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A METHODOLOGY FOR DETERMINING THE ROLE OF VEHICLE HANDLING IN ACCIDENT CAUSATION

Summary Report

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16. Abstract

A review of the literature on the role of vehicle handling in accident causation shows that there has been much conjecture regarding the link between vehicle handling and accidents. Little of a defensible nature is apparent other than vehicle size seems to correlate with accident experience. An examination of available mass accident data also shows this apparent size effect as well as some correlations between (1) vehicle track width and rollover accidents, (2) driver age and size of car, (3) size of car and accidents on curves, and (4) driver age and accidents on curves.

For purposes of the present study, hypotheses were developed linking vehicle handling characteristics to accident descriptors. Careful consideration is then given towards developing a statistical analysis method that would serve to support or negate such hypotheses and which would further define the amount of data required to support a given hypothesis. Implementation of the methodology to investigate the role of vehicle handling, as proposed, requires that four kinds of data be collected: exposure-to-risk data, accident data, vehicle handling descriptors, and "image risk" data. The requirement for each of these data categories is discussed at length. In addition to defining an accident data collection and analysis methodology, efforts were also devoted towards advancing the present state of the art in reconstructing the pre-crash phase of accidents and towards outlining a deterministic analysis procedure for relating vehicle handling performance directly to accident avoidance performance. The conclusions emphasize the formidable and costly nature of implementing the proposed methodology, but point up that by dovetailing efforts with other areas (of concern to accident causation analysis) agencies could substantially increase the benefit/cost ratio of follow-on research and implementation.

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1. INTRODUCTION

This report describes a study designed to develop a methodology for determining the role of vehicle handling in accident causation. The methodology developed in the study has three parts:

1. Data definition, collection, and analysis
2. Indepth accident reconstruction
3. Accident avoidance analysis

The first part deals with methods for uncovering statistical links between vehicle handling performance and accident experience. The second part consists of detailed methods for reconstructing the pre-crash phase of the accident—the phase in which vehicle handling factors are most important. The third part of the methodology consists of methods of defining the influence of specific vehicle handling characteristics on accident avoidance performance.

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2. A PERSPECTIVE

Some maintain that research into vehicle handling as a causative factor in accidents is infeasible. They argue that even if vehicle handling factors contribute to accidents, the contribution is impossible to isolate, and therefore such research is pointless. The study findings discussed in this report do not support that contention, but they do point out how difficult it is to isolate "vehicle handling" factors from other factors in accident causation. A research effort of the scope necessary to produce definitive conclusions would require expenditures of time and funds much greater than those expended in any previous effort in accident data analysis. Not only would more and better accident data be required, but data relating to (1) vehicle accident-risk exposure, (2) vehicle handling performance, and (3) vehicle use patterns would also be required. Further, in each case, the amount, accuracy, and detail of the required data would have to be an order of magnitude greater than data now available.

The difficulty of the research task is partly evident in the limitations of existing research findings. There is much evidence to suggest that if accident rates are considered alone (without considering confounding influences), vehicles that are considered to be the "best handling" are the very ones that have the highest accident rates. Those findings, of course, cannot be taken at face value, since it is strongly suspected that persons who drive the "better handling" vehicles are also those who are more likely to drive more aggressively than other drivers.

Driving aggressiveness is just one of the confounding factors that must be accounted for. Among other factors there is the exposure to accident risk posed by the environment within which the vehicle is driven, the manner in which the vehicle is maintained, and the "handling performance" characteristics of the

driver/vehicle system in an accident-avoidance maneuver. Without exception, adequate information has not been available in previous research efforts in the amount, detail, and accuracy necessary for deriving statistically defensible conclusions. As the literature review in the full report shows, many fragmentary "conclusions" reported in past research efforts are little more than conjured hypotheses. Results from even some of the best and most carefully conducted studies have been contradictory.

The methodology outlined here can be used to determine the role of vehicle handling in accident causation. However, nothing short of a major effort will produce valid conclusions. A partial effort, as all past efforts have been, would again produce partial and questionable results.

3. DEFINITIONS

There has been little agreement among researchers as to a definition of the term "vehicle handling." The most narrow definition limits the term to the lateral response characteristics of a vehicle, i.e., cornering performance. A wider definition of vehicle handling, but one still restricted to the vehicle, would include longitudinal as well as lateral response characteristics, i.e., braking and acceleration as well as cornering.

A yet wider definition would include the interaction of the driver and vehicle in jointly producing longitudinal and lateral control motions. The control actions of the driver represent the primary area of direct interaction between the driver and vehicle, and hence influence "vehicle handling" performance. The control actions are short-term, high-frequency activities the driver performs to avoid obstacles, augment directional stability, keep in a lane, etc. The driver performs these control actions by manipulating the steering wheel, accelerator pedal, and brake pedal. His performance is limited by his reactions, his strengths, his relative "fit" with the work space and controls, and ultimately by the motions of the vehicle itself. A vehicle that corners at 0.9 g but does not provide means for the driver to stay fixed relative to his controls is not a good handling vehicle, regardless of its "mechanical" cornering characteristics. Similarly, a vehicle that requires an inordinate amount of brake pedal force is not a good handling vehicle. Thus, it is evident that any definition of vehicle handling must include the driver's control tasks as well as the vehicle itself.

A still broader and more appropriate definition of vehicle handling includes considerations of the road surface. All forces acting on a vehicle, other than aerodynamic forces, must arise at the tire-road interface. The friction couple at the interface effectively limits the maximum force levels that can be applied

during an accident-avoidance maneuver. Thus, the sought-after definition takes the following form:

> Vehicle Handling: The lateral and longitudinal motion characteristics of the driver/vehicle/road-surface system in response to short-term, high-frequency control inputs.

Given that definition of vehicle handling, a vehicle handling accident is one wherein a deficiency in the short-term cornering, braking, or acceleration response characteristics of the driver/vehicle/road-surface system was a causative or highly contributing factor in the accident. The critical issue here is what constitutes a deficiency. If an emergency situation arises such that 0.6 g braking action would avoid the accident, while the "system" is capable of producing only 0.4 g, then it is reasonably safe to say that a deficiency exists. If, on the other hand, a 3.0 g braking deceleration is required, but only 0.9 g is available, it is apparent that no "practical" braking action (within the accepted state of the art) could have avoided the accident. Thus, the definition of a vehicle handling accident must lie within the band of unsuccessful driving maneuvers bounded on one side by available handling performance and on the other by performance that is practically achievable. An accident that could have been avoided only by impractical levels of handling performance is not a vehicle handling accident. An accident that could have been avoided by practical improvements in handling performance is a vehicle handling accident.

Given the above considerations, a vehicle handling accident is defined as follows:

> Vehicle Handling Accident: An accident that could have been prevented by better vehicle handling performance, where such performance could be practically upgraded by improvements in the driver/vehicle/road-surface system.

Thus, an accident is a vehicle handling accident when (a) a "system" deficiency exists; (b) that deficiency was a causative factor in the accident; and (c) the deficiency could have been eliminated by practical improvements in (1) driver skills, (2) vehicle design or maintenance, and/or (3) the road surface.

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4. LITERATURE REVIEW

It is apparent from a review of the research literature that vehicle factors play a role in accident causation, that the role is not understood, and that past research efforts provide no means of accurately quantifying the magnitude of the role.

The works reviewed contradict one another in many respects. While in-depth investigations have failed to identify vehicle performance as a frequent causal factor, other less direct evidence suggests that it may be. The role of driver inexperience in loss-of-control accidents is generally recognized. So also is the potential for achieving safer highways by means of better emergency maneuver training. These observations indicate a driver failure problem in the driver/vehicle/road-surface system. What is not indicated is the degree to which that system's performance can be improved by changes in the vehicle alone.

Research outside the U.S. has indicated that tire pressure or tire condition, which affects handling almost exclusively, can cause accidents. Better braking systems have also been shown to be a path to lower accident rates. How these results apply to the type of driving situations found in the U.S. is not readily apparent.

Within this country, the most significant finding is that those cars with the best avoidance capabilities, particularly small cars, have serious stability problems. The vehicle classes with the lowest rates of overall accident involvement consistently fare poorly with respect to loss-of-control or single-vehicle accidents. Determining the optimal mix of small-car maneuverability and big-car stability may be the most significant impact we can make in this field.

Other work in this country tends to be largely contradictory, whether in the area of accident-cause determination or model-to-model accident-risk comparisons. Much of the problem is

a lack of adequate data; many studies reported on too few accidents to produce meaningful results. Another aspect of the problem is a failure to account for the myriad of independent variables which make every accident unique.

One disappointing aspect of even the best research that uses accident data to point out dangerous design characteristics is the failure of the researchers to ask, let alone try to answer, the question of "Why?" In many reports evidence is presented that suggests certain vehicle models are very accident-prone, or that certain general vehicle configurations are over-involved in accidents. No attempt is made to look further, however, to see if those extra, unpredicted accidents were indeed the result of vehicular factors. And even if the statistics indicate that the fault lies with the vehicle, could not the fault be poor visibility, or poor ergonomic design, or poor headlight or taillight effectiveness? The extent of the role of vehicle performance in accident causation is not likely to be known before statistical research, vehicle testing and rating, and improved accident reporting are combined for the purpose of answering that specific question.

5. EVIDENCE OF VEHICLE HANDLING FACTORS IN AVAILABLE ACCIDENT DATA

While much accident data has been collected and organized in computer files in the United States, few of these files have been examined with the idea of determining the role of vehicle handling in accident causation. One of the purposes of the present study was to conduct such an examination.

At the Highway Safety Research Institute there are upwards of two hundred separate accident files available for research purposes. Most of these are special-purpose files that have little utility in the present application. These police-reported accident cases too often lack sufficient detail on the accident-involved vehicles. The cases also do not differentiate the parameters describing an accident in such a way that they can be analyzed with respect to vehicle handling considerations. Two other requirements for the present application are that a data file must contain enough cases to produce meaningful statistical results, and the raw data must be reasonably accurate and represent a random sample of an accident population. At present, no existing data file satisfies all of those requirements. Two files do, however, come close enough to provide useful information. Those two are mass-accident data files from King County (Seattle), Washington, and from the State of Texas. Analyses of those files produced findings associated with vehicle handling. But, because of the absence of exposure data, the findings are expressed as accident frequencies and not accident rates.

The CPIR file of 7,799 multidisciplinary accident investigation cases was examined to determine whether the file is useful for learning more about the role of vehicle handling in accident causation. It was established that the file is not suited for making deterministic decisions regarding the presence or non-presence of such factors in those cases. For such cases to be useful, a more specific scheme for gathering data on the pre-crash phase of the accident would need to be employed in the case investigations.

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6. SELECTION OF VEHICLE HANDLING PERFORMANCE DESCRIPTORS AND CONSTRUCTION OF A VEHICLE HANDLING DATA FILE

To determine the role of vehicle handling in accident causation, it is necesary to break down the elements of a passenger car into those qualities, quantities, descriptors, dimensions, etc., that describe its handling performance. Next it is necessary to do the same with the accident event, i.e., break down the event into its elemental descriptors, each of which may have a connection with the vehicle handling properties of the driver/vehicle/road-surface system. One then must proceed to (1) collect the necessary vehicle and accident data and (2) construct the related computerized data files. The final step is to compute normalized accident rates and analyze the resultant data for correlations between vehicle descriptors, accident descriptors, and accident rates.

The process of defining and selecting vehicle handling descriptors is discussed in detail in the full report. Also described are the form and content of a vehicle handling data file that can be constructed with data available for collection.

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7. STATISTICAL ANALYSIS AND DATA COLLECTION METHODOLOGY

The proposed methodology requires collection and analysis of four types of data: (1) accident data; (2) vehicle handling data; (3) exposure-to-risk data; and (4) image-risk data. In the present study the methodology has been partially applied, in a preliminary way, to demonstrate that it is feasible to combine data libraries to attain the desired objectives. The methodology should be applied in a full-scale research program that would entail collecting handling data for approximately 100 vehicle models. The additional data required to implement the methodology should be obtained within a two-year time frame and within a common geographic area.

At least 300,000 accident cases should be collected through a police accident reporting system, using a supplemental reporting form. The exposure-to-risk data should be acquired both through a mailed questionnaire survey and through interviews at license renewal offices. Vehicle handling performance data should be acquired by means of a dynamic testing activity—both for normal handling and limit handling properties. Finally, image-risk data should be collected by means of automated traffic surveys at selected locations. These surveys should identify the driver and vehicle while simultaneously recording such variables as speed, lane of travel, position in lane, car-following distance, and weather conditions.

Those data would be analyzed to produce true accident rates, namely, rates that are normalized for confounding influences such as driver, exposure, and image factors. On comparing true accident rates with various accident descriptors, the researchers would be able to define the relative accident-causation potential that can be associated with a given level of a specific vehicle-handling descriptor.

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8. ACCIDENT RECONSTRUCTION METHODOLOGY

If handling-related causation factors are to be identified, emphasis in accident reconstruction must be placed on the pre-crash phase of the accident. To establish beyond question whether vehicle handling factors were involved in an accident, several types of information are needed:

1. The history of the driving cues presented to the driver, his decision processes, and his control actions. (This would require having a recording device on the vehicle.)

2. The pre-crash path(s) of the vehicle(s), including the length, location, and microscopic characteristics of skid marks.

3. The characteristics of the friction at the tire-road interface.

4. The handling characteristics of involved vehicles, as determined by basic design, and as modified by loading, tire wear and pressures, and other first-order effects.

5. The maintenance and repair status of the involved vehicle—particularly in relation to identifying the influence of mechanical condition as a factor other than the influence of basic design.

6. The physical condition and capacities of the driver(s) (e.g., alertness, experience, reaction capacity, physical strength, etc.).

7. The ergonomic matching of the driver with the vehicle, i.e., the arrangement and placement of driving controls and the required forces for their manipulation.

8. The ambient environment.

9. The macroscopic characteristics of the roadway, e.g., geometric alignment, pavement roughness, sight obstructions, etc.

While there are obvious difficulties involved in obtaining all of the above-described information, accident reconstruction methods can be improved in several ways to provide a better understanding of the pre-crash phase. In this connection, the study examined five aspects of pre-crash reconstruction: analysis of skid marks; determination of pavement skid resistance; measurements of pavement slope, curve speed, and light intensity; measurements of driver reaction time, pedal force strength, and grip strength; and determination of the maintenance repair status of the involved vehicle(s).

A Vehicle Handling Supplement to the CPIR form was developed for use in collecting information that can be used to identify vehicle handling factors in an accident. This modular supplement has five sections that deal with the environment, the roadway, the vehicle, the operator, and the accident kinematics. The approach employed in developing this supplemental form was to include every variable that could either be directly related to a vehicle handling factor or could confound an analysis seeking to establish the influence of vehicle handling.

9. A DETERMINISTIC METHODOLOGY

The analytical methodology described in several sections of the report is based on the use of statistical inference as a means of determining the role of vehicle handling in accident causation. In this section, a different approach is used to evaluate the accident avoidance capabilities of a vehicle/driver system. This approach is a means of supplementing the findings obtainable through use of the tools of statistical inference. The approach is an adaptation of the pursuit-evasion analysis methods developed to evaluate air-to-air combat weapons systems.

In a military context, the objective is to get an air-to-air attack missile as close as possible to a target aircraft before its warhead is detonated. The magnitude of this closest approach, or miss distance, is a measure of the effectiveness of the missile. In automotive accident avoidance, the objective is just the opposite with respect to miss distance. The better performing car is one that can increase the miss distance and carry out a safe recovery phase.

This approach is described in the full report in terms of (1) a simple mathematical model describing the differential geometry of two vehicles involved in accident avoidance; (2) application of the model to the simulation of a single accident avoidance scenario; and (3) manipulation of the simulation results into a form that can be used to show the influence of cornering capability on accident avoidance performance. The simulation results show that improving the lateral acceleration performance of a vehicle from 0.6 g to 0.8 g—a 33% increase—results in only an 8% increase in accident avoidance performance. The costs of increasing cornering capability and the benefits accruing from reduced accident experience have not been computed, but such computations could be undertaken.

The mathematical model employed in this simulation is based on several simplifying assumptions. For example, the model does not account for the complicated handling performance of a vehicle as it approaches its limit maneuvering regime. Nor does it account for the manner in which braking action limits a vehicle's ability to corner. However, such refinements could be added to the model. A full-fledged vehicle dynamics simulation could be employed. Simulations offer the potential for investigating the influence of any specific handling property on the accident-avoidance performance of a motor vehicle. Further, it is possible to add driver influences (reaction time, control force limitations, maneuver actions, etc.) and roadway influences (surface skid resistance, geometric features, roughness, etc.) to this approach. Although pursuit-evasion methods are not a panacea, they offer a deterministic approach to examining the role of vehicle handling in collision or accident causation, as opposed to examining, on a statistical basis, factors which may be deemed causative or contributory. Given the complexity of the issue, it could be argued that both approaches should be pursued in parallel.

10. CONCLUSIONS

The use of a statistical approach in determining the role of vehicle handling in accident causation calls for collecting and analyzing several types of data in unprecedented amounts. Implementing the program will be a formidable and costly undertaking. Pressures will undoubtedly arise for reducing the scope of the program recommended herein as a means of answering the questions of interest. Certainly there is nothing wrong with reducing scope and costs—provided the eventual objectives are not jeopardized. A good deal of care should therefore be exercised before making any decisions to reduce segments of the proposed program. The consequences of collecting fewer data elements in terms of reduced confidence in results can be clearly established through the methods developed in Section 7.

Although the recommended program will be costly to implement, there are supplementary benefits that should be carefully considered. Much of the derived data (having the form recommended here) will be applicable to studying and confirming hypotheses not necessarily related to vehicle handling. In particular, the accident and exposure-to-risk data, plus a few additional data elements in each collection program, could provide very useful information. After all, truly valid exposure-to-risk data is now virtually non-existent. Consequently, valid accident rate information is also virtually non-existent. It would therefore be worthwhile to consider the utility of the data to be derived from research investigating the role of vehicle handling factors in terms of studying the influence and role of other factors, and to plan the collection task accordingly.