Development of Performance Specifications for Collision Avoidance Systems for Lane Change, Merging and Backing

Task 2 Interim Report:

Functional Goals Establishment

February 1995

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Notice

Preface

This is an interim report that establishes the functional goals (i.e., the changes to the precrash situations) that would help to eliminate, or to decrease the severity of, lane change, merging, and backing accidents.

The functional goals presented herein reflect the work of Task 2 of Phase I of the project. This work will lead to determining the preliminary performance specifications that will be presented in the interim report for Task 4, the last task of Phase I. Both the functional goals and the preliminary performance specifications will be refined after the research that will be conducted in the remaining Phases, II and III, of the project. The current schedule calls for the completion of this research project in the third quarter of 1997.

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16. Abstract

This report determines the set of functional goals, i.e. those changes to the situation, which would help to eliminate the lane change, merge and backing crashes or decrease their frequency or severity. The functional goals include consideration of changes or additions to the vehicle and/or additions to the roadway infrastructure. They have been identified from an examination of crash events, appropriately classified, from the 1992 General Estimate System and Crashworthiness Data System. Significance of crash types is ranked by frequency of occurrence as well as by "fatal crash equivalents".

In addition to the most basic goal of eliminating the "blind spot", significant crash avoidanceopportunities can be realized by guarding against "fast closing" vehicles during lane change and merging. These "fast approach" collisions, though infrequent relative to the "blind spot" crashes, have relatively large "fatal crash equivalents". Similarly for backing collisions, significant reduction of "fatal crash equivalents" can be realized by guarding against vehicles in a crossing path trajectory relative to the backing vehicle.

These functional goals translate into top level requirements for collision avoidance systems. These requirements are briefly discussed and their implications on several system design issues are noted. This report forms the basis for Task 4: Development of Preliminary Performance Specifications.

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1.0 Introduction

In Task 1, Problem Analysis, a thorough investigation of the 1992 General Estimate System (GES) and Crash Worthiness Data System (CDS) databases was performed in order to identify causes for lane change/merge and backing accidents. A taxonomy of collision subset classifications and crash-related events was developed. Based on an examination of these classifications, opportunities for collision avoidance are identified. It is the purpose of Task 2. Functional Goals Establishment, to determine a set of functional goals. i.e. descriptions of driver or vehicle actions or infrastructure modifications that are deemed necessary to avoid or mitigate a collision that would otherwise occur. The functional goals include consideration of changes or additions to the vehicle and/or additions to the roadway infrastructure. This report summarizes the findings of Task 2.

The functional goals established here will "flow" down into the requirements for collision avoidance systems (CAS), be they vehicle or roadway based. These specific goals will also serve as guidelines for driver actions during lane-change/merge and backing maneuvers.

This report is organized as follows. The taxonomy of collision subsets are reproduced in Section 2 to guide the discussions that follow. Accident scenarios obtained from Task 1 are further analyzed in Section 3. General collision characteristics are described in Section 4 and Functional goals are specified in Section 5. Section 6 discusses key requirements for the CAS and concludes the report.

2.0 Taxonomy of Collision Subsets

Under Task 1 of this contract, we have analyzed in depth the accident statistics, using: the '92 GES as the accident data base. A taxonomy of collision subsets for lane change, merge and backing collisions emerge from the study. These simple classifications form the rudimentary accident scenarios that are to be used in defining the CAS functional goals for this report. They will drive numerical simulations in Task 4 in which preliminary performance specifications for the CAS will be specified.

2.1 Lane Change/Merge Crash Classifications

After studying the types of lane change/merge maneuvers, eight classifications are identified. Some of these classifications are further divided by the manner of collision resulting in a detailed taxonomy. The manner of collision - typically same-direction sideswipe, angle or rear-end, etc. - is identified by the investigating police officer who completes the Police Accident Report (PAR). In some cases, the eight classifications are further divided by the manner of collision. A summary of the classifications and the weighted number populations follows in Table 2.1-1. Detailed diagrams of each classification may be found in the accompanying Figure 2.1-1.

TABLE 2.1-1: Summary of Lane Change/Merge Crash Classifications

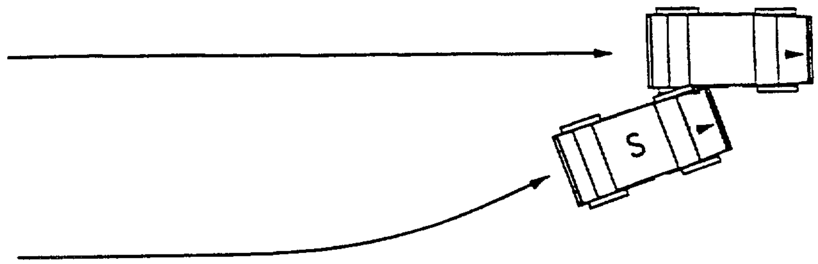
Number	Name	Description
87,264	LCM1	the vehicle changing lanes or merging strikes another vehicle going straight; the manner of collision is "angle"; should be considered in conjunction with LCM7
26,410	LCM2	the vehicle changing lanes or merging is struck by another vehicle going straight; the manner of collision is "angle"
9,803	LCM2A	the vehicle changing lanes or merging is struck by another vehicle going straight; the manner of collision is "sideswipe"
22,614	LCM3 (DRIFTING)	neither vehicle intends to change lanes or merge; both vehicles are going straight but they drift together in a "sideswipe" collision
26,003	LCM3A (DRIFTING)	neither vehicle intends to change lanes or merge; both vehicles are going straight but they drift together in an "angle" collision
10,656	LCM4	the vehicle changing lanes or merging is struck in the rear by the car going straight (The set corresponding to dual lane changes which would otherwise be entirely included in this category has been removed.)
21,805	LCM5	a vehicle leaves a parking place and strikes or is struck by another vehicle; the following three classifications are included.
	LCM51	vehicle leaving a parked position strikes another vehicle (angle or sideswipe, same direction) - 14,673 crashes

	LCM52	vehicle leaving a parked position is struck by another vehicle (angle or sideswipe, same direction) - 6,444 crashes
	LCM53	vehicle leaving a parked position is struck by another vehicle in a rearend crash - 688 crashes
4,790	LCM6	both vehicles are changing lanes or merging
80,676	LCM7	the vehicle changing lanes or merging strikes another vehicle going straight: the manner of collision is sideswipe: should be considered in conjunction with LCM 1
16,351	LCM8	the vehicle changing lanes or merging strikes another vehicle in the rear end (The set corresponding to dual lane changes which would otherwise be entirely included in this category has been removed.)

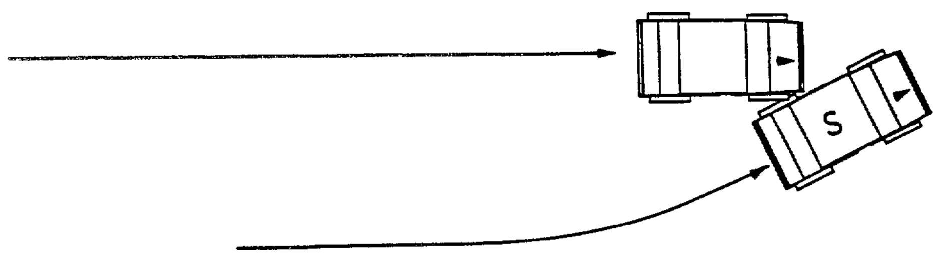
In 1992, there are a total of 306,372 lane change/merge crashes (standard error 23,645) as determined from the GES analysis described above. This is approximately 5.1 % of the 5,982,606 police reported crashes represented by the GES. Please note that LCM3 and LCM5 are not usually included as lane change/merge maneuvers. Without LCM3 and LCM5, the total is 235,950 crashes (standard error 18,854) which is 3.9 % of the total.

FIGURE 2.1-1: Diagrams of the Classifications of Lane Change/Merge Crashes

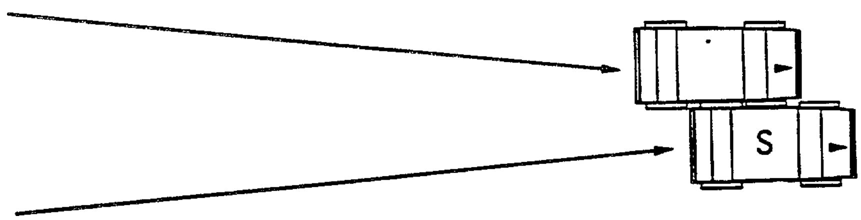
1. Angle Striking



2. Angle Struck



3. Drifting



4. Rearend Struck

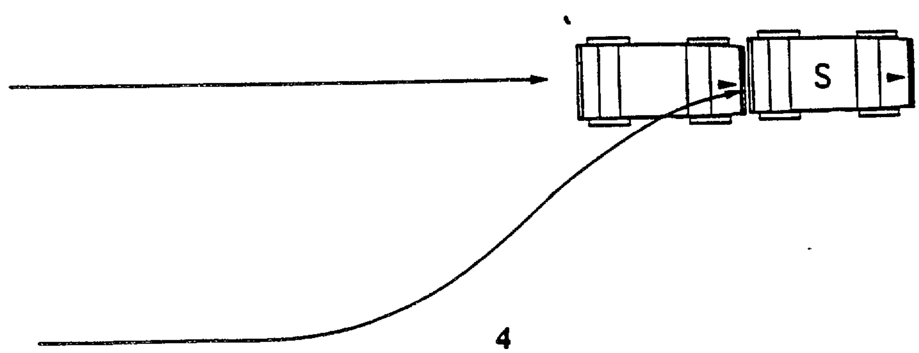
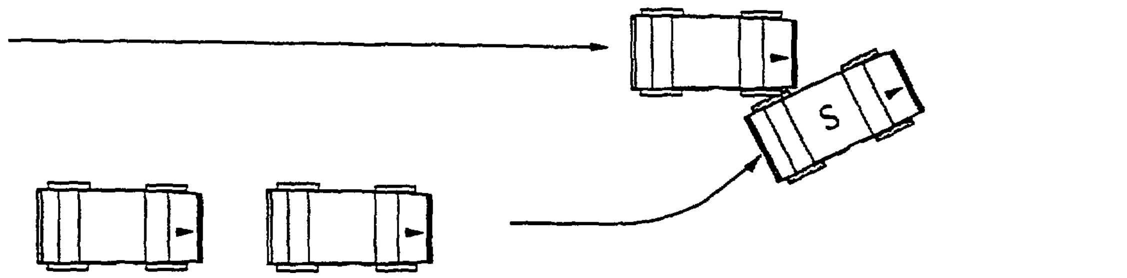
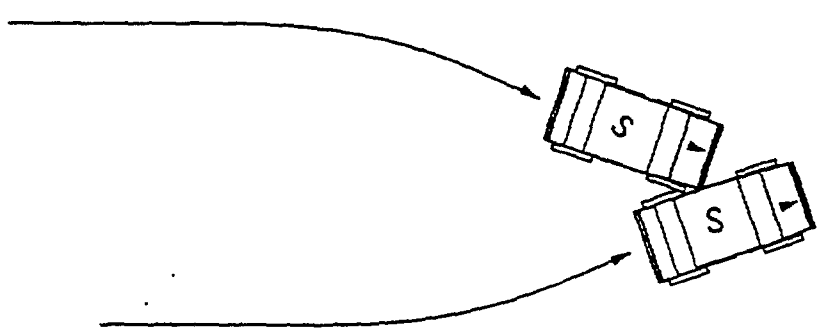


FIGURE 2.1- 1 (continued):

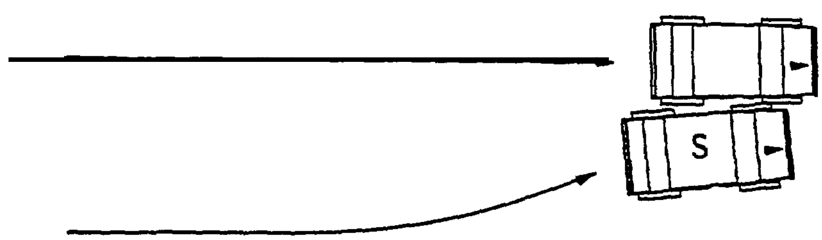
5. Leaving A Parking Place



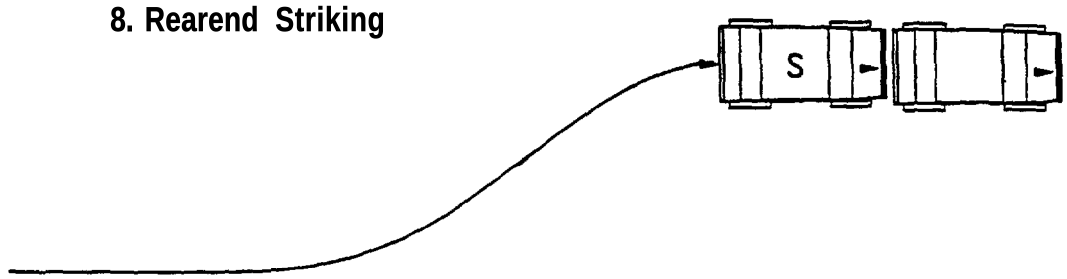
6. Both Changing Lanes



7. Sideswipe



8. Rearend Striking



2.2 Backing Classifications

After studying the types of backing crashes. eight classifications are identified corresponding to backing maneuvers. A summary of the classifications and the populations follows in Table 2.2- 1. Detailed diagrams of each classification of one-vehicle and two-vehicle backing crashes may be found in Figures 2.2-l and 2.2-2.

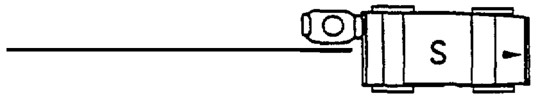
TABLE 2.2- 1: Summary of Backing Crash Classifications

Number	Name	Description
3,177	BACK1 (STRIKING PEDESTRIAN)	the vehicle which is backing strikes a pedestrian
815	BACK2 (STRIKING PEDACYCLIST)	the vehicle which is backing strikes a pedacycle/pedacyclist
10 1.728	BACK3 (BACKING AND STRIKING)	the vehicle which is backing strikes another motor vehicle in transport (“parallel backing” is removed)
69,676	BACK4 (STRIKING A PARKED CAR)	the vehicle which is backing strikes a parked motor vehicle (or other motor vehicle not in transport)
25,920	BACK5 (STRIKING A PARALLEL PATH . . VEHICLE)	the backing vehicle strikes another vehicle stopped behind (at an intersection, railroad crossing, traffic control device or sign, etc.)
4,500	BACK6 (LEAVING A PARKING SPACE)	the backing vehicle is leaving a parking space and strikes a motor vehicle in transport
14,529	BACK7 (STRUCK BY A VEHICLE IN TRANSPORT)	backing vehicle is struck by motor vehicle in transport
12,499	BACK8 (STRIKING A FIXED OBJECT)	the vehicle which is backing strikes a fixed object

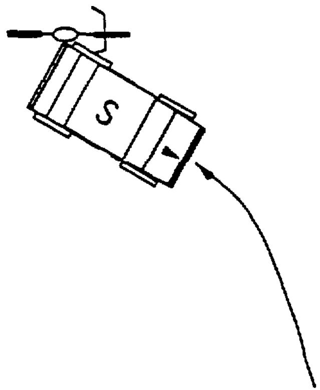
'The total number of the backing crashes listed above is 232,844 (standard error 18,641), which is 3.9 % of the 5,982,606 crashes represented by the GES.

FIGURE 2.2- 1: Diagrams of the Classifications of One-Vehicle Backing Crashes

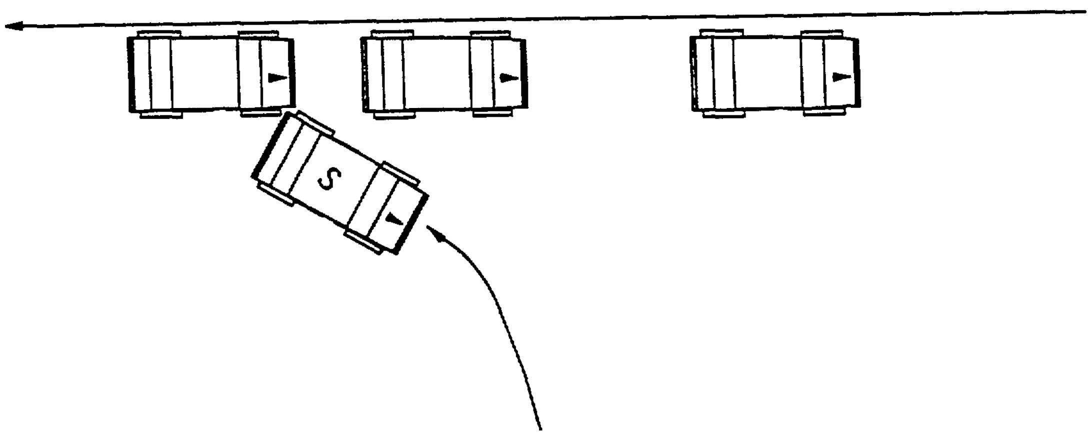
1. Striking Pedestrian



2. Striking Pedacyclists



4. Striking a Parked Car



8. Striking a Fixed Object

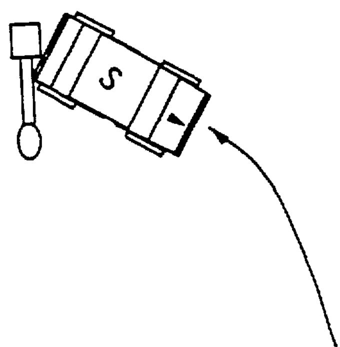
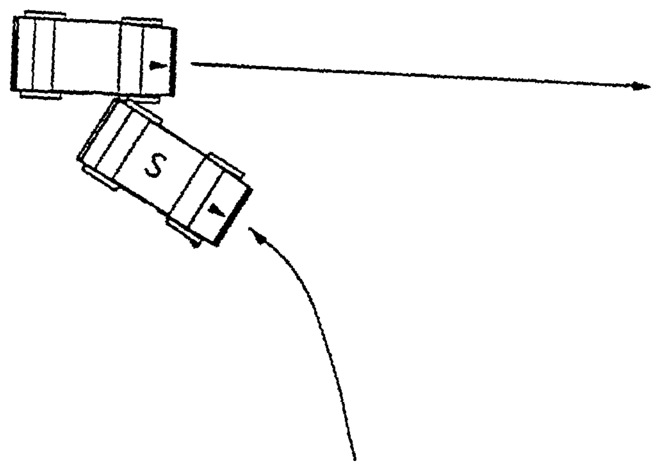
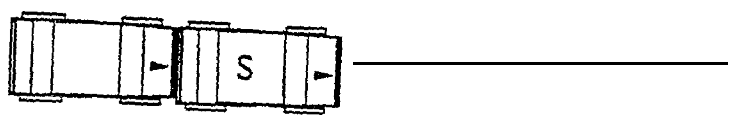


FIGURE 2.2-2: Diagrams of the Classifications of Two-Vehicle Backing Crashes

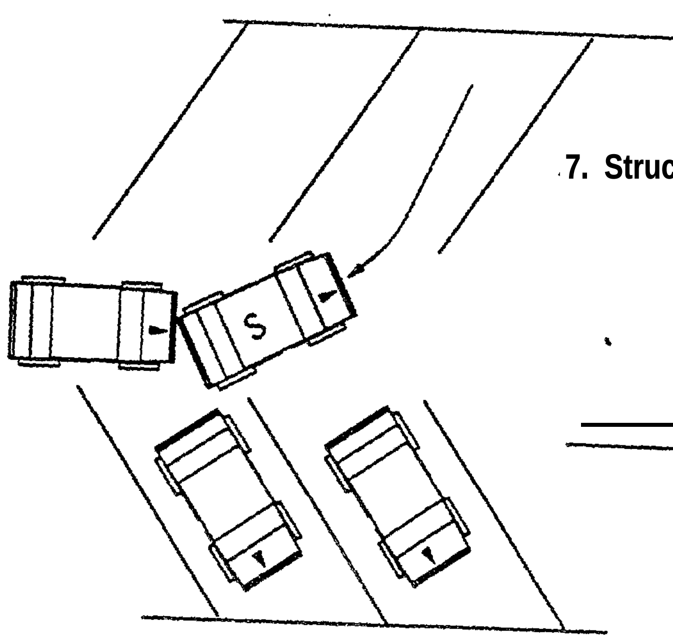
3. Striking Vehicle in Transport



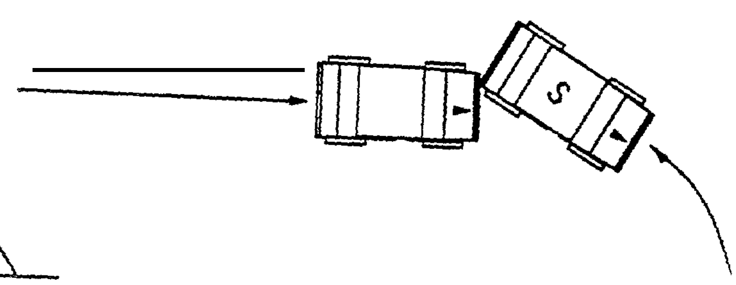
5 Striking a Parallel Path Vehicle



6. Leaving Parking Space



7. Struck by Vehicle in Transport



3.0 Accident Scenarios

In this section, the accident scenarios for lane change/merge and backing collisions are summarized. They have been developed under Task 1 and are described in more detail in the Task 1 Final Report (Reference 7.7). These scenarios, when viewed in terms of their relative significance by their frequency of occurrence and by their “fatal crash equivalents” (References 7.10 and 7.3) in the GES data base, serve as a guide to the development of the functional goals in Section 5. They will be used extensively in Task 4, where crash simulations will be performed and the collision avoidance potential will be used to specify requirements for the collision avoidance systems.

There are three sources of scenario information used on this contract. They are 1) the ‘92 GES electronic data base for lane change, merge and backing crashes, 2) the ‘92 hard copy analyses of the Police Accident Reports (PARs), used primarily for backing scenarios, and 3) the ‘92 CDS individual hard copy case analyses.

In our Task 1 report, the CDS-derived scenarios for passenger vehicles and for trucks are documented in some detail. For the purpose of this report, these scenarios are the least useful for reasons we will explain below. Nonetheless, they are consistent with scenarios derived from the GES and, with improved accuracy and completeness in case documentation, they may yet prove to be useful in future studies.

The scarcity of kinematics data from the CDS hard copies was a great disappointment for us. On the other hand, the PARs proved to be extremely useful for the backing crashes. In fact, PAR-derived velocity and kinematics information were the only available source of such data for use in our backing simulations. We suspect, in hind sight, that it may have been useful to examine the PARs for lane change and merge collisions also.

The CDS data is skewed. In the CDS, the data is weighted to represent all police reported crashes involving light motor vehicles (gross vehicle weight under 10,000 pounds) occurring on a public trafficway in which at least one vehicle was towed due to damage. However, heavier vehicles may be involved and they often are as they are capable of inflicting more serious damage than passenger vehicles. The CDS does not record data on these heavy vehicles (gross vehicle weight in excess of 10,000 pounds) nor does it document interviews with the drivers of these heavy vehicles. The CDS also gives “special consideration” to late model vehicles (the 5 most recent years) and emphasizes more serious accidents. The pedestrian and non-motorist records are also eliminated. All of these biases are consistent with its goal of determining the crash worthiness of late model passenger vehicles. As a result of all these restrictions, the CDS is often incomplete for a case study of precrash conditions, driver intentions, speed and other specific crash details of relevance to collision avoidance researchers. We note, however, that the CDS-derived scenarios are consistent with those gleaned from the GES in terms of whatever kinematics data they have available. As we will note in Section 4, the severity of truck-related accidents underscored by their prominence in the CDS hard copy cases points to significant benefits in truck-based CAS. Simulations involving trucks will be studied in Task 4 in order to set performance requirements for CAS on these longer platforms.

While frequency of crash occurrence is a useful measure of the importance of each crash type or scenario, another meaningful measure is the Fatal Crash Equivalents (FCEs). The FCE per crash for each crash type gives an indication of how “dangerous” that type is in terms of loss of life or property. The total FCEs for each crash type provides a frequency-weighted measure. This measure may guide us in assessing the relative importance of a specific functional goal for mitigating against a given crash type versus another.

To summarize, the classifications of collisions presented in Section 2 are used as the basic configurations in our collision scenarios. Kinematics data are gleaned from the GES electronic data base or from the PARs where available. Total FCEs are used as a measure to guide us in assessing the relative importance of the functional goals.

3.1 Prioritization of Crashes by FCEs

We summarize here the results of our Task 1 study and rank the significance of the different types of collisions by their total FCEs and by FCE per crash.

Reflecting the fact that most lane change/merge collisions do not cause injury or death, the very large number of low injury crashes gives the highest total FCEs to the most frequently encountered lane change/merge accidents, those in which the SV strikes or sideswipes the POV during a simple lane change/merge process. Despite the low FCE/crash and fatalities, the damages of these crashes are nonetheless significant in its aggregate. The majority of these crashes involve low closing speeds. Averting these low closing speed crashes should be a high priority functional goal for the CAS. This is Goal #1 for the Lane Change CAS.

In lane change/merge, the most severe accidents in terms of FCEs/crash and fatalities are those in which the SV strikes the POV from behind after a lane change/merge (LCM8). Despite their relative infrequent occurrence (5.3%) in the '92 GES, this class of collisions ranks second in total FCEs. These are mostly of the type described as "fast approach crashes" in Section 4 below. Averting these relatively deadly crashes is a high priority functional goal for the CAS. This important functional goal is not addressed by most existing CAS.

The least hazardous of lane change/merge crashes are those involving the SV leaving a parking place, due to the relatively low speeds involved. Nonetheless, the closing speeds here can be significant. In any case, the two previously discussed functional goals will cover this class of collisions.

For backing collisions, the most damaging crashes, in terms of FCE/crash, are those in which a pedestrian is struck (BACKl). Despite its relative infrequent occurrence (1.4%), this class of collision ranks fourth in terms of total FCEs among all backing crashes. Striking a pedacylist (BACK2) is next, again due to the involvement of unprotected humans being struck. However, the very rarity of these events (0.35% of the '92 GES) places it second to last in terms of total FCEs, slightly ahead of the FCEs of those backing crashes involving a **SV** backing from a parking place and colliding with the POV. To mitigate against backing into a pedestrian or pedacyclist, the collision avoidance system must be able to discern a relatively small target. This will be reflected in the performance specification of the CAS. A typical human target has a radar cross-section on the order of 0.5 - 1 meter**2 in the microwave and millimeter wave regime. This is comparable to the physical cross-sectional area of the target.

The most severe (in terms of FCE/crash) backing collisions involving two vehicles are those in which the backing vehicle is struck by a POV in transport, due mainly to the relatively high speeds of the POV in these crashes. Overall, this type of crashes (BACK7) ranks third behind BACK1 and BACK2 described above in terms of FCE/crash. In aggregate, it ranks third behind BACK3 (striking a vehicle in transport) and BACK4 (striking a parked car). BACK3 has the highest overall total FCE, despite a relatively low

FCE/crash. This is due to the large number of collisions of this type. At 44% of the total backing crashes, BACK3 outnumbers the next two closest categories BACK4 and BACK5 (striking a parallel path vehicle) by nearly 3 to 2 and 4 to 1 respectively. The importance of mitigating against the potentially severe BACK7 collisions underscores the need to include crossing path type scenarios in the backing scenarios. Traditional backing systems do not have this as a functional goal. We must include this goal in our study. This goal can be realized by a CAS on the SV or on the POV, as we will discussed in Subsection 5.3 below.

4.0 General Collision Characteristics

4.1 Lane-change only

In the '92 GES, the Rear-End collisions (LCM8 for a striking Subject Vehicle - SV and LCM4 for a struck SV), the Drifting collisions (LCM3) and the collisions involving vehicles Leaving a Parking Place (LCM5) are incorporated into the lane-change category for the first time. Although the categories Angle Striking (LCM1), Angle Struck (LCM2), Sideswipe Striking (LCM7) and Sideswipe Struck (LCM2A) still account for about 2/3 (66%) of all lane change collisions, the Drifting collisions are the next most significant category at 16%. Rear-End collisions are third at 9%. Leaving a Parking Place collisions rank 4th at 7%.

In the majority of lane-changes, the driver is unaware of the impending collision and takes no evasive action. Moreover, the small relative speed between the colliding vehicles recorded in the majority of the collision events implies that the vehicles are in close proximity to one another so that there is little or no longitudinal gap between the SV and the principal other vehicle (POV). For a relative speed (closing speed) of 15 mph, the relative distance closed in an assumed human reaction time of 0.5 s is 11 ft. which is short of a car length. Lack of driver awareness is likely due to the fact that one vehicle is in the blind zone of another. These "low closing speed crashes", defined in this report as those in which the relative speed is less than 15 mph, constitute 78% of the 1992 GES lane-shange collisions. For collisions in which relative speeds are in excess of 15 mph, the term "fast approach crashes" are used. Of all lane-changes, 94% of them have relative speeds less than 30 mph. (For completeness, 38% of the collisions have zero closing speeds. These are the truly proximity crashes. Collisions with closing speeds less than 5 mph total 58%, a clear majority.)

T'he usefulness of a detection and warning device for an obstacle in the "blind spot" is immediately apparent. Relative speed information between the SV and the POV is useful but not essential for sensor operation in these situations where the longitudinal gap between the two vehicles is on the order of a car length. Any lane change under this circumstance is ill-advised although depending on the action of the driver in the POV, an accident may or may not occur. This "blind spot" detector can therefore be relatively short range, as most blind zones extend no more than a car length or two behind the SV. (The exact range depends of course on the size of the side-view minor, the eye-to-mirror distance and the obliquity angle from which the mirror is viewed and is in general driver dependent.) However, for the "fast approach crashes", the relative velocity between the SV and the POV is of prime importance and a crash avoidance system must have sufficient range to provide enough time for the driver to take action. To avoid unnecessary false alarm and nuisance alarms, these collision avoidance systems may be activated at the start of the lane-change maneuver. (Since an intent for lane change is usually manifested through the activation of the turn-signal, tying system activation to the turn-signal would be a logical consideration. On the other hand, the use of the turn-signal cannot be universally assumed and tying system activation to sensed driver steering action may be advantageous. However, in this latter case, automatic system turn-on without the conscious driver action of turn-signal activation may be unacceptable from a different consideration. It may lead to driver "complacency" and may breed driver inattention. Whatever benefit the collision avoidance system may provide could be offset by a decreased use of the turn-signal. The eventual design may hinge on a policy decision.)

Most "fast approach crashes" during lane-changes are of the category Rear-End (LCM8 and LCM4) and Leaving a Parking Place (LCM4). 78% of all rear-end collisions that result after a lane-change have relative speeds in excess of 15 mph, while 80% of all

Leaving a Parking Place type collisions are "fast approach crashes". These two categories combine for a total of 16% of all lane-change collisions. The posted speed limits in the Leaving a Parking Place type collisions are at or under 35 mph for 89% of the cases, pointing to generally slow-moving POVs.

Nearly 40% of all lane-change collisions in the '92 GES are sideswipes (with near 0 degree collision angle). This reflects the facts that many lane-change maneuvers are gradual and are of the "proximity" type. For a nominal vehicle speed of 55 mph and a typical lane width of 12 ft, the time required to execute a lane change ranges from 0.85 s for a vehicle pointing angle of 10 degrees to 8.5 s for a vehicle pointing angle of 1 degree. For closing longitudinal velocities of 15 mph and 30 mph, the times required for the faster vehicle to gain a longitudinal distance equal to one car length (15 ft) are 0.68 s and 0.34 s respectively. If the SV is a truck with a typical length of 60 ft., the times are increased 4-fold to 2.72 s and 1.36 s respectively. From these considerations, the significant time scale is on the order of 1 s, from fractions of a second to several seconds.

In over 70% of all '92 GES lane-change collisions, the lane-changing SV strikes the POV. This points to the usefulness of defensive driving, in which the POV (assumed to be equipped also with a CAS) can take evasive action upon warning of the intrusion of the SV into its lane of travel. These collision warning systems need to be activated at all times and warning can be issued based on the proximity of other vehicles in a given vehicle's "space" and of their predicted trajectories. These types of collision avoidance systems are the most advanced. They provide "situational awareness" and are most prone to false alarms and nuisance alarms unless very sophisticated trajectory prediction algorithms are implemented. These "situational awareness" systems can also guard against the drifting collisions, which at 16% of all lane-change collisions, are caused by inadvertent lane-changes due to driver inattentiveness. To our knowledge, none of these systems currently exist but are considered within reach of current technological state-of-the-art.

From the GES statistics for lane change only, collisions due to lane change to the right are as frequent as those due to lane change to the left. This points to the need for collision avoidance systems that monitor lanes to the left and right of the instrumented vehicle.

Most lane change collisions occur on surface streets (84%) as opposed to interstate highways or within interchange areas. About 70% of lane-change collisions occur in non-junction zones. In about 80% of all cases, there are no traffic controls present. This applies equally to junction-related lane change collisions as well as the more frequent non-junction related collisions. As most collisions occur on regular streets, the posted speed limit in 69% of the cases is found to be $\leq$45 mph. Nearly all (98.5%) of Vehicle Leaving a Parking Place collisions occur on surface streets.

Among the different category of lane-change collisions, Rear-End collisions are, most likely to occur at an interstate (24.4%). This is due to the fast relative speeds involved which can be achieved on the interstate. (The only other means of achieving high relative speeds in a low speed zone is where one vehicle is moving extremely slowly, as in the case of the vehicle leaving a parking place.) . Those involving both SV and POV changing lanes are next at 21%. Multiple lanes are needed here, placing a bias on the interstate. Among the simple lane changes, one small sub-class, namely that in which the SV is side-swiped by the POV, occurs with 32% probability on the interstate.

In general, based simply on the number of accidents, weather and lighting conditions do not seem to be a factor: 78% of lane-change collisions occur on dry roads, 85% in fair weather and 76% in daylight. Road geometry is also not significant: 77% Of lane-change crashes occur on level roads and 95% on straight roadways. (These numbers are consistent with published Federal Highway Administration data on road geometry. Thus, if one defines “straight” as deviation from linear by less than 0.4 degrees on a “100 ft radius” basis, 75% and 83% of US urban and rural Interstates fall under the “straight” category. Similarly, if “level” is defined as having gradients less than 0.4%, about 50% of U.S. Interstates satisfy that criterion.)

When one takes into account the severity of the crashes, some factors stand out as potential contributors to the more severe accidents. An example is compromised lighting conditions during lane change/merge. This indicates specific conditions, environmental and other, under which the CAS must operate in order to prevent or mitigate the more severe crashes. The methodology for uncovering differences between the severe and the less severe accidents by the use of Duncan’s Multiple Range Test has been described in detail in Section 4.6 of reference 7.7. To summarize the findings relevant for lane change and merge crashes, crashes tend to be more severe if 1) lighting is compromised such as at dawn, dusk or at night, 2) closing velocities are in excess of 35 mph, 3) the crash takes place at an interchange, 4) if the speed of either vehicle is in excess of 55 mph, 5) if alcohol is involved, and 6) if no restraints are used. Thus the functional goals stated below in Section 5 must be specified for all the conditions found to be significant per a meaningful metric. For example, one may not dismiss lane change/merge collisions at an interchange offhand, even though it is relatively infrequent. Similarly, avoidance of “fast closing” collisions must be retained as one of the functional goals to be explored because of the severity of the accidents involved. The ultimate metric, however, is damage as measured in total FCEs (Section 3.1) which takes into account both crash severity and frequency of crash occurrence. As for lighting conditions, since day-night and all-weather operation must be an integral part of our goal in any case, this particular crash severity analysis only serves to reinforce that requirement.

4.2 Merge

In our study, we adhere to the GES definition of merging per the 1992 GES Coding Manual (Reference 7.9).

Merging collisions constituted 7% of all lane change/merge collisions in the ‘92 GES. We have segregated merging collisions from those in normal lane changes. Distinctive characteristics of merging collisions are discussed below. The majority of merge collisions involve angle striking, angle struck and sideswipes as the manner of collision. Those involving rear-end collisions (striking or struck) comprise 18% of all merge collisions.

The merging vehicle is also the striking vehicle in 80% of the cases where there is an angle striking, angle struck or sideswipe collisions. If we include those merges that result in rear-end collisions, the percentage drops to 75%. This is due to the almost equal probability of the merging vehicle being rear-ended after a merge (47%) as its rear-ending the POV.

The speed of the merging vehicle is slower than that of the POV in about 80% of the cases.

34% of the merging collisions are sideswipe crashes while 48% are angle collisions. Of the minority of cases where the merging vehicle is the struck vehicle, angle crashes outnumbers sideswipe crashes by 4 to 1 and rear-end crashes by 2 to 1. While sideswipe merge crashes involving a struck SV are not prevalent, they occur predominantly

(93%) (<u>this comes from a low number of observations data set</u>) on the interstates, possibly on the interchange ramps at the freeway or possibly where the number of lane decreases. However, only 6% of the sideswipe striking merge crashes occur on the interstate as are 6% of all angle merge crashes (striking or struck). This underscores the fact that merge collisions by and large are not interstate-related (91% overall). The posted speed limit in 71% of the cases is under 45 mph. In 62% of the cases, there are no traffic signals. However, warning signs such as yield signs and stop signs are posted in 20% and 3% of the cases respectively. Of all merge collisions, 42% occur at a non-junction. (These are not merges from vehicles leaving their parking places. In the GES, those merges are separately categorized under LCM5. See Section 2. We adhere to the GES definition of merging.) The rest, 58%, occur either at or near an intersection (40%), at an entrance/exit ramp (11 %), at driveways and alley accesses (4%), or other interchange locations (3%). Thus intersections and entrance/exit ramps are locations where significant number of merge collisions occur.

Collisions during a left-merge outnumber those during a right-merge by roughly 3 to 1 (reflecting that right-merges are uncommon).

Like lane-change collisions, the relative speeds between the SV and the POV in merge collisions are predominantly low. In 56% of the cases, the relative speed between the SV and the POV is less than 5 mph. In 28% of the cases, the relative speed is in fact zero. A relative speed of 15 mph or less characterizes 68% of all merge collisions and fewer than 6% of all merge crashes involve relative speeds in excess of 30 mph. The percentages of "fast approach" crashes in which the closing speed is greater than 15 mph (32% of all merge crashes) for the various categories are shown below:

Angle striking fast approach:	0.3%
Sideswipe striking fast approach:	19.2%
Angle struck fast approach:	71.6% *
Sideswipe struck fast approach:	0.0% **
Rear-end striking fast approach:	9.1%
Rear-end struck fast approach:	3.7%

* The data set of all angle struck merge collisions consists of only 16 observations. Of these observations, less than half of them contain relative speeds information. When the data set is composed of only a few observations, caution should be observed before drawing many conclusions.
** The data set of all sideswipe struck merge collisions consists of only 7 observations. Again caution must be exercised in drawing conclusions.

As in lane-change collisions, most merge collisions occur in fair weather and favorable lighting and road conditions: 74% on dry roads, 70% in daylight and 8 1% in fair weather. **Road** geometries also do not play a significant role: 69% on level roads and 8 1% on straight roadways.

We want to make an observation about the CDS merge scenarios. The '92 CDS hard copy cases show a disproportionately larger number of merge collisions relative to simple lane change collisions than the GES would indicate. This may reflect the bias of the CDS towards the more severe damages which can be inflicted if one of the vehicles is a truck or tractor trailer, as is indeed the case upon closer examination.

Of the 7 merge accidents in the '92 CDS. 4 involves non-NASS vehicles as the POV. These POVs include motor homes, tractor-trailers and trucks. The merge maneuvers are clearly deliberate acts and the accidents arise out of misjudgment in terms of the proximity of the POV during the merge or of the relative longitudinal speed between the SV and the POV. Since 3 of the 4 cases involve a merging vehicle being struck which is a relatively infrequent event (as discussed above), the disproportionate number of CDS cases involving these larger vehicles may simply reflect that they cause greater damage than passenger vehicles and therefore skew the CDS.

Of the same 7 merges, 4 involve merging at an on-ramp, 1 involves merging from the center median and 1 involves passing from the right shoulder of the road during a merge. Of the 4 on-ramp related crashes, 3 are of the type that the merging vehicle is struck which we know to be relatively infrequent as compared to those where the merging vehicle is striking (by a factor of 3 to 1). Of the 4,3 are truck-related. Again, this may reflect the bias in the CDS towards the involvement of large vehicles.

The large FCE/crash for the truck/tractor trailer-related merges as we infer from the CDS underscores the importance of a merge CAS for these heavy vehicles. Though relatively infrequent, these truck-related merge crashes represent some of the most severe lane change/merge crashes. Mitigating against them must be considered as a functional goal, During Task 4, Monte Carlo simulations involving trucks will be performed in order to define the performance requirements for CAS on these longer platforms.

4.3 Backing

From the 1992 GES, approximately 50% of the backing collisions involved a POV which was in transport. The next largest category, 30%, involved backing into parked cars. Backing into a parallel path vehicle is next, with 11%. Striking a fixed object constituted 5% of the backing accidents. Striking of pedestrians or pedacyclists constituted 1% each of all backing collisions. However, there were 2 fatalities associated with the struck pedestrians from our analysis of the '92 PARs.

Backing collisions involve vehicles at low speeds. In the '92 GES, the posted speed limit in 84% of all backing crashes is at or under 35 mph.

As in lane change collisions, in the majority of cases (86%), the driver is unaware of impending danger and makes no avoidance maneuvers. His or her vision is in general not obscured (81%) and not distracted (85%). It is clear that an obstacle detection and warning aid will be useful. However, in the majority of backing crashes where the POV is a vehicle in transport transverse to the backing trajectory of the SV, there is little time for detecting the POV and for reaction even for a relatively slow (15 mph) POV. Thus, even for a relatively wide field-of-view (FOV) mirror (40 degrees) and **a** distance of 30 ft., the dwell time on the POV is 1.1 s. For a fairly wide planar mirror FOV of 20 degrees, this time is reduced to 0.5 s. Here a backward-looking CAS on the SV is useful only if it has a very large FOV, much in excess of 40 degrees, which may not be practical to implement. A side-looking CAS mounted on the back of the SV will be useful, however. In this case, a forward looking collision warning system on the POV can also serve to mitigate against these collisions.

Of the most prevalent category of backing accidents, namely, Backing into Vehicles In Transpon, nearly half (47%) of the crashes occur when the SV is backing out of driveways and alley accesses. Like other backing crashes, the posted speed limit is at or under 3.5 mph in 83% of these crash events, However, because of the near orthogonal nature of the two vehicle trajectories, the timeline is stressing regardless. Intrusion of the backing vehicle into the path of the vehicle in transport can take place in fractions of a second, despite a relatively slow backing speed. Thus it takes a 15 mph vehicle 0.55 s to completely block a 12-ft wide lane. In 88% of this type of crashes, the backing vehicle is also the striking vehicle. This again points to the usefulness of a forward warning collision device on the POV which would alert the driver in time to take defensive maneuvers. In the ‘92 GES, in 98% of the cases involving a vehicle in transport, the drivers in the POV take no evasive maneuvers. Prominent warning signs (visual or audio) on the SV, easily accessible to the POV, will also be helpful. The range of these warning signs or of the forward collision warning system, must be far enough so that ample reaction time is available to the driver of the POV. A range of 100 ft. will theoretically allow the driver of a 35 mph vehicle up to 2 s to initiate corrective action. To bring that vehicle to a complete halt at that distance, an average deceleration of 0.4 g must be applied, starting at the detection range of 100 ft from target. (Total time elapsed between start of braking action to vehicle stoppage is 3.9 s.) Allowing 0.5 s for driver reaction time prior to taking action, that deceleration must be increased to 0.55 g. Driver reaction times much in excess of 0.5 s will require unrealistically large decelerations in order to avert the crash. Ultimately, the required range will be set by considering a distribution of reaction times and decelerations.

Backing and striking a parallel path vehicle has been studied extensively in the past. In agreement with previous findings, we observe that in the ‘92 GES, 98% of these crashes occur at an intersection or are intersection-related. In 52% of the cases, there are traffic controls on colors. In another 36%, stop signs are present. The manner of collision is 80% rear-end and 16% angle. As we intuitively expect, 100% of these crashes in the ‘92 GES occur on surface streets, away from the Interstate Highway.

Backing into parked cars represent 5% of all backing crashes. 92% of these crashes occur in zones with speed limit at or under 35 mph. Driver inattentiveness is often the cause. “Hit and run” is significant at 2 1%.

The backing collisions that involve a pedestrian or a pedacyclist merit a separate look despite their relative infrequent nature. These collisions have the potential for serious bodily injuries as 1% of backing accidents involving pedestrians result in a fatal injury according to the ‘92 GES. Because of the relatively small size of the targets involved, we would intuitively expect to see a relatively larger fraction of cases involving lack of driver visibility. However, the statistics do not support that intuition. Although only 67% of the drivers report that their vision is not obscured and 67% report that they are not distracted as opposed to the 85% and 90% corresponding figures in backing accidents involving 2-vehicles, the remaining 33% represents the “hit-and-run” population, not driver vision obscuration or distraction as one may be tempted to infer.

As in lane-change/merge crashes, backing crashes are not clearly linked to stressing weather or road conditions. From the ‘92 GES, 89% of the backing crashes occur in fair weather. The roads are straight (97%) and level (78%). The road surface is dry (83%) and the accidents occur in daylight (77%).

5.0 Functional Goals

In this section, we will enumerate. for each crash type, those changes to the situation, or "functional goals" , which would help to eliminate the crashes or decrease their frequency or severity. These functional goals shall include consideration of changes to the vehicle or additions to the roadway, as stipulated in our Contractual Engineering Task (CET) description. Since these goals will guide the rest of the program effort, it is important at the outset to state the ground rules and to review our methodology for determining the performance specifications of collision avoidance systems.

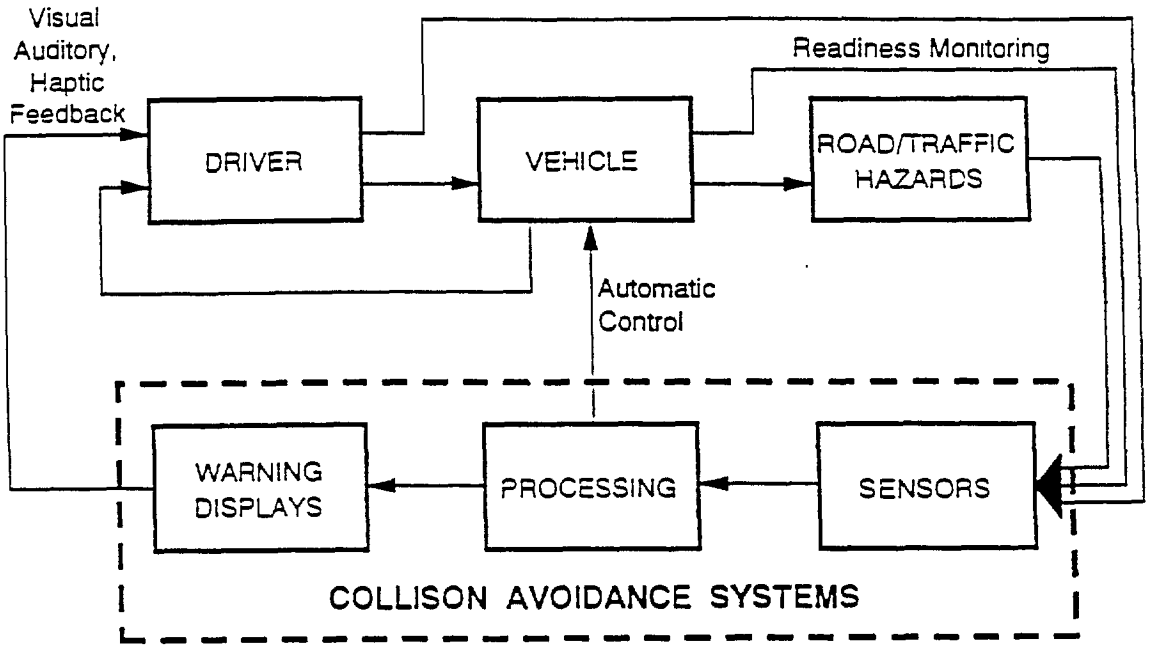
In general, the goals specified herein are system-independent. They are in general dependent on the dynamics of the crash situation , including vehicle velocities and trajectories. Environmental conditions, to the extent that they impose constraints on potential systems and are potential causes of the crash themselves, are important considerations.

From these functional goals, functional requirements for the collision avoidance systems will be specified. These requirements are defined with candidate systems in mind and reflect a balance between the ideal and the technologically achievable within the time frame of interest. Therefore, these CAS functional requirements are not entirely system-independent. Carrying this further, the functional requirement for the system is in turn allocated to the subsystems that constitute the CAS. For example, the detection function is allocated to the sensor subsystem, the decision-making function (that a specific detection constitutes a collision threat) is allocated to the processor subsystem and the warning function is allocated to the warning/display subsystem. For those systems that automatically take action as a result of the confirmation of a threat, this warning/display system is replaced by actuators and servo motors which will initiate braking and possibly steering action. As the "brain" for the CAS, the processor subsystem also serves as the interface between the system and the vehicle itself. On the other hand, the warning/display subsystem serves as the interface between the CAS and the vehicle operator. For automatic crash avoidance, the CAS is a closed-loop system. However, human intervention can provide system override in case of system malfunction. This requirement flow-down process is a complex one. Care must be taken to consider all aspects of the human-CAS-vehicle interactions as well as interactions amongst the CAS subsystems themselves. (See Figure 5.0-l.) The resulting performance specifications for the CAS will be determined after extensive trades and analysis and are indeed dependent on all components of the vehicle-CAS-human system.

The function goals defined here serves as the starting point for the requirement flow-down process outlined above which will occupy us for the rest of the CASPS Program. Test of existing systems in Phase I and more in-depth tests of available subsystems in Phase III will provide the "reality check" as to where the technology is in regards to collision avoidance. Use of driving simulators and Monte Carlo statistical evaluation tools will allow the specifications of the requirements of the CAS subsystems within the human-CAS-vehicle system context. The requirements of the CAS subsystems are inter-related. For example, a warning time-line can be met by 2 entirely different sensing techniques, one processing intensive relative to the other. In the one case, short processing times allow multiple sensor looks at ffie potential threat to achieve high confidence in confirming it as a threat. In the other instance, sophisticated processing may achieve the same detection confidence despite time-line constraint which limits the sensor dwell-time on target.

Lastly, we want to emphasize that the functional goals are independent of the countermeasure system technology. Thus elimination of the "blind spot" is a functional

Figure 5.0-1. Driver/Vehicle Interaction with Collision Avoidance Systems



goal regardless of how it is achieved. It may be achieved via a radar, acoustic, electro-optical/infra-red system, with differing implications in terms of the processor subsystem requirements. Indeed, the functional goals specified in this report are the fountainheads from which the performance specifications of the CAS will spring. In Section 6 below, we will provide a brief preview of the CAS top level system requirements which will form the starting point of Task 4 - Preliminary Performance Specifications.

5.1 Lane-Change

Goal #l **To alert the driver of the presence of vehicles in the left and right adjacent lanes immediately prior to his or her initiation of lane-change maneuvers.**

Lane coverage should be at least one car length but preferably longer to the fore and aft of the vehicle. A minimal length for this zone is 15 ft. fore and aft, leaving one car length after the lane-change. A longer length is highly desirable.

Initiation of lane change maneuvers should be a deliberate action as marked by the activation of the turn signal.

This change to the driver's situational awareness will mitigate against collisions originating from the presence of blind spots.

Goal #2 **To alert the driver of vehicle drifting motion across lanes.**

Vehicle drift is defined as an unintentional transverse movement of the vehicle which results in its intrusion into the adjacent lanes (to the left or to the right) of its original lane of travel. Since there is no intention at lane change, the turn signal is unlikely to be engaged.

Goal #3 **To alert the driver of the presence of high speed or slow speed vehicles (relative to the SV) in the adjacent lanes immediately prior to his or her initiation of lane-change maneuvers.**

A minimal length for zone coverage is 50 ft. fore and aft, allowing 2 seconds of reaction time for a relative longitudinal speed of 15 mph.* A better length would be 100 ft. to accommodate a relative speed of 30 mph.** However, comprehensive coverage of such an extended zone will be difficult with a single beam CAS if there is to be a minimum of nuisance alarms. This will be discussed in more details in the Section 6.

This change to the driver's situation awareness will mitigate against "fast approach" collisions. The 30 mph threshold is adequate for over 90% of all "fast approach" collisions from lane-changes.

Initiation of lane-change maneuvers should be a deliberate action as marked by the activation of the turn signal.

A limiting case that can benefit from this functional goal is the situation where the SV is leaving a parking place (initial vehicle speed = 0) and a large longitudinal closing speed (30 mph in a 30 mph speed zone) can be realized. This is borne out by the 4 CDS hard copies that we analyzed where all cases occurred in a low speed zone (20-30 mph) and where longitudinal closing speeds on the order of 30 mph were reported. As discussed in the previous section, 89% of all crashes involving vehicles leaving a parking place occur in speed zones 30-35 mph or lower.

*Note that these ranges are approximate and will be better defined based on the simulation results of Task 4. As mentioned in the beginning of the section, the goals are dependent on the specific dynamics of the crash situation. Thus, for example, for a closing speed of 15 mph and a longitudinal gap of 50 ft. between the SV and the POV, the POV can initiate braking action as late as 1.6 s after the start of lane-change maneuver by the SV and still avert the accident, provided that its deceleration is at least 0.5 g. For faster response time and for improved deceleration, this longitudinal gap can be decreased. The figures listed here are estimates to guide further studies.

**Again note that the scaling of zone length with closing speed is approximate and will depend on detailed dynamics as noted above. For example, assuming the same deceleration capability of 0.5 g, braking action must be initiated 0.9 s after the start of lane-change maneuver in order to avert the collision, if the initial longitudinal gap is only 100 ft. To allow the same response time of 1.6 s as in the low closing speed case, the zone length has to be increased to 130 ft. or the deceleration must be increased to 1g, which is not feasible.

Goal #4 **To alert the driver of the SV during the course of lane-changing of the presence of vehicles initially two lanes over to either its left or right which are also executing lane change maneuvers into the same lane.**

This goal will mitigate against collisions in which both the SV and the POV are simultaneously executing a lane change operation, oblivious of impending danger.

There are several ways of realizing this goal via a collision avoidance system. An ideal system would monitor vehicle presence in the two lanes to the SV during the lane-change maneuvers. At a predetermined time threshold to predicted impact, a warning will be issued. This system requires a large field of view and must determine the range and azimuth of the vehicle targets in order to determine the requisite vehicle velocities. A more modest system would involve vehicle monitoring in 2 adjacent lanes to the right and to the left, activated for a short time prior to the actual lane-change maneuvers. The presence of vehicles with closing transverse gap relatively to the SV will be reported to the driver of the SV, who will momentarily delay his lane-change action and who will take defensive action if necessary.

We would like to point out that the measurement of relative transverse velocities **is** not a simple task with a ranging device. The CAS envisioned will be presented in Section 6.

5.2 Merge

Goal #l **To heighten the state of awareness of drivers as their vehicles approach a merge in the roadway.**

This can be accomplished by changes in the roadway, such as posted signs for caution and for the need to yield to right-of-way traffic. This can also be achieved by a widening and lengthening of the roadway at the merge. Since the merging vehicle often is the striking vehicle, the warning device serves to heighten his or her awareness of the Impending merge. At the same time, it warns the driver of the vehicle with the right of way to drive defensively.

The majority (91%) of merge collisions occur on regular streets and roads, as opposed to interstates and exchanges, and 64% of all merge collisions occur where there are no traffic control. This includes 97% of all non-junction* merge collisions reported in the '92 GES. There is therefore ample opportunity for increased awareness.

*Definition of " Non-Junction" as per Reference 7.9.

Goal #2 **To provide situational awareness to the SV as it merges into traffic, including presence of vehicles in the merged lane as well as their longitudinal velocities relative to the SV. The awareness need to extend to vehicles both fore and aft of the SV in the merged lane.**

As the merging vehicle is often the striking vehicle, it can avoid the collisions if the driver can better judge the relative distance between his vehicle and the POV and of the relative speed between the two. The zone of coverage should extend to approximately 100 ft.* fore and aft, sufficient to provide 2 s of reaction time for a relative longitudinal speed of 30 mph. For each vehicle, the quantity: t = z (relative)/ v(relative) should be evaluated. Here z (relative) is the relative longitudinal separation between the SV and the POV while v(relative) is the corresponding relative longitudinal velocity. For positive t, the merge maneuver can be safely performed and the driver can proceed with caution. For negative t, there is a collision potential and with no change in dynamics in the vehicles, collision will occur at a time -t seconds later. With the input regarding t, the driver of the SV can either speed up or slow down depending on whether z (relative) is greater than or less than zero. Again it should be noted that monitoring the sign oft can only provide a very crude idea about the safety of merging. Much more sophisticated schemes will be actually needed, based on a more detailed knowledge of the dynamic situation. The important point to emphasize is that knowledge of both vehicle longitudinal gap and relative velocity is required to meet this goal.

The initiation of merge maneuvers should be marked by the activation of the turn signal. This action is synergistic with Goal #l above and will heighten the awareness of the driver in the POV.

*The comments in relation to the discussion of dynamical effects in the discussion of Goal #3 in Lane Change above applies here.

5.3 Backing

Goal #l **To enhance the awareness of the driver of the presence of obstacles, both animate and inanimate, at rest or in motion, in a zone to the rear and to the side of the vehicle in a timely fashion so that preventive action may be undertaken.**

This can be achieved by enhancing the driver field of view to the rear, and to the side so that more reaction can be garnered for a POV-in-transport type scenario. In the case of backing from a driveway, a wide field of mirror can be used on either the vehicle or the roadway for the simplest realization of this goal. In general, a vehicle-based obstacle detection sensor is needed. Zone of coverage extends to the back with a range on the order of 15 ft as well as angle coverage of TBD extent. The 15 ft range is the mid-point of ranges found in existing systems for an automobile target, as reported in Reference 7.2. An internal TRW-funded study confirmed via numerical simulations with reasonable velocity distributions that a system detection range of 15 feet would achieve a crash avoidance potential in excess of 90%. However, the angular coverage requirement has not been well specified and it will be the subject of future studies on the current program. Besides a coverage zone to the back, a zone to the left and right of the SV should be monitored (by side-looking CAS mounted on the left and right rear of the vehicle) for the POV-in-transport type collisions. The range should be on the order of 100 ft to the left and right, allowing approximately 2 s of reaction time for crossing POV speeds on the order of 30 mph. (Note that, in 2s, a POV moving at 30 mph would have traveled 100 ft. Thus the driver of the SV has less than 2 s to make evasive maneuvers, since he or she has a finite reaction time to the warning.)

The collision avoidance system should be activated automatically when the SV is put in reverse gear.

Goal #2 **To warn pedestrians, pedacyclists as well as drivers of the POV of imminent backing maneuvers by the SV so that appropriate defensive action may be taken.**

Backing lights are synergistic with this goal. Additional changes to the situation' can be brought about by some additional form of warning, either audio or visual. For mitigation against collisions with POV in transport type scenarios, visibility or audibility of the warning to the side of the vehicle is highly desirable. The warning should be accessible to the driver of the POV over a range on the order of 100 ft. so as to provide adequate reaction time.

Goal #3 **To warn the driver of the POV of the impending intrusion of the SV into its lane of travel.**

This goal can be realized by a forward collision warning system on the POV which will detect obstacles in range and azimuth and wam the driver of imminent danger. The range of this system is on the order of 100 ft and it must have a relatively large field of view. For a 15 mph backing vehicle, the distance traversed in 2 s is 44 ft. This implies a FOV for the CAS on the order of +/- 25 degrees in a cluttered street environment. (Here it is assumed that the SV can be backing out of a long driveway at a constant speed of 15 mph and the sensor has to detect that motion at the beginning of its backing trajectory at the maximum range of 100 ft. Hence the angle of 25 degrees. To cover both sides of the street. +/- 25 degrees FOV is required.)

6.0 Implications for Collision Avoidance Systems

The functional goals enumerated above can be translated into requirements for collision avoidance systems (CAS) that are installed on the vehicle or on the roadway. A preview of some of the key requirements has already been discussed in some of the instances above and will be summarized below. Detailed determination of these requirements will be the subject of Task 4. That process must take into account the driver-CAS-vehicle interactions as emphasized in Section 5.0 as well as tradeoffs between the benefits (in terms of crash avoidance potential) and system complexity (translated into cost). In some instances, the requirements imposed on the CAS will be tempered by what is technologically feasible within the state of the art. Our technology assessment will be guided by the testing of existing hardware systems that is currently underway in Task 3. We will also evaluate future technologies by extrapolating from their current status, using as a guide current research and development trends. The requirements shown below are very preliminary and must be viewed as "point-of-departure" numbers to be refined by a careful examination of detailed multi-vehicle dynamics and complex human-CAS interactions and by performing cost-benefit trades. We will undertake these endeavors during the rest of the current program using this Task 2 report as a guide.

6.1 Sensor Issues

Several issues merit discussions. They are presented below and they will be the subject of further studies in Task 4 as we attempt to set preliminary requirements for the CAS.

6.1.1 Sensor Coverage

The first issue concerns the idealized rectangular coverage zones for lane-change/merge CAS. We want to monitor the right and left lanes adjacent to the SV out to a range (TBD) of about 100 ft. A typical lane, 12 ft. wide subtends an angle of about 7 degrees at this range. A fixed single beam sensor designed to work at this range would have a very narrow FOV and will therefore have a significant "blind spot" problem. This problem can in principle be overcome in several ways.

First, we can widen the beam so that the beam will now spill into adjacent lanes and will "see" targets which are of no interest. Using range and angle information, one can eliminate "nuisance targets" via a discrimination algorithm.

A second approach, a little less stressing on the discrimination algorithm, is to use a scanned beam. While the instantaneous FOV can remain narrow, one can increase the sensor field of regard (FOR) by scanning the beam and hence eliminate the "blind spots". However, one has to time-multiplex the sensor and scanning must be rapid in order to minimize the "revisit" time. This approach also stresses the hardware. One can either perform the scanning mechanically or electronically. Mechanical systems are prone to maintenance problems. Electronic scanning is preferred. Phase arrays provide beam agility without the mechanical problems associated with a scanner. However, the technology status is such that such systems are wont to be costly and beyond the cost target of CAS at this point in time. Moreover, most demonstrated systems are at X-band (8- 12 GHz) or below and sensor packaging is an issue due to the relatively large system size. While technologies such as Microwave High Density Interconnect and digital beam forming are making rapid advancements, we will probably not see low cost electronic scanning systems in the millimeter wave regime (35 GHz - 300 GHz) until the next century.

Yet a third approach is a multi-beam approach, using an array of sensors or beam switching to increase the FOR.

We must add however that the thoughts expressed here reflect current thinking and we will further investigate these ideas at later phases in the current program.

The eventual system design approach will be decided by a cost and technology trades.

6.1.2 Dynamical Issues

The FOR of a lane-change/merge CAS is designed to cover lanes parallel to the vehicle direction of travel. As the SV attempts a lane-change, this FOR is constantly changing and will spill into those lanes of no import to a safe lane-change. Many "nuisance" alarms will be reported during the lane-change. The issue of human factor is clearly paramount in sensor design and this must be properly dealt with. One possibility is to suppress these *nuisance" reports via a smart algorithm.

To encourage the driver to utilize the turn-signal during a lane-change, we may tie the lane-change CAS operation to turn-signal activation. This is also desirable for minimizing "nuisance alarms" since continuous CAS operation will lead to warnings of no consequence to the driver who has no intention of making a lane change maneuver. (However, as noted in Section 4.1, the means for activation of the CAS is a complicated issue and may eventually be a policy decision.) Since several CAS currently available on the market are always activated when the vehicle is being operated, we will test and study these types of systems on our program. (These types of systems are known as Category 1 systems and are meant to be advisory, noting potential hazards. Category 2 systems warn the driver of pending crashes. In some sense, tying the activation of the CAS to the turn-signal or to sensed steering action converts the system to Category 2, since, a lane change maneuver would follow the activation of the turn-signal or the sensed steering action. This would create a transverse closing speed between the SV and potential targets that could render a collision imminent. Warnings issued by the CAS would avert a potential collision.)

During a turn, the vehicle's FOR again is changing rapidly so that roadside obstacle and parked cars will appear to the CAS as genuine targets. They may appear to stay constant in range or can have time-varying velocity relative to the SV. Such "nuisance" alarms again have to be eliminated by sophisticated algorithms.

6 1.3 Velocity Measurement

In Section 5, we alluded to the difficulty in measuring the relative transverse velocity between two moving vehicles. This is due to the method of measurement, namely, that of using a ranging system. There is range information only and no angle information. One can measure range and range rate. Since the relative orientation of the vehicles is unknown and it is in general time-varying, one cannot deduce the longitudinal and transverse velocities in one single measurement. In general, at least two measurements are required and that is possible only if one knows a priori the change in the relative velocity vector between the two measurements. This is unlikely during a dynamic lane-change process. Multiple sensors can also be used if they are sufficiently separated spatially. This is a challenging problem to the CAS designer.

Most existing CAS assumes that lane-changes are small angle maneuvers (as supported by the GES and CDS databases) so that the velocity measured by the ranging system is a good approximation to the relative longitudinal velocity.

6.1.4 Conflicts between Wide FOR and minimal "Nuisance" Alarms

Wide FOR is needed for CAS. This is particularly true for backing and forward collision warning. This requirement is not always commensurate wirh the desire to minimize "nuisance" alarms which we believe is important to gain user acceptance. For guards against backing into obstacles, FOR much larger than 20 degrees may be required based on preliminary simulations. The increased benefit of a larger FOR must be balanced against the technical difficulty in keeping the "nuisance" alarms to acceptable level. In conjunction with Goal #3 under Backing in subsection 5.3, we have discussed the need for a forward collision warning system with a 50 degree FOR. Sophisticated algorithms must be employed in order to realize such wide FOR in a clutter environment. One useful discriminator is target motion and target trajectory relative to the SV.

6.2 Requirements for Lane-Change CAS

As noted in 6.0, the numbers provided in 6.2, 6.3 and 6.4 below are very preliminary. The acronyms TBD and TBR stand for "to be determined" and "to be refined/revised" respectively.

6.2.1 Goal #l: Minimal System

- Function: Target Detection within a given zone; Driver alert
- Coverage: 1 lane (12 ft) to left and right in the transverse direction; 15 ft. to the fore and aft of the vehicle in the longitudinal direction (to serve only as a minimal "blind spot" eliminator) 1 - 10 ft in height
- Size of Target:: Small vehicles to tractor-trailer; Include bicycles as a goal
- Target Velocity: 0-80mph
- Target Acceleration: TBD
- Number of Targets: At least 1 but in general multiple targets (TBD)
- Platform (SV) Velocity: 0- 80mph
- Platform (SV) Acceleration: TBD
- Measurement Latency: much less than 1 s (TBD)
- Measurement Accuracy: several feet (TBD)
- Performance:
  - Probability of Detection - very high (TBD)
  - Probability of False Alarm - very low (TBD)
  - Probability of Nuisance Alarm - very low (TBD)

  Interference: Shall not interfere with the operation of other in-board or out-board systems; Interference to include electromagnetic effects as well as physical and mechanical constraints

  Duty Cycle: On-demand operation with TBD activation mechanism

6.2.2 Goal #2: Lane Keeping

- Function: Detect unplanned transverse vehicle motion and alert driver
- Measurement Range: Drift from 2 ft/s to 30 ft/s (TBD)
- Accuracy: 2ft/s (TBD)

- Vehicle Velocity: 0-80mph
- Special Interface: Determine if transverse motion is internal via interface to vehicle steering unit ; Synergistic with Driver Alertness Sensor

6.2.3 Goal #3: Counter-Fast-Approach

Additions/Modifications to 6.2.1:

- Coverage: Modifications - Coverage in the longitudinal direction to 50 ft. (TBR) fore and aft of the SV as a minimum requirement: 100 ft. (TBR) or greater fore and aft as a goal, depending on sensor technology status per discussion in 6.1,l above
- Function: Addition - Longitudinal relative velocity measurement: Relative Speeds up to a maximum of 30 mph (TBR)
- Number of Targets: Multiple (TBD)
- Measurement Accuracy: 5 ft/s*(TBD)

*This corresponds to about a 10% accuracy on a closing speed of 30 mph and is an accuracy achievable with state-of-the-art systems. However, the requirement is ultimately tied to the detection/warning algorithm and is design dependent.

6.2.4 Goal #4 Counter-Convergence/Situational Awareness

Additions/Modifications to 6.2.1 and 6.2.3:

- Coverage: Modifications - 2 Lanes to the left and right of the SV in the transverse direction; 50 ft.(TBR) fore and aft of the SV in the longitudinal direction: 100 ft. (TBR) fore and aft as a goal
- Function: Add - Transverse relative velocity measurement for relative transverse speeds from 0 - 30 mph (TBR)
- Measurement Accuracy: TBD
- Concept of Operation: TBD; at one extreme: a Situational Awareness System can be functional at ail times, detecting vehicle targets, measuring their velocity relative to the SV and predicting their trajectories relative to the SV - a warning signal will be issued upon imminent danger; at the other extreme: a Counter-Convergence System can be activated on demand and the driver of the SV will postpone lane-change until the System declares it is safe to do so
- Duty Cycle: On-demand operation with TBD activation mechanism or, 100% depending on the concept of operation as described above

6.3 Requirements for Merge CAS

6.3.1 Goal #l Driver Advisory/Warning

- Function: Provide warning to drivers approaching a merge of potential merging traffic; Provide warning to drivers performing a merge of potential conflict with through traffic

- Concept of Operation: Roadway advisory system ranging from simple warning signs to vehicle detection and velocity measurement systems
- Vehicle Interface: Via warning display on the roadway visible to the drivers or via direct communication link to a receiver onboard the vehicle which in turn issues a warning to alert the driver

6.3.2 **Goal #2 Merging Aid**

The same requirements as for 6.2.3 apply but with additional requirement for

- Coverage: Modification - Coverage in adjacent lanes to include lanes that intersect the merging lane at angles up to TBD degrees

6.4 Requirements for Backing CAS

6.4.1 Goal #l Rear Obstacle Detection

- Function: Target Detection and Warning; Velocity Measurement
- Range: Near Zone - 15 ft. (TBR) to the rear of the vehicle in range; TBD in azimuth; 1 - 8 ft (TBD) in height
  Far Zone - 100 ft. to the left and right of the vehicle; TBD FOV
- Target Size: From small child to large vehicles
- Target Number: at least one and multiple (TBD) in general
- Target Motion: 0 - 45 mph (TBD)
- Performance: Probability of Detection - TBD
  Probability of False Alarm - TBD
  Probability of Nuisance Alarm -TBD
- Concept of Operation: Near Zone detection of stationary obstacles (range); Far Zone detection of vehicles in transport (range and velocity)
- Duty Cycle: Operational on demand when vehicle is put in reverse-gear
- Interfaces: Can be interfaced with vehicle braking system

6.4.2 **Goal #2 Forward Collision Warning**

This system falls outside the purview of the current contract. However, we include key requirements below for completeness.

- Function: Detect vehicles and pedacyclists in the crossing path of the SV; range and velocity measurement translated into trajectory and time to impact prediction
- Coverage: 100 ft (TBR) range in front of the vehicle; +/- 25 degrees in azimuth
- Size of Target: Pedacycles to trucks
- Target **Velocity:** 0 - 15 mph transverse to the velocity of the SV
- Target Acceleration: TBD
- Number of Targets: one
- Platform Velocity: 0-60mph
- Platform Acceleration: TBD
- Measurement Latency: much less than 1 s (TBD)
- Measurement Accuracy: sufficient to predict time to impact accurate to about 0.5 s (TBD)
- Display Requirement: Issue warning if target is in collision course with SV;

Optional display of safe speed for SV in order to avert collision

- Performance:
  - Probability of Detection - very high (TBD)
  - Probability of False-Alarm - very low (TBD)
  - Probability of Nuisance-Alarm - very low (TBD)
- Interference: Shall not interfere with the operation of other in -board or out-board systems
  Interference to include electromagnetic effects as well as physical and mechanical constraints
- Duty Cycle: On-demand operation with TBD activation mechanism

6.5 Summary

In this report, we have specified the functional goals for CAS based on a careful examination of the '92 GES and CDS data. We have built on the findings of Task 1 where we have investigated the causes that lead to lane-change/merge and backing collisions and constructed accident scenarios. These scenarios point to crash avoidance opportunities and the usefulness of CAS. The functional goals, or changes to the situation, that will help eliminate these crashes are enunciated in Section 5. Realism based on our knowledge of remote sensing and of the state of the art in hardware is injected into the very general discussions of the requirements for the CAS in this section. We will continue to assess the state of the art in CAS hardware via our test program at VRTC under Task 3. At the same time, we will initiate Task 4, namely an analytical study that will set Preliminary Performance Specifications for the CAS. Human factors will be considered and computer simulations will be extensively employed. Completion of Task 3 and Task 4 will end Phase 1 - Laying the Foundation of the current contract.

7.0 General References

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