ANALYSIS OF TARGET CRASHES AND ITS/COUNTERMEASURE ACTIONS

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ABSTRACT

This paper summarizes some of the results of a 3-year project that was undertaken by the Research and Special Programs Administration's Volpe National Transportation Systems Center to identify crash causal factors and applicable Intelligent Transportation System (ITS) countermeasure concepts, model crash scenarios and avoidance maneuvers, provide preliminary estimates of countermeasure effectiveness when appropriate, and identify research and data needs. Eight target crash types were examined: (1) rear-end, (2) backing, (3) lane change and merge, (4) single vehicle roadway departure, (5) opposite direction, (6) signalized intersection, straight crossing path, (7) unsignalized intersection, straight crossing path, and (8) left turn across path crashes. This paper identifies target crash subtypes and causal factors that were determined by a case-by-case examination of a sample of crashes drawn from two National Highway Traffic Safety Administration's accident data bases; defines and categorizes ITS countermeasure system concepts; and includes a sample of kinematic models representing crash avoidance actions.

INTRODUCTION

Recent advances in sensors, communications, processors, controllers, and driver/system interfaces can now allow for the design of collision avoidance systems with increased sophistication, reduced cost, and high reliability. However, there is a weak link in the logic chain between available technologies and the prevention of crashes (l). The mechanisms of intervention of high-technology devices in crash scenarios are not well understood. In order to facilitate the development of safety products and systems, one major thrust in the National Highway Traffic Safety Administration's (NHTSA) Intelligent Transportation System (ITS) strategic plan identifies promising opportunities for the application of advanced technologies for inproving the crash avoidance capabilities of the driver-vehicle system (2). A key element to defining crash avoidance opportunities is the problem definition and analysis of target crashes and ITS/countermeasure actions. By analyzing candidate technological solutions in relation to the parameters of target crash scenarios and the capabilities and limitations of drivers, countermeasure functions can be identified which, in turn, can lead to assessments of the most promising applications of technology and associated R&D needs.

The preliminary stage of 'problem definition and analysis of target crashes and ITS/countermeasure actions was performed, in a 3-year project, by the Research and Special Programs Administration's Volpe National Transportation Systems Center in conjunction with NHTSA's Office of Crash Avoidance Research, with contract support from Battelle Memorial Institute and its subcontractor ARVIN/Calspan. This project developed and applied a seven-element methodology, illustrated in Figure 1, to describe target crash characteristics, identify crash subtypes and causal factors, devise applicable ITS countermeasure concepts, model crash scenarios and avoidance maneuvers, develop sensitivity curves, provide preliminary estimates of countermeasure effectiveness when appropriate, and identify research and data needs (3)(4). The purpose of this study was to help guide R&D on high-technology crash countermeasures. Specifically, results of these analyses support NHTSA's sponsored research to develop performance specifications for advanced collision avoidance systems (1).

Eight major crash types were addressed in this project:

Rear-End (RE) (5)
Backing (BK) (6)
Lane Change and Merge (LCM) (7)
Single Vehicle Roadway Departure (SVRD) (8)
Opposite Direction (OD) (9)
Signalized Intersection, Straight Crossing Path (SI/SCP) (10)
Unsignalized Intersection, Straight Crossing Path (UI/SCP) (11)
Left Turn Across Path (LTAP) (12)

In addition to target crashes listed above, this project also examined crashes that occurred in reduced visibility conditions (e.g., nighttime/inclement weather).

According to NHTSA's General Estimates System (GES) accident data base, there were approximately 6,093,000 Police-Reported (PR) crashes in 1993. The GES is a nationally-representative survey of nearly 44,000 Police Accident Reports (PARs) that are gathered from sixty geographic sites and include all vehicle types and crash severities. The relative problem sizes of the eight target crash types are indicated in Figure 2, which add up to about 71% of total crashes in 1993. Note that target crash types are defined on the basis of pre-crash vehicle movement and are all mutually exclusive. The remaining crashes involve pedestrians/cyclists, on-road rollovers, other intersection crash types, non-lane change sideswipes, and non-intersection crossing paths. The relative target crash sizes in Figure 2 are used as weighting coefficients, later in this paper, to determine the weighted average of crash causal factors.

This paper summarizes some results of this project. First, an assessment of target crash subtypes and causes is provided. Second, three basic categories of potential ITS countermeasure system concepts are discussed. Finally, a sample of kinematic models of crash avoidance actions is presented to illustrate crash avoidance requirements. To facilitate the readability of this paper, the reader is referred to the Appendix for the definitions of acronyms used throughout this paper.

TARGET CRASH SUBTYPES AND CAUSES

A detailed analysis of 942 cases of target crashes was conducted to identify crash subtypes and causal factors. Case samples were primarily drawn from the NHTSA's Crashworthiness Data System (CDS) accident data base. In addition, PARs were picked from the NHTSA's GES accident data base to supplement the case samples if an insufficient number of CDS cases were available for a particular crash type. The CDS investigates a nationally representative sample of about 5,000 PR crashes annually, involving at least one towed passenger car, light truck, van, or utility vehicle. Although the CDS was designed primarily for crashworthiness/occupant protection research, CDS files typically provide detailed information to successfully determine crash subtypes and principal causal factors. Note that both CDS and GES have added new variables on pre-crash events beginning with the 1992 data collection year, including (1) attempted avoidance maneuver, (2) pre-event movement (prior to recognition of critical event), (3) critical pre-crash event, (4) pre-crash stability after avoidance maneuver, and (5) pre-crash directional consequences of avoidance maneuver.

The analysis' approach adopted in this study entailed subjective assessment by an expert analyst, which involved content analysis of narrative statements and kinematic assessment to cross-check narratives. The analyst developed an impression of the crash subtypes or causal factors from the reviews. Error sources in this analysis process might include limited sample size, incomplete case files, and analyst decision processes that are subject to cognitive heuristics and biases in judgement. Despite these error sources, the detailed analysis of case files represented an invaluable aid to understanding the nature of crashes. In addition, this analysis opened up data sources (e.g., additional uncoded information in PARS) that were otherwise unavailable.

A representativeness check performed subsequent to the detailed analysis of crash cases indicated that the crash and injury severity profile of the case sample was more severe than the GES profile. In order to correct for this bias and to characterize the results statistically, the CDS data were weighted based on the distribution of four crash severity levels in the GES for each crash type. Hence, all percentages cited in this report are severity-weighted. Although severity-weighting of sample cases was necessary to correct for differential sampling of crashes of different severities in the original GES and CDS sampling, it resulted in analysis samples consisting of cases of unequal weights. One or two heavily-weighted cases could greatly affect the profile of crash causes for a given sample. For example, one heavily-weighted case in which the driver became ill represented a *weighted* percentage of nearly 10 percent of the 74 cases in the rear-end crash sample. Thus, although the case weighting scheme was necessary, it admittedly resulted in some anomalous findings.

Crash Subtypes

The examination of individual cases identifed a sample of 595 cases suitable to determine subtypes of target crashes, excluding backing crashes. The case sample comprised 5 16 CDS files and 79 GES PARS. The subtypes of backing crashes were identified by a code search of the 1990 GES data base. Table I identifies and defines the subtypes of each target crash type and lists their respective sample size and percent distributions. Note that the subject vehicle (SV) refers to the one that initiated the hazardous maneuver (e.g., changed lane) and collided with another vehicle, referred to as the principal other vehicle (POV). Of backing crashes, parallel path, curved path, and pedestrian/pedalcyclist crash subtypes are encompassed under one slow-closing-speed *encroachment* subtype. From Table 1, the encroachment crash subtype constitutes 43% of all backing crashes. Table 1 also shows that the majority of LCM crashes *are proximity* crashes involving two vehicles traveling at almost similar velocities and small longitudinal gaps. Moreover, about 1% of opposite direction crashes were attributed to *passing* maneuvers. The remaining 99% of opposite direction crashes resemble SVRD crash subtypes (i.e., lane keeping failure and evasive maneuver).

Crash Causes

The causal factors of target crashes were determined by an in-depth review of 554 CDS files and 133 GES PARS. Note that a larger sample of 927 crash cases was initially examined. However, a number of cases were discounted because they lacked sufficient information to identify a dominant cause. Some collisions were attributed to a combination of causes and contributing circumstances; but, one dominant cause was assigned based on the expert analyst's subjective assessment. Table 2 shows the distribution of causal factors for each target crash type. The causal factor distributions within **each** target crash subtypes were also determined (5-

12). Additional results of the causal factor analysis are revealed below.

- A combination of *tailgating* (following too closely) and driver *Inattention* contributed to 19.4 % of rear-end crashes. By subjective judgement, tailgating was noted as the primary cause.
- 2.2% of LCM crashes were due to *excessive speed* combined with *bad roadway surface conditions.* In these cases, excessive speed was judged to be the primary cause.
- 3.9% of SVRD crashes that were primarily caused by *excessive speed* involved *drunk* drivers.
- The SV drifted out of its travel lane due to driver *inattention* and resulted in 3.8% of lane change crashes and 6.8% of SVRD crashes.
- 13.7 % of SVRD crashes were the result of *an evasive maneuver* by the SV to avoid crossing pedestrians or animals (5.8%), opposite direction collisions with other vehicles in its travel path (6.5%), and lane change crashes initiated by other vehicles (1.4%).
- 7.0% of SVRD crashes caused by driver *inattention* resulted from an evasive action to avoid a rear-end crash with a lead vehicle. Similarly, about 12% of opposite direction crashes occurred as a result of a rear-end crash evasive maneuver.
- SV drivers committed all the signal/sign violations in SI/SCP and UI/SCP crashes while, in contrast, POV drivers were cited for such violations in 7.1% of LTAP crashes compared to only 0.3% for SV drivers. Both SV and POV tried concurrently to beat the amber light at signalized intersections in 3.5% of LTAP crashes. Solely, SV and POV tried to beat the amber light in 1.7 and 2.8% of LTAP crashes, respectively.
- Miscellaneous causes included various erratic actions such as the POV changing lane and cutting in the SV travel path in rear-end crashes, a passenger fell out and being hit by same vehicle in a backing crash, POV driver misusing turn signal in LTAP crashes, and SI/SCP crashes involving hit and run cases (2.4%) and emergency vehicles (3.5%).

Synthesis of Causal Factors

The causal factors of target crash types are synthesized in five major categories employing the taxonomy shown in Figure 3. These categories include driving task errors, driver physiological impairment, vehicle defects, low-friction roadway surface, and reduced visibility. This particular classification will facilitate the development of ITS crash countermeasure concepts, discussed in the following Section. Table 3 shows the causal factor distribution across target crashes in terms of percentage of occurrence, weighted by the 1993 GES relative problem sizes shown in Figure 2. According to GES estimates, target crash types addressed in this program (i.e., rear-end, backing, LCM, SVRD, SI/SCP, UI/SCP, LTAP, and opposite direction crashes) accounted for 71% of all 1993 crashes. As seen in Table 3, about 75 % of target crashes were caused by driving task errors. The remaining target crashes were attributed to driver physiological state and vehicle, roadway and visibility conditions. In general, driver recognition errors were the leading cause of crashes investigated (43.6%), followed by driver decision errors (23.3%).

ITS CRASH COUNTERMEASURE CONCEPTS

Functional countermeasure concepts that address a particular target crash type are ideally devised based on its dynamic situation and concomitant causes, contributing circumstances, and pre-crash timeline of events. These concepts may provide mechanisms of intervention in three basic categories, as illustrated in Figure 4 (13). The first category addresses *advisory* means which apply to potential collision situations, vehicle(s) not on a collision course, where urgent crash avoidance action is not necessary. The second category incorporates *warning* systems which apply to imminent collision situations, vehicle(s) on a collision course, where immediate driver action is needed. The third category provides *automatic control intervention* needed to avoid an imminent collision, vehicle(s) on a collision course, where driver intervention alone is not sufficient (e.g., automatic braking or steering). In addition, hybrid concepts may be suggested which employ concepts of the three previous categories and provide timely transitions among them.

In this study, the timeline of pre-crash events in most cases was not established by the crash analyst due to a lack of details in the crash file. Consequently, various countermeasure concepts were developed and assigned to each of the three categories based on the target crash dynamic situation and associated causal factors. For instance, a driver advisory of a vehicle approaching the intersection would be applicable to UI/SCP crashes (proceeded against cross traffic crash subtype) caused by subject vehicle drivers who were *unaware* of the approaching vehicle. However, this particular countermeasure concept would not help drivers who saw the other vehicle and *misjudged its gap/velocity*. A gap acceptance aid that warns the driver when it is unsafe to cross the intersection would most likely aid the latter drivers.

Most crashes caused by driving task errors (e.g., driver recognition and decision errors and erratic actions) are amenable to countermeasures that depend on the specific crash scenario and relative dynamics. Based on Table 3, about 75.4% of target crashes might be addressed by scenario-specific countermeasures. Crashes caused by driver physiological impairment, vehicle defects, low-friction roadway surface, and reduced visibility may be alleviated by crash type-independent countermeasures which would intervene in the “normal driving” region at the left end of the spectrum of systems in Figure 4. For instance, brake failure may contribute to multiple crash types and its countermeasure does not depend on a particular causal factor. According to Table 3, such countermeasures might address about 24.6% of target crashes.

KINEMATIC REPRESENTATION OF COUNTERMEASURE ACTIONS

Kinematic models were formulated to represent crash dynamic situations and effects of ITS countermeasure actions on crash avoidance. This modeling representation allows for estimation of crash avoidance requirements for the various crash subtypes identified in Table 1. Consequently, these models would be used, in part, to estimate the effectiveness of crash-scenario-specific ITS countermeasures and to identify critical countermeasure functional requirements and data needs. As an example of crash avoidance requirements, the maximum available time (or distance) to enable the SV to avoid a collision with the POV was determined for different intensity levels of evasive actions. Note that the available time must accomodate both machine delays (i.e., ITS countermeasure system + vehicle delays) and driver reaction times. For a certain machine delay, the available time can be used to estimate the proportion of drivers who might be able to respond within that time based on a situation-specific driver reaction times. In addition, the available time can determine whether warning or control intervention systems may be required for successful evasive maneuvers, as illustrated in Figure 4. Note that negative values of available time indicate the case when a crash could not be avoided under any circumstances.

To avoid a crash, driver/countermeasure actions may include braking, steering, or holding course (maintaining the status quo). In some extreme cases, an acceleration action might prevent an incident, but these cases are rare and not considered in this study. In a braking maneuver, the brakes may be applied to either bring the vehicle to a complete stop or slow down to a speed more appropriate for the surrounding conditions. Steering maneuvers may be taken to either correct a deviation from the intended path or avoid a hazard in the roadway. In many situations, a crash may be avoided by simply continuing on the present course and not initiating a potentially hazardous maneuver. Next, kinematic models are discussed as applied to target crash subtypes in terms of braking, steering, and holding course actions, respectively.

Braking Actions

Some crash scenarios can be evaded by braking actions to stop the vehicle or to slow down to a safe speed. This braking action may be intiated by either the SV or POV, depending on the crash situation. Braking to a stop was represented by different kinematic equations that depend on the initial state of braking vehicle and on the type and state of the hazard. A common action across several crash subtypes is to stop to avoid a stationary obstacle or to stop at the stop line of an Intersection, where the SV is initially traveling at constant speed. This crash avoidance action is applicable to (1) rear-end crash, lead vehicle stationary subtype, (2) UI/SCP crash, ran stop sign subtype, and (3) SVRD and opposite direction crashes, evasive maneuver subtype to avoid a rear-end crash with a stopped vehicle or crossing pedestrians/animals. This action is also applicable to SI/SCP crash and LTAP crash, did not stop before turn subtype under some conditions. In SI/SCP crashes, the avoidance maneuver of the SV is to stop if (1) the light status is red or (2) the time for the SV to clear the intersection is greater than the time remaining for the light to turn to red. In LTAP crashes, did not stop before turn subtype, the SV is to stop if (1) the time for the SV to slow down to turn is less than the time for the POV to clear the SV turning path or (2) the time for the SV to slow down to turn, to make the turn, and to clear the intersection is greater than the time for the POV to reach the SV turning path.

The maximum time delay available for driver and machine response, $t_{max\ available}$ (s), to avoid a crash is determined by:

$$t_{max\ available} = \frac{D_{Loc} - \left(\frac{V^2}{2a}\right)}{V}$$

where, D_{Loc} = Braking vehicle location from obstacle or stop line when countermeasure action is initiated, ft

V = Initial velocity of braking vehicle, ft/s

a = Deceleration level of braking vehicle, ft/s^2

Figure 5 illustrates the relationship between $t_{max\ available}$ and D_{Loc} for three levels of braking intensity and an initial speed of 35 mph. To determine the proportion of drivers who could brake as fast or faster than $t_{max\ available}$ subtract the machine time delay and look up the remaining value on a cumulative probability of a suitable, surprise brake reaction time. In addition to SV braking action, POV braking to a stop was also analyzed in this project, especially in intersection crashes, to assess the feasibility of a POV countermeasure action in case an approaching SV is not decelerating at certain levels as it should.

Braking action to a stop was also represented by other kinematic equations for situations such as avoiding a lead vehicle decelerating (rear-end crashes, lead vehicle moving subtype) and avoiding obstacles when the SV is in reverse acceleration (backing crashes). Braking to a slower speed was suggested to avoid (1) rear-end crashes, lead vehicle moving (cruising) subtype , (2) SVRD and opposite-direction crashes, lane keeping failure subtype, especially those caused by excessive speed, and (3) LCM crashes, fast approach subtype (braking action is taken by the POV) .

Steering Actions

Crash avoidance maneuvers using steering actions were described either to avoid an obstacle or to correct a heading deviation error so as to maintain the vehicle in its travel lane. In lane change crashes, proximity subtype, a crash avoidance steering maneuver in the SV was suggested to avoid the POV in the adjacent lane after the SV initiated the lane change maneuver. Thus, a reverse steering action by the SV is required to end the normal lane change maneuver with a step input in steering away from the POV. As a first approximation, the normal lane change maneuver was modeled as a sine function of time for lateral acceleration. The crash avoidance steering action was described by a trapezoidal acceleration model with a maximum recovery accleration value that the driver does not exceed. This acceleration, a, is defined as:

$$a=\begin{cases} a_0-kt, & a<A_I \\ A_r, & otherwise \end{cases}$$

where, a_0= lateral acceleration at the start of recovery maneuver, ft/s^2
k = rate of change in recovery acceleration buildup, ft/s^3
A_r= peak recovery acceleration, ft/s^2

Note that the lag between steering input and lateral acceleration is represented in k. As an example, Figure 6 indicates $t_{max\ available}$ to enable the SV to avoid a collision with the POV by means of an evasive steering action. The graph shows $t_{max\ available}$ for every combination of the intended lane change distance (ILCD) between 9 ft and 15 ft, in 1 ft intervals, and the total time to complete the lane change ($t_{1,c}$ ranging between 2 s and 16 s in 1s interval. The parameter, LATGAP, denotes the lateral gap between the SV and POV at the start of the lane change maneuver. The values of $t_{max\ available}$ were determined under the two conditions: (1) SV lateral velocity= 0 and (2) total lateral distance traveled by the SV < LATGAP.

Steering action to correct a heading deviation error was the SV avoidance maneuver to many SVRD and opposite direction crashes, lane keeping failure subtype. In some SVRD crashes, the SV took an evasive maneuver to avoid a POV encroaching onto its travel lane from opposite direction. Thus, a steering action by the POV to stay in its travel lane was suggested.

Holding Course

Some crashes can be avoided by simply holding course and not attempting a hazardous maneuver (e.g., not changing lane if a collision threat exists with another vehicle in the adjacent lane). This action applies to (1) UI/SCP, proceeded against cross traffic subtype, (2) LTAP, stopped and then turned subtype, (3) LCM crashes, and (4) backing crashes. To avoid a crash, a Go/No Go decision needs to be made which depends on the time-gap between the SV and the POV. To illustrate, let's consider an SV making a left turn from stop across the path of a POV. For any given POV speed, V_{POV}, there is a minimum distance of the POV from the SV turning path, D_{POV}, beyond which the SV can safely turn left and clear the intersection. If the POV is within this minimum distance, a NO GO decision should be made. Figure 7 illustrates such an example, given that it takes 4.25 s for the SV to turn left and clear the intersection from a stop.

CONCLUDING REMARKS

This project conducted a preliminary problem definition and analysis of target crashes and ITS/countermeasure actions. These crash problem analyses included a detailed review of individual crash cases, identification of relevant pre-crash circumstances, and preliminary assessment of some mechanisms of intervention. These analyses contribute to the development of performance specifications for ITS crash avoidance systems by identifying preliminary functional requirements of countermeasure concepts. Currently, NHTSA has several research efforts underway to establish functional and performance requirements of promising crash avoidance systems. Research efforts which address LCM and backing crashes, rear-end crashes, SVRD crashes, and intersection crashes are in place and underway. Research activities are also underway to test and evaluate and develop performance specifications for driver vision enhancement systems and drowsy driver detection/warning systems.

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APPENDIX. LIST OF ACRONYMS

BK:	Backing
CDS:	Crashworthiness Data System
GES:	General Estimates System
ITS:	Intelligent Transportation System
LCM:	Lane Change and Merge
LTAP:	Left Turn Across Path
NHTSA:	National Highway Traffic Safety Administration
OD:	Opposite Direction
PAR:	Police Accident Report
POV:	Principal Other Vehicle
PR:	Police-Reported
RE:	Rear-End

SI/SCP: Signalized Intersection, Straight Crossing Path
SV: Subject Vehicle
SVRD: Single Vehicle Roadway Departure
UI/SCP: Unsignalized Intersection, Straight Crossing Path

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LIST OF TABLES AND FIGURES

Tables

Figures

Table 1. Target Crash Subtypes (Percent of Target Crash Samples)

Type	Crash Subtypes	%
Rear-End 74 Cases	Lead Vehicle Stationary: POV decelerates to a stop and is then struck by SV.	74.8
	Lead Vehicle Moving: POV is decelerating and is struck before coming to a atop, or is traveling at a constant speed when struck.	25.2
Backing 1990 GES	Parallel Path: SV stops at an intersection, reverses direction and backs into a following vehicle, either stationary or very slow-moving.	24.0
	Curved Path: SV strikes a stationary vehicle or object while backing out of a parking space or private driveway along a curved travel path.	17.0
	Pedestrian/Pedalcyclist: SV hits pedestrian or pedalcyclist while backing on roadway or in off-roadway locations.	2.0
	Straight Crossing Path: SV backs out of a parking space or driveway onto a road and strikes or is struck by a crossing, fast-moving vehicle.	57.0
LCM 66 Cases	Proximity There is little or no longitudinal gap and small speed differential between the SV and the WV. It may involve a POV location to the rear *(Forward Overlap:* 31.7%), middle *(Side-by-Side:* 26%), or front lateral area beside the SV *(Rearward Overlap:* 35%)	92.7
	Fast Approach: There is a longitudinal gap and a substantial velocity differential between the SV and POV prior to the start of the lane change maneuver. It may involve a POV that is fast approaching as the SV changer lanes *(Forward:* 4.6%) or an SV that is fast approaching and changes Ianes *(Rearward:* 2.7%). A vehicle is struck on eitber the rear or the side.	7.3
SVRD 100 Cases	Lane Keeping Failure: SV driver failed to keep vehicle in lane and ran off the road unintentionally.	79.3
	Evasive Maneuver: SV driver steered off roadway in an evasive maneuver to avoid bitting another vehicle, animal, or pedestrian.	20.7
OD 98 Cases	Lane Keeping Failure: SV driver failed to keep vehicle in lane and encroached onto opposing lane unintentionally.	80.3
	Evasive Maneuver: SV driver steered onto opporing lane in an evasive maneuver to avoid hitting another vehicle, animal, or pedestrian.	18.6
	Passing: SV attempted to pass another vehicle and strikes POV in opposing lane.	1.1
SI/SCP 50 Cases	Ran Red Light: SV dnver ran red light and strikes or is struck by POV.	100.0
UI/SCP 100 Cases	Ran Stop Sign: SV driver ran stop sign and strikes or is struck by POV.	42.3
	Proceeded against Cross Traffic: SV driver first stopped at the stop sign, then proceeded against cross traffic and strikes or is struck by POV.	57.6
LTAP I07 case8	Did Not Stop before Turn: SV slows down, but does not stop. begins the left turn and strikes or is struck by oncoming POV.	71.5
	Stopped and then Turned: SV stops, then proceeds with the left turn, and strikes or is struck by POV.	28.5

Table 2. Target Crash Causes (Percent of Target Crash Samples)

Causal Factor	RE	BK	LCM	SVRD	OD	SI/SCP	UI/SCP	LTAP
Inattention	56.7	0.0	3.8	15.5	17.8	36.4	22.6	1.4
Looked-Did Not See	0.0	60.8	61.2	0.0	0.0	0.0	36.7	23.2
Obstructed Vision	0.0	0.0	0.0	0.0	0.0	4.3	14.3	24.4
Tailgating/ Unsafe Passing	26.5	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Misjudged Gap/Velocity	0.4	0.0	29.9	0.0	5.9	0.0	12.2	30.0
Excessive Speed	0.0	26.6	2.2	17.8	0.0	0.0	0.0	0.0
Tried to Beat Signal/POV	0.0	0.0	0.0	0.0	0.0	16.2	0.0	11.2
Failure to Control Vehicle	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0
Evasive Maneuver	0.0	0.0	2.6	13.7	18.6	0.0	0.0	0.0
Violation of Signal/Sign	0.0	0.0	0.0	0.0	0.0	23.2	3.4	7.4
Deliberate Unsafe Driving Act	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0
Miscellaneous	1.3	0.1	0.0	0.0	1.0	5.9	0.0	1.7
Drunk	2.1	3.0	0.0	10.1	31.7	12.6	2.7	0.4
Asleep	0.0	1.9	0.0	11.8	0.0	0.0	0.0	0.0
Ill	9.6	0.0	0.0	3.5	1.1	0.0	0.0	0.0
Vehicle Defects	1.2	5.7	0.3	5.3	4.5	1.6	0.0	0.0
Bad Roadway Surface Conditions	2.3	0.0	0.0	20.2	18.3	0.0	7.0	0.0
Reduced Visibility/ Glare	0.1	0.0	0.0	0.0	0.0	0.0	1.1	0.1
Total %	100.0	100.0	100.0	100.1	100.0	100.2	100.0	99.8
No. of Cases	74	74	46	100	98	50	91	154

Table 3. Causal Factor Distribution of Target Crashes

Crash Type	Driving Task Errors			Driver Physiological State			Vehicle Defects	Road Surface	Atmosp Visib.	Total
	Rec. Er.	Dec. Er.	Err. Ac.	Drunk	Asleep	Ill				
RE	56.7	26.9	1.1	2.1	0.0	9.6	1.2	2.3	0.1	100.0
BK	60.8	26.6	2.0	3.0	1.9	0.0	5.7	0.0	0.0	100.0
LCM	65.0	32.1	2.6	0.0	0.0	0.0	0.3	0.0	0.0	100.0
SVRD	15.5	17.8	15.9	10.1	11.8	3.5	5.3	20.2	0.0	100.1
OD	17.8	7.0	19.6	31.7	0.0	1.1	4.5	18.3	0.0	100.0
SI/SCP	40.7	16.2	29.1	12.6	0.0	0.0	1.6	0.0	0.0	100.2
UI/SCP	73.6	12.2	3.4	2.7	0.0	0.0	0.0	7.0	1.1	100.0
LTAP	49.0	41.2	9.1	0.4	0.0	0.0	0.0	0.0	0.1	99.8
%*	43.6	23.3	8.5	6.0	3.5	4.5	2.5	8.0	0.1	100.0

* Percentage of all target crashes (71% of 1993 GES)

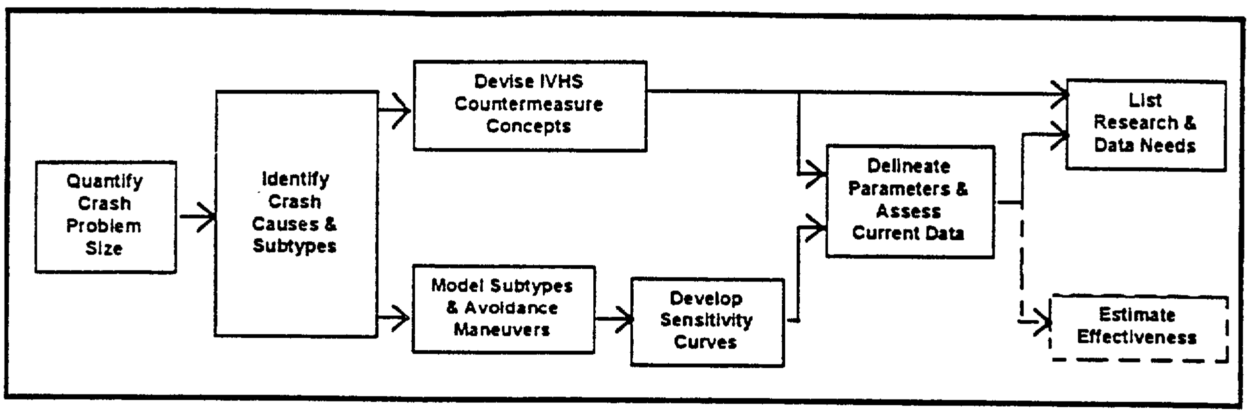

Figure 1. Block Diagram of Crash Problem Analysis Methodology

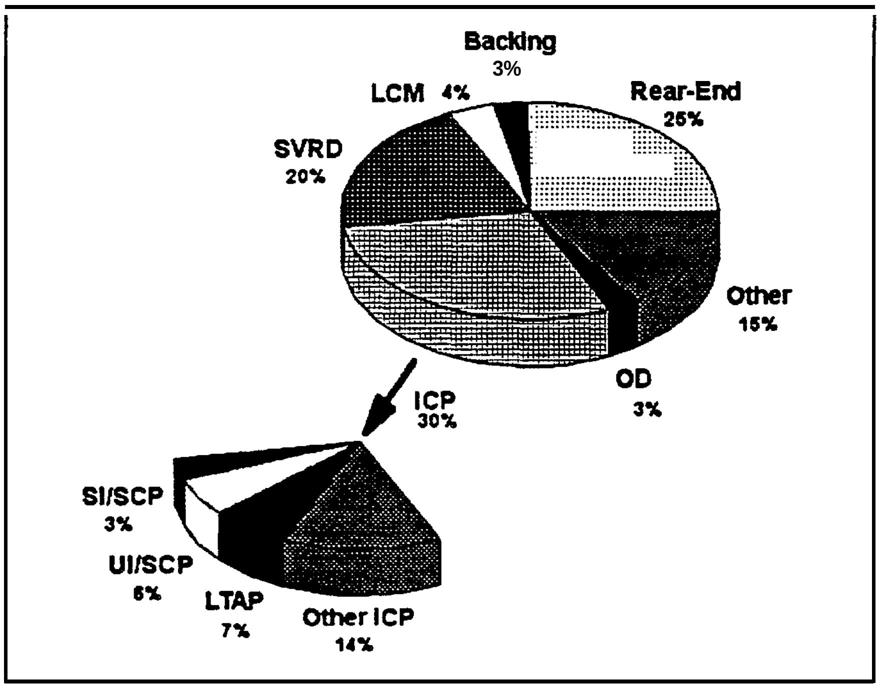

Figure 2. Crash Problem Size, 1993 GES Data

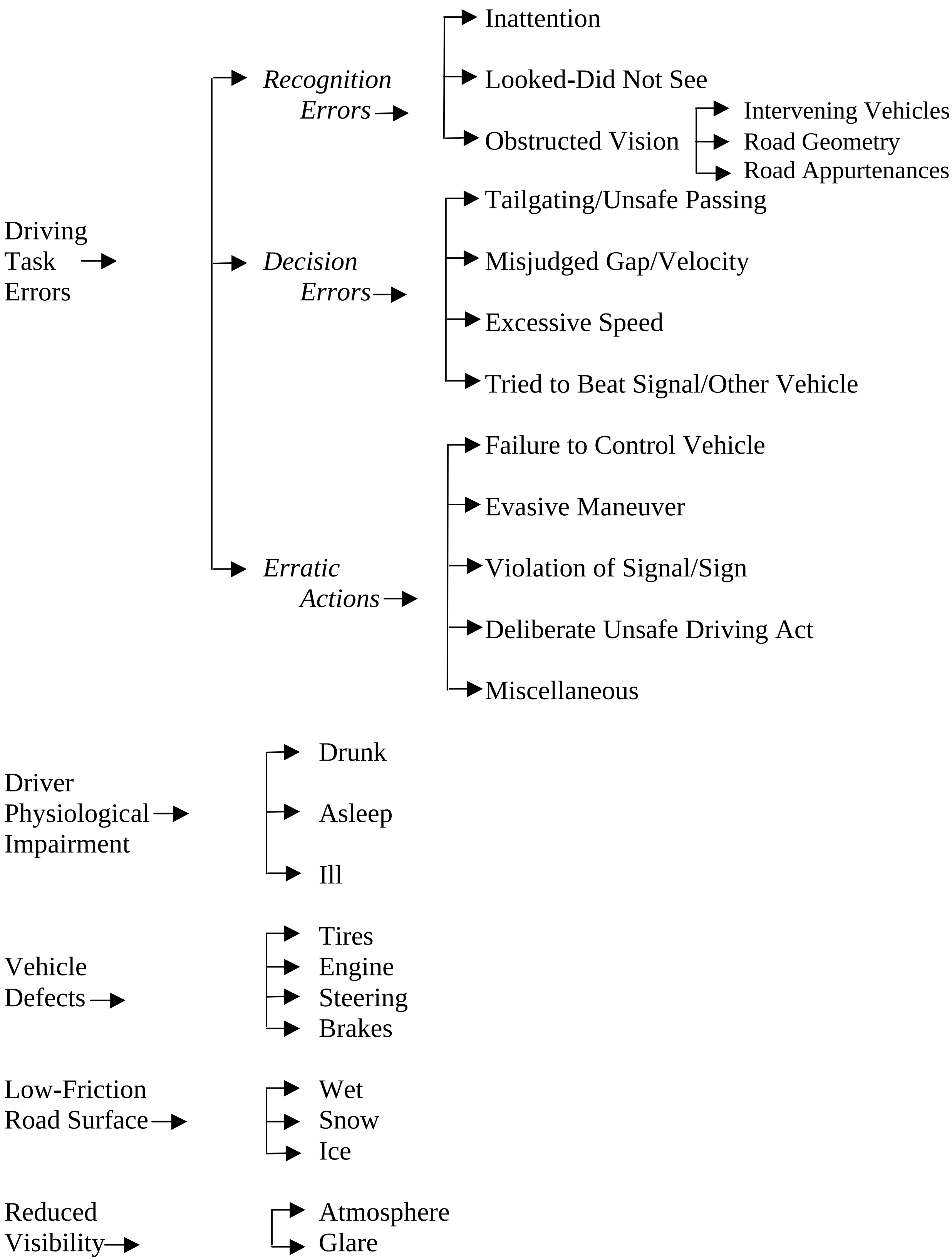

Figure 3. Causal Factor Taxonomy

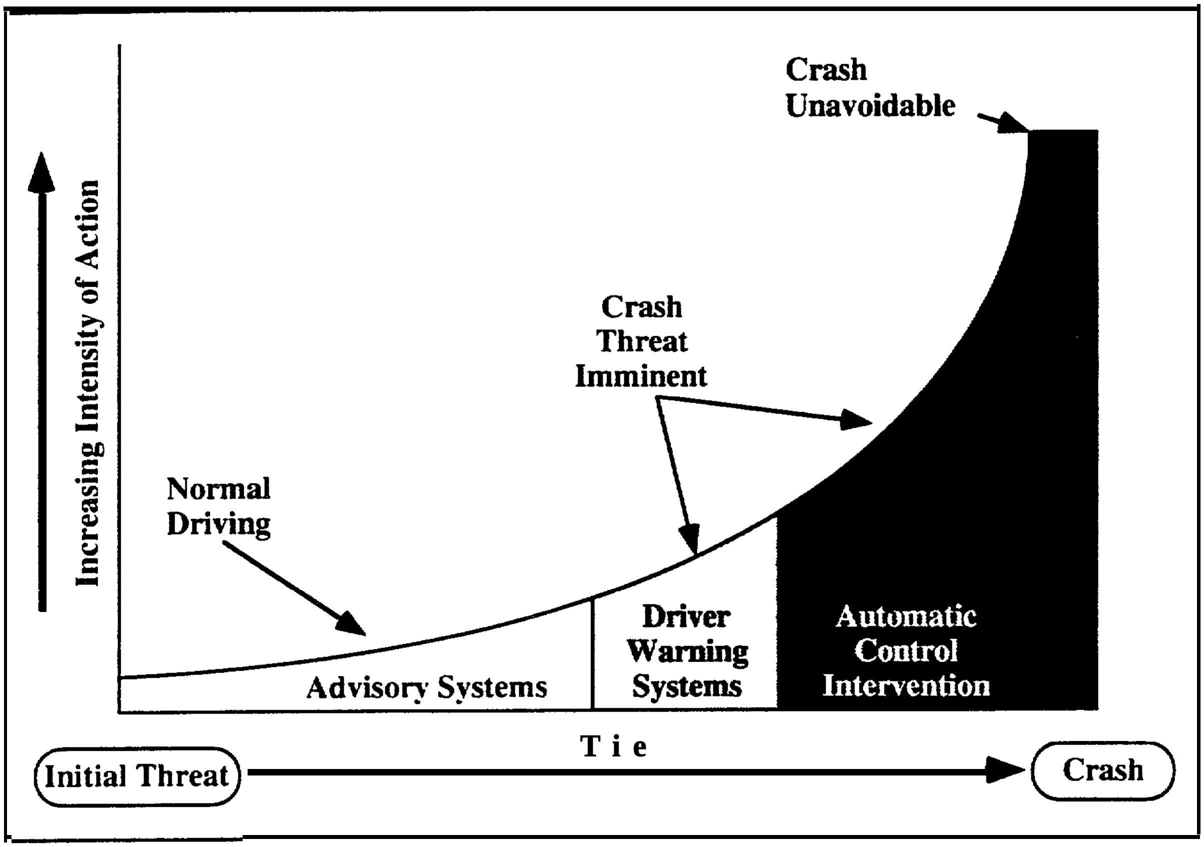

Figure 4. Categories of Crash Avoidance Systems

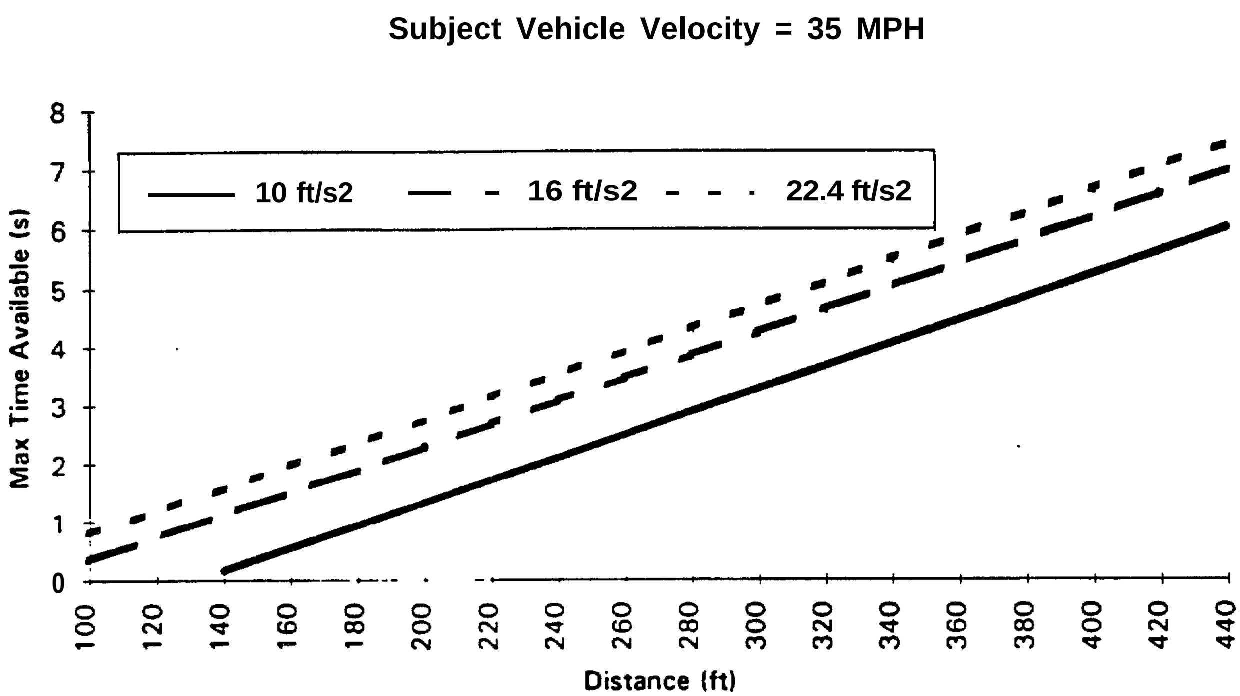

Figure 5. Tie Available to Avoid a Stationary Hazard by Braking to a Stop

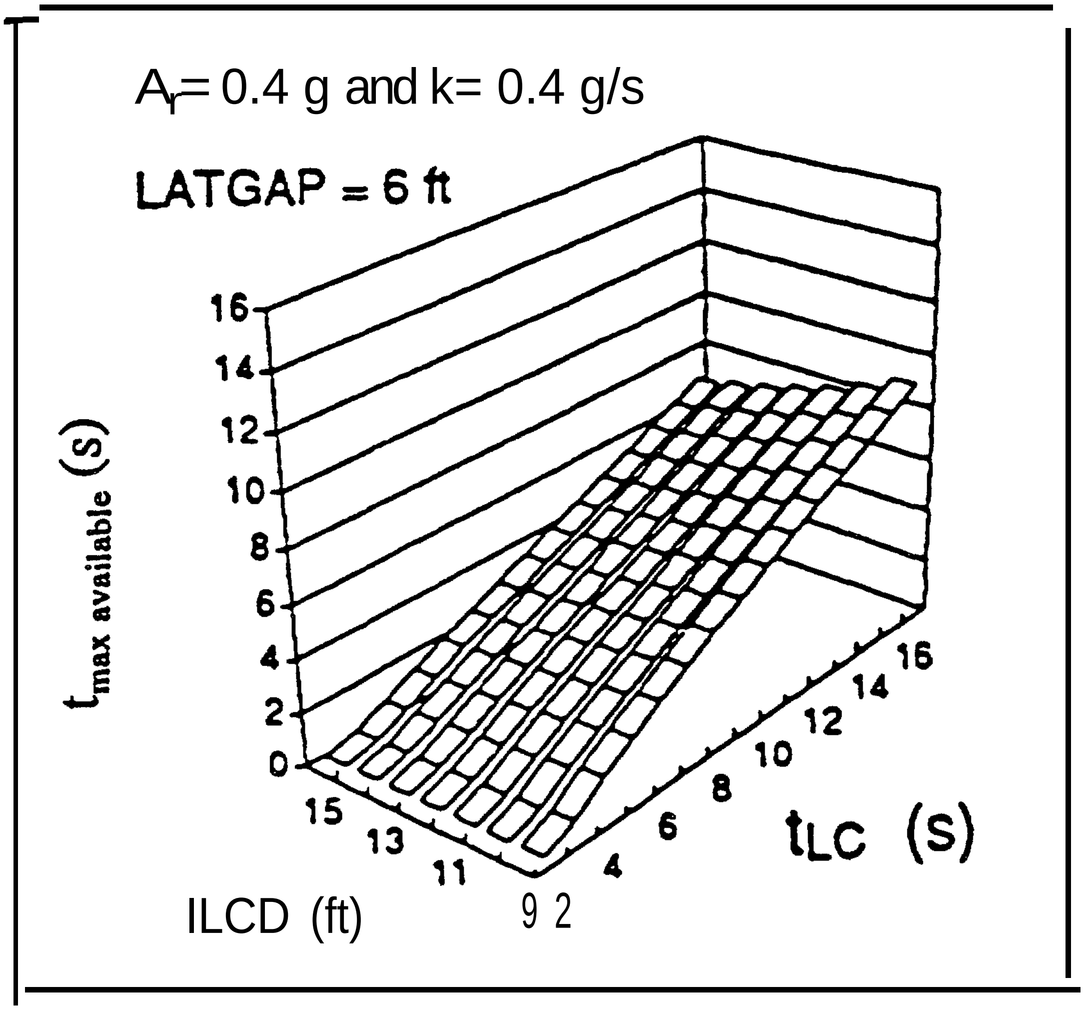

Figure 6. Tie Available to Avoid a Proximity Lane Change Crash by Steering Action

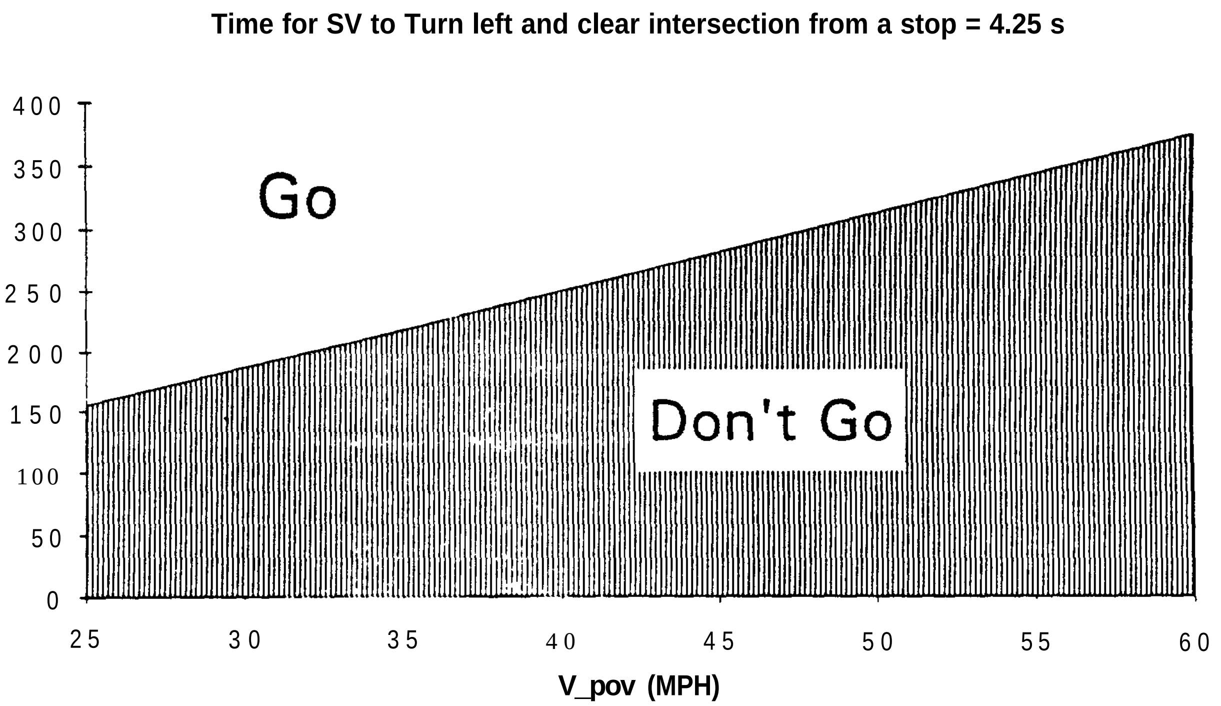

Figure 7. Envelope for Deciding to Turn Left at Intersections