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**TRUCK CAB VIBRATIONS
AND HIGHWAY SAFETY**

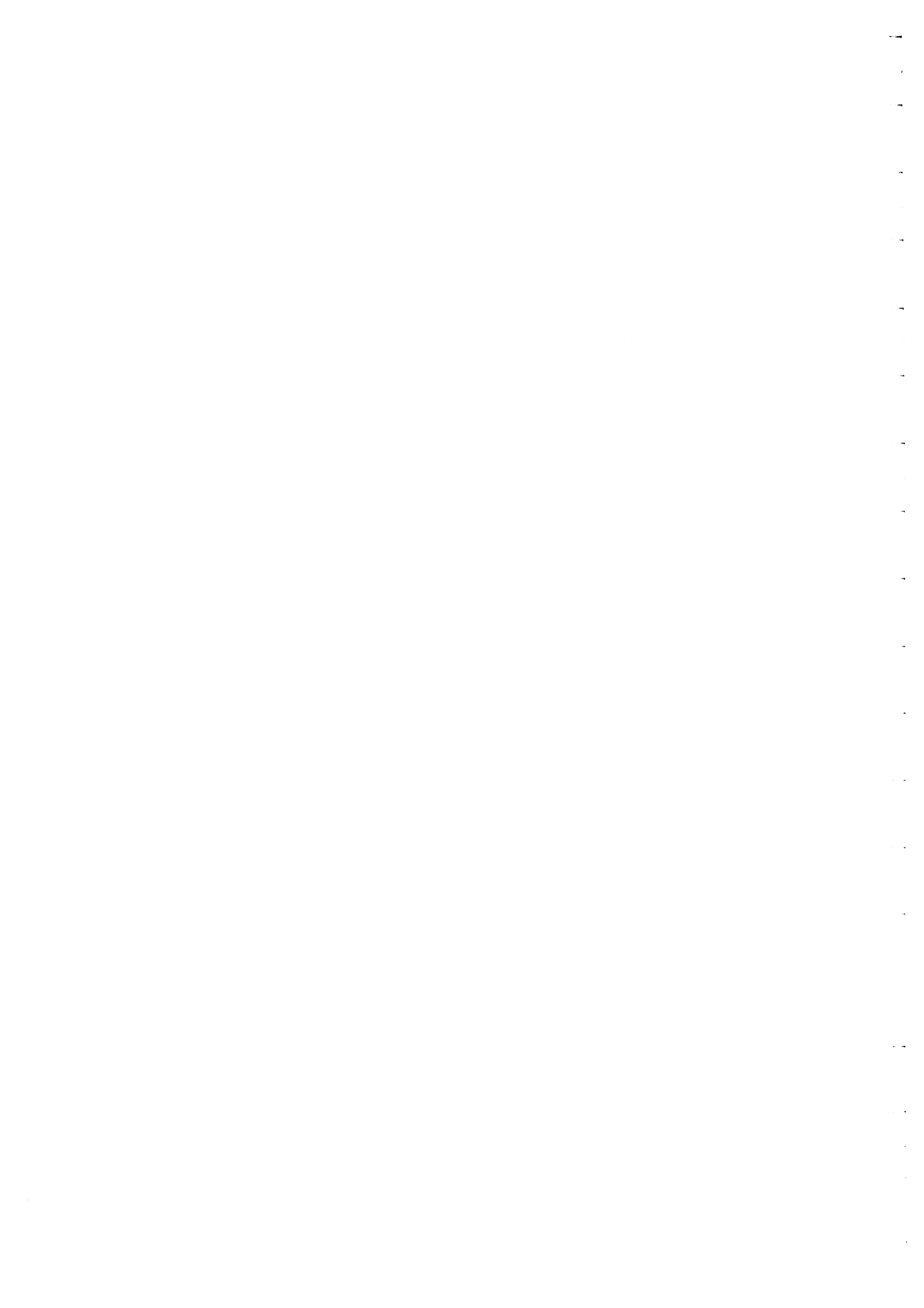
**T.D. Gillespie
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VOLUME I

**MARCH 1982
SUMMARY REPORT**



**THE UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE**



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Volume I

Summary Report

Contract No. DTFH61-81-C-00083

Highway Safety Research Institute
The University of Michigan

March, 1982



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| 16. Abstract Exposure to vibration of drivers of trucks and tractor-trailers has often been implicated as a negative influence on driver health and highway safety. This document reports the findings of a research project in which the state-of-knowledge on the links between the truck ride vibration environment and accident involvement was critically reviewed by a panel of experts in an effort to evaluate its significance as a public safety issue. The state-of-knowledge linking the truck vibration environment to effects on driver performance, and ultimately accident involvement, is insufficient to provide direct evidence of the significance at this time. Experimental data obtained in this project demonstrate that truck vibration level is related to road roughness from which it may be inferred that the vibrations levels will increase in the future if the highway system continues to deteriorate. The panel of experts recommends the continuation of research in the area of truck ride vibration and its effects on driver performance, and in the area of road roughness as it affects ride, safety, and roadway deterioration. This report consists of two volumes: Volume I - Summary Report; Volume II - Technical Report with Appendices | | | | | |
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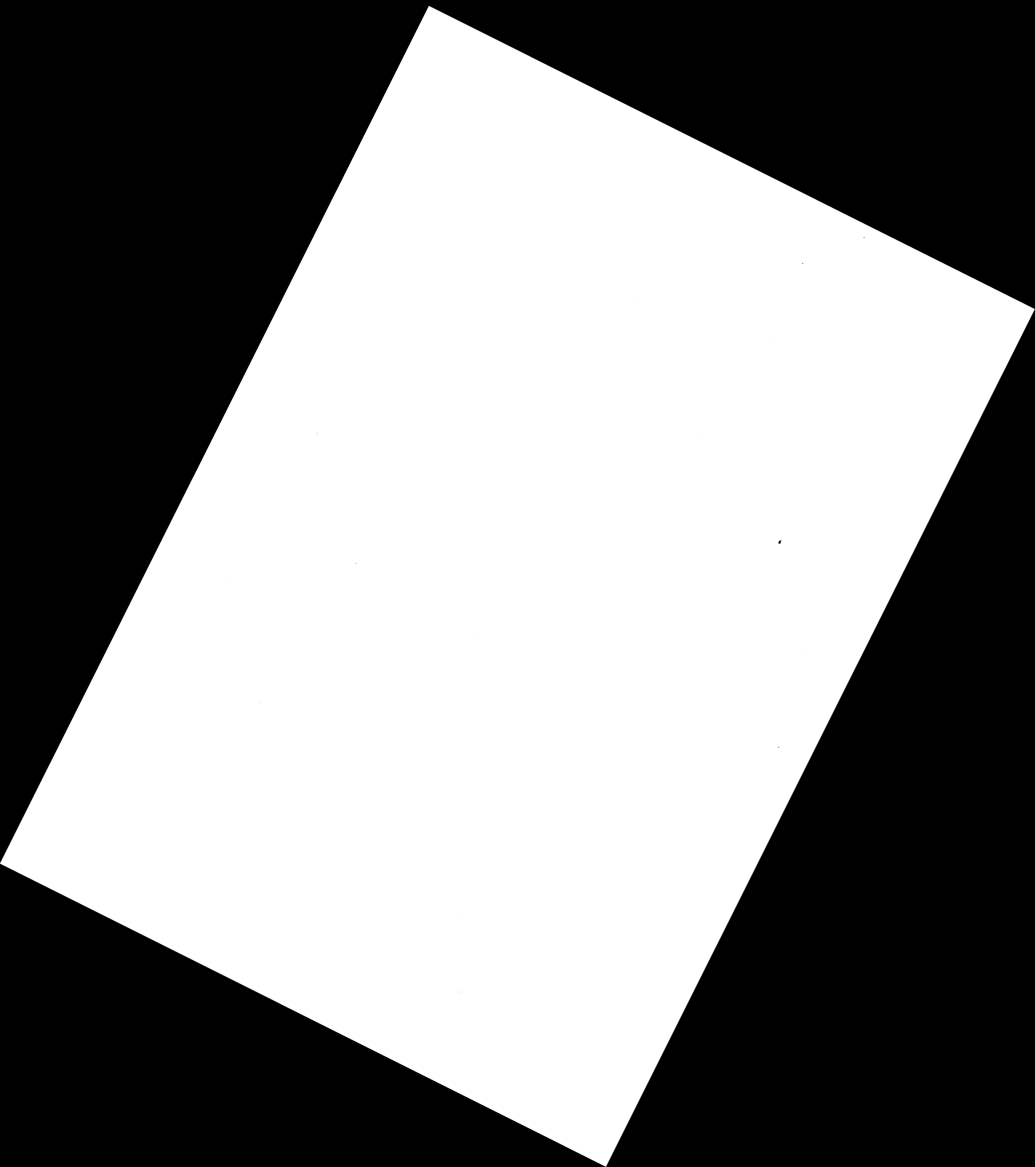


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ACKNOWLEDGEMENTS

This report documents a research program performed for the Federal Highway Administration examining the relationship between truck vibration and highway safety. The research involved experimental measurements of truck vibrations, a state-of-the-knowledge review of the vibration/safety relationship, and the conduct of a conference to explore the consensus among experts on the topic.

The authors wish to thank Messrs. Michael Sayers, John Campbell, and Don Foster for their help in the collection and analysis of experimental data.

The State-of-Knowledge Review on the Relationship of Truck Ride Vibration to Highway Safety (Section 2.0 of the Technical Report) involved broad areas and disciplines. Many people on the HSRI staff contributed to its writing, both in the preliminary form and as reflected in the Technical Report. Professor Leonard Segel authored the introductory section; Dr. Thomas D. Gillespie, the section describing the truck ride environment. Dr. Lawrence Schneider prepared to section elaborating the effects of vibration on man, with able assistance of HSRI staff members—Melissa Pflug, Dr. Robert Matteson, and Cynthia Donahey. The last section, examining the evidence to relate vibration exposure to accident frequency, was prepared by Dr. Kenneth Campbell with assistance from Dr. Oliver Carsten. Throughout the endeavor, the staff received able assistance from Kris Huber of the HSRI Library in identifying and obtaining the relevant literature.

In preparation for the conference, Dr. Ronald Lippett, Professor Emeritus at The University of Michigan, and his associate Kathleen D. Dannemiller, provided the advice and concepts from which the conference design was selected. Ms. Jeannette Nafe attended to the myriad of administrative details essential to its conduct. Finally, the conference participants, as identified in Appendix A of the Technical Report, deserve recognition for their professional dedication, as reflected in their contributions to the conference and their many helpful suggestions for improving the State-of-Knowledge Review.

1.0 INTRODUCTION

1.1 Introductory Remarks

This report documents a study sponsored by the Federal Highway Administration (FHWA) and conducted over the period of July 1, 1981 through February 1982. The project was conceived out of need to provide governmental decision-makers with guidance on the urgency of truck vibration as a societal issue meriting federal involvement.

In the mid-1970's, the vibration exposure of drivers of commercial trucks was raised as an issue to the federal government—namely, do vibrations (as well as noise, toxic fumes, and other factors that contribute to truck "ride quality") have a negative effect on driver health and on highway safety. The responsible federal agencies, including the Federal Highway Administration and the National Highway Traffic Safety Administration, pooled their resources in a coordinated program addressing the issue. The FHWA took responsibility for investigating the safety aspects of this issue, leading to a comprehensive research program entitled "Ride Quality of Commercial Motor Vehicles and the Impact on Truck Driver Performance" being established in 1977.

In the first few years, funding was obtained for the program to proceed into its initial phases. In the budget decision process for Fiscal 1981, Congress saw fit to question the need for the program and allocated funds for an assessment of that need. As stated in the 1981 Appropriations Bill for the House of Representatives

".....the bill includes the budget request of \$100,000 to study truck ride quality. The Committee, however, expects that these funds will conclude this research effort and that an appropriate report will be provided delineating any truck ride quality safety problems as well as the actions required to correct any such problems."

1.2 Problem Statement

The design of trucks and tractor-trailers for efficiency in cargo transport involves compromises in "packaging" the driver. As a consequence, the driver's environment in a heavy-duty commercial vehicle characteristically involves higher vibration levels than that experienced in other transport vehicles, namely, passenger cars and buses. It has been argued that the vibration exposure of commercial truck drivers could have long-term effects on driver health, or short-term effects on the driver's ability to control the vehicle safely. If these hypothesized health and safety effects are real, certain agencies within the federal government have authority and responsibility under public law to take action which will ameliorate these effects. Further, irrespective of the significance these issues may have today, it can be anticipated that they could become more serious in the future, as a result of a continuing deterioration of the national highway system.

Ultimately, the rationale for expending federal funds on this issue depends on its seriousness in comparison to other social problems. In the ideal case, the technical community will support the legislative decision-makers by providing quantitative measures of the seriousness of a problem, which can be weighed against that of other problems in society competing for federal resources. Unfortunately, the published knowledge about the effects of truck vibration on driver health and highway safety is insufficient to provide those measures.

Therefore, the objectives of this project were twofold:

- 1) To demonstrate experimentally the direct dependence of truck driver vibration levels on the roughness of the highway surface in order to validate the predictions that the seriousness of the issue will grow with continuing deterioration of the national highway network.
- 2) To assess the collective knowledge on the potential impact of truck driver vibration on highway safety in an effort to estimate the significance of the problem.

1.3 Approach

The methodology for addressing the first objective in the project is well within current technology and was approached in a straightforward manner. A tractor-trailer was acquired as a test vehicle and instrumented in accordance with the most commonly used practices to measure the ride vibrations in the cab and on the driver's seat. The vehicle was driven over a selection of road surfaces known to be representative of the general spectrum of roughness conditions. The surface roughness was measured by means of the wheel track profiles obtained by a GMR-type inertial profilometer. The truck vibration measurements were analyzed to determine spectral characteristics and other statistical measures, as commonly used to describe the properties of vibration exposure. Similarly, the road profiles were processed to obtain spectral characteristics and the summary roughness numeric commonly used by the highway community to characterize road roughness. The relationships between the road roughness and various measures of truck vibration were then examined. A detailed discussion of this portion of the study is provided in Appendix B of the report. The findings most relevant to the vibration/safety issue are presented, where appropriate, within the main body of the Technical Report (Volume II).

The second objective of the project, dealing with the assessment of knowledge and estimating the significance of the vibration/safety connection, presents a more difficult problem. The approach suggested by the sponsor and agreed upon by the research staff was to convene a conference of experts for the purpose of (a) establishing a consensus on the state of knowledge, (b) obtaining their collective judgments on the importance of the issue, and (c) defining the courses of action that should be taken.

The initial steps in this phase of the project focused on the identification of a selection of experts, and design of a conference bringing the appropriate methodology to bear on the group, so as to extract the desired products. (In this latter step, consultation was obtained from experts experienced in the design of such conferences.)

A key feature of the approach involved the preparation of a state-of-knowledge document addressing the relationship of truck ride vibration to highway safety. The document, which attempted to provide a basic structure to the links between vibration and safety, was sent to each conferee prior to the conference in order to provoke thought and discussion.

1.4 Report Organization

This Summary Report presents an abridgement of the overall project results. The state of knowledge on the relationship between truck ride vibration and highway safety was assembled and reviewed in the course of the project. The main findings of the review were hypothesized ways in which vibration could potentially affect driver performance, as a basis for examining the accident record in search for accidents attributable to vibration effects. These findings are presented in Section 2.0. The examination of the issue in a conference of experts provided the setting to evaluate their judgments of the "truths" of the issue and the degree of consensus on each. The products of the conference are given in Section 3.0.

In the last section (Section 4.0), the research staff attempts to interpret and summarize the findings of the knowledge review, the ride measurements, and the conference as they apply to the issue being addressed in this project.

2.0 FINDINGS FROM THE STATE-OF-THE-KNOWLEDGE REVIEW

2.1 Hypothesized Ways in Which Vibration Could Contribute to Accidents

The state-of-knowledge was reviewed in order to characterize the truck ride environment, and draw from the literature on the effects of vibration on man, to determine in what ways the driver's biodynamic state may be altered by the presence of vibration. The ultimate objective, however, is to look for vibration effects on safety as measured by accident frequency. Since the accident record lacks information which would define the vibration levels present in an accident-involved truck, alternative methods must be used for correlating vibration with accident frequency. The alternative chosen here is to hypothesize the possible ways in which vibration could impact on performance of the driver/vehicle system and look for associated effects in the accident record. It should be noted that these mechanisms, as listed below, are hypothesized as ways in which truck vibration could increase the potential for accidents simply for the purpose of guiding the analysis of accident data. However, only the results from that analysis can infer whether these mechanisms are potentially significant. Further, it should be recognized that this process cannot assess the potentially positive influences that truck vibration could have on accident prevention.

The first possible way that the truck ride vibration environment can lead to decrements in driving performance of consequence to motor carrier safety is due to the blurring of images in the rear-view mirror. Loss of visual acuity, in this instance, is probably most severe when the mirror vibrates at higher frequencies than the driver's head (i.e., the object moves and the head doesn't), in which case the visual pursuit reflex is completely inadequate for image stabilization. It may also occur as a result of inappropriate vestibular compensation, if the mirror is moving with the head. In any case, the decrease in image clarity could possibly lead to errors in perceiving a passing vehicle or in deciding when to merge back into a lane after passing. At a minimum, it would increase the time required to look in the mirror (i.e., look away from the traffic ahead), and this interruption could be a factor in

accident causation, especially in heavy traffic. A decrement in the ability to see images clearly in the rear-view mirror would be especially significant at dawn or dusk when headlights are possibly turned off and during wet weather when visual acuity is already decreased and glare and road surface reflection add to the problem of image clarity.

A second way in which vibration may lead to performance decrements of significance to safety is the possible increase in fatigue experienced after a long period (e.g., four hours or more) of driving. Such fatigue appears to be caused mainly by the increased muscle tension required to maintain a seated position and reduce head and shoulder vibration, or because of tonic reflex stimulation through muscle spindle receptors in the muscles themselves. Presumably, fatigue would lead to decreased vigilance and alertness, resulting in delayed or inappropriate responses to emergency situations. On the other hand, the muscle tension response to vibration may act to prevent sleep and this result would be a positive factor. The increased vigilance or alertness due to vibration-induced muscle tension has been previously noted and, presumably, is a positive factor, prior to fatigue setting in.

A third way in which vibration can lead to an increased potential for an accident event is the large amplitude oscillation or bump which jars a driver from his seat and therefore from a position of control. Such an event is likely to be an infrequent occurrence and would only be safety related if the driver were executing a maneuver (e.g., a sharp turn or an emergency stop), or if the road conditions were such as to require constant and careful attention to the control process.

A fourth way in which vibration may lead to performance decrements on the part of the driver is the morbidity that might occur or be aggravated with long-term exposure to vibration. If a truck driver suffers from physical ailments such as low back pain or gastrointestinal disorders (regardless of the initial cause), truck vibration may aggravate the symptoms and disease severity. The resulting discomfort may lead to increased stress, fatigue, distraction, and perhaps to seated positions which could reduce driving effectiveness.

A fifth way in which vibration could lead to an increased potential for truck accidents derives from the influence of vibration on a driver's ability to manipulate the steering, braking, and throttle controls on the vehicle. The practice of using laboratory tracking tasks to measure the influence of vibration on the ability of a human operator to perform a control function implies that the investigator believes that these laboratory findings have relevance to the real-world tasks of controlling a truck and resolving traffic conflicts. However, there is no direct evidence to support this assumption. There is, however, some anecdotal evidence to suggest that the vibration experienced in a truck cab can interfere with the ability of the driver to modulate the brake pedal when making an emergency stop on a rough section of roadway.

Although not involving the driver directly and thereby not justifying the term "ride," a sixth way in which vibrations, per se, can influence the accident record derives from the vertical response of the running gear to the disturbance created by the uneven road surface. To the extent that the tires lose contact with the road surface, the ability of the truck to "hold the road" will be degraded. In other words, steering and braking performance will suffer irrespective of what control actions are taken by the driver, other than the significant action of selecting a speed which will reduce the disturbance created by the road. Not only is there very little analytical and experimental research addressing the dynamics of the "road-holding" phenomenon (as occurs in heavy goods vehicles), there is little evidence to indicate the importance of the "road-holding" process to the accident record.

2.2 Results from Examination of the Accident Records

Given that the literature can be interpreted to suggest several possible vibration mechanisms (as identified above) that may contribute to the accident record, it follows that some attempt should be made to determine whether the accident record can be interpreted to shed light on any, or all, of the identified paths by which the safety of motor carrier operations may be influenced by truck ride quality. At present, it appears that no such studies have ever been made. Consequently, an effort was

made to review existing information on the use and accident experience of one specific segment of the motor carrier fleet, namely, the combination vehicle which consists of a truck tractor hauling a semitrailer. An interpretation of that data with respect to the possible impact of ride vibration on accident involvement leads to the following conclusions:

1. Given accident data files in their existing form and the current state of accident causation research, it is not possible to establish any significant link between ride vibrations and accident involvement. In those cases where the accident data files provided sufficient detail to examine hypothesized mechanisms, the possible occurrences were infrequent. For other mechanisms, the existing data were inadequate.

2. With regard to short-term effects of ride vibration—degraded vision in vibrating mirrors, reduced proficiency in control modulation, and loss of control due to severe bumps—the available data do not provide significant evidence to support the hypothesized mechanisms relating these short-term vibratory effects to accident involvement.

3. Thus, the most likely connection between truck ride quality and accident involvement is the synergism between multi-hour exposure to vibration and all of the other negative aspects associated with driving a heavy goods vehicle. (For lack of a more objective definition of the manner in which drivers respond and react to a host of negative elements, both internal and external, we are forced to refer to this ill-defined state as "fatigue.")

The available accident data indicate that extreme fatigue (falling asleep) is a contributing factor to a significant fraction (1-2%) of all combination-vehicle accidents and 2-4% of all fatal combination-vehicle accidents. It is reasonable to conjecture that less extreme fatigue has a more pervasive influence on aspects of the driving task, such as vigilance. However, the available data provide no means of identifying the contribution of ride vibrations to fatigue. Thus, the most likely hypothesis relating ride vibrations and accident involvement is the interaction of vibration with all of the other stresses associated with driving a heavy truck. The current state of knowledge is not adequate to evaluate this hypothesis.

4. In general, the existing literature and the interpretation of the accident data do not provide evidence that the hypothesized mechanisms relating truck ride vibrations to accident involvement are important or significant. This finding does not necessarily imply that ride vibrations do not contribute significantly to highway safety. However, if ride vibration does contribute significantly to highway safety, it means that the mechanisms operating may be more complex than those hypothesized, or that more detailed data and sophisticated analysis techniques are required.

3.0 FINDINGS OF THE CONFERENCE

A panel of experts was assembled at a 2-1/2-day conference to review and assess the knowledge on the relationship of truck vibration to safety and driver's health.

The products of the conference are compiled here in terms of three types of results—the findings of an Opinion Survey, a set of "truth statements," and a set of recommendations. (The interpretations drawn from these products are contained in Section 4.0.) Each of these products serves to register the individual and collective views of the conferees on the significance and character of the truck ride problem. To the maximum extent possible, the presented material accurately reflects the specific statements and recommendations actually made by conference participants. The authors have exercised an editing role to add to the clarity of the statements where deemed appropriate. In the editing function, the authors have tried to be guided by the context of the discussion and debate which ensued during the progress of the conference itself.

3.1 Opinion Survey

Part One - Ranking of Accident Factors

On the first evening, the conferees were given an Opinion Survey form (see Appendix A) to fill out prior to convening the opening session. As indicated earlier, the purpose of the Survey was to provide some scale of comparable issues against which to measure the significance of the vibration/safety issue. The Survey required the conferee to rank three sets of factors which were selected as having some potential connection with the accident involvement of heavy trucks. The factors were organized into the following sets:

- Vehicle Factors
- Highway Factors
- Truck Driver Factors

Each set consisted of eight factors, often identified as having a potential relevance to highway safety. The participants were instructed to

rank the eight factors to reflect their view of the relative importance of each as contributors to truck accidents. The instruction sheet acknowledged that the participants may have had little information or experience from which to draw their ranking choices. The specific ranking was not of direct importance. Rather, it was acquired to serve as a relative scale, prior to any discussions of vibration, against which to rank the significance of vibration. These initial lists did not include any ride-vibration-related factors. In a subsequent ranking activity on the second day of the conference, the conferees received their first ranking forms back and were asked to place ride-related factors relative to the other factors which had been previously ranked.

The results of this exercise are presented in Figures 1, 2, and 3. Note that each figure shows the average rank order of each factors as established by the conferees within each of the three above-mentioned sets. Although individual rankings could range from one to eight, the averaged results typically range from 2 to approximately 6.5.

In the Vehicle Factors set (Fig. 1), the averaged rankings reported by the overall group (on the right side of the figure) range from 2.8 to 6.5, with "poor maintenance" and "poor truck conspicuity" defining the most and least important factors, respectively. The other six Vehicle Factors have rank values which cover a narrow range, but which are rather distinctly separated from the first- and last-ranked items. The narrow grouping is generally indicative of disagreement among the conferees as to the order of priority for these factors. (A random ranking would place each factor at a value of 4.5.) At the left side of the figure, the rankings of a factor labeled "Rough Ride Vibrations" are shown as determined by each of the four groups into which the conferees were divided on Tuesday, namely,

- Driver Group (including those involved in research on human tolerance to vibration, and others concerned with the health and safety of truck drivers)
- Manufacturing (including those employed by motor vehicle, trailer, and vehicle component manufacturing organizations or their trade associations)
- Highway (including those involved in highway engineering and research)

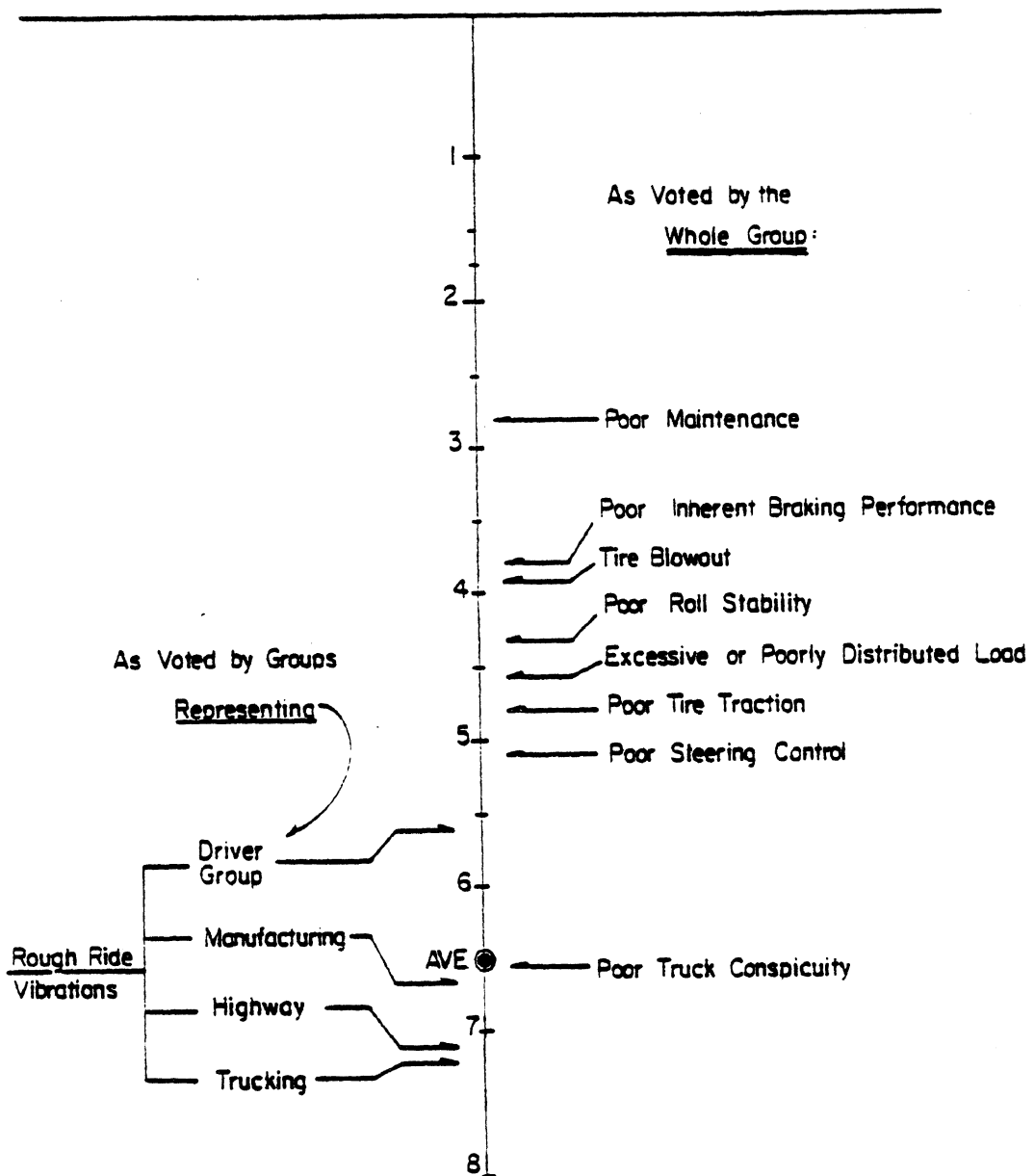


Figure 1. Rank order of vehicle factors, in terms of their relative importance as contributors to truck accidents.

-Trucking (including those involved in motor freight operations, motor carrier safety regulation, and trucking trade associations)

The average ranking obtained for "Rough Ride Vibrations" as a contributing factor to accidents is 6.5, a ranking approximately equal to that given to "poor truck conspicuity," which falls at the bottom of the initial ranking list. Given that the standard deviation of the rankings for the rough ride factor is 1.6, the specific differences obtained in the rankings given by the four interest groups is not of great significance, but is indicative of general agreement that rough ride vibrations are of low priority among truck factors contributing to accidents.

Figure 2 shows the rank order given to highway factors as potential contributors to truck accidents. On the right side are the factors which were ranked before the start of the conference, showing "Slippery Pavement" as the distinctly first-ranked item, followed by "Poor Interchange Design" and "Inadequate Bank on Curves." The very tight grouping of the five remaining factors in a virtual last place is indicative of little agreement among the participants as to their order of importance. At the left of the figure are shown the rankings given by the four respective interest groups to the highway factor "Distributed and Localized Roughness." In this instance, the pavement roughness factor has been given an average rank of 5.1—a value that places it in the vicinity of the five closely grouped factors as ranked initially by all of the conferees. The standard deviation of the ranking given to the highway roughness factor is 2.1, again indicating that the spread in rankings yielded by the four interest groups is of marginal significance.

In Figure 3, the ranking of truck driver factors is presented. The results show that the conferees viewed "Aggressive Driving Tactics" as a decidedly important factor, with a fairly broad distinction of rankings obtained for the other seven factors, ranging from 3.5 to 6.2. On the left side are shown the rankings given by each interest group to the factor labeled "Performance Degraded by Vibration." Although a larger spread in the rankings given to this ride-related factor by the four interest groups is evident, the average ranking again appears at the

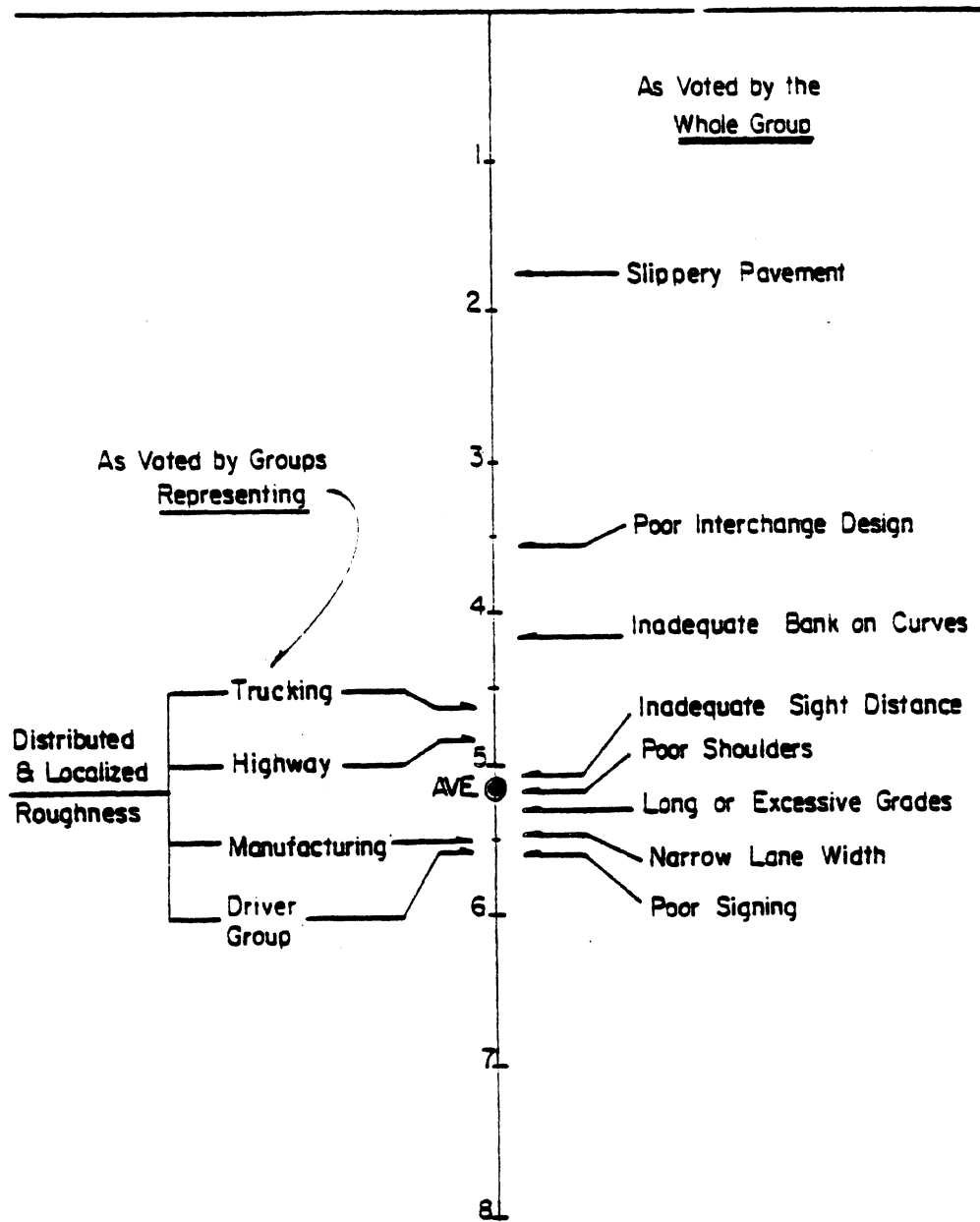


Figure 2. Rank order of highway factors, in terms of their relative importance as contributors to truck accidents.

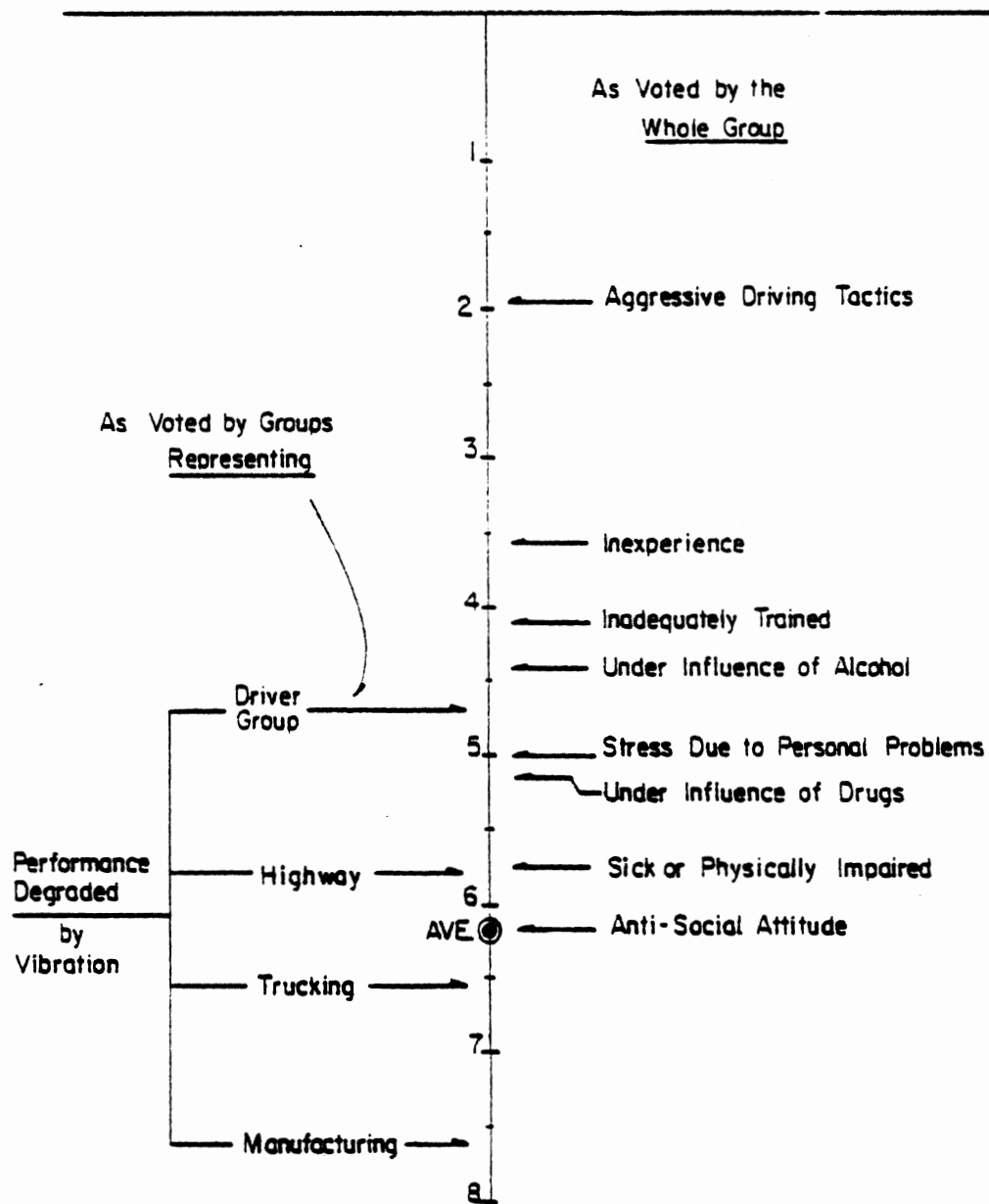


Figure 3. Rank order of driver factors, in terms of their relative importance as contributors to truck accidents.

bottom of the scale as developed in the initial ranking exercise. It should be noted that the standard deviation of the rankings obtained for the vibration factor is 1.9.

The ranking of ride-related factors was determined as a function of the respective interest groups on the supposition that the differing groups possessed differing levels of information or experience in each of the subject areas, viz., vehicle, highway, and driver factors. For example, it might be assumed that vehicle manufacturers and trucking organizations would have a stronger basis upon which to rate the importance of ride vibrations among vehicle factors because of their direct involvement in vehicle design and usage. Following this line of reasoning, we observe that:

- 1) Individuals in the manufacturing and truck groups placed the truck factor, "Rough Ride Vibrations," lower in rank than the average ranking produced by the entire group of conferees.
- 2) The highway group ranked the highway factor, "Distributed and Localized Roughness," slightly, but insignificantly, higher than the average ranking.
- 3) The driver-oriented group placed the driver factor, "Performance Degraded by Vibration," significantly above the average ranking established by the conferees at large. Given the number of individuals in the driver-oriented group, as well as in the overall group, we can be 80 percent confident that the mean value of the driver-oriented group's ranking would be above the overall mean should a larger data sample be taken (assuming normal distribution). Whereas this observation may be statistically satisfying, the net outcome appears to be that all of the interest groups have placed this vibration-related driver factor near the bottom of the overall rankings, with the driver-oriented group giving a somewhat higher importance to the driver factor.

Part Two - Numerical Estimates

Following this establishment of the relative importance of vibration as a contributor to the accident record, a second part of the Opinion Survey was administered to obtain some absolute readings. Specifically, questions were posed asking for a numerical estimate of the involvement of vibration-related factors in the causation of:

- 1) accidents,
- 2) driver health problems,
- 3) freight damage, and
- 4) component wear and degradation.

The first two factors were of primary interest, the last two being included simply to provide a supplementary measure for evaluating the results.

At the time Part Two was administered, the conferees had heard and discussed the evidence linking vibration to safety, with secondary considerations of health. The Survey now asked for their considered judgment based on the weighing of that information.

In response to each question, the conferees were asked to check one of the seven boxes (as shown below) to indicate his estimate (or guess) of the likely involvement of a vibration-related factor.

| | | | |
|--------------------------|--------------------------|--------------------------|--------------------------|
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| less than 1% | 1 to 2% | 2 to 5% | 5 to 10% |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | |
| 10 to 20% | 20 to 50% | Over 50% | |

Shown in Figures 4 through 7 are the results as compiled for the four interest groups, as well as for the conferees at large. Figure 4 illustrates the percentage of truck accidents estimated by the conferees

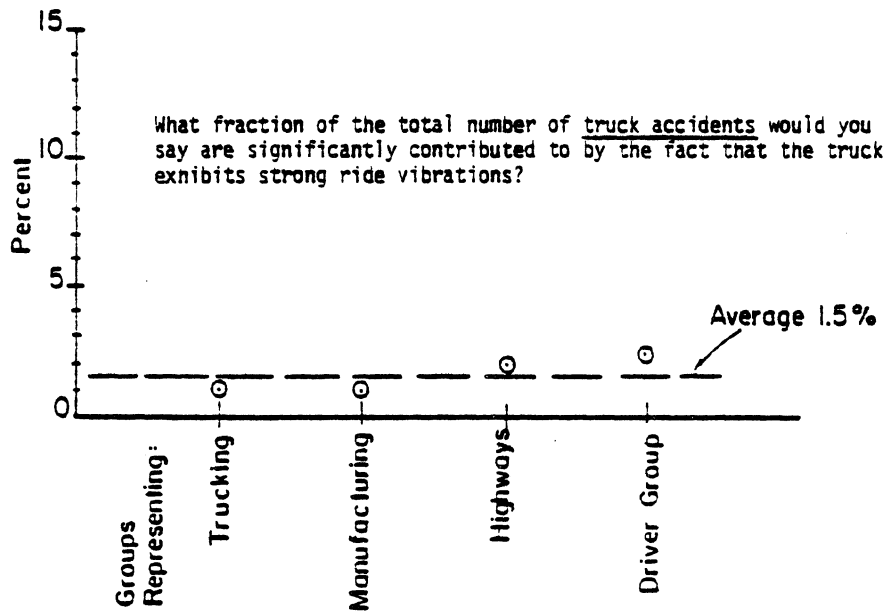


Figure 4. Opinion Survey results for truck accident relationship to ride vibration.

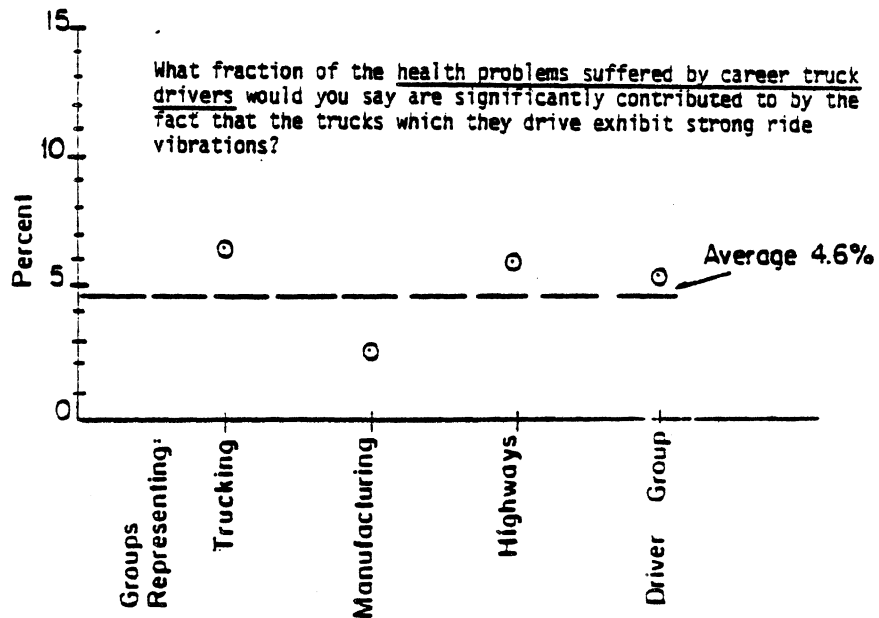


Figure 5. Opinion Survey results for driver health relationship to ride vibration.

as being significantly contributed to by the fact that the involved trucks exhibited strong ride vibrations. The overall, and the individual interest group, estimates were in the vicinity of 1 to 2 percent.

In estimating the likely contribution of ride vibration to the health problems suffered by career truck drivers, the conferees produced the results shown in Figure 5. More scatter exists in the values registered, with the average percentage fraction being 4.6 percent.

In Figure 6, the estimates of the contribution of ride vibration to the incidence of freight damage during the cartage of goods is shown. One conferee pointed out, during verbal discussion of these results, that only trucking organizations would be likely to have any direct experience with the freight damage problem. Accordingly, he suggested that it is significant that the "Trucking" group entered an estimate which was markedly lower than those entered by all other groups. (It should also be stated that 50 percent of the conferees elected not to enter an estimate for "freight damage.")

In Figure 7, we see that the conferees at large estimated that 7.3 percent of the wear and deterioration of truck components can be attributed to the mechanical vibration induced by road roughness. Again, it is noted that the driver-oriented group, which probably possesses the minimum basis for making such an estimate, placed this factor at 15 percent, while the manufacturing group (presumably having the greatest basis for making an estimate of this influence) produced an estimate of approximately 4 percent.

3.2 Compiled Truth Statements

A major output of the conference consists of "truth statements" reflecting the participants' views of the most significant facts or judgments which describe the current state of affairs with regard to truck ride and traffic safety. Certain of these statements address the focal issue (i.e., ride versus safety) of the conference. Other statements speak to the state of the sciences and the technologies which, limited though they may be, form the basis for determining the factual relationship between ride and safety.

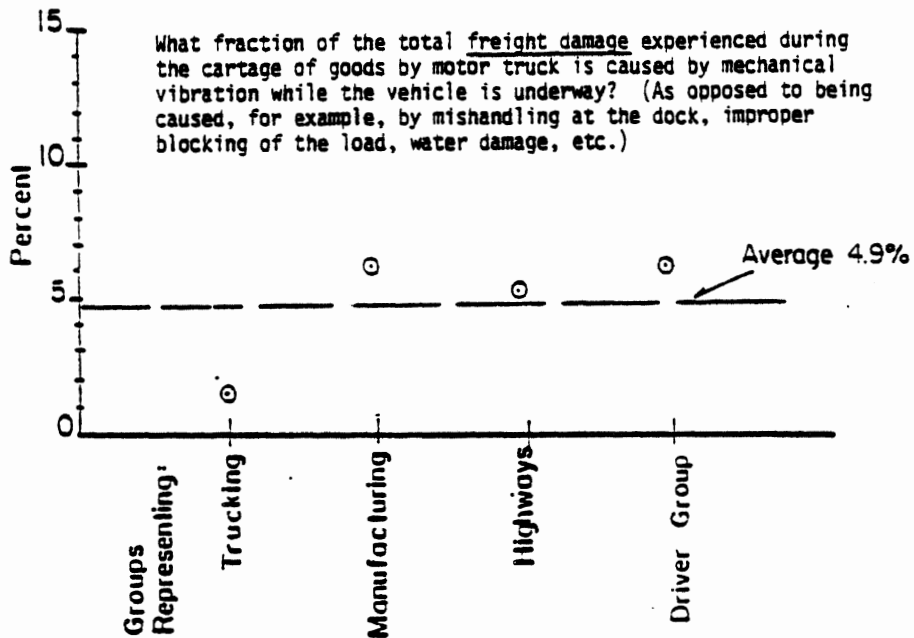


Figure 6. Opinion Survey results for freight damage relationship to truck vibration.

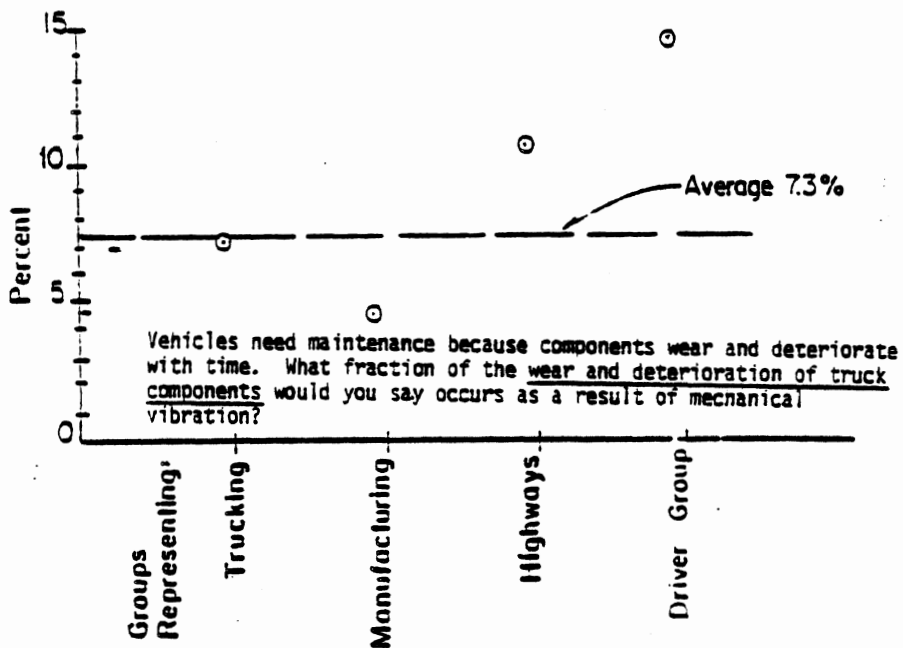


Figure 7. Opinion Survey results for wear and deterioration relationship to truck vibration.

Presented below are the final versions of the "truth statements" which were produced by the conferees. The statements were developed in the following manner:

- a) On the second day of the conference, each of the heterogeneous groups compiled statements of truth subsequent to hearing brief presentations on the state of knowledge in each subject area.
- b) The conference staff edited and combined these statements into a set which was reproduced and distributed for consideration by the homogeneous groupings on the third day.
- c) Each homogeneous group went through this combined set of statements and selected those which, with perhaps some modification, represented the points which they most wanted to present to the conferees at large in seeking a consensus endorsement. Each group presented one statement for consideration and voting by the conferees at large. As each statement was presented, suggestions were entertained from other participants for possible modification of the statement. After all suggested modifications had been considered by the group which originally offered the statement, votes were taken to determine (1) the number of participants who agreed and disagreed with the (as-modified) statement and (2) the number of conferees who felt that the statement was important to the issue.
- d) Step (c), above, was repeated in the time available until each interest group had the opportunity of presenting at least three statements for consideration by the conferees at large. In a few cases, a specific interest group opted to produce a completely new truth statement and offer it for voting by the conferees at large.

Preceding each truth statement (listed by the group of origin) is the vote tally which registers the degree of AGREEMENT or DIS-AGREEMENT and the degree of IMPORTANCE assigned by the conferees to each statement. It should be noted that at the beginning of this session, 25 participants remained in attendance. As the session proceeded, however, certain persons were being pressed by their travel schedules such that only 21 persons remained at the time of the last vote-taking.

Truth Statements Submitted by the Driver-Oriented Group

- 1) (Agreement: 22 yes, 0 no; Important: 15 yes, 1 no)
ISO (International Organization for Standardization) Standard Number 2631 is the most widely recognized guide for evaluating human response to vibration, but the application of this standard to the truck ride process may require that the boundaries in the standard be adjusted in the light of real data for the truck driving environment.
- 2) (Agreement: 23 yes, 0 no; Important: 8 yes, 0 no)
If morbidity is associated with long-term vibration exposure or if chronic diseases are present in the truck driver through other causes, the afflicted state of the driver may reduce driving effectiveness as a result of discomfort, stress, fatigue, and distraction.
- 3) (Agreement: 14 yes, 3 no; Important: 11 yes, 0 no)
Vibration may increase fatigue, and as a result of diminished vigilance and alertness, cause delayed or inappropriate responses to emergency situations; although it must be noted that prior to fatigue, vibration may increase vigilance and alertness.
- 4) (Agreement: 18 yes, 0 no; Important: 8 yes, 5 no)
Large amplitude momentary vibrations may jar the driver, who is not adequately restrained by a seat belt, from his seat and therefore from a position of control.

- 5) (Agreement: 17 yes, 4 no; Important: 5 yes, 1 no)
Severe vibration may decrease the driver's ability to manipulate or modulate the steering, braking, and throttle controls in an emergency maneuver.
- 6) (Agreement: 5 yes, 14 no; Important: 2 yes, 14 no)
Loss of visual acuity incident to mirror vibrations would increase the time required to assimilate rear vision information (a distraction from forward vision tasks) with the possibility for increasing errors in passing and merging maneuvers.

Truth Statements Submitted by the Vehicle Manufacturing Group

- 1) (Agreement: 18 yes, 1 no; Important: 14 yes, 0 no)
The state-of-the-art in truck design exists to make line-haul trucks "comfortable" on a road surface having a PSI rating of 3.0 or better. (Ed. Note: The designation "PSI" stands for a rating of pavement roughness level called "Present Serviceability Index." An index number of 3.0 pertains to road surfaces which are in fair condition, on the verge of needing resurfacing.)
- 2) (Agreement: 25 yes, 0 no; Important: 20 yes, 0 no)
There is currently no bank of data available documenting the typical ride vibrations of trucks for real periods of exposure and for yearly driving patterns.
- 3) (Agreement: 23 yes, 0 no; Important: 19 yes, 0 no)
Any investigations into the relationship between truck ride vibrations and accident involvement must consider interactions between vibration and the other factors contributing to fatigue.

Truth Statements Submitted by the Trucking Group

- 1) (Agreement: 25 yes, 0 no; Important: 25 yes, 0 no)
Current accident data are not sufficient to establish any significant link between ride vibrations and accident involvement.
- 2) (Agreement: 23 yes, 0 no; Important: 20 yes, 0 no)
There is insufficient evidence that vibration-induced fatigue is a significant factor in truck accidents.

Truth Statements Submitted by the Highway Group

- 1) (Agreement: 25 yes, 0 no; Important: 19 yes, 0 no)
We are able, with current methods, to reasonably characterize pavement roughness as experienced by trucks except for two special pavement features, namely,
 - a) Periodic roughness such as excites truck resonances
 - b) Local, severe bumps and pot-holes
- 2) (Agreement: 25 yes, 0 no; Important: 23 yes, 0 no)
With data showing a significant sensitivity of truck vibrations to road roughness, future deterioration of pavements, if uncorrected, is expected to increase the vibration exposure of truck drivers.
- 3) (Agreement: 8 yes, 0 no; Important: 8 yes, 1 no)
Limited data, currently available, show that a truck driver spends a significant portion of his time driving with vibration levels that exceed the unadjusted ISO four-hour criterion.

Although the exercise that produced the above statements served to establish the degree to which the conferees agreed on most points which had been raised during the conference, time was not available to present and vote upon all of the truth statements which had been generated. Listed below are three statements which were included in the set of statements considered by the homogeneous groups and which were recorded on their worksheets as meriting rather broad endorsement:

- 1) The shape of the ISO weighting curves (i.e, plotting RMS acceleration level versus frequency) is a reasonable way of assessing the relative importance of various parts of the vibration spectrum.
- 2) There are no applicable data for evaluating the response of humans to short transient excitations such as experienced by the drivers of trucks encountering pot-holes and the like.
- 3) There is no standard practice for measuring the ride vibrations applied to truck drivers.

Other statements were considered by the homogeneous groups, but were either discarded as having low importance or were seen as lacking a sufficient consensus within the homogeneous group and thus were not submitted for the voting process.

A third set of truth statements which deserves mention includes those statements which were produced by the heterogeneous groupings after listening to the state-of-knowledge presentations made on the second day of the conference. As already noted, the conference staff drew from these statements in compiling lists of statements for consideration by the homogeneous groups on the third day. Some of these "statements," however, received a strong but not unanimous level of support from their source group, such that they were not included in the compiled set. On observing that some of these "orphaned" statements had been the subject of a considerable degree of discussion, they are seen as being worthy of inclusion here. Accordingly, the following statements should be seen as having been the subjects of substantial amounts of discussion, albeit with some degree of controversy or lack of general agreement:

- 1) The phenomenon of "fatigue" is not well understood.
- 2) The truck driver's problem with respect to safety involves vigilance more than motor-sensory skills such as vision and control. Therefore, if vibration is important to truck safety, the effect of vibration on vigilance is the most important mechanism of concern.
- 3) Truck vibrations tend to increase muscle tension which initially increases alertness and vigilance, but eventually causes fatigue insofar as it constitutes a form of mild exercise.
- 4) Interspersed road sections having extended lengths of rough pavement followed by quite smooth sections may pose a peculiar safety problem. (Ed. Note: The scenario under consideration in this statement involves a truck driver sustaining the vigilance-enhancing effect of a rather rough roadway, who then comes onto a quite smooth section of roadway. The stimulus which is provided by the muscle action and exercise associated with the harsh vibration exposure will essentially be absent on the smooth roadway. As the driver then relaxes, it may be that he becomes especially prone to accident threats due to inattentiveness and, perhaps, a state of drowsiness.)
- 5) Contrary to evidence existing in the literature regarding vibration and stress, drivers report significant "stress" and attitude changes due to rough roads and bumps.
- 6) Life-style factors typifying truck drivers may be more important causes of health problems (of all kinds) than is vibration.
- 7) It is erroneous to assume that "cab-over" style road tractors exhibit a ride vibration level that is more severe than that exhibited by "conventional" style tractors.

- 8) The amount of time and funding required to obtain definitive accident data serving to illustrate the relationship between truck ride vibration and safety is prohibitive.

3.3 Conference Recommendations

In addition to considering and voting upon truth statements, each special interest group submitted recommendations to the conferees at large, which were then voted upon. This exercise constituted the final activity of the conference. Since time was limited at this juncture, there was somewhat less discussion of possible modifications to each proposed recommendation statement. Accordingly, the number of votes in agreement with the statements were, in certain cases, relatively low—presumably due, in part, to differences in wording which may have been minor. The results of this exercise are listed below. Note that the recommendations are listed in terms of the interest group which originated the recommendation. Vote tallies are also shown.

Recommendations Made by the Driver-Oriented Group

- 1) Initiate research on driver performance and stress effects of the truck driving environment in the following areas: (Ed. Note: Each of the lettered sub-recommendations was voted upon separately as cited.)
 - a) (Agreement: 18 yes, 0 no)
Potential increase in fatigue, tendency toward drowsiness, etc., due to various factors specific to the truck driving occupation (e.g., vibration, noise, monotony, schedule demands, etc.).
 - b) (Agreement: 21 yes, 0 no)
Effects of transients on immediate driving performance.
 - c) (Agreement: 15 yes, 0 no)
Possible long-term health effects.

d) (Agreement: 18 yes, 0 no)

Possible effects of fatigue, monotony, desynchronization (i.e., frequent shifting of normal day/night sleep periods), on truck driving habits.

e) (Agreement: 5 yes, 0 no)

Detection of distant objects under conditions of severe vibration.

2) (Agreement: 13 yes, 0 no)

ISO and ANSI writing groups should be encouraged to work on amendments to ISO 2631 and/or ANSI S3.18-1979 for the application of these documents to the evaluation of truck driver vibration environments. Vibration exposure doses of truck drivers should be collected according to the cited standards for comparison with human response data. High-amplitude, short-duration, single-acceleration transients should receive further consideration in the evaluation procedure.

3) (Agreement: 10 yes, 0 no)

Available quality truck vibration data should be analyzed with respect to improvement of correlations between vibration exposure and subjective ride measures and/or available (e.g., ISO) guidelines. Such truck vibration data should continue to be collected.

4) (Agreement: 17 yes, 0 no)

An experimental program utilizing a driving simulator should be initiated to study connections between truck ride vibrations, driver performance, fatigue, and safety factors.

Recommendations Made by the Manufacturing Group

- 1) (Agreement: 17 yes, 0 no)

Typical ride vibration data should be gathered which is characteristic of real periods of exposure and yearly patterns as experienced by truck drivers.

- 2) (Agreement: 22 yes, 0 no)

Research should be conducted to determine the interaction between truck ride vibrations and the other confounding factors that may influence driver performance.

- 3) (Agreement: 14 yes, 0 no)

The Federal Highway Administration should, through research and development, improve the technology needed to increase highway life expectancy and smoothness and to reduce those vibrations which are input at the frequencies falling in the normal driving range.

Recommendations Made by the Trucking Group

Pending the development of a convincing body of data showing the existence or absence of a positive link between vibration and highway safety, it is recommended that:

- a) (Agreement: 17 yes, 0 no)

Research on truck ride quality be encouraged within the private sector (Society of Automotive Engineers, manufacturers, etc.).

- b) (Agreement: 17 yes, 0 no)

There be continued research into the long-term health effects of truck driving.

- c) (Agreement: 21 yes, 0 no)

Roads be improved and repaired as expeditiously as possible.

d) (Agreement: 21 yes, 0 no)

Simulator techniques should be developed to permit systematic investigation of the various stimuli influencing driver performance.

Recommendations Made by the Highway Group

1) (Agreement: 21 yes, 0 no)

The adverse effects of road roughness on vehicle ride, pavement life, and highway safety should be assessed.

2) (Agreement: 4 yes, 15 no)

Technology should be implemented permitting trucks to be designed so that drivers are isolated from vibrations which affect their ability to control the vehicle.

4.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The relationship between truck ride vibration and safety as explored by (a) an examination of the literature, (b) the conduct of additional truck ride measurements, and (c) the convening of a conference of knowledgeable people involves many diverse aspects. In order to render that extensive and detailed information more easy to assimilate, the findings from this exercise are summarized below in the context of what may be concluded and what likely courses of action would be endorsed by those with a knowledge of the issue.

4.1 Summary and Conclusions

Though the actual data characterizing the long-term vibration exposure of truck drivers are limited in scope, those data which are available give evidence that significant portions of the time spent driving trucks involves exposure to vibrations which, depending on the road surface, approach the ISO/ANSI three-hour Fatigue-Decreased Proficiency Boundary. Whether or not this finding is significant to issues of traffic safety or driver health is a debatable matter. The ISO "FDP" criteria do not constitute a universal "standard" in the sense of an absolute scale and thus require a special effort in their application to the subject of truck ride vibrations. To do so, the technical community sees the need for both more detailed data describing the continuous exposure of drivers over days and weeks and the opportunity to apply the knowledge. Therefore, it must be concluded that the technical community involved in the influence of vibrations on humans does not currently have a basis to provide a direct assessment of the significance of truck ride vibration as it may affect an individual's performance as the driver of a truck, or as it may affect his health.

The conferees who represented the human vibration field of research (i.e., the Driver-Oriented Group) did, however, register their personal "hunches" or suspicions in response to the Opinion Survey question regarding the relative importance of differing driver factors

as contributors to accidents. This group ranked "performance degraded by vibration" at the midpoint of the scale of driver-related factors (above other factors ranked by the overall group, which were "stress due to personal problems," "under the influence of drugs," "sick or physically impaired," and "anti-social attitude"). Likewise, the overall group estimated that nearly five percent of the health problems of career truck drivers are significantly contributed to by the fact that drivers are exposed to strong ride vibrations. Accordingly, while the human performance experts involved in the vibration subject are rigorous in not drawing firm conclusions from the available data on the truck ride vibration issue, the overall group judgments would indicate reservations that vibration may play a role in five percent of career driver health problems.

The expressions of judgment on the part of the overall group of conference participants shows that vibration-related factors are given the lowest priority among those vehicle and driver factors which are seen to contribute to accidents, whereas it is of intermediate importance as a highway concern. Perhaps the one group which was most concerned about the likely significance of a factor which was in its own area of expertise was the highway group. The highway experts ranked the factor "distributed and localized roughness" slightly higher than five other highway factors which might contribute to truck accidents. What may be of greater significance, however, is the concern expressed by these experts with the continuing deterioration in the pavement quality of the nation's road system. The highway group chose to submit for endorsement by the conferees a statement projecting an increase in the vibration exposure of truck drivers if the deterioration in the road system is permitted to continue uncorrected. The statement, which accepted the data generated in this project relating truck ride vibration to the actual roughness condition of road surfaces, received unanimous agreement from the conferees.

The pavement roughness condition was given attention throughout the conference in terms of both the random, small amplitude, roughness of the surface (which accounts for much of the more-or-less continuous background vibration which truck drivers experience) and the severe localized

pavement faults which may momentarily jar the driver. While the relative importance of each type of roughness in the overall safety picture is not at all understood, severe vibration as may result from localized pavement faults was viewed as a possible mechanism affecting safety by disturbing the driver's ability to maintain control of the vehicle.

Fatigue was identified as the other most likely causal linkage between vibration and safety. It was recognized that vibration exposure may both increase driver vigilance, on the short term, as well as diminish vigilance as fatigue sets in. In addition, it would appear that many of the other stress factors characteristic of long-haul truck driving could act, synergistically, with vibration to influence the state of fatigue which may result. The question of fatigue, then, is seen as a very complex problem. This point of view was articulated in the consensus statement that read: "Any investigations into the relationship between truck ride vibrations and accident involvement must consider interactions between vibration and other factors contributing to fatigue."

The alternative route of looking to the accident record for evidence of a safety effect provides little information. Specifically, the accident data currently available are not sufficient to prove that any significant link between truck ride vibrations and accident involvement exists or does not exist. Although the data are inconclusive, they do provide guidance for recommending further work in this area. In general, the review of existing accident data implies that if ride vibrations play a significant role in highway safety, then the mechanisms involved are complex and involve interactions with other factors as in the case of fatigue. For the most part, the accident data were sufficient to reject the straightforward direct links between ride vibration and accident involvement, such as the loss of control due to inability to modulate foot controls.

Finally, there was concern among some of the experts that driver morbidity could reduce the proficiency of driving skills, thereby influencing safety. It was generally agreed that such an effect is possible, although there was no consensus that morbidity is, itself, produced by long-term exposure to truck ride vibrations.

4.2 Recommendations

In spite of a lack of evidence on the relationship between truck vibration and safety or health, nevertheless the group proffered recommendations to continue work on the subject. In some cases, they were willing to propose recommendations directed toward certain factions, while in other cases, no responsible faction would be identified. The following recommendations are drawn from the conference with some expansion and interpretation applied by the authors.

1) The SAE should be encouraged to develop Standards and Recommended Practices for the measurement and analysis of truck ride vibration data.

2) The ISO and ANSI writing groups should be encouraged to work on amendments to ISO 2631 and/or ANSI S3.18-1979 for application to the evaluation of truck driver vibration environments, with emphasis on the high-amplitude, short-duration transient accelerations.

3) Both the government and the trucking industry should be encouraged to continue research on measurement and characterization of the truck ride vibration environment, with emphasis on characterizing the long-term vibration exposure of truck drivers, including occurrences of short-duration, high-level transients.

4) The federal government should consider continuing research in the following areas:

- a) Effects of factors specific to the truck driving environment (vibration, noise, schedule, etc.) on driver fatigue, performance, safety, and health. The experimental simulator method is specifically identified as a recommended means to study these connections.
- b) Effects of road roughness on vehicle vibrations as may adversely affect ride, safety, and roadway deterioration.
- c) Effects of vibration on the long-term health of truck drivers.

