed limits (M-39/Southfield), and dense surface arterial traffic regulated by traffic control devices (US-24/Telegraph Road).

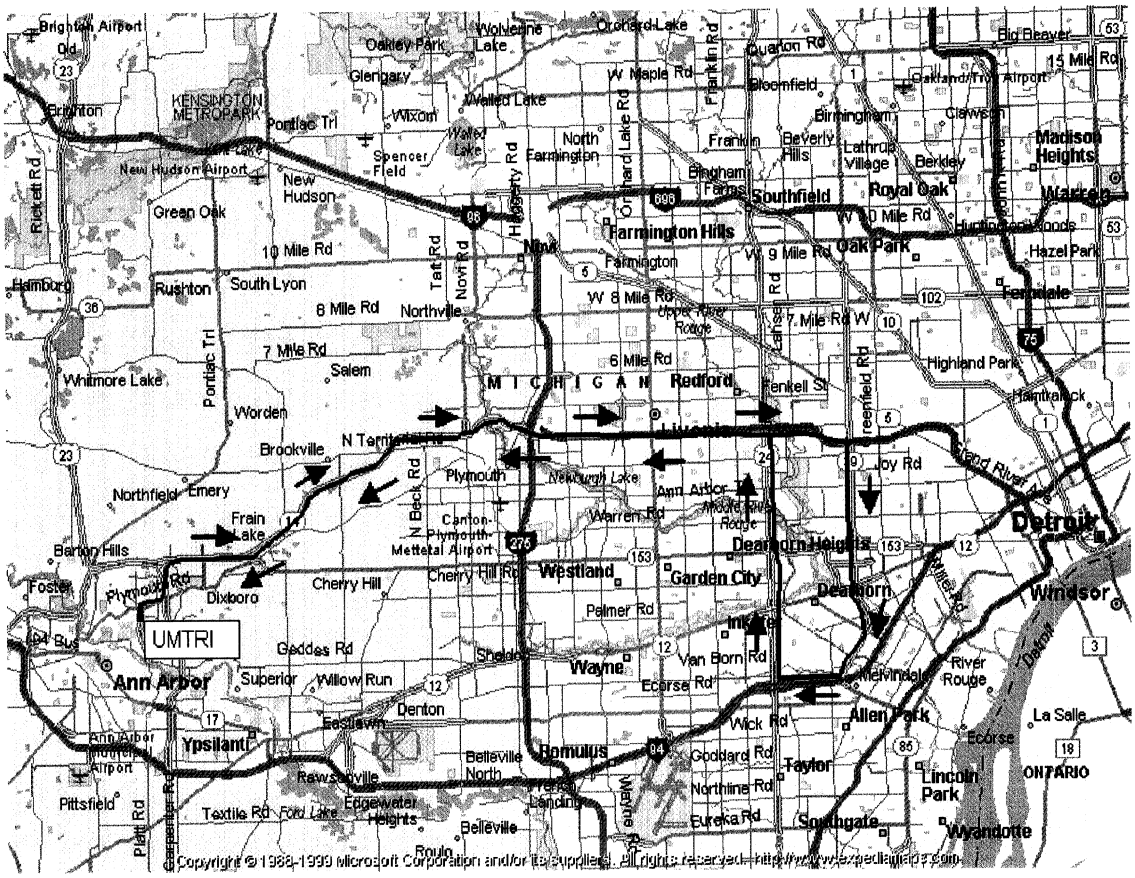


Figure 14. Morning rush-hour route

Table 6. Annual average 24-hour traffic volumes for the selected morning rush hour route (Michigan Department of Transportation, 1999)

Segment	Average Volume
US-23 (North)	51,000
M-14 (East)	50,300 - 84,200
I-96 (East)	142,000 - 184,000
M-39 (South)	88,100 - 161,000
I-94 (West)	153,000
US-24 (North)	60,200 - 76,300
I-96 (West, return)	142,000 - 184,000
M-14 (West, return)	50,300 - 84,200
US-23 (South, return)	51,000

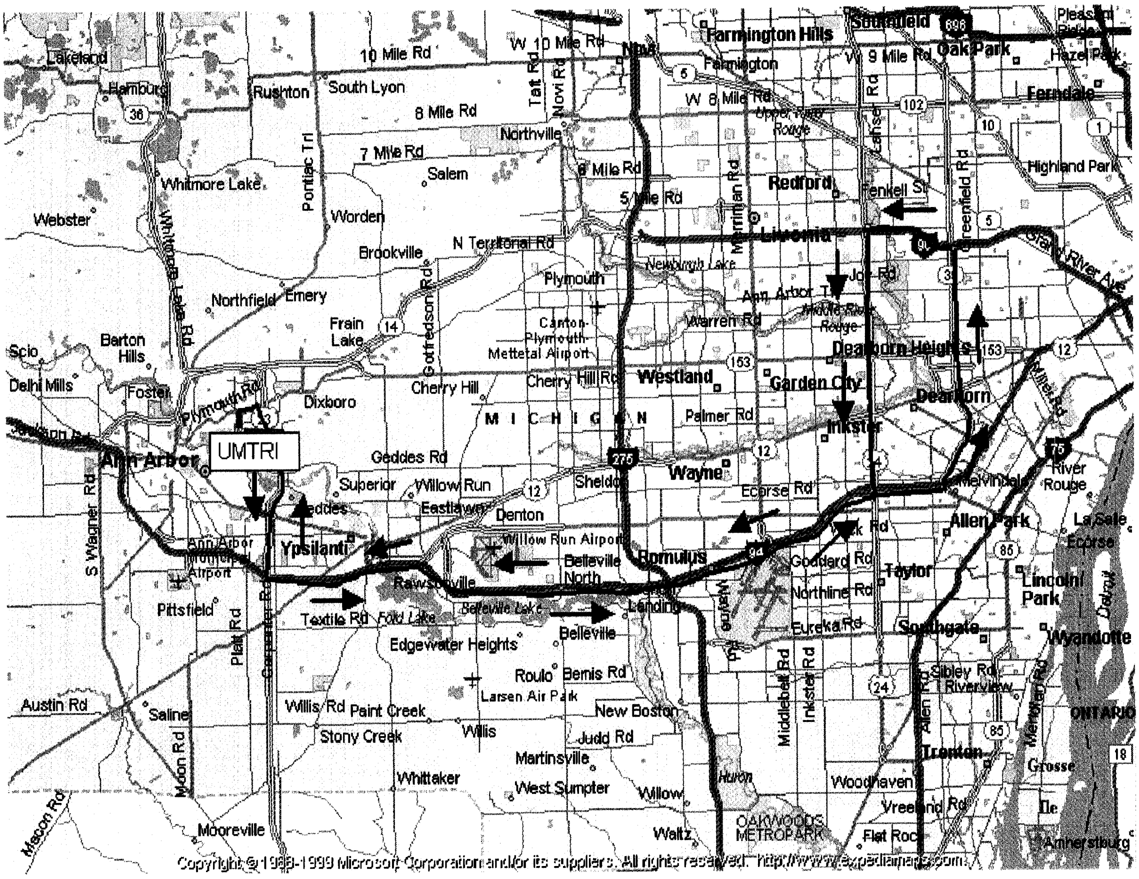


Figure 15. Evening rush-hour route

Table 7. Annual average 24-hour traffic volume for selected afternoon rush-hour route segments (Michigan Department of Transportation, 1999)

Segment	Average Volume
US-23 (South)	66,400 - 87,200
I-94 (East)	76,600 - 139,000
M-39 (North)	88,100 - 161,000
I-96 (West)	174,000 - 181,000
US-24 (South)	60,200 - 76,300
I-94 (West, return)	76,600 - 139,000
US-23 (North, return)	66,400 - 87,200

5.0 TEST RESULTS

5.1 Overview of the results

This section presents results from tests conducted per the procedure and methodology described in section 4.2 above. The results represent normal driving by five individuals in rush-hour traffic (morning and afternoon) along the route described in section 4.2. The total distance driven by the five participants while the altercontrol algorithm was "observing" and providing feedback to the experimenter was 491 km (307 miles). The mean overall speed during that period was 25 m/sec (90 kph, 56 mph).

The following figures provide overview statistics of the data from which the results in this section were derived. Figure 16 depicts the speed distribution as the percentage of time spent in any given speed range, for all the drivers. The data presented in Figure 16 pertain only to driving time during which the host vehicle's speed and the range-to-target were within the domain of the altercontrol algorithm (see section 3). Three main speed categories may be observed in the figure:

- Low speed ($V \leq 58kph\,(35mph)$), which covers the stop-and-go operating range. Drivers spent 20.1% of their time in this condition.
- High speed ($V \geq 101kph\,(63mph)$), which covers the non-congested highway operating range. Drivers spent 61.5% of their time in this condition.
- Medium speed ($58 < V < 101kph\,(35 < V < 63mph)$), which may be considered as covering the operating range of congested highways and non-congested arterials. Drivers spent 18.4% of their time in this condition.

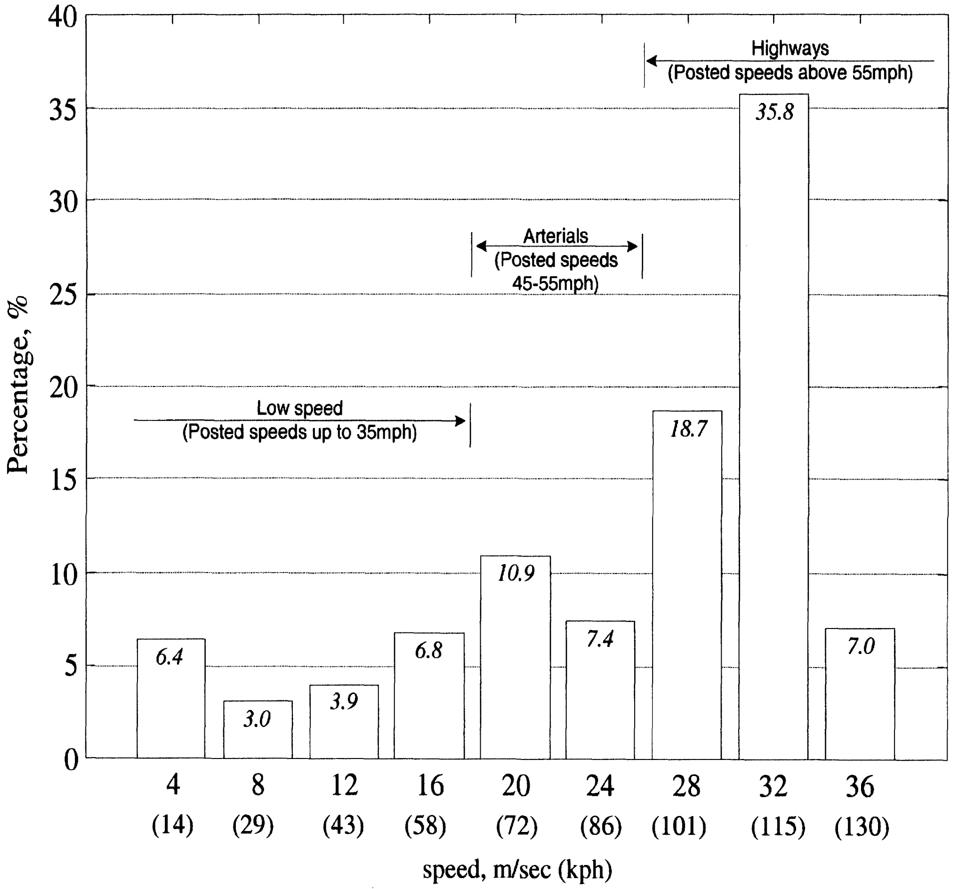


Figure 16. All-drivers speed histogram

Another measure which is indicative of the route traffic and conditions for altercontrol observation is the headway time (R/V), or headway-time margin (T_h). Two quantifiers can be considered in this context: One, the value of the parameter T_h, whose value is continuously adapted to the driver's apparent preference by the altercontrol algorithm. Second, the value of actual headway-time margin, which is simply the result of R/V, calculated for each time sample. A histogram plot of these two measures is presented in Figure 17. The horizontal axis represents the headway-time "bins", set by increments of 0.2 sec. The vertical axis is the percentage of time spent inside each bin by all drivers. The dark bars and the light bars in Figure 17 depict the distribution of headway-time margin and that of R/V and T_h respectively.

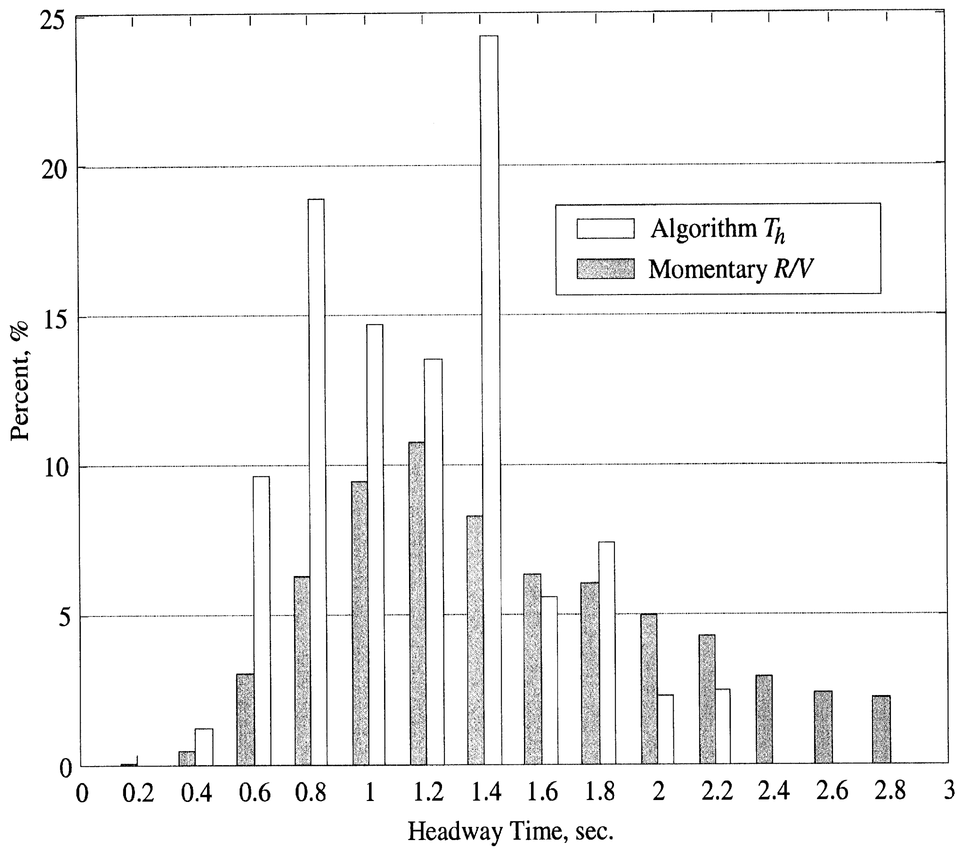


Figure 17. Headway time distribution for data in the altercontrol algorithm domain

Figure 17 shows that an unusually high percentage of the time was spent with the adaptive T_h parameters at a value of 1.4 sec. This is due to the fact that 1.4 sec is the default value of T_h set by the algorithm when the car is first started. Often, it could take a significant length of time before all the conditions needed to update T_h were satisfied.

The histogram of R/V values is distributed more towards higher values than are seen with the T_h histogram. This can be reasoned by the fact that R/V, as presented in the histogram, is computed all the time regardless of the prevailing range value, while the T_h parameter is computed only when the range value lies within the constraint set by the altercontrol algorithm. (see section 3.2.)

Another very noticeable aspect of the data shown in Figure 17, and perhaps the most striking observation from the figure, is the difference between the most-likely values of R/V and T_h. We see that the most-likely value of R/V in the figure is 1.2 sec. Considering the anomaly associated with the prevalence of the 1.4-sec. value, the most-likely value of a "true" T_h would be in the vicinity of 0.8 sec. This value – the headway-time determined by the altercontrol algorithm as the driver's preferred setting – emerges from this experiment as 0.4 seconds shorter (30% less) than the most-likely value of headway-time margin. The reason for this difference is not as clear.

One may argue that even though the histogram of R/V contains data that pertain to a wide spectrum of conditions, the scenes that mainly contribute to the most-likely value involve car following. Drivers spend more time "oscillating" about some headway, than during closing-in, passing, etc. – which are transitional maneuvers by nature. So why is it that the most-likely value of T_h is not the same? Probably it is an artifact of the logic that drives the T_h-determination algorithm: the very strict rules (see section 3) are not fulfilled when drivers follow just by "satisficing", so new T_h values are not established. However, when drivers follow at short headways such as 0.8 sec., they may be more vigilant, and they may do a much better job in keeping headway than merely "satisficing." The strict rules are more likely to be fulfilled then, resulting in a new value for T_h.

5.2 Characterizing Altercontrol Transitions

5.2.1 Scheme for Altercontrol Characterization

During its operation in the car, the algorithm evaluated the forward situation and the driver's actions as detailed in section 3.2 to identify many altercontrol events. When such an event was detected, it was flagged with a *Control Indicator* (see Table 3), a measure to indicate which of the rules or expectations was violated. The nature of these indicators, however, which was based on algorithmic formulation, made them rather cryptic. By themselves, they could not provide an insight to the observed altercontrol in the context of the driver's intentions (e.g., traffic lights, road geometry, etc.)

Tactics that motivate altercontrol events

In order to categorize altercontrol events in a way that will contribute to a methodical approach for developing Driver Assistance Systems, a more complete understanding of those events is needed. Such understanding was made possible by examining the data, event by event, with the aid of the video recording of the forward scene. Figure 18 provides an overarching illustration of the experimental data processing.

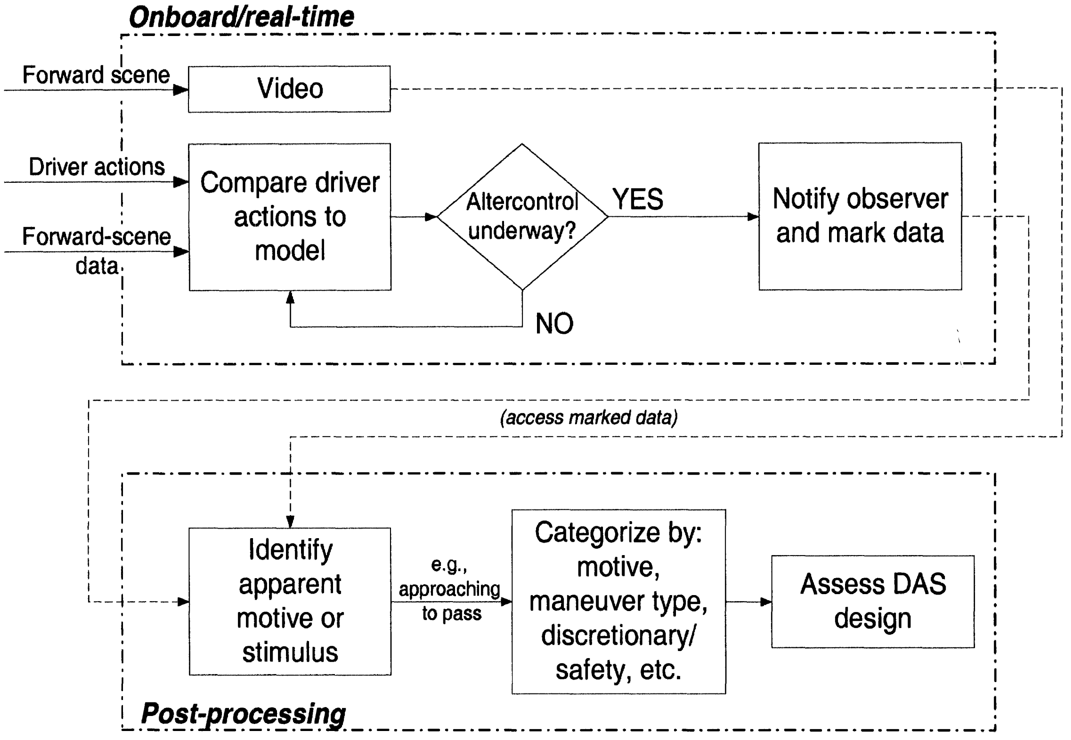


Figure 18. Processing of experimental data

In support of this analysis, a list of *Apparent Control Tactics* was developed. This list is presented in Table 8.

Table 8. Apparent control tactics

No.	Apparent Control Tactic	Code
1	***Brake lamps ahead***. No immediate headway relationship accounts for the driver's response, but the video shows that one or more vehicles further ahead has its brake lamps illuminated. It is assumed that the driver has responded to these lamps as a precautionary measure.	O
	Passing and Lane Change	
2	***Passing***. The video shows clearly that a passing maneuver has taken place.	C
3	***Preparing to exit***. The driver is maneuvering to exit a limited-access highway and may be moving to the exit lane.	D
4	***Expecting a clearance***. With the preceding vehicle about to clear the lane ahead, the host driver proceeds ahead, treating the pending clearance as virtually certain.	G
5	***Undecided about lane***. The driver is hesitant about the current lane choice. The resulting indecisiveness is expressed as a headway-control anomaly, and thus an altercontrol event.	V1
6	***Change pass strategy***. The driver starts a pass maneuver, but changes his/her mind and remains in the original lane. This scenario is to some extent a combination of tactics 2 and 5 although tactic 5 does not involve a pass intention. Here, a clear intention to pass is aborted through deceleration.	V2
7	***Weaving***. The host vehicle is in lane "A" whereas another vehicle is in the adjacent lane, "B". The host driver realizes that the other car is about to change lane into "A", and he/she decides to take its place in lane "B". The two vehicles "swap" lanes more or less simultaneously. This case involve more aggressive and dynamic driving than simply a lane change.	Z

No.	Apparent Control Tactic	Code
	Gap – Moving traffic	
8	***Closing a gap to pass***. The driver closes the gap as a preamble to passing. This tactic is always followed by either tactic 2 or tactic 6.	A
9	***Intimidation***. The host driver communicates impatience to the car ahead by increasingly-close tailgating (which often involves high closure rates – "charging behind"). Interpretation of this tactic involves a considerable level of uncertainty and hypothesis.	B
10	***Closing gap (I)***. The headway gap increases unexpectedly. (Perhaps the lead vehicle accelerated, or maybe it left the host's lane, exposing a new preceding vehicle). In the process of re-establishing the desired headway time, the host driver typically employs a moderate closure rate.	P
11	***Closing gap (II)***. Under dense/competitive traffic conditions, the host driver shortens the gap to prevent a cut-in. The new headway may be short-lived, since the driver does not typically intend to sustain this tactic. This maneuver typically involves more aggressive closure rates than tactic 10. (Note that, eventually, if this situation is maintained, the preferred-headway algorithm will set a new, short value for T_h.)	S
12	***Closing gap (III)***. The host driver either intends to pass (but no passing maneuver is seen to be completed on the video record), or he/she closes the gap being "pressured" by traffic behind. Since there is no video that looks backwards, and the experimenter may have recorded no comment to confirm or refute the hypothesis, this interpretation also involves some uncertainty and hypothesis.	N
13	***Making room for cutin.*** The driver allows the headway gap to widen, recognizing that another vehicle wishes to enter his/her lane. This tactic is the opposite of tactic 11.	T

No.	Apparent Control Tactic	Code
14	***Lax T_h management***. This falls under the general classification of “satisficing.” The headway oscillations that are involved trigger one or more *Control Indicators*, and subsequently the altercontrol flag.	M
	Stop & Go	
15	***Downhill in Stop & Go***. This gap-management issue arises under the combined condition of short headway distance, low traffic speed, and downhill slope. The host driver is seen to brake much sooner than if he/she were at the same $R, \dot{R}$ coordinates on level ground and at highway speeds.	R
16	***Start of “Go” in Stop & Go***. The driver expects the car ahead to move and gain speed at a rate that is higher than what is currently indicated by the range and range-rate data. The outcome, typically, is a higher level of acceleration than is expected.	Q
	Lights and Turns	
17	***Starting at a traffic light***. This tactic is very similar to that of number 16 insofar as both involve the driver’s gap management tactic during a startup transient. In this case the stereotypical situation is an arterial street and a traffic light which turns to green.	J
18	***Braking to a stop light***. The driver recognizes that the light ahead turns red, and he/she will stop. If another vehicle in front stops as well, this tactic typically involves a relaxation in the gap which is not expected strictly from the perspective of the R and $\dot{R}$ data alone. If the vehicle in front goes through the light, the host driver is seen to brake even though the headway gap opens radically.	H

No.	Apparent Control Tactic	Code
19	***Braking to enter a left-turn lane***. This tactic may be considered as a sub-tactic of 18. The traffic light for the through lane may still be green and traffic still flows through it. The data in the test car, however, shows that the host driver slows down for no apparent reason, perhaps stopping behind another car that is already waiting in the left-turn lane.	E
20	***Braking to turn***. This tactic is employed exclusively on arterial roads (not on limited-access highways.) The host driver brakes in anticipation of an intended intersection turn.	U
	Ramps	
21	***Accelerate on a ramp***. The driver accelerates on an access/transition ramp at a rate that is higher than expected from the R and $\dot{R}$ data. The acceleration in this maneuver is motivated by the need to reach the highway posted speed.	F
22	***Slow on exit/transition ramp***. The driver is forced to slow down on a ramp due to its layout/curvature.	K
23	***Ramp merge with highway traffic***. This maneuver often follows tactic 21. The expectations that are violated are based on combinations of acceleration, closure rate, and range. This maneuver is motivated by trying to “squeeze” into a spot in tightly-moving highway traffic (often at unusually short range).	L
	Special Cases and Errors	
24	***False target***. The altercontrol flag was triggered by a target that is clearly out of the test vehicle’s path or apparent “view”. Such observations are established by examining the video images synchronized with the Radar data.	XX
25	***Unrepresentative T_h computed***. When the algorithm that determines the driver’s preferred T_h makes a mistake, the boundaries of the zones as they are depicted in Figure 3 are also incorrect. The R and $\dot{R}$ data may then be interpreted falsely for the detection of altercontrol.	WW

The column labeled "Code" in Table 8 contains a letter which serves as a unique identifier for each altercontrol tactic. The process of analyzing each trip, which involved examining both video and numerical data, focused on identifying and interpreting each altercontrol event. When labeling those events and cataloguing them, it was convenient to use codes rather than the longer textual description for each altercontrol type.

Sequences of altercontrol tactics

While assigning apparent control tactics, it became apparent that altercontrol events may occur both singly and in combinations within a single maneuver. At this point, the term *sequence*, as applied to the data analysis process, needs to be introduced. A sequence is an attempt to capture the one or more control tactics that triggered altercontrol within a single driving episode, as it may be mentally viewed by the driver. As examples of single-tactic sequences, consider that a driver might follow another car for a long period of time, and then decide to tighten the headway in order to prevent a cut-in (corresponding to tactic code S in Table 8). Then, that driver might decide to exit the highway (i.e., tactic D in the table). Although each of the two scenarios described above involve the same target, they are considered in this method of data analysis as two separate sequences. It is argued that the driver considered each of them as a stand-alone issue that had to be resolved by means of altercontrol.

Furthermore, a single sequence may be comprised of more than one altercontrol tactic. A passing maneuver for example, may commence with "closing a gap to pass" (tactic code A in Table 8), followed by the actual "Passing" tactic (code C). The approach employed here contends that mentally, the driver considers the whole passing maneuver as a single, integral operation which should be amalgamated into one sequence.

A sequence may traverse several zones in the range versus range-rate space in Figure 3, and consequently it may invoke more than one control indicator. A passing sequence may serve as a good example:

- This sequence may start in zone 3 with the driver "closing a gap to pass," employing tactic A, (and invoking control indicator 4).
- The sequence enters zone 2 as the gap gets shorter, the tactic code is still the same (A), but the control indicator is now 3.
- The gap gets shorter still as the driver accelerates, and the sequence enters zone 1. The control indicator in effect is now 1.
- The driver steers into the adjacent lane, control indicator 1 is still active but the analysis now recognizes the code C tactic.

The above passing example is summarized in Table 9. A single sequence in this case, has generated four distinct altercontrol tactics. Considering each of these elements, both individually and as a whole, merits the methodical approach outlined here: (1) each tactic can occur individually, so its impact on a given driver assistance system should be evaluated singly, and (2) as a whole, when the combination constitutes a sequence, certain patterns may emerge that will advance the identification of an altercontrol process.

Table 9. Elements of an example passing sequence

Zone	Control Indicator	Tactic
3	4	A
2	3	A
1	1	A
1	1	C

The data-analysis process is described in details next. The trip data for each driver, which is stored in a *Microsoft*® Access database, was queried to extract only those segments that contain altercontrol events. The results of this query were then used to accurately and immediately access the pertinent video scene. Concurrent with the vehicle data (i.e., speed, range, acceleration, etc.), the video clip of each altercontrol event was examined to (1) identify sequences, and (2) recognize and catalogue the driver's apparent tactic. Table 10 shows sample output from such an analysis. For the particular driver whose results are presented in Table 10, 36 distinct altercontrol sequences were identified during the 1.5-hour test drive.

The first and second columns in the table contain test time and video frame data (see Table 5). Test time 38428, for example, represents 3842.8 seconds (1hr;4min;2.8sec) that had elapsed since the data record began. The third and fourth columns provide information regarding the control indicator that was invoked by the altercontrol event (see Table 3). These four columns are a direct output of querying the database, as they contain data that were acquired during the test drive. The next three columns were determined, item by item, during the data analysis by actually observing the video.

Sequence 1, for example, corresponds to "braking to a stop light" (tactic H). The query returned three entries for this maneuver, but observing the video provided a basis for the belief that all three entries pertain to a single sequence. The reason why there were three entries for the same sequence is that as the driver was slowing to a stop while being inside zone 8, he/she braked intermittently, thus invoking control indicator 10 several times.

Table 10. Sample output from altercontrol analysis

{Driver Name}, data file #

TestTime	Frame	CI No.	Control Indicator (CI)	Apparent Altercontrol Tactics	Code	sequence
				Arterial		
3983	13673	10	Braking in Zone 8	braking to a stop light	H	1
3993	13703	10	Braking in Zone 8			1
4008	13751	10	Braking in Zone 8			1
				Highway		
9080	28947	3	Ax>0, Zone 2	False target	XX	2
10316	32651	3	Ax>0, Zone 2	closing a gap expecting to pass	A	3
10334	32705	3	Ax>0, Zone 2	passing	C	3
12121	38064	3	Ax>0, Zone 2	passing	C	4
12135	38106	1	Accel pedal, Zone 1			4
12402	38904	3	Ax>0, Zone 2	passing	C	5
13143	41125	10	Braking in Zone 8	making room for a cutin	T	6
15969	49594	7	Ax>0.05g, Zone 5	car leaves our lane, expecting clearence	G	7
16299	50585	4	Ax>0.06g, Zone 3	trying to find a spot to exit	D	8
16384	50837	10	Braking in Zone 8	undecided about lane choice	V1	8
16438	50999	4	Ax>0.06g, Zone 3	closing a gap expecting to pass	A	8
[illegible]	51275	3	[illegible]	passing	[illegible]	8
				Highway		
38428	116908	4	Ax>0.06g, Zone 3	closing a gap expecting to pass	A	17
38434	116926	3	Ax>0, Zone 2	passing	C	17
38447	116962	1	Accel pedal, Zone 1			17
39182	119165	3	Ax>0, Zone 2	False target	XX	18
39189	119189	1	Accel pedal, Zone 1			18
39425	119897	3	Ax>0, Zone 2	passing	C	19
41492	126092	3	Ax>0, Zone 2	passing - tight	C1	20
42174	128133	7	Ax>0.05g, Zone 5	weaving	Z	21
42890	130281	1	Accel pedal, Zone 1	passing	C	22
43439	131926	3	Ax>0, Zone 2	passing	C	23
44583	135353	3	Ax>0, Zone 2	car leaves our lane, expecting clearence	G	24
44636	135509	1	Accel pedal, Zone 1			24
46286	140455	3	Ax>0, Zone 2	passing	C	25
47683	144644	3	Ax>0, Zone 2	passing	C	26
48660	147573	3	Ax>0, Zone 2	passing	C	27
48683	147639	1	Accel pedal, Zone 1			27
49012	148629	10	Braking in Zone 8	change pass strategy	V2	28
50304	152501	10	Braking in Zone 8	trying to find a spot to exit	D	29
50667	153587	10	Braking in Zone 8	slowing down on exit/transition ramp	K	30
Additional Stop&Go data from Matlab:						
18293	56563	4	Ax>0.06g, Zone 3	start of "Go" in Stop&Go	Q	31
19951	61532	4	Ax>0.06g, Zone 3	start of "Go" in Stop&Go	Q	32
19973	61598	3	Ax>0, Zone 2			32
20061	61862	5	Accel pedal, Ax>0.1g, Zone 4	start of "Go" in Stop&Go	Q	33
20887	64335	8	Braking in Zone 6	making room for a cutin	T	34
21232	65368	7	Ax>0.05g, Zone 5	accel on a ramp	F	35
21343	65704	8	Braking in Zone 6	merging from onramp with hwy traffic	L	36

Sequences 3, 4, 17, and 27 are passing maneuvers which encompass more than one zone, more than one control indicator, or more than one tactic. Thus they are similar to the example cited earlier in conjunction with Table 9. Note at the bottom of the table the data labeled "Additional Stop & Go data from Matlab." These results were not derived directly from the data file acquired during the test drive, but rather were generated by means of post-processing of the data. Further details regarding the additional results obtained by post-processing are provided in Appendix A.

Sequences, as described earlier, can span more than one zone or encompass more than one apparent altercontrol tactic. Sequences can be long or short, single- or multi-tactic, single- or multi-zone. In any case, they must have at least one zone and one apparent tactic associated with their starting point. This set of zone and apparent tactic is referred to as the *commencing set* of the sequence.

5.2.2 Distribution of Transitions by Altercontrol Categories

This section presents histograms and statistical measures drawn from an analysis of the data of the five test drivers. Many of the results and analyses presented in this report were done on a driver-by-driver basis. However, it was not possible to obtain equivalent amounts of data for each driver. It should be noted that the drivers labeled 113, 114, and 116 are those for whom complete data were acquired during the test drive. Data for drivers 117 and 121-122 on the other hand, were significantly limited in their extent (the designation 121-122 indicates that the data for that particular driver were comprised of two separate files.)

Overview Statistics of Altercontrol Sequences

Table 11 presents a statistical summary of the altercontrol sequences investigated in this report. Driver 113, whose data output was depicted as an example in Table 10, had a total of 36 sequences. This individual spent 2359.9 seconds (39min 19.9sec) driving with a target engaged within the headway range limit of the algorithm. Of this period, a total of 46.5 seconds were spent with some *Control Indicator* (see Table 3) being flagged. The remaining 2313.4 seconds of data taken for this driver, with a target in range, showed the person operating within the rules of a simple headway controller. The average target-tracking time between each altercontrol sequence was 64.3 sec., and the average duration of each sequence was 1.29 sec. A total of 130 altercontrol sequences was observed across the five drivers.

Note that duration and time-length analysis is not provided in Table 11 for drivers 117 and 121-122. That is due to the fact that these two drivers experienced frequent failures of the data system, and as a result much of the data acquired were incomplete. Although discrete analysis — counts and examination of individual altercontrol sequences — is still applicable, time-based analysis such as depicted in Table 11 will be flawed.

Table 11. Altercontrol sequences – counts and durations

Driver	Altercontrol sequences	Driving time, sec. (in altercontrol + in headway)	Average time between sequences, sec.	Average sequence duration, sec.
113	36	46.5 + 2313.4 = 2359.9	64.3	1.29
114	33	35.3 + 2843.3 = 2878.6	86.2	1.07
116	45	60.5 + 2100.8 = 2161.3	46.7	1.34
117	7	—	—	—
121-122	9	—	—	—
Total:	*130*	*7399.8*		

It is tempting to interpret the numbers shown in Table 11 in terms of characteristic driving behavior. A limited-scope analysis in that direction, though with a qualification, is presented later in this section.

Time in Zone Analysis

Since the foundation of the altercontrol-detection algorithm lies within the zones that have been defined for dividing the range versus range-rate space (Figure 3), it may be prudent to first draw some statistics about how drivers operated the vehicle in this context. Figure 19 shows the distribution of the relative time spent by all the drivers in each of the eight zones that are pertinent to altercontrol.

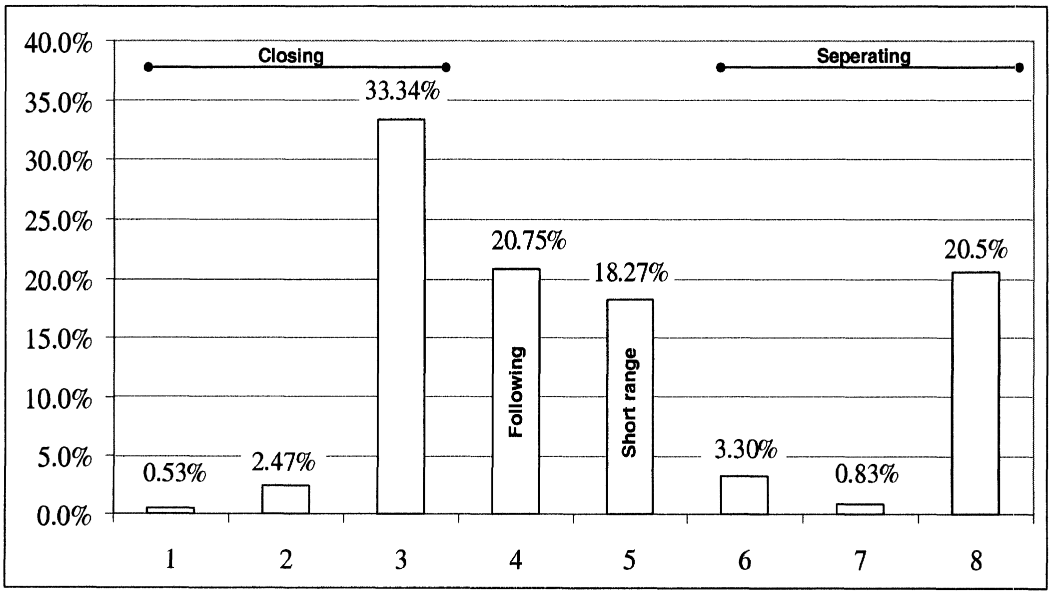


Figure 19. Time-in-zone ratio to total time

Total time, in the context of Figure 19, is the cumulative driving time which "qualifies" for altercontrol evaluation, for all the drivers. That is, this is all the time during which (1) the vehicle was driven above $V_{\min}$, and (2) a target was present, and (3) the operative zone was between 1 and 8. Note that a target that was too far or too close does not qualify. In this study, the total time for all the drivers was 3 hours.

The drivers in this experiment spent a third of the driving time moderately closing the gap to another vehicle (zone 3). From the perspective of time spent in a zone, zone 3 is seen to be dominant. Considering the overall balance between closure versus opening of headway ($\dot{R} < 0$ vs. $\dot{R} > 0$), Figure 19 shows that in 55% of the time the drivers were closing the gap, while in 45% of the time they were relaxing it (zones 4 and 5 are evenly split here between $\dot{R} < 0$ and $\dot{R} > 0$). That is, on the average, the test drivers drove slightly faster than the surrounding traffic.

Another noteworthy observation from Figure 19 may be that drivers are quite reluctant to be in the *rapid-closing* and the *danger* zones (zones 2 and 1 respectively.) They spent only 2.54% of the time in the rapid-closing zone, and even a much smaller time period – 0.54% – in the danger zone. Reference to this observation will be made again later, in the context of driver characterization.

Distribution of Sequences and Their Apparent-Tactic Components

Figure 20 on the next page depicts a summary of all the commencing sets observed in this study. That is, each of the 130 altercontrol sequences was accounted for once by entering in the appropriate zone the letter-code designation of the apparent tactic used. All the same code letters within a given zone were then tallied for summary presented in Figure 20.

The greatest number of the commencing sets, or the starting points of sequences, lies within zone 3. Using the terminology and parametric values denoted earlier in Table 1 and Table 2, about a third of the altercontrol sequences started when the driver accelerated more than 0.07g while closing behind another vehicle.

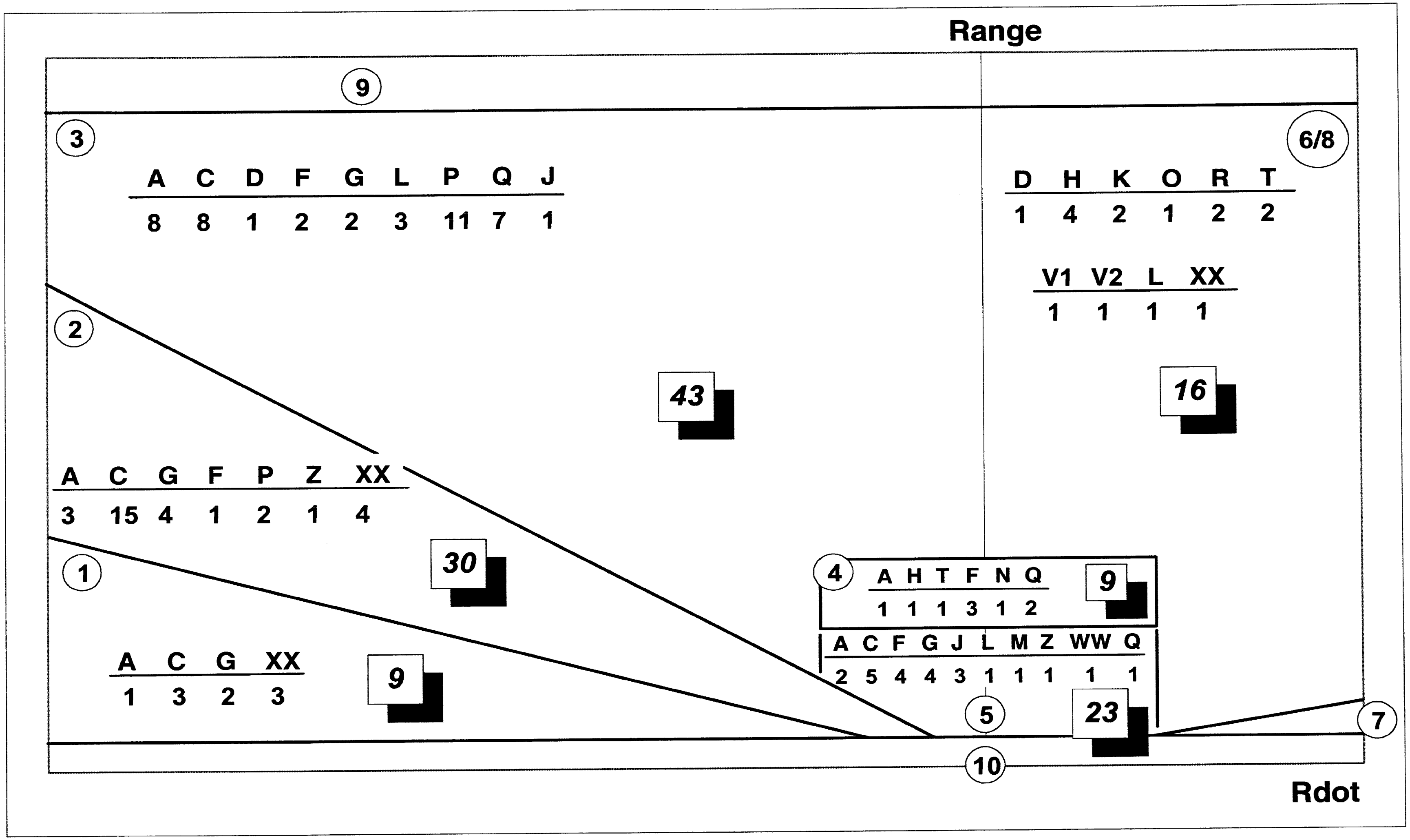


Figure 20. Summary of commencing sets by zone (Total = 130; letter designations correspond to apparent control tactics)

Once commenced, a sequence may stay within the same zone, it may even maintain the same apparent tactic code throughout its duration. Alternatively, a sequence could evolve into a different altercontrol tactic, and even advance to adjacent zones. A natural next question is: "Once a sequence has commenced – how does it progress and what patterns can be observed?"

Figure 21 on the next page depicts a cumulative summary of all the apparent altercontrol tactics observed in this study. That is, a tally was made for the 130 altercontrol sequences, which included all the individual zone/tactic-code combinations comprising each sequence, a total of 183. (Note that the sequence example in Table 9 would have contributed four counts to this tally.)

The summary numbers for each zone in Figure 20 and Figure 21 are presented side by side in Table 12. An important observation from this table is the fact that the total number of altercontrol marks in zone 1 is three times the number of sequences that commenced from that zone. This zone appears to be primarily of a transitional nature rather than an initiating one. Drivers typically start the maneuver that involves altercontrol from inside a zone that they occupy more often (e.g., zone 3, see Figure 19), and then the sequence tends to "transition" them into zone 1. Furthermore, one can argue that those sequences shown in the data as commencing in zone 1, are actually sequences that started earlier without being detected by the algorithm. The nature of zone 1 is such that one does not simply arrive there casually.

Table 12. Comparative summary of commencing sets and all altercontrol tactics

Zone	Commencing sets	Total altercontrol events
1	9	26
2	30	42
3	43	56
4	9	11
5	23	26
6/8	16	22
Total	*130*	*183*

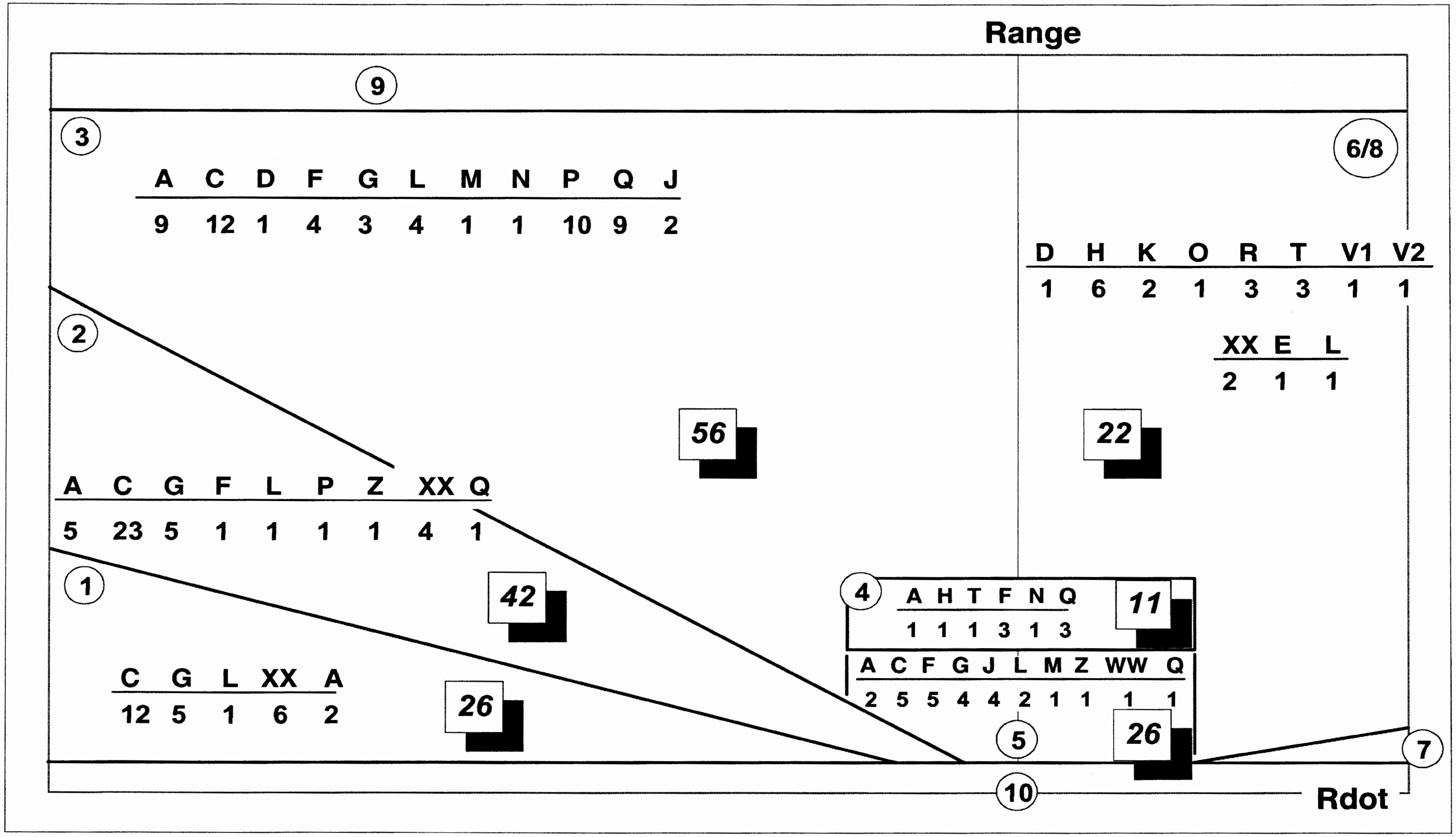


Figure 21. Cumulative summary of all apparent altercontrol tactics (Total = 183)

The counts in zones 4 and 5 show almost the same numbers of "commencing sets" and "total" events. Clearly, these zones are principally spaces within which altercontrol commences. Sequences which start elsewhere very rarely transition through these zones. Zone 3 is again seen as the chief contributor to the total count of altercontrol tactics. This fact accords with other evidence indicating that drivers spend most of their driving time in zone 3 (see Figure 19).

Another observation from Table 12 is the consistently-higher number of totals over commencing sets in zones 2, 3, and 6/8. Since the totals are 30-40% above the commencing sets numbers, zones 2, 3, and 6/8 may therefore be approximated as 75% "commencing zones," and 25% "transition zones."

Plotting the trajectories of altercontrol sequences also appears to be an illustrative way to examine them. Such a graphical depiction of the sequences is provided in Figure 22. Note that only those sequences which cross zone boundaries are plotted (otherwise they do not form a trajectory).

Of the trajectories shown in Figure 22, the group of nine (shown as (9) on the figure) that go from zone 2 to zone 1 stands out. These pertain to sequences that are associated with passing maneuvers (e.g., apparent tactic code C). In these maneuvers, the driver accelerates to close the gap, reducing the range while penetrating into the negative $\dot{R}$ space, eventually changing lanes so that the target disappears, terminating the trajectory.

Observing Figure 22, it appears that no trajectories started in zone 1 (recall that range can only proceed downward in the negative $\dot{R}$ quadrant and only upward in the positive $\dot{R}$ quadrant.) This fact supports the earlier suggestion that zone 1 is a transitional zone rather than a commencing one. Figure 22 also shows that no sustained-altercontrol trajectories (across zones) were terminated in either zone 4 or zone 6/8. Altercontrol sequences that terminate either in following another car (zone 4) or in separating from it (zone 6/8), typically start in that same zone.

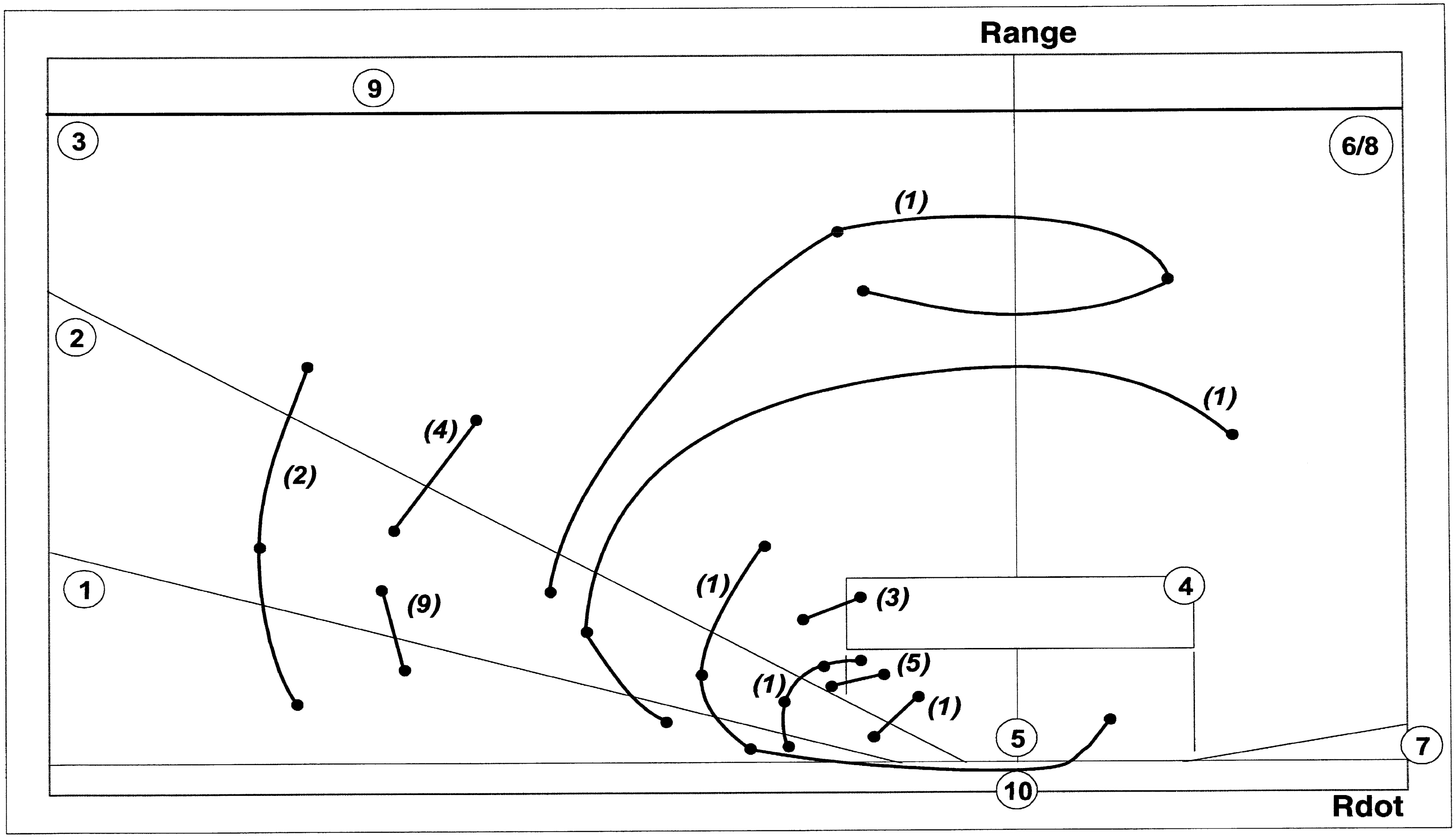


Figure 22. Trajectories and counts of sequences across zones

An Approach to Driver Characterization

Characterizing individual driving behavior is always an issue of interest that directly affects altercontrol prevalence. The following discussion reflects on this issue. Special care should be taken, however, when evaluating the results presented here since the sample is very limited. It may be considered overly enterprising to develop characterizing schemes based on the data of three drivers plus partial data for two more drivers — nevertheless, we feel that there is merit in presenting this approach here, at least as a basis for further work when more data become available.

Figure 23 illustrates how the driving time, for each driver, was distributed among the different zones. Some differences between drivers are readily apparent. For example, driver 117 may be considered as the most *following-seeker* — he avoided dramatically short ranges (i.e., short ranges that involve large negative range rates) while spending by far the most amount of time in the "following space," zone 4. That driver never got into zone 1 and spent the least amount of time in zones 2 and 7. He also spent significant time in zone 5, but that may be due to the oscillatory nature of following (i.e., satisficing).

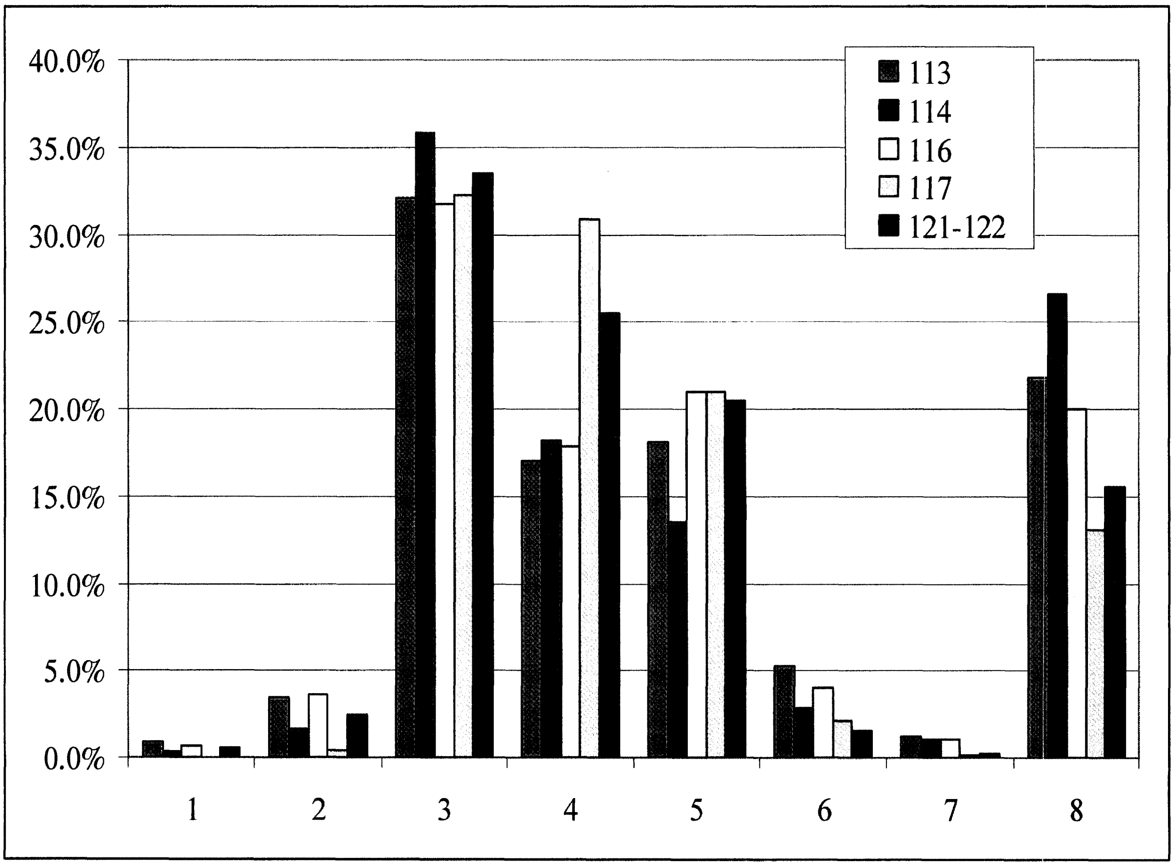


Figure 23. Distribution of time-spent-in-zone per driver

Regarding the three drivers who had their whole trip captured in the data, drivers 113 and 116 are quite similar in their approach to driving in the sense of how their time is distributed among the different zones. Further differentiation between the two may be enabled by examining the distribution of time per driver and per zone which follows. Driver 114 as portrayed in Figure 23 is a more conservative planner, keeping away from the short-range zones of 1, 2, 5, and 6 while spending more time in zones 3 and 8. This driver also spends slightly more time following. These observations match the analysis summarized in Table 11: driver 114 had the shortest average duration of altercontrol sequence as well as the longest average time period between sequences. Drivers 113 and 116 had similar sequence durations.

It should be emphasized that the above discussion does not intend to portray the three drivers (113, 114, and 116) as significantly different from each other. The structure of the accompanied test drive tend to a-priori eliminate outstanding driving patterns. Nevertheless, the merit of this discussion is in exploring the possibility to develop driver characterization methods based on altercontrol behavior, as well as to exercise them.

Further insight into driver characterization may be gained by examining the per-driver-per-zone distribution of the altercontrol activities. Figure 24, Figure 25, and Figure 26 depict the altercontrol time ratios for each driver in zones 1, 3, and 8 respectively. The time ratio in these figures denotes the ratio between the time spent in a given zone with the altercontrol flag turned "on", and the total time spent in that zone. As an example, Figure 24 shows that 50% of the time spent by driver 113 in zone 1 was with the altercontrol flag turned "on".

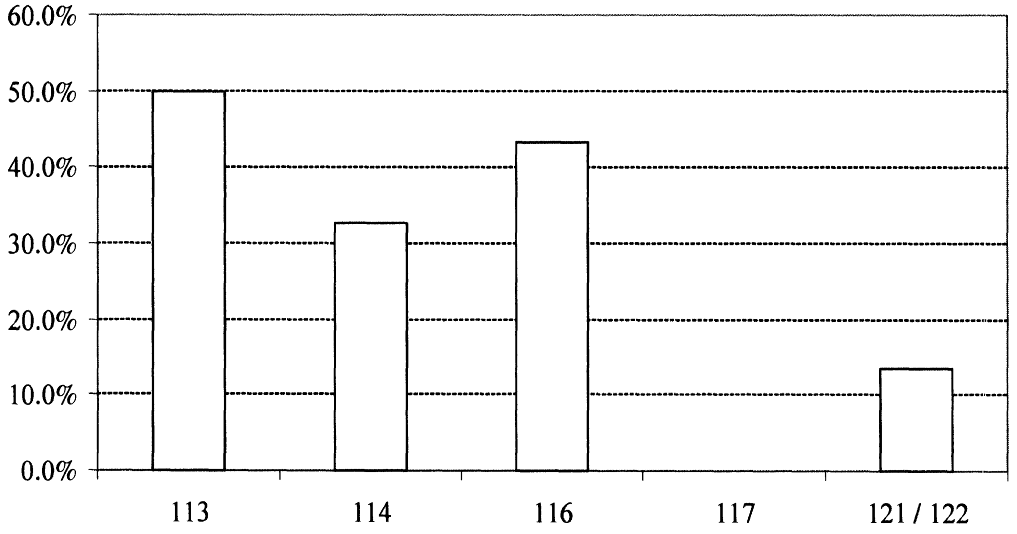


Figure 24. Altercontrol time ratio in zone 1

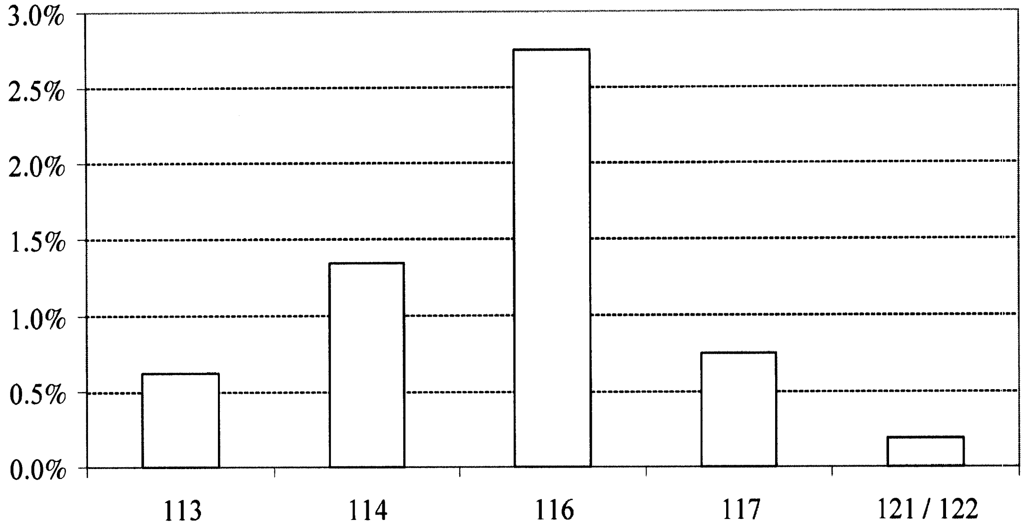


Figure 25. Altercontrol time ratio in zone 3

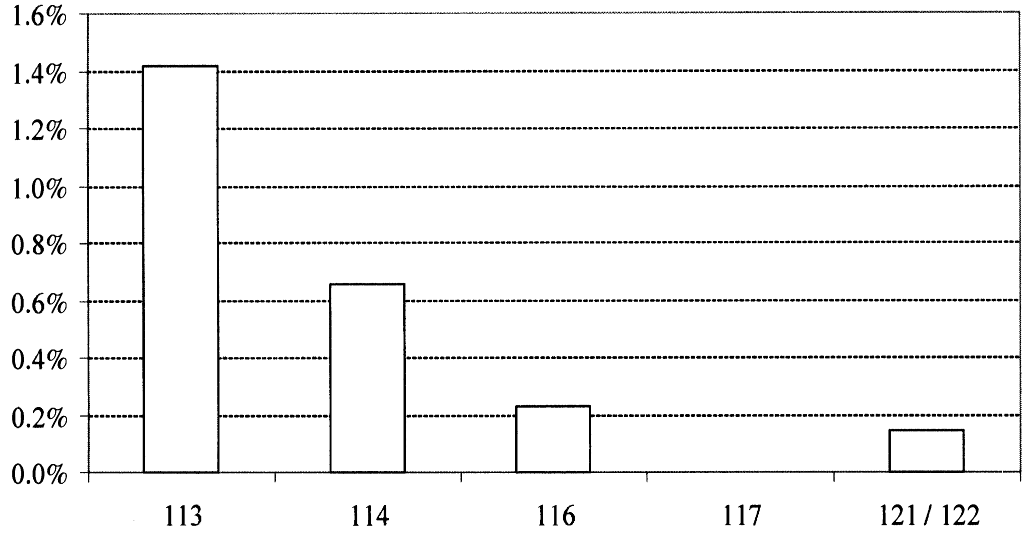


Figure 26. Altercontrol time ratio in zone 8

Of the three drivers discussed earlier, driver 114 conformed the most with the headway-control rules in zone 1, resulting in the smallest altercontrol time ratio in that zone. Drivers 113 and 116 were least in compliance with headway-keeping expectations, but driver 116 had a slightly lower "bar" in Figure 24. Driver 116 demonstrated more of a "safe planning" behavior by limiting the altercontrol sequences more to zone 3 (Figure 25) and keeping more generally out of zone 1. The higher altercontrol time ratio in zone 3 for that driver may also be a result of another manifestation of this safe-planning approach: by minimizing altercontrol in zone 8 (Figure 26), the driver takes advantage of the safety in accelerating in that zone (gap is opening), which carries the driver then into zone 3, possibly triggering the altercontrol flag there. Driver 113 does not demonstrate the planning needed to complete most altercontrol maneuvers in zones 2 or 3 (perhaps due to the fact that this driver is significantly less experienced than driver 116); While having the tallest bar in zone 1 (shown in Figure 24), driver113 has the lowest one in zone 3 (i.e., Figure 25).

When compared to drivers 113 and 116, we see that driver 114 is consistently more in agreement with the expectations in each zone, supporting an earlier speculation that this person drives in the style of a conservative planner.

A qualification for the above analysis should be reiterated here: one must consider the limited amount of data and the small counts of altercontrol sequences. These issues can dramatically affect the numerical results and distributions presented here. The approach presented here is a suggested method for characterizing drivers and not an absolute supposition. It needs to be re-evaluated when more data become available.

Figure 27 presents a distribution of altercontrol time ratio per zone for all drivers. When compared to Figure 23, the contrasting height of the bars for zones 1 and 2 is immediately obvious. Zone 1 in Figure 23 is where drivers spent the least amount of time, but from Figure 27 this zone emerges as the one in which an altercontrol response is most commonly observed.

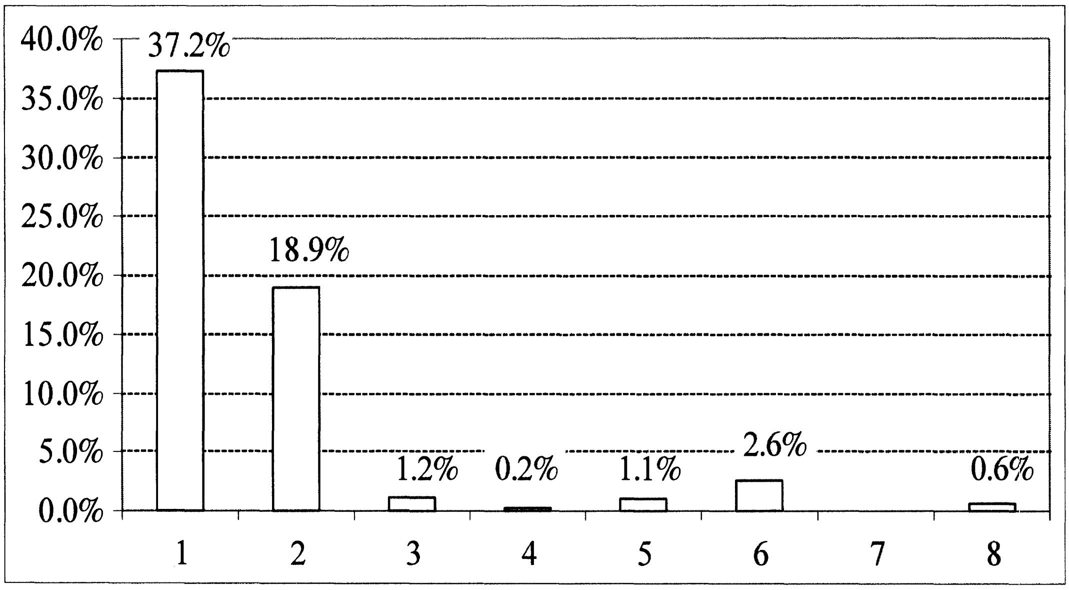


Figure 27. Altercontrol time ratio for all drivers, by zone number

5.2.3 A Matrix Framework for Summarizing Altercontrol in Driving

In the foregoing presentation, the method for capturing altercontrol transitions in test data has been defined, employing four layers for specifying each event, as follows:

- The instantaneous R and $\dot{R}$ coordinate serves to place the vehicle's headway state in one of nine zones within which the control state is tested to detect altercontrol;
- Either one or two control indicators (or rules) apply in each zone, defining the altercontrol transition by either a pedal application or an inequality in longitudinal acceleration;
- Once altercontrol is detected, an observation is made by the experimenter to judge the Apparent Altercontrol Tactic, putting the perceived reasoning and intent of the driver into the form of a text statement.
- The text form of the Apparent Altercontrol Tactic is then given a Tactic Code (Table 8) so that all such commonly-coded events can be consolidated in summarizing altercontrol behavior.

In this section, each of the full set of Tactic Codes are consolidated into one of five cells comprising the "Altercontrol Categorization Framework". This framework helps in the interpretation of a driver's altercontrol behavior because it addresses:

- the nature of the conflict within which each altercontrol transition is exercised, and
- the polarity of the "error" (or difference) between the control exercised by the driver and the H(only) rules.

The breakdown identifies four types of conflicts under which an altercontrol transition is observed, as follows:

- <u>minimal conflict</u> (such that altercontrol constitutes only a mild form of discretionary preference, or simple indifference, on the driver's part)
- <u>current conflict</u> that is significant but NOT sensed by radar (such that the driver's own sensory vigilance has detected the need to resolve an immediate conflict that does not lie in the range, range-rate domain of the forward-looking sensor.)
- <u>current conflict</u> that is significant and sensed by radar (but which the driver allows to prevail for a limited period of time, often due to preferences in driving style.)

- future conflict that is anticipated based upon route plans and situational forecasts that the driver knows of or deduces, quite apart from the immediate management of the headway condition.

Shown in Table 13 is the framework that employs each of the conflict types. The four types of conflict comprise the columns of a table whose two rows represent the two polarities of difference between actual and headway-only control (corresponding to a relaxing, or lengthening, headway condition as opposed to a tightening, or shortening, condition.) Headings are presented around the outside of the table to summarize the respective categories as a convenience to the reader. Examples of common altercontrol tactics are expressed corresponding to each cell of the table as are the control indicators, #1 through #10, that match up with each of the two polarities of difference between the current headway state and the dictates of the simple headway controller.

Note that of the eight conceivable cells of this matrix, only five are generally possible in driving. Note also that the two cells lying in the bottom row, both of which imply a discretionary choice by the driver to tighten or shorten the prevailing headway, differ from one another by the nominal magnitude of their $\dot{R}$ values. In the first column, a minimal conflict exists, such that $\dot{R}$ is approximately zero. In the third column, a substantial conflict appears to exist based upon a significant, negative, value of $\dot{R}$ (even though the conflict is usually short-lived and the driver is anticipating its resolution.)

Table 13. Altercontrol categorization framework

Current headway condition relative to the model	**ALTERCONTROL Managing Space & Style under conditions of Minimal Conflict** *($\dot{R}$ ~ zero)*	**ALTERCONTROL Ensuring Safety by reacting to a Current Conflict UNSENSED by Radar**	**ALTERCONTROL Cultivating, for the sake of utility, a Current Conflict SENSED by Radar** *($\dot{R}$ << zero)*	**ALTERCONTROL Anticipating a Future Conflict based upon PLANS & FORECASTS**
▪ Relaxing (lengthening) Headway ▪ (Control Indicators: # 6, 8, 9)	▪ Relax for cut-in ▪ Relax for adjacent gap ▪ Relax for indecision ▪ Satisficing on headway	▪ Relax for a traffic control device ▪ Relax for an obstacle ▪ Relax for road geometry		▪ Relaxing headway, preparing for a turn ▪ Relaxing, with brake lamps ahead
▪ Tightening (shortening) Headway ▪ (Control Indicators: # 1, 2, 3, 4, 5, 7, 10)	▪ Tighten to prevent cut-in ▪ Tighten to intimidate ▪ Tighten to access an adjacent gap ▪ Tighten while accelerating from a stop or on a ramp ▪ Satisficing on headway		▪ Approaching a turning vehicle ▪ Approaching-to-pass ▪ Approaching during merge ▪ Approaching when weaving lanes	

Taking one step in generalization from the preceding figure, the qualitative nature of the altercontrol events occurring in each of the five cells is summarized in Table 14. Here, the columns and rows have been labeled such that we can now refer to individual cells as (A+), (C-), etc. whereby the + and – designations of the two rows appeal to one's intuitive sense of headway getting longer (+) or headway getting shorter (-), respectively, than simple headway-keeping would require. The cells have qualitative meaning as follows:

(A+) *Stylistic-Discretionary:* as an expression of the driver's stylistic preference, headway is being lengthened, perhaps sustaining a small positive range rate, either because the driver's comfort level calls for it or because the driver is indifferent to controlling headway more precisely;

(A-) *Stylistic-Discretionary:* the driver acts in a discretionary way, as above, except that the preferred driving style results in a shortened headway, and perhaps a mildly negative range rate. (A strongly conservative driver should exhibit much greater incidence of (A+) altercontrol events than (A-), while the reverse is expected of a strongly aggressive driver.) As in the case of the (A+) cell, the variations from simple headway control may also be due to the driver's indifference to control precision, as in the satisficing concept.

(B+) *Safety-Critical:* the driver acts to resolve safety threats that lie outside of the sensory range or modality of the remote sensor(s). Thus, the need for the altercontrol action is more or less safety-critical, since a headway controller is basically oblivious to the threat and will not resolve it by any automatic operation.

(C-) *Utility-Preference:* the driver exercises a discretionary tactic that in some way cultivates a headway conflict for the sake of a utility benefit. The conflict is deemed to be manageable based upon the driver's estimate that the hazard probability level is low. In any case, an actual conflict is present and detectable in the R, $\dot{R}$ space, at least for a brief time.

(D+) *Safety-Satisfying:* the driver acts to satisfy a control need that is anticipated to arise in the near future, based upon foreknowledge of routing plans or facts that the driver can otherwise predict. The need for altercontrol is not deducible from the current headway condition, but is desired for satisfying the requirements for safe control in the proximate future.

Table 14. Altercontrol categorization – qualitative significance of the cells

Current headway condition relative to the model	**(A) ALTERCONTROL Managing Space & Style under conditions of Minimal Conflict**	**(B) ALTERCONTROL Ensuring Safety by reacting to a Current Conflict** **UNSENSED by Radar**	**(C) ALTERCONTROL Cultivating, for the sake of utility, a Current Conflict** **SENSED by Radar**	**(D) ALTERCONTROL Anticipating a Future Conflict based upon** **PLANS & FORECASTS**
(+) **Relaxing (lengthening) Headway**	**Altercontrol** expresses a more conservative, defensive, and courteous driving style *Stylistic - Discretionary*	**Altercontrol** obtains safe resolution of a conflict arising from outside of the spatial domain of headway control *Safety - Critical*		**Altercontrol** begins to address a conflict that will arise outside of the temporal domain of headway control. *Safety-Satisfying*
(-) **Tightening (shortening) Headway**	**Altercontrol** expresses a more competitive driving style *Stylistic - Discretionary*		**Altercontrol** expresses a driver-preferred tactic, accepting a temporary conflict in return for some utility gain *Utility-Preference*	

Based upon the qualitative interpretation of each of the five cells, it is straightforward to assign each of the Tactic Codes to a cell, as shown in Table 15. We see, for example, that several different codes combine under the first-column entry labeled, “satisficing on headway”. Most generic types of altercontrol, however, correspond to a single Tactic Code. Please also note that some types of altercontrol tactic are listed in the table, with no code shown. These cases represent conceivable and not-uncommon tactics that did not happen to prevail during any of the testing conducted during this project. In a larger driving exercise than was conducted here, it is anticipated that these “currently-uncoded” tactics and perhaps others not yet recognized would be added to the framework.

Having now allocated Tactic Codes as the direct way of linking each altercontrol event in the test data to one of the five cells in the matrix, Figure 28 presents an overall compilation of the measured results from the limited driving tests conducted here. The grand total of observed altercontrol events is presented in the Five-Cell Matrix lying in the center of the figure. Around the outside, individual bar charts show the distribution of tactics that were observed in each cell. We see that the various cells are highly differentiated from one another by their total count of events. The great majority of the events lie in the bottom (-) row, where the driver is choosing to (or is satisficed to…) shorten headway relative to that which the reference headway controller would do. As expected, those cells in the top row, by which safety is critical or in which the driver acts to anticipate a safety need, are seen to occur rather infrequently [showing, counts of only 8 and 2, in cells (B+) and (D+), respectively.] About 1/3 of the altercontrol events involved “minimal conflict”, lying in the A column of the matrix.

The entire data set is clearly dominated by the 96 events that fell into the cell, (C-) whereby the driver cultivates or tolerates a conflict that is sensed by the radar, tending to close on a target vehicle at a substantial, negative value of $\dot{R}$ for the sake of some form of driving utility. The box in which these results are distributed shows that this group is comprised largely of cases in which the host vehicle approached another vehicle and passed it. Clearly, in all such cases, a simple ACC controller would essentially impede the normal control preferences of the human driver by slowing down to limit the headway intrusion, unless more sophisticated features were provided.

Table 15. Five-cell matrix, with tactic codes allocated to individual cells

Current headway condition relative to the model	**(A)** **ALTERCONTROL** **Managing Space & Style under conditions of <u>Minimal Conflict</u>**	**(B)** **ALTERCONTROL** **Ensuring Safety by reacting to a <u>Current Conflict</u>** **UNSENSED by Radar**	**(C)** **ALTERCONTROL** **Cultivating, for the sake of utility, a <u>Current Conflict</u>** **SENSED by Radar**	**(D)** **ALTERCONTROL** **Anticipating a <u>Future Conflict</u> based upon** **PLANS & FORECASTS**
(+) **Relaxing (lengthening) Headway** (Control Indicators: # 6, 8, 9)	▪ Relax for cut-in [T] ▪ Relax for adjacent gap ▪ Relax-indecision [D, V1] ▪ Satisficing [M1, R1]	▪ Relax for a TCD [H] ▪ Relax for an obstacle ▪ Relax for road geom. [K]		▪ Relax, preparing for a turn [E, U] ▪ Relax, with brake lamps ahead [O]
(-) **Tightening (shortening) Headway** (Control Indicators: # 1, 2, 3, 4, 5, 7, 10)	*(Rdot ~ zero)* ▪ Tighten : cut-in [S] ▪ Tighten to intimidate [B] ▪ Tighten for adjacent gap ▪ Tighten: accelerating from stop or on a ramp [Q, J, F] ▪ Satisficing [M2, R2, P, N]		*(Rdot << zero)* ▪ Approach: turning vehicle [G] ▪ Approaching-pass [C, V2, A] ▪ Approaching-merge [L] ▪ Approaching when weaving lanes [Z]	

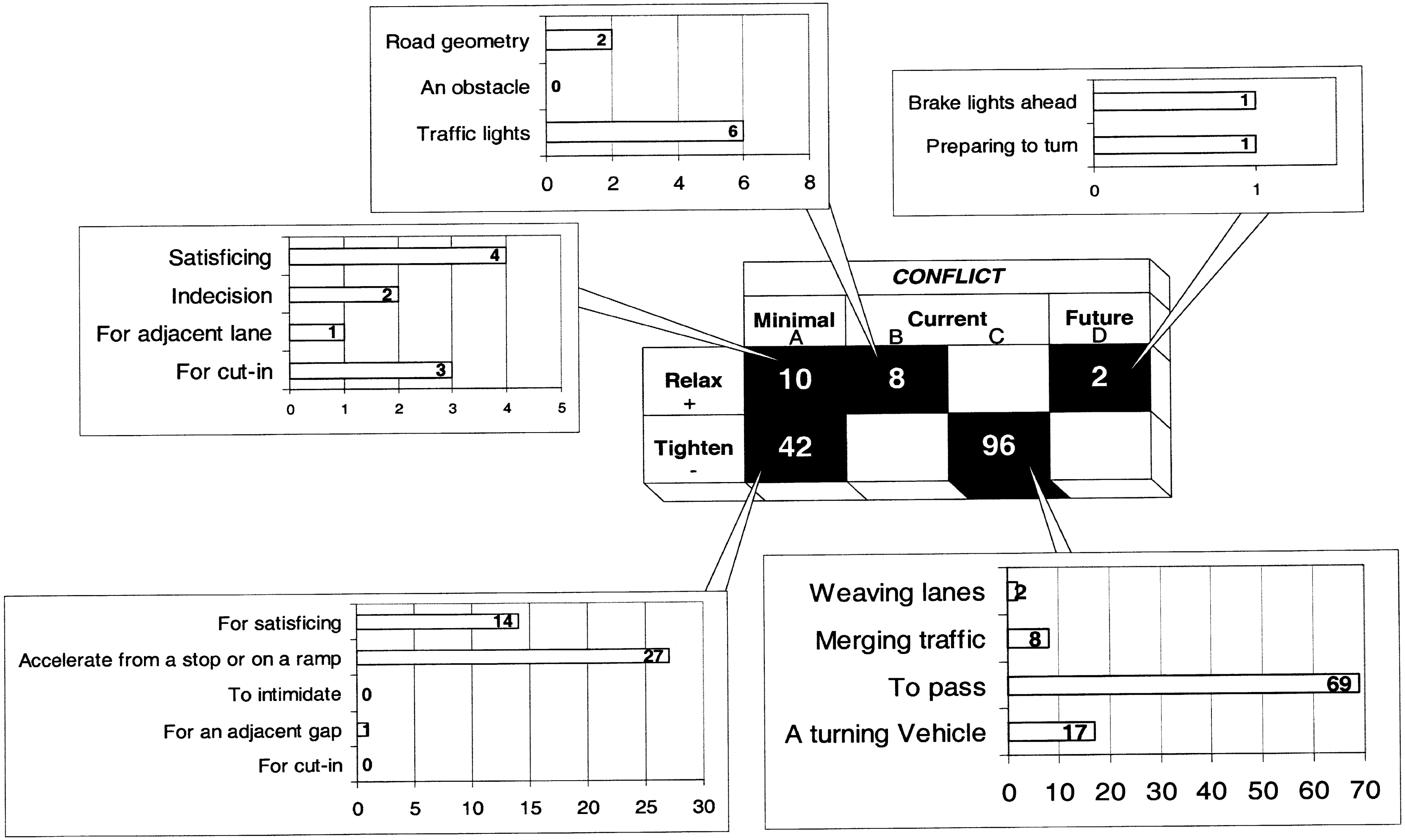


Figure 28. Count of altercontrol tactics, mapped into conflicts

Summarizing the Five-Cell Matrix

Shown in Figure 29, each of the five cells covers a domain that is distinct from the others (even though it must be admitted that some ambiguity can still exist in classifying certain events.) The figure shows that:

(A+) events lie in the R, $\dot{R}$ space, perhaps at small positive $\dot{R}$, in current time
(A-) events lie in the R, $\dot{R}$ space, perhaps at small negative $\dot{R}$, in current time
(C-) events lie in the R, $\dot{R}$ space, at substantially-negative $\dot{R}$, in current time
(B+) events address a reality lying in other than the R, $\dot{R}$ space
(D+) events address a reality lying in other than the current time.

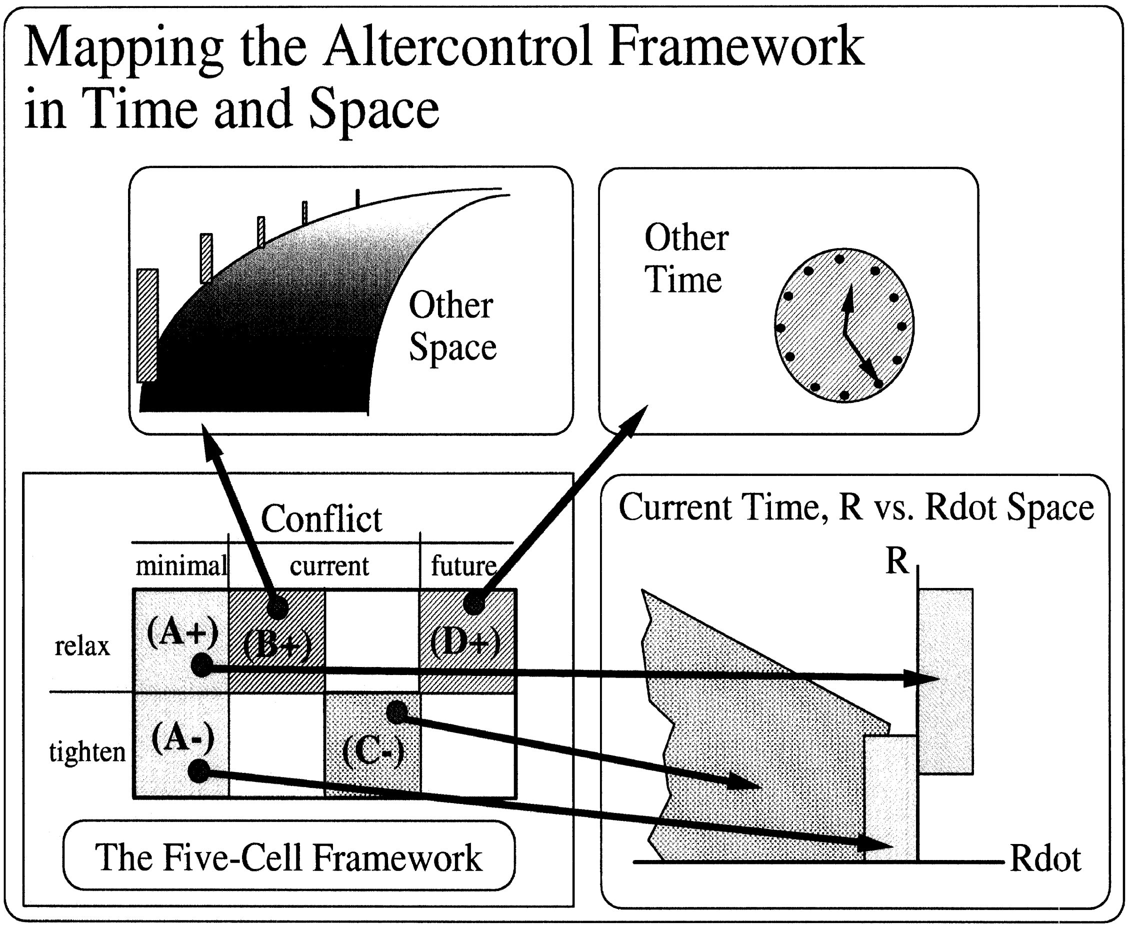


Figure 29. A summary of the Altercontrol Categorization Framework, accounting for the space and time domain applying to each of the five cells

6.0 CONSIDERATIONS OF THE MODEL, GIVEN THE TEST EXPERIENCE

This section discusses possible future improvements to the model that is used to identify instances of altercontrol.

6.1 A Better Way To Judge Altercontrol In Zone 4 (Following).

Operating inside zone 4 actually represents the epitome of headway control. Zone 4 is defined as following — and following a preceding vehicle at a constant headway is often perceived as the ultimate objective of headway control. The current algorithm stemmed from the thought that following was a constant-speed activity. It defined altercontrol within zone 4 as exceeding some reasonable acceleration bounds. This appears to be a less-than-optimum approach. Given the test experience and the results, a more appropriate approach for observing altercontrol in zone 4 would be to consider staying inside the zone as headway control, and any intentional departure from that zone would be altercontrol. Whatever the driver does in order to keep inside zone 4 is “legitimate”. He/she can brake or accelerate as needed – after all, by doing so the driver demonstrates in the clearest way that the intent is to follow and maintain headway.

The question that should be asked in that context, is: “How can we observe and determine that the driver departed zone 4 intentionally?” To answer this question one needs to consider the forward scene, in particular the preceding vehicle. As long as this vehicle did not execute some maneuver which “forced” the host driver out of the boundaries of zone 4, all other departures may be considered as altercontrol. A possible alternative for altercontrol rules within zone 4 may be:

- the driver is expected to stay within zone 4; any departure will be considered altercontrol unless it is accompanied by:
    - a new target, or
    - the current target leaving our lane, or
    - a deceleration/acceleration level by the lead car which is beyond ± *axLead* (value to be determined)

6.2 An Improved Model of Driver Behavior

The computerized model included in the first report to BMW [2] simulated the behavior of the human driver in stop-and-go driving on a freeway. That model introduced concepts that associate driving rules with zones described by areas in the range versus range-rate diagram. These areas are centered on a desired headway range that depends upon the speed of the preceding vehicle.

The work performed in the earlier study showed that the value of the parameter T_h, which determined the desired headway range, had a critical influence on the quality of the results predicted using the driver model. In this study, the headway time T_h was evaluated on-line in order to keep its value as current as possible while the driver was proceeding along the chosen route. This feature made it possible to use a low-bandwidth projection of driver behavior to assess if altercontrol appeared to be present.

At the beginning of this study, it was intended that the original model be used directly for recognizing altercontrol . However, further consideration indicated that the original model would be difficult to use in the context of real-driving tests. In a sense, the original model was too specific in its control actions. These actions would frequently get out of synchronization with what the driver chose to do. The study of altercontrol called for a more general approach that covered the sets of reasonable actions that a driver might take in maintaining headway control. Hence, the zones and associated actions presented earlier in Figure 3 and Table 1 were adopted for use in the study of altercontrol .

Since the zones and acceptable actions (i.e., control-indicators) used in this study are different from the zones used in the preceding phase of the project, it is useful to consider how the test experiences in this study points to the development of an improved driver model. A basic difference between the "old zones" and the "new zones" is that many of the new ones are based upon lines passing through the origin (R = zero and $\dot{R}$ = zero) in the R versus $\dot{R}$ space. This implies driver tendencies towards using braking deceleration to avoid the "looming-object" stress rather than simply trying to get to the desired headway range. We believe that the driver is often trying to avoid situations that could lead to a crash. Once the driver feels secure in the current situation, headway control becomes relevant again. Although we have not been charged with developing specific changes in the driver model, we believe that it would be worthwhile to include these considerations in a refined model.

The original driver model did include a wedge-shaped zone in which control actions were based on stopping distance criteria. However, the boundaries of that zone now seem to be misplaced. In addition, it is not clear how well drivers can estimate the deceleration of the preceding vehicle. Along with the suggestion to consider new zones (as indicated in the previous paragraph), we believe it would be wise to develop new rules for zones involving relatively high levels of braking deceleration. Perhaps comfort-and-convenience actions and crash-avoidance actions overlap to the extent that the distinction between them is not as distinct as we had previously portrayed.

We have become aware of additional driver modeling factors during the course of the study of altercontrol . These factors have a direct bearing on developing a methodical approach for the study of driver assistance systems. The idea behind developing an improved model of the driver is to use the concepts supporting the model to aid in identifying how proposed assistance systems might assist the driver. In its way, a computerized model serves as a check on conceptual reasoning in that its predictions can be compared to observations. This check provides a special type of quality assessment regarding our understanding of driver behavior.

In order to make our computerized model more like a driver, it needs to include features representing the driver's mental work load and decision processes associated with switching between control rules. We have given thought to these matters in preparing this report.

Based on observations of drivers, we note that drivers tend to check the situation and then determine a control action that will be continued for a brief period. In this sense, drivers employ a type of sample-and-hold operation. The frequency of sampling appears to depend upon the nature of the driving environment. More stressful situations tend to involve more frequent sampling. If the amount of mental activity is nearly the same for each control determination, the level of workload is approximately proportional to the sampling rate. In this regard, we would propose to add a sample-and-hold feature to the driver model. This feature would have an adjustable sampling frequency depending upon severity of the driving situation.

It has been observed that as long as humans feel that their current tactics are producing satisfactory results, they are hesitant to change. They will change tactics (to behavior based on another rule) when the situation becomes unsatisfactory. These observations indicate the need for an extension of the sign-concept as previously used for selecting which rule to use. The idea is to view each rule as a control mode or state. The sign for initiating a control state may be different from the sign for ending that state and starting another state. In this way, the boundaries for each control rule overlap those for other control rules. To switch rules, the current rule would need to be sufficiently less desirable than some other competing rule. This process of evaluating the suitability of the existing rule would require a new set of considerations associated with benefits and risks.

Although we have not used these ideas explicitly in our previous model, there was an implicit assumption that the boundaries of the zones represented a first order approximation to the selection process. In order to progress beyond that previous level of approximation, a more advanced method of changing control tactics is warranted.

The following block diagram (Figure 30) indicates how the new features described above would fit in with the commander-controller concepts applied in previous work. The commands to the controller would be the output of a sample-and-hold device. (An approximation for use in a continuous model would be a time delay of 1/2 of the time between samples.) The decisions as to what rule to use would be more complicated than before. Instead of straightforward inequalities that identify zones and their associated rules for generating commands, the zones would overlap. Only after the estimated risk (and perhaps the cost) of maintaining the current rule became unfavorable would another rule be selected. Hence, there is an additional computational step associated with checking whether the current rule is satisfactory. The additional step involves selecting the next rule to use in determining the next command. With these additions, the computerized model would provide a closer look at the decision and control processes involved in manual driving.

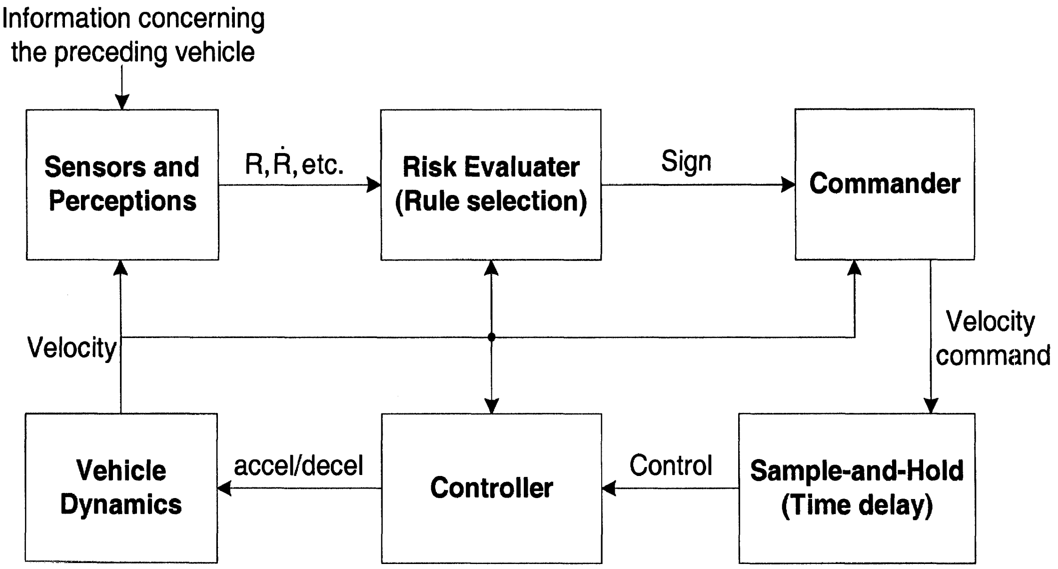


Figure 30. New Features in an Improved Driver Model

The purpose of adding these features would be to aid in understanding how features of driver assistance systems might improve driving performance over that attained in manual driving. Specifically for systems that assist the driver by being more perceptive, more diligent, quicker, and/or more accurate, the model could be useful in providing insights into the amount and type of performance improvement to expect. Although the model has been discussed with longitudinal control in mind, the ideas and concepts involved are sufficiently broad that they apply to driving in general. As overall driver assistance packages develop, models containing generalized concepts (principles) of driver behavior are needed for predicting and evaluating system capabilities and performance as compared to manual driving.

7.0 PLACING ALTERCONTROL IN THE CONTEXT OF A METHODICAL APPROACH FOR DAS DEVELOPMENT AND EVALUATION

The observation of altercontrol behavior has been applied here to the case of headway-keeping as the reference task in manual driving. This baseline domain of vehicle control corresponds to that which is displaced, or assisted, by an ACC system—especially a Stop & Go form of ACC. Clearly, the tracking and cataloguing of altercontrol activity is motivated by the commercial intent to develop highly pleasing and safe products, such as ACC. It is believed that by detecting and carefully examining the altercontrol activity that drivers naturally employ, one gains product-pertinent insight into the otherwise-ambiguous domain of the driving process. Thus, the altercontrol observation method is seen as a significant step toward the "methodical approach" that BMW seeks to develop.

Understanding the possible conflicts between the DAS functionality and the driver's preferred actions is already part of the process of designing and evaluating a new DAS. Currently, though, the functional suitability of the design is most often determined through trial and error by engineers who drive the prototype vehicle through traffic and make observations. The DAS is then redefined or tuned so that its design fits more naturally with the desires of drivers. By applying a systematic identification and categorization of altercontrol tactics, the designer could receive this information sooner, even before a DAS prototype is available, and could also quantify the relative frequencies and types of altercontrol conflicts that should be expected. The designer could then consider each of the individual altercontrol types that will occur and their possible remedies. Altercontrol conflicts arising from a given DAS design may be resolved or reduced by:

- A re-tuning of the DAS parameters. In this case, even though the same types of altercontrol transition may still occur, their frequency of occurrence can be reduced; and/or
- Extending the function set of the DAS controller such that one or more altercontrol tactics become subsumed within the definition of the system (e.g., suppressing the normal ACC deceleration response when the state of the turn signal and other evidence implies that the driver intends to pass on the fly).

The second of these approaches toward managing altercontrol conflicts may be enabled by:

- adding new sensing capabilities such as additional onboard sensors, communication with infrastructure elements, or vehicle-to-vehicle communication (e.g., sensing lead vehicle accelerations from a stop, identifying changes in the state of traffic control devices such as a traffic light turning to amber, identifying vehicle location relative to a roadway feature such as a motorway entrance ramp, and receiving information from a preceding vehicle about its braking status);
- adding algorithms that infer the onset of driving maneuvers (e.g., use of sensor data to determine that the preceding vehicle is moving out of the host vehicle's travel lane so that the ACC can proceed with a shortening headway), and/or
- adding or extending automatic control capabilities to the original DAS function.

As sketched in Figure 31, any given DAS system will project its own functional envelope onto the control domain of all driving. The concept of altercontrol, as developed here, is to identify the boundary that distinguishes driver-exercised control from that which is within the DAS domain. Whatever the specific design of a DAS function may be, the boundary in question will always be somewhat personalized by the individual driver. Furthermore, the boundary will be somewhat flexible since a person can always choose to change their driving style in response to the DAS. Such a change might serve to lessen the incidence of altercontrol , thereby accommodating personal driving habits to the DAS function. Accommodations of this kind have been seen, for example, in the willingness of some drivers to apply a throttle override when pulling out to pass, with ACC engaged.

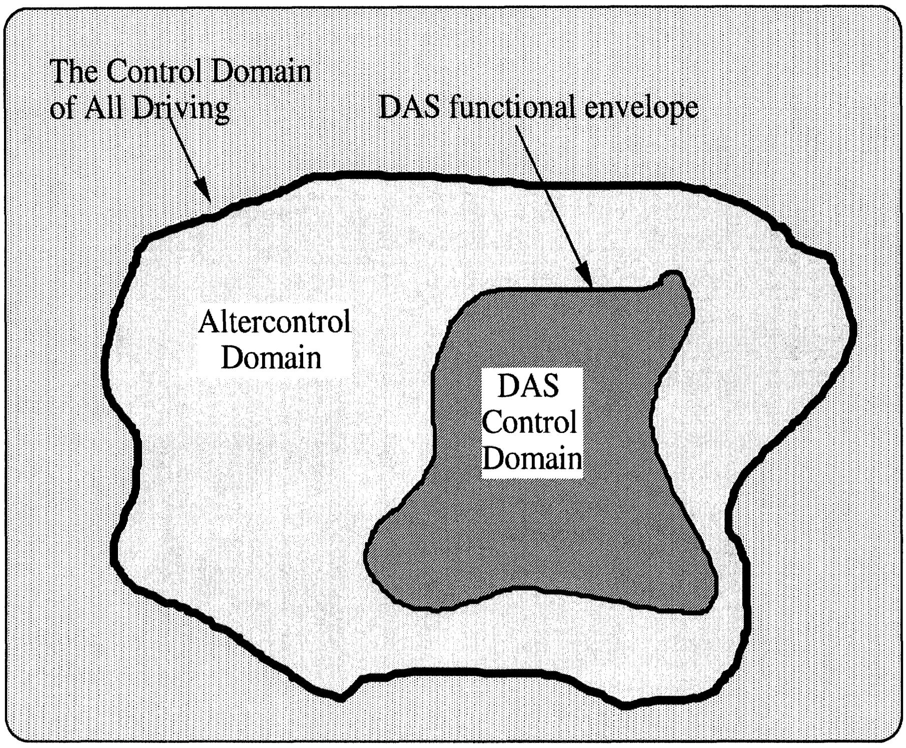


Figure 31. Altercontrol and DAS control domains

The domain of altercontrol is determined entirely by the *operational coverage* of the specific DAS control device under consideration, given the way that a driver exercises human judgment and preference when controlling the actual driving process. While we will recommend in the next section that the altercontrol method be validated for its immediate application to ACC development, nevertheless the method is not restricted to ACC and applies in concept to other DAS functionalities, as well.

Driver assistance systems directly addressed by the concepts in this report include automatic control functions that take on limited responsibility for common driving tasks (such as ACC or low-authority lane-keeping assistance). The results may also be useful for the design and evaluation of related collision warning or collision avoidance systems. Limited-authority controllers and collision warning/avoidance systems share weaknesses relative to the human driver—for example, limited capability in sensing the driving situation and limited ability to anticipate the actions of both the host vehicle and the surrounding traffic. Since the altercontrol method is one way to identify driver control tactics that are different from the set of basic tactics that the DAS presumes, it may also help guide the development of crash warning/avoidance systems.

For example, consider forward collision warning (FCW) systems that provide alerts to drivers with the objective of helping them avoid or mitigate a crash into the rear-end of another vehicle. Alerts are typically provided so that the driver has just enough time to react to the alert and execute an assumed avoidance maneuver, such as a hard braking response. Because these systems are designed to reduce crashes caused by driver inattention, distraction, or misjudgments, they typically assume that the prevailing scenario will continue unchanged; for example, that the host and the preceding vehicles will each maintain their current longitudinal accelerations and yaw rates. In practice, many false alerts occur because the driver's control actions anticipate that the scenario *will* change substantially, perhaps through a lane change or a change in accelerations. It is noted that for FCW, these situations are likely to be a subset of those altercontrol tactics in the "C-" cell of the altercontrol framework shown earlier in Table 14. This cell applies to instances in which the human driver accepts a reducing headway clearance for a limited period of time based upon confidence in their ability to sense and predict the outcome. Clearly, while altercontrol has been defined primarily in relation to convenience types of DAS controllers, the results may also be useful in the design of collision warning/avoidance systems.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The project has succeeded in developing a workable method for observing altercontrol for the application in which headway-keeping is the reference driving task. Below, we offer several conclusions that follow from this work and we recommend the next steps that lead toward application of the altercontrol method to product engineering.

8.1 Conclusions

- The altercontrol observation method is relatively straightforward, given progress that was made earlier on the development of a modeled-basis for representing the headway-keeping task in manual driving.
- The method is implementable in a practical test-driving environment when supported by an on-board computer containing the model-reference algorithm, remote and on-board sensors as dictated by the modeled domain of control, and both video recording and on-board researcher-interface tools by which to support observation of the driving context for altercontrol.
- Four elements were found to be essential to the method of altercontrol observation and analysis, namely:
    1. A practical formulation of the reference (i.e., modeled) control task—in this case implemented as subdivided zones of the R vs. Rdot space, each of which is associated with…
    2. Control indicators (such as throttle or brake application, decel level, etc.), the violation of any of which serves to indicate that an altercontrol tactic is underway;
    3. Each tactic is rationalized according to one of several text statements that portray the apparent intent of the driver (e.g., "approaching a turning vehicle while anticipating its clearance from the lane", "slowing in response to brake lamps up ahead", etc.);
    4. Tactic categories are coded and sorted within an "Altercontrol Categorization Framework" by which the observed events are classified and counted to express: a) their significance among the stylistic, safety, and utility concerns of the driver, b) the polarity of the difference in modeled vs. actual-driving

9.0 REFERENCES

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headways—viz., headway-lengthening or headway-shortening, and c) the frequency of occurrence and nature of the differing altercontrol behaviors.

- Altercontrol observations from actual driving can be meaningfully interpreted in terms of both high-level statistics (histograms and distributions of altercontrol events, zones of occurrence, apparent driver tactic, etc.) and rational deductions that yield natural-language statements on the suitability of a driver-assistance product whose function is more or less captured in the reference control model.
- The obtained results allow the DAS system developer to distinguish which of the system's features seem to foretell: a) operational safety problems, b) the need for driver-adjustable, or perhaps adaptive, parameters to accommodate personal driving style, and c) the utilization percentage that DAS drivers might enjoy, given the altercontrol burdens that are expected.

8.2 Recommendation

Since the current work has managed only a very modest field trial of the method presented herein, it is recommended that the next step include a more extensive set of manual driving tests from which altercontrol observations can be made. Improvements in the reference model, discussed earlier in section 6.0, should be made so that the implemented method be as up to date and as efficient as possible. The resulting data should be analyzed using the tools and altercontrol categorization framework outlined here.

The recommended second step is to collect a companion set of measurements and subjective assessment from driving an ACC system over the same nominal route and traffic conditions that are used in making altercontrol observations from manual driving. At least a dozen laypersons should be employed as the test drivers. An analysis should then be done on the two corresponding sets of data (i.e., manual and ACC driving) by which to arrive at a means for validating the application of altercontrol observations to an actual DAS function. The intent is to demonstrate, from a direct comparison of data, how altercontrol results can inform the process of evaluating an ACC system.

The recommended two-step activity is to be conducted as an integrated project, yielding direct evidence of the utility of the altercontrol method to support the process of engineering driver assistance systems.

APPENDIX A

POST-PROCESSING SIMULATION FOR OBSERVING ALTERCONTROL

A-1. Motivation and Rationale

The algorithm for observing altercontrol which is described in section 3 in the main body of the report, employs a suite of parameters and settings during its operation. The values selected for these parameters determine if, and under what circumstances, altercontrol behavior by the driver will be detected.

During the developmental stages of the pilot tests the value of the minimum speed — the speed below which no altercontrol behavior was considered or evaluated — was set to be comparable to that of an ACC system – i.e., 8.9 m/sec (32 kph, 20 mph). This speed boundary was set due to "data noise" concerns, that were thought to affect the understanding of altercontrol behavior at very low speeds. Mid-way through executing the sequence of test drives, it was determined that the minimum speed setting should be reduced since: (1) the low-speed data obtained during stop-and-go traffic is not too noisy to analyze, especially if the post-drive analysis is carried out in conjunction with the video data, and (2) examining the low-speed environment provides a meaningful enrichment of the understanding of altercontrol behavior. Accordingly, the parametric value of the minimum speed was modified by setting it to be practically zero – i.e., 0.9 m/sec (3.2 kph, 2.0 mph). This parameter was not set to be exactly zero in order to avoid the computational problem of division by a zero value for speed.

The rest of the tests were carried out with the new, lower value for the minimum speed threshold. However, constraints on time, hardware, and the availability of participant drivers did not allow for a repeat of the earlier test drives.

As has been described, the system for observing altercontrol is a passive, non-intrusive system. That is, it does not affect how the driver operates the vehicle (other than some psychological affects that might be associated with having an observer in the car). Therefore it was determined that data collected during any of the test drives could be post-processed with the same altercontrol algorithm code used in the test vehicle – only with different parameters. It is assumed that the results from such post-processing would be virtually the same as if the algorithm had been operating in the car, on-the-fly, during the actual test drive. Accordingly, a post-processing computation "simulated" the operation of a revised altercontrol algorithm whose minimum-speed parameter was set to 0.9 m/sec. The algorithm simulation was run on the data from the early set of drives (when the minimum-speed threshold had actually been set to 8.9 m/sec), expecting that the altercontrol events would include: (1) exactly the same altercontrol detections as were observed on the test drive at speeds above 8.9 m/sec, plus (2) additional, new altercontrol detections at speeds between 0.9 and 8.9 m/sec. The simulation results confirmed this expectation, as detailed below.

A-2. Simulation

The simulation was carried out using the computational tools of MATLAB®. First, the test-drive data which are normally stored in *Microsoft*® Access database format, were exported to a format that is compatible with MATLAB®. A script file was then executed to perform the following tasks:

1. read the data
2. set values for parameters
3. for each point in the data, determine whether the altercontrol "flag" should be set
4. for each altercontrol event detected in step 3 above, determine the appropriate control indicator
5. record each altercontrol event, its control indicator, the time, and the corresponding time-frame of the video

Once the simulation was completed, the altercontrol events were examined and interpreted per their apparent altercontrol tactics (see section 5.2.1) with the aid of the video. Table 16 provides a listing of the code used in step 3 above in determining the state of the altercontrol flag (note that the code uses the variable, "buzzer" for the flag).

Table 16. MATLAB® Code of the altercontrol algorithm

```
function buzzer = alterControl(accPedal,bp,ax,Vp,Th,Velocity,R_corrected,NewTarget,Zone)

globalVars   % set some global variables

% it's the altercontrol function
% based on the function "BYTE f_Buzzer(Frame *fr)" from the car.

buzzer = 0;
doCases = 0;
out = 0;

%--- select rmax to use
 temp = (2.0)*(Vp)*(Th); %// 2*Rh
 if (rmaxPAR > temp)
  rmax = temp; %// rmax = min(2*Rh,Rmax)
 else
  rmax = rmaxPAR;
 end;
```

```
if ( (Velocity < Vmin) | (R_corrected > rmax) | (R_corrected < Rmin) )
 waitCount = 0;
 waiting = 0;
else
 if (NewTarget)
  waitCount = 1;
  waiting = 1;
 else
  if (waiting)
   waitCount = waitCount + 1;
   if (waitCount>=waitingTime)
    waiting = 0;
    waitCount = 0;
    doCases = 1;
   end;
  else
   doCases = 1;
  end;
 end;
end;

if (doCases)
 switch (Zone)
  case 1
   if (bp>0.0)
    wasBraking = 1;
    buzzer = 0;
   else
    if ( (accPedal>0.0) | ((bp<=0.0) & (ax>-axb1)) )
     buzzer = 1;
    else
     buzzer = 0;
    end;
   end;

  case 2
   if (bp>0.0)
    wasBraking = 1;
    buzzer = 0;
   else
    if ( (accPedal>0.0) & (ax>0.0) )
     buzzer = 1;
    else
     buzzer = 0;
    end;
   end;

  case 3
   if (bp>0.0)
    wasBraking = 1;
    buzzer = 0;
   else
    if ( ax>axb2 )
     buzzer = 1;
    else
     buzzer = 0;
    end;
   end;

  case 4
   if (wasBraking)
    buzzer = 0;
    if (bp<=0.0)
     wasBraking = 0;
    end;
   else
    if ( ((accPedal>0.0) & (ax>axb1)) | ((bp>0.0) & (ax<-axb1)) )
     buzzer = 1;
    else
     buzzer = 0;
    end;
   end;
```

```
  case 5
   if (ax>axb3)
    buzzer = 1;
   else
    buzzer = 0;
   end;

  case 6
   if (bp>0.0)
    buzzer = 1;
   else
    buzzer = 0;
   end;

  case 7
   if (bp>bpb1)
    buzzer = 1;
   else
    buzzer = 0;
   end;

  case 8
   if (bp>0.0)
    buzzer = 1;
   else
    buzzer = 0;
   end;

  case 9   %// too far
   buzzer = 0;

  case 10  %// too close
   buzzer = 0;

  otherwise
   buzzer = 0;
 end %// end switch
end  %// end doCases

if (buzzer)
 buzzerCount = buzzerCount + 1;
 if (buzzerCount < BuzSamples)
  buzzer = 0;
 else
  buzzerCount = 20; %// just to avoid overflow of counter
 end;
else
 buzzerCount = 0;
end;
```

A-3. Summary

The validity of this analysis approach was verified first by setting the minimum-speed parameter ($V_{\min}$) to the same value as during the test drive. The results showed full agreement with the initial altercontrol detections: the same altercontrol flags that were set by the algorithm in the car, were set by the simulated algorithm. Thus the expectation (1) above was verified. The minimum-speed parameter was then set to be 0.9 m/sec, and the data taken with the earlier drivers (who drove with $V_{\min}$ = 8.9 m/sec) were analyzed. The additional altercontrol events flagged by the simulation were further evaluated by observing the video data, to confirm their suitability and to assign appropriate tactic code designations.

Clearly the post-processing method outlined here, which was used simply to recomputed a simple parameter change in the altercontrol algorithm, could be employed to study any other algorithm that operates on the same raw sensory data. Furthermore, alternative schemes for determining the driver's preferred headway time (T_h), the preferred open-road speed (V_{set}), etc., could also be devised and evaluated using the "simulated algorithm" approach.