CEM Report 4206-583

DOT-HS-802 591

COPY FOR YOUR INFORMATION

CONSTRUCTION OF A COMPREHENSIVE CAUSAL NETWORK PHASE III: FINAL REPORT (VOLUME 1)

Hans C. Joksch
Joesph C. Reidy, Jr.
John T. Ball

Contract No. DOT-HS-6-01506
Contract Amount - $94,302

The Center for the Environment and Man, Inc.
275 Windsor Street Hartford, Conn. 06120

July 1977

PHASE III REPORT

This document is available to the public through
The National Technical Information Service,
Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration
Washington, D.C. 20590

1. Report No. DOT-HS-802 591	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CONSTRUCTION OF A COMPREHENSIVE CAUSAL NETWORK PHASE III: FINAL REPORT (VOLUME 1)		5. Report Date September 1977 6. Performing Organization Code
7. Author(s) Hans C. Joksch; Joseph C. Reidy, Jr.; John T. Ball		8. Performing Organization Report No. CEM Report 4206-583
9. Performing Organization Name and Address The Center for the Environment and Man, Inc. 275 Windsor Street Hartford, Connecticut 06120		10. Work Unit No. 11. Contract or Grant No. DOT-HS-6-01506
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration Washington, D.C. 20590		13. Type of Report and Period Covered Phase III Report March 1977 - July 1977 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A comprehensive causal network was constructed which gives a conceptual framework for accident-related factors. These factors are presented in graphical and tabular form. A coding scheme was developed to organize factors according to accident element (driver, vehicle, environment, traffic situation, etc.), time (long term and short term factors and events immediately preceding the crash), and hierarchical relationships. Uses of the network are discussed and recommendations for future study given. The construction of the causal network revealed gaps in information on causative factors and interactions--in particular the driver's perception and decision-making processes.

Volume 2 of this report is a review of the literature on accident causation for Phase II of this study.

17. Key Words Accident Causes Causal Network	18. Distribution Statement Document is available to the public through the National Technical Infprmation Service, Springfield, Virginia 22161

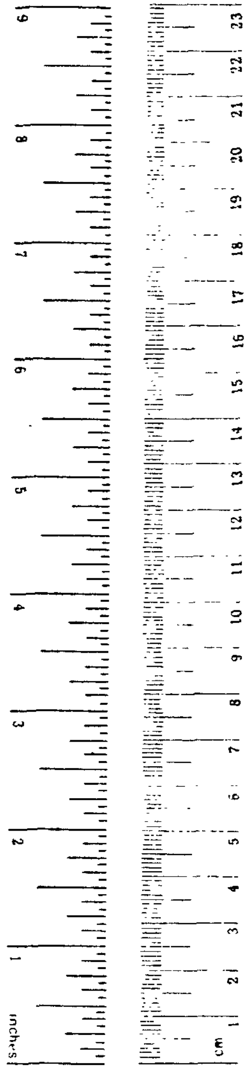
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	129	

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

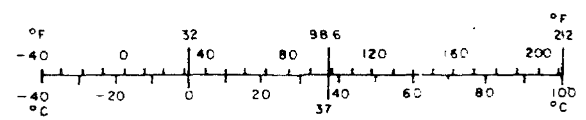
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY

This report describes the development of a comprehensive causal network, indicating motor vehicle accident causation, and presents the conceptual network in detail.

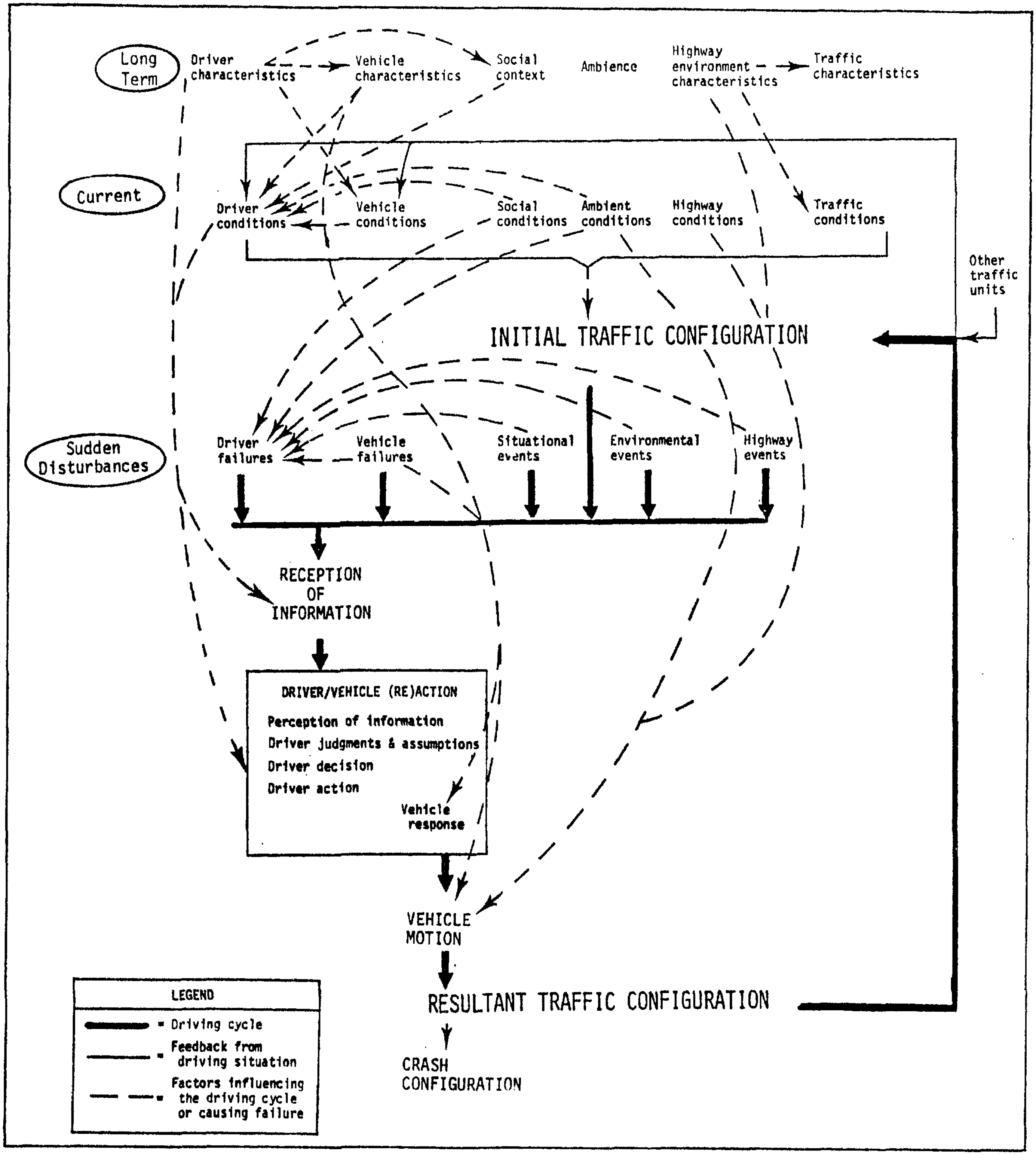
A review of the literature on accident causation was the basis for this development. Though quantitative studies of accident causation and accident factors provided valuable information for the development of the causal network, the quantitative information was not sufficient to go beyond a conceptual network and quantify it. Conceptual causal networks were proposed and outlined before by Goeller, Hall and O'Day, Perchonok, Fell, Kontratos, Wilde, Kurucz and Morrow. We did not initially use these networks but approached the problem independently. Later, however, we used these networks to refine and modify our initial network.

The Figure below shows the overall structure of the network. This network is organized under two aspects: the element concerned, and the temporal sequence. The major elements are: the driver, the vehicle, the social context (encompassing factors such as laws and regulations, general driving patterns, trip purposes, vehicle occupants, etc.), the ambience, the highway/environment, and traffic. If more than one vehicle (or a pedestrian) is involved, some of the elements are repeated. The time sequence distinguishes the long-term factors, current condition, and the elements of the driving cycle. This driving cycle is a sequential arrangement of activities which (in reality) overlap to a large extent and may change continuously, not cyclically. The initial traffic situation is the starting point, sometimes modified by sudden disturbances. The driver receives information on the situation; he has to perceive its content, make judgments and assumptions and make a decision. Then he performs actions to which the vehicle responds. According to this response and the highway conditions, the vehicle moves, creating a new traffic configuration. If this situation is not an accident, a new cycle starts. There are two types of causal sequences in this network: 1) those which describe the "normal" events when driving; and 2) those which cause "failures" which may lead to crashes. The normal driving cycle is extremely complex, and the possibilities too numerous to be represented in a useful fashion. Therefore, this study was essentially limited to the causal sequences which are leading to failures and, thereby, to crashes.

Even the aggregated and simplified network shown in the Figure is complex. Any reasonably comprehensive network is too complex to be represented as one unit. Therefore, we presented 15 detailed networks, each describing the causal chain leading to failures in a specific part of the network. An even finer breakdown of causal and other factors is given in an extensive list, containing a coding scheme which, for example, would allow one to computerize a given network.

We found that the network structure is not sufficient to describe all important aspects of accident causation. One type of element outside the network structure deals with analytical models (based on theory or empirical data), describing the interactions of several factors, and the probability that they lead to a failure and perhaps the degree of such a failure. Another element is the addition of several independent time delays which may make it impossible to react to a pre-crash situation "in time."

The report also describes what needs to be done to quantify the causal network, and uses of the network in its current conceptual form. Potential uses in an actually quantified form are also discussed.



Overview of the Causal Network

ACKNOWLEDGMENTS

In addition to the authors, the following staff of The Center for the Environment and Man, Inc. (CEM) and its subcontractor, the Highway Safety Research Insitute (HSRI) of the University of Michigan were responsible for the screening and review of material presented in Volume 2: Messrs. Gary Haas, Michael Horne, and Edward Sweeton of CEM, and Dr. William Pollack of HSRI. Also, Ms. Kayla Costenoble provided much of the editing and administrative support for conducting this literature review.

We would also like to thank the publishers of *Accident Analysis and Prevention*, Pergamon Press; the publishers of *Highway Research Record (Transportation Research Record)*, the Transportation Research Board; and the Highway Safety Research Center of the University of North Carolina for permission to reproduce selected material from their publications.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

1.0 INTRODUCTION

1.1 Study Objectives and Approach

The objective of this study was to develop a comprehensive causal network which reflected the relation between "risk factors" (which have a direct or indirect causal relation to the occurrence of motor vehicle accidents), other factors (which have an empirical, though not necessarily causal relation with risk factors), and motor vehicle accidents.

This network was also to indicate how highway safety programs might directly or indirectly affect the occurrence of accidents.

To the extent possible, the relations described by the network were to be quantified on the basis of existing information on accident causation.

The objective of Phase I was to develop a plan for performing Phase II - Locate Identified Causal Relationships - and Phase III - Construction of a Comprehensive Network. The plan specified:

- How to identify available research and information on causal networks, empirical and theoretical relations between various factors and motor vehicle accidents, and highway safety programs.
- How to review the various sources of information and extract the relevant results.
- How to organize these results in a manner useful for developing a network.
- How to develop a comprehensive network from the information collected, and from general background knowledge.

The objective of Phase II was to review the literature for studies hypothesizing or establishing causal relationships between traffic accidents and causal factors, and to identify causal relationships. Also, a plan for Phase III was to be developed.

The Phase II report described how sources were identified, selected and reviewed; it summarized the findings and presented a structural overview of the findings. An annotated and general bibliography and detailed reviews were in the appendices. Finally, a plan for Phase III describing the tasks to be performed and a time schedule were also presented.

The objectives of Phase III were to construct a comprehensive causal network which incorporated known quantitative causal relationships and to identify gaps and inconsistencies in information revealed by the construction of the network.

This final report presents the causal network developed in Phase III both graphically at different levels of detail, in hierarchical listings of factors, and with a coding scheme. Attempts to incorporate the known quantitative relationships on accident factors into the causal network revealed the sketchy nature of current knowledge about accident causation mechanisms. The second volume contains, as an Appendix to this final report, those parts of the Phase II report presenting the results of the literature review.

From the very beginning, we have had an idea of the structure of the network to be developed. This idea was, however, very general, and various realizations were possible. Three somewhat different types of networks were presented in the first phase. Though the study proceeded in three distinct phases with different objectives (plan development, literature review, and construction of the network), the initial concepts of the network were refined in an iterative fashion as new information and insights became available. The last refinements of the network were accomplished through attempted applications of the network to accident situations.

During the second phase of the study, we found that existing quantitative knowledge on accident causation was inadequate to empirically support even a rudimentary network. Therefore, we had to rely more and more on general physical and engineering knowledge, and on hypotheses formulated and studied in the literature, though not usually quantified or even substantiated empirically, and on anecdotal evidence from the literature, including newspaper reports and personal experience.

1.2 Earlier Causal Networks

Though we were, in broad terms, familiar with several published causal networks, we intentionally did not review these studies until we had outlined several conceptual approaches and developed them in some detail. Only then did we review earlier work on causal networks to check our network for completeness and to modify details, if it appeared advantageous.

Although the networks developed by the different authors differ in many aspects, a basic structure appears to be common to all, once one accounts for differences in definitions and purpose of the network. The basic structure is a sequence where the driver has to perceive the current situation, has to make a decision, and has to take action. The resulting vehicle movement leads either to an accident or to a new situation, to which the same sequence applies. There are greater differences in the finer breakdown, and in the factors considered and the causal relationships assumed. However, no contradictions are apparent, and it was possible to develop a comprehensive network which is compatible with all networks discussed here.

Goeller* develops a logical structure comprising the pre-accident, intra-accident and post-accident stage. Only the first is of interest in our study. It is further broken down into a predisposition, initiation, juxtaposition and evasion phase. The predisposition phase comprises factors such as the driver's sobriety, traffic density, weather, etc. The initiation phase is essentially continuous, as long as the driver moves along the highway. The outcome of the initiation phase is either "safe driving," which leads back into the initiation phase, or "vulnerable" driving, which leads to the juxtaposition phase. Depending on whether another vehicle (or object, pedestrian, etc.) is present, or not, a "confrontation" or a "non-dangerous hazard" is the outcome of this phase. If a confrontation results, an evasion phase begins, which results either in an accident or a near miss. Of these four phases, only the initiation phase is presented by a detailed network (reproduced in Figure 1.2-1). The overall sequence of events is as follows: traffic events are perceived, subject to mechanical and sensory limitations and distractions. Observations relate to driving or not to driving, or events may not be observed. Decisions are made which are correct or incorrect, and actions follow. Again, actions may be correct or incorrect. The final result is either "safe driving" or "vulnerability."

The structure is complex, comprising several branching points and feedback loops. Detailed lists of factors are presented on principal traffic events and mechanical limitations. Results from other studies are used to estimate the frequency of vulnerabilities on "near misses" and factors related to them are presented. Simple mathematical models for certain aspects of the problem are developed, expressing numbers of confrontations, near misses, and collisions.

---

*B. F. Goeller, *Modelling the Traffic-Safety System*. Memorandum RM-5633-DOT. The RAND Corporation, Santa Monica, California, April 1968.

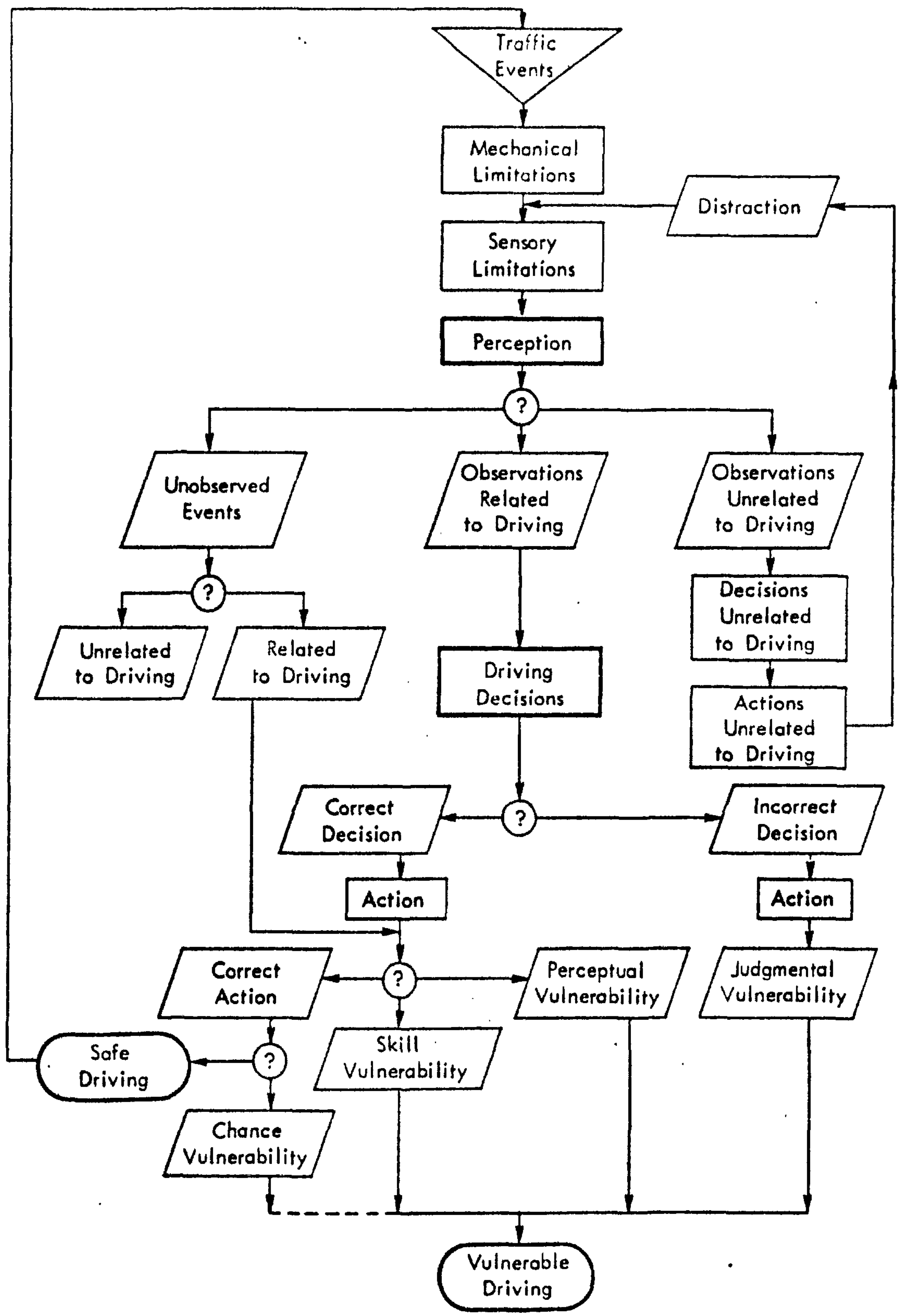


Figure 1.2-1. Subnetwork for the initiation phase of Goeller's network.
Source: Op.cit., p. 17, Figure 2.

Hall and O'Day* develop a conceptual system to describe the interaction of highway safety countermeasures and accident causation factors. Of interest to us is the "highway safety model." It consists of three levels: the first comprising models of roadway characteristics, vehicle characteristics and driver characteristics. These models provide inputs to the second level models--roadway performance, vehicle performance, and driver performance. The vehicle performance model provides impacts to the last level models--traffic flow and accidents. Only the model of the vehicle's characteristics is developed into further detail. Environment, vehicle population, level of law enforcement, usage, level of inspection and owners' attitudes provide inputs to the model of the mechanical condition of the car. There is a brief allusion to a probability model. Figure 1.2-2 presents this network, re-arranged to show the similarities with CEM's network.

Kontratos** presents, among other things, a conceptual model of the driver-vehicle-environment system. The driver part has three aspects, ordered in sequence: predisposition, alertness, experience/skill and attentiveness; the formulation of an action plan; and "muscular exertion," which is controlling the vehicle part of the system. Inputs to the driver part are from the vehicle, and from the environment via the vehicle. The environmental part influences the driver by information, via intervening vehicle structures, and the vehicle by mechanical forces. The vehicle part of the model consists of the intervening structures already mentioned; the dynamic behavior, which is influenced by the driver; control, the mechanical forces from the roadway, and the mechanical conditions of the vehicle. Resulting from the dynamic behavior are direction and speed. Finally, the vehicle's response closes a feedback loop influencing the driver's formulation of action plan. Accidents are not directly incorporated into this structure, but are discussed separately. Lists of human, environmental and vehicular accident causation factors are presented. This network is shown in Figure 1.2-3.

Fell† presents a feedback-loop network for the driver-vehicle-information flow in the driving task. Vehicle, highway, and ambience are providing information, subject to ambience and vehicle information restriction, to the driver. He processes information in four stages: perception, comprehension, decision, and action. Action influences the vehicle which then, directly or via other road users, provides information which closes the loop. Accidents are not explicitly included in the network, but failures of the information flow which can lead to accidents are discussed and listed (see Figure 1.2-4).

---

*W. K. Hall, J. O'Day. "Causal Chain Approaches to the Evaluation of Highway Safety Countermeasures," *Journal of Safety Research, 3:1,* March 1971, 9-20.

**A. N. Kontratos. "A System Analysis of the Problem of Road Casualties in the United States." *Accident Analysis and Prevention, 6,* 1974, 223-241.

†J. C. Fell. "A Motor Vehicle Accident Causal System: The Human Element." In *Motor Vehicle Collision Investigation Symposium, Vol. 1: Proceedings.* J. W. Garrett, Editor. Calspan Corporation, August 1976. DOT-HS-801979. Also published in *Human Factors, 18,* 1976, 85-94.

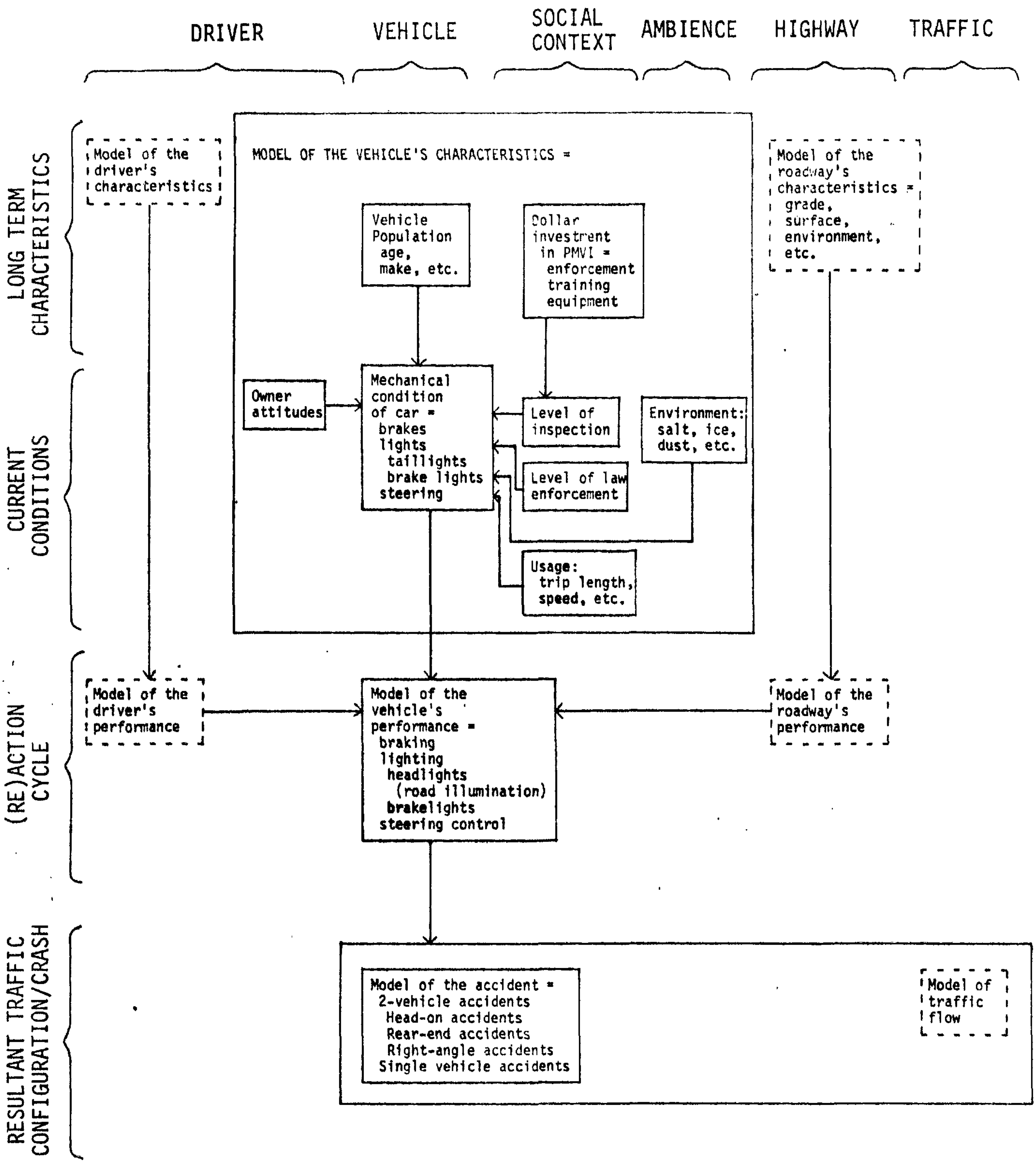


Figure 1.2-2. Hall and O'Day's "Highway Safety Model" rearranged to fit into the framework of CEM's causal network (left and upper marginal readings). Source: Op. cit., p. 18, Figure 7.

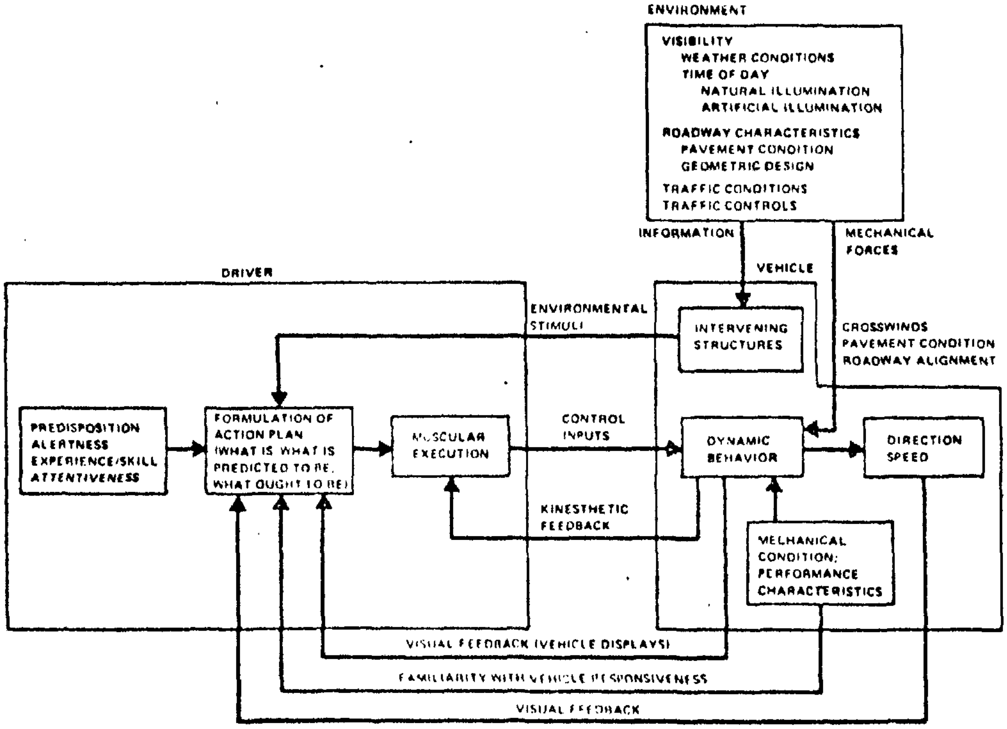


Figure 1.2-3. The driver vehicle environment system network developed by Kontratos. Source: Op. cit., p. 228, Figure 1.

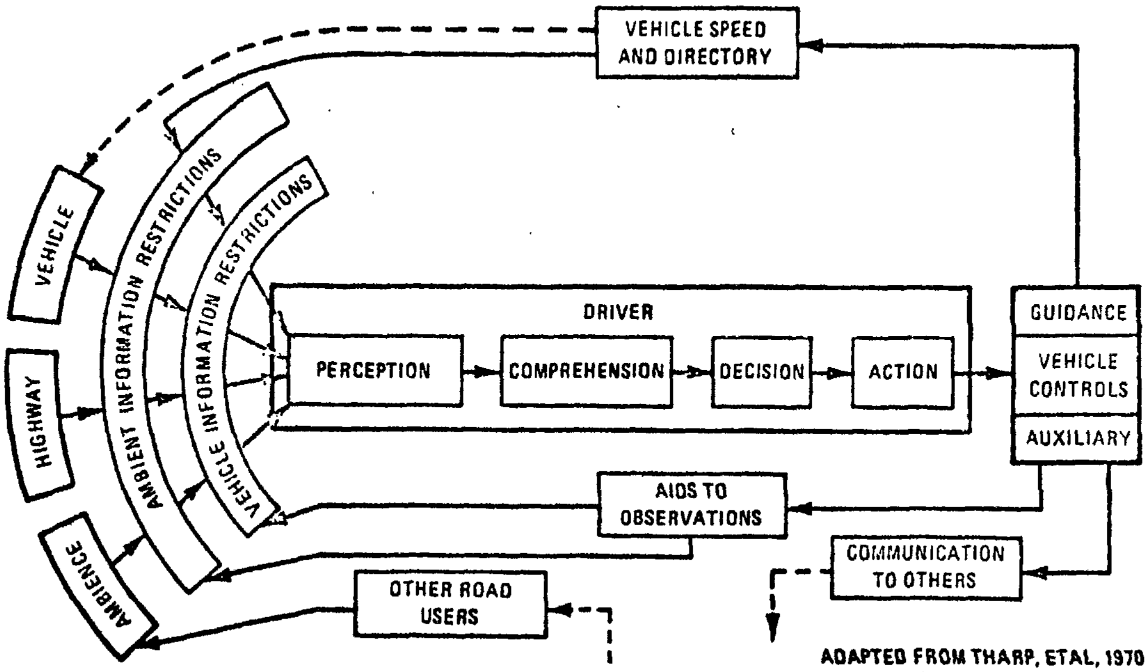
Kurucz and Morrow* develop a model for single vehicle accident causation. The main sequence of events is as follows: in a certain maneuver, the driver is faced with a situation requiring certain tasks. The driver has to process information and take action which results in vehicle action. The result is either a successful response (after which the driver faces a new situation), a crash with an object or a rollover, or leaving the roadway. In this last case, the same sequence repeats, resulting either in a crash or return to the roadway. Classifications for pre-accident maneuvers, tasks, driver actions and resultant vehicle actions are given, and lists of human factors in accident causation are presented (see Figure 1.2-5).

Wilde** presents a network of a cognitive and motivational model of driver behavior. Environment, the vehicle of the driver, and other vehicles provide information to the driver. This information intake is influenced by cognitive states and motiational states. The information, together with expectations about the environment, his own vehicle and other vehicles provide a basis for his subjective estimation of danger. Comparison with "tolerable" danger, which is determined by motivational states, lead, together with cognitive states, to the decision taken, the consequent action upon the vehicle's controls, and the vehicle response. The vehicle response, leading to a new situation, closes the loop. Accidents are not explicitly considered in the network (see Figure 1.2-6).

---

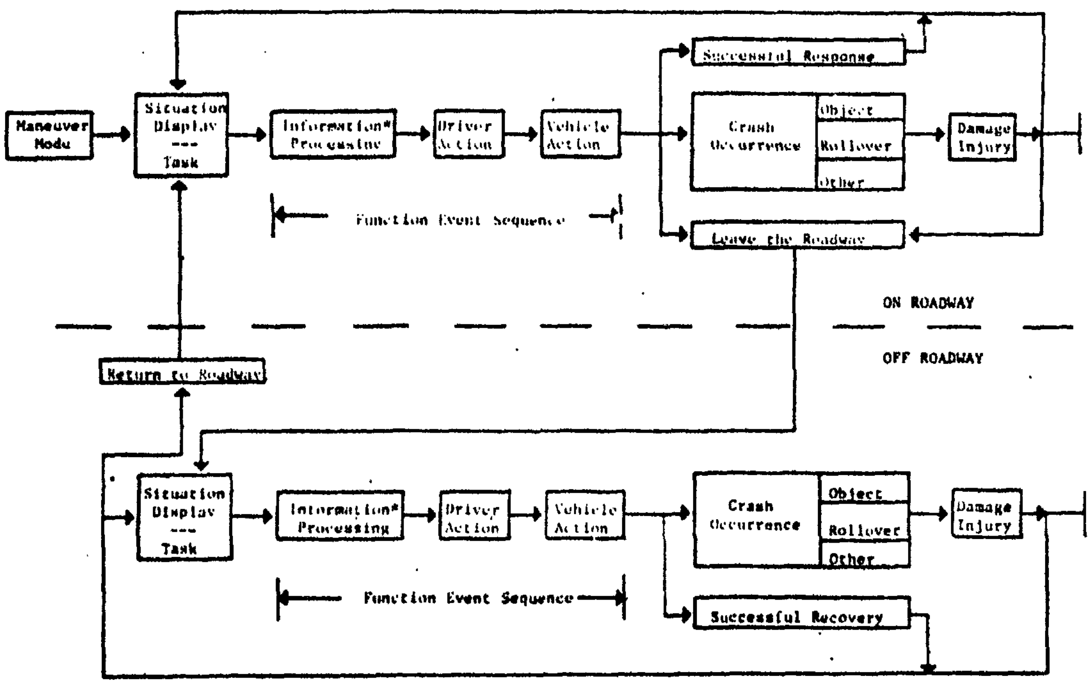
*C. N. Kurucz and B. W. Morrow. "A Causal Model for Single Vehicle Accidents." In *Motor Vehicle Collision Investigation Symposium, Vol. 1: Proceedings*. J. W. Garrett, editor. Calspan Corporation, August 1976. DOT-HS-801979.

**G. S. Wilde. "Social Interaction Patterns in Driver Behavior: An Introductory Review," *Human Factors, 18*, 1976, 477-492.



Source: Figure 1 from Fell, p. 508.

Figure 1.2-4. The driver/vehicle/environment information flow in the driving task.



* Search - Identification - Evaluation - Decision

Source: Figure 1 from Kurucz and Morrow, p. 537.

Figure 1.2-5. Accident sequence model.

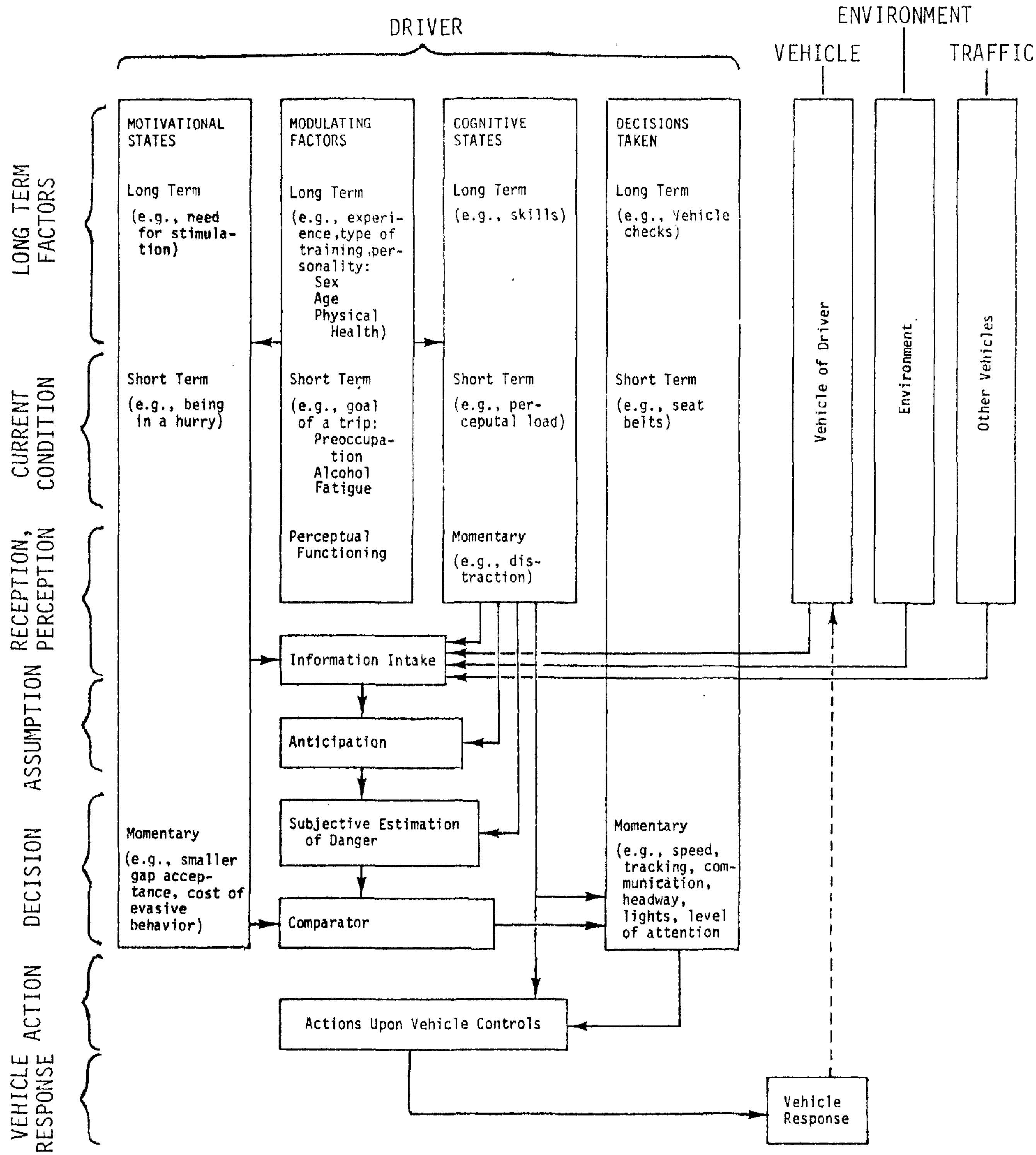


Figure 1.2-6. Cognitive and motivational model of driver behavior according to Wilde, modified to fit into CEM's framework. Source: op.cit., p.479, Figure 1.

2.0 DEVELOPMENT OF THE CAUSAL NETWORK

This section describes how the causal network presented in Section 3.0 developed from our initial concepts.

During the first Phase of this study, CEM developed three conceptually different types of networks. The first type (Figure 2-1) took a global view of the accident causation and prevention process. About equal emphasis was placed on accident prevention activities, and on long-term factors influencing the occurrence of accidents. The actual accident generating process was only one of the many elements of the network. The second type (Figure 2-2) concentrated on more immediate grounds, recognizing longer term factors and their probable influence on accident occurrence, but emphasized and detailed the processes immediately preceding the accident. Accident prevention and system management activities (such as driver licensing) were omitted from this network. The third type of network (Figure 2-3) focused on the immediate physically present factors which interacted during the accident sequence. Driver activities were included, but at a low level of detail. During initial meetings with NHTSA representatives, the second type of network was found to be closest to the desired concept. During the course of the study, however, more aspects of the network of the third type have been incorporated into the structure of the Type II network, in addition to modification of its overall structure and refinements of details. Figure 2-4 presents the resulting modification of the Type II network.

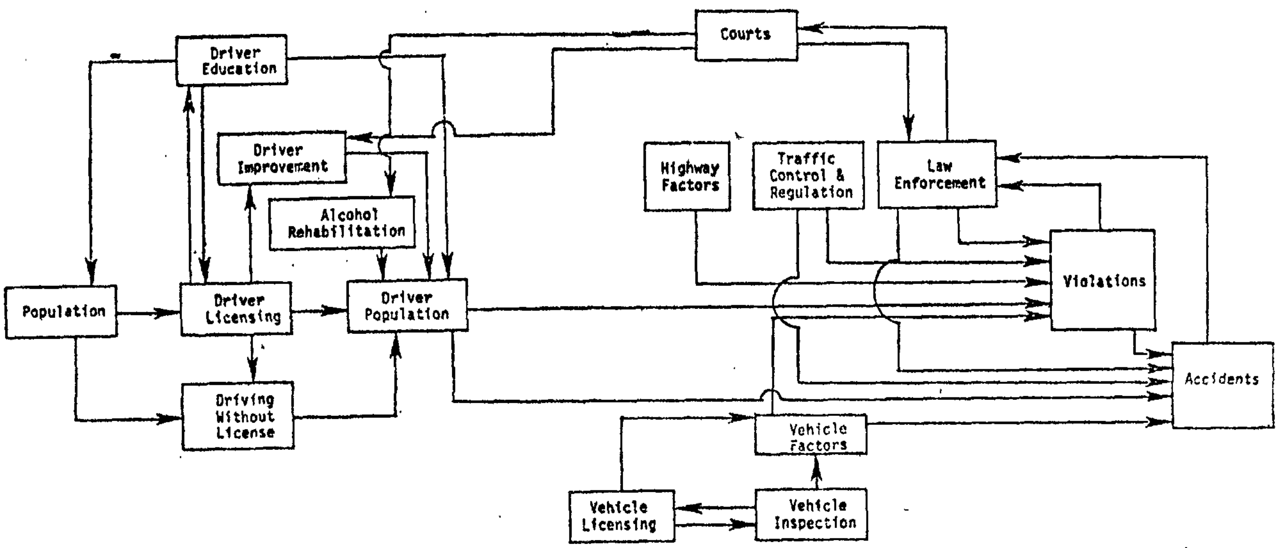


Figure 2-1. Illustration of network Type I, comprising accident prevention programs, highway traffic management activities and violations, in addition to accident occurrence.

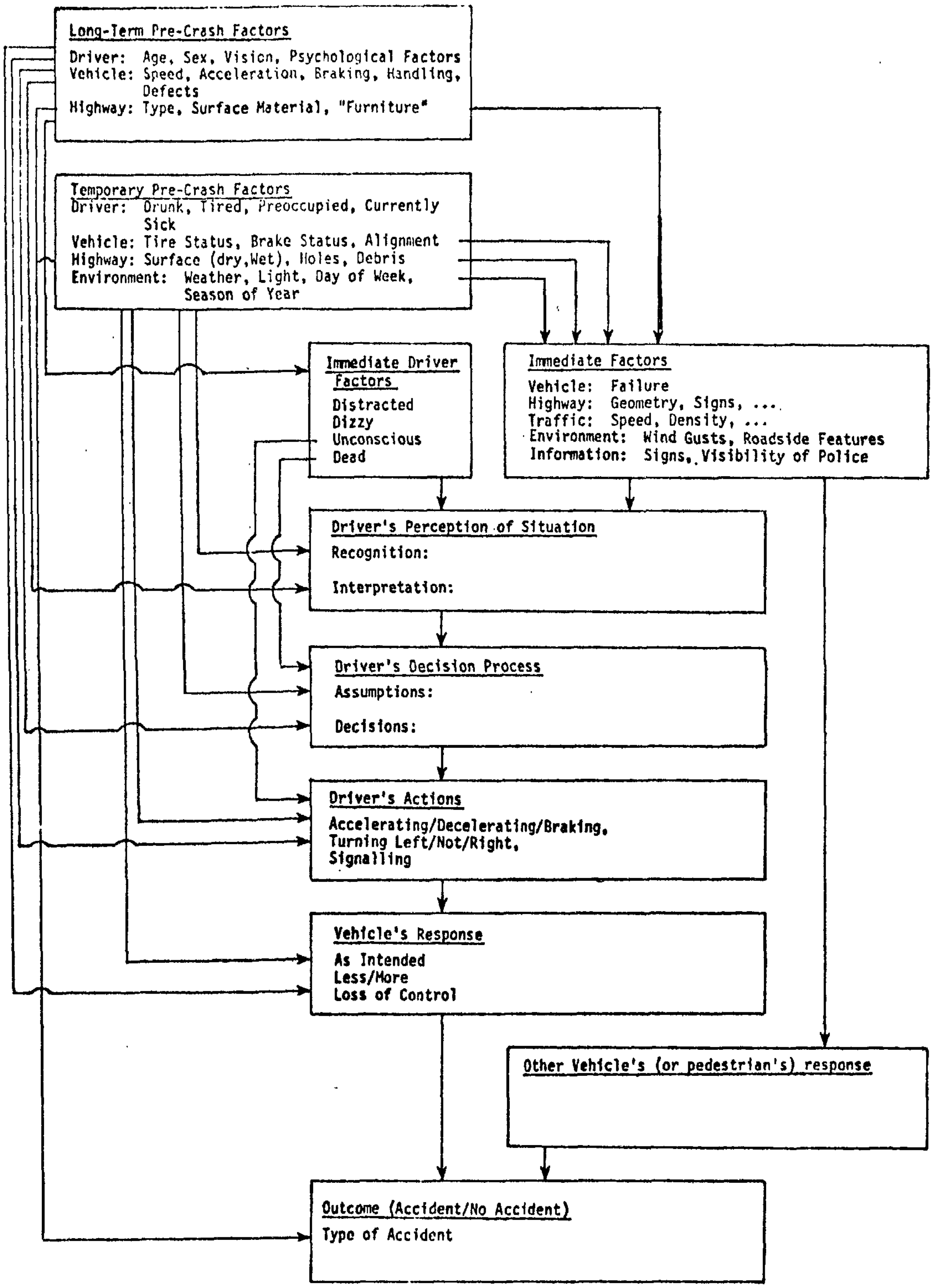


Figure 2-2. Illustration of network Type II, emphasizing the sequence of events preceding an accident. The factors listed are illustrative, not comprehensive.

In the original network prototypes the major causal elements were the driver, the vehicle and the driving environment (highway and non-highway). These elements are immediately obvious because of their physical presence and interaction in the accident sequence. However, when developing the details of the structure, we found that certain elements did not easily fit into the categories. *Social context* was introduced as a new category which encompasses social aspects ranging from long-term legal and regulatory institutions to immediate social conditions like vehicle occupancy and trip purpose (and by obvious generalization to the cargo of passenger cars and trucks). *Ambience* is not a completely new element; however, it was judged that these measures of the physical (non-highway) background conditions justify separate treatment,primarily because of their current uncontrollability. *Highway/environment* is now limited to the hardware aspects of the highway, and to the topography and structures near the highway. This category is now more clearly focused on the discrete highway related elements which interact with the driver and the vehicle. *Traffic* is another element which has been split out of the original driving environment element. This element is important in that it reflects how conditions generated by the activity of many drivers affect an individual driver and vehicle in an accident situation. Also, this element is important in that it begins to reflect the potential of representing any individual traffic situation with complete causal networks for each driver/vehicle involved. In addition to traffic in general, other traffic units have to be considered individually, if they are specific objects of the considered driver's attention or maneuvers, or if they are actively interacting with the unit under consideration.

The temporal element of accident causation was originally divided into three time frames, one very long term, one essentially instantaneous, and one intermediate range which covered factors which did not naturally fit into

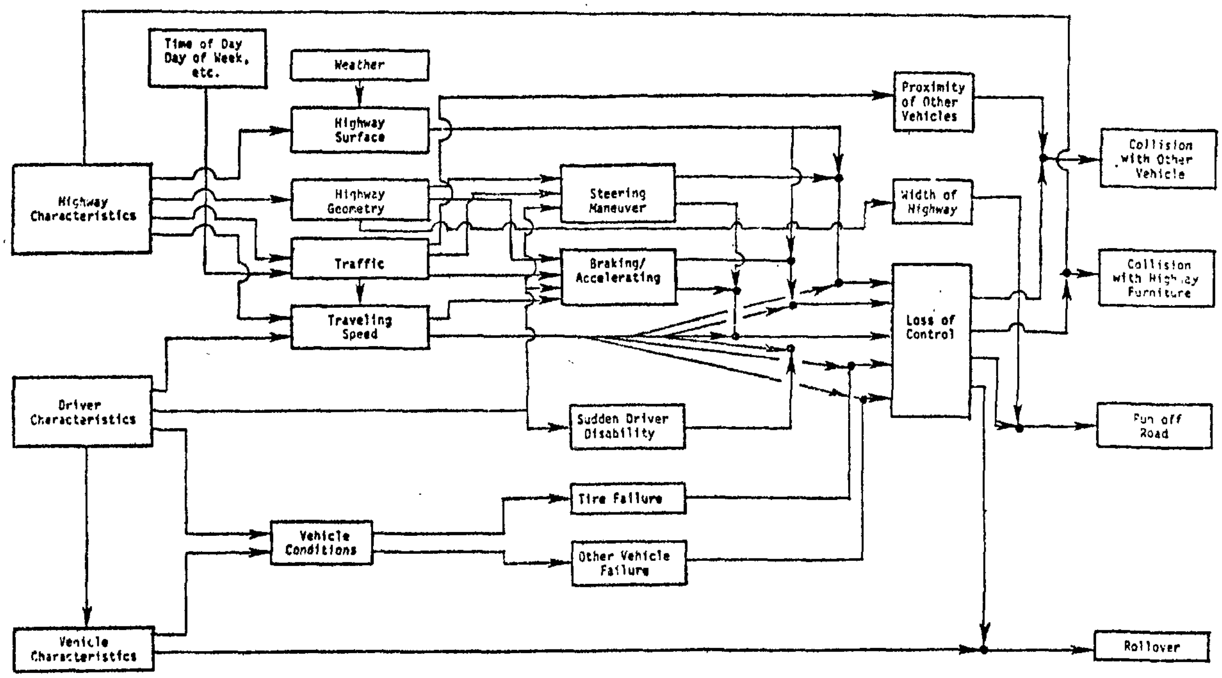


Figure 2-3. Illustration of a part of Type III network, centered around the event, "loss of control." This type of network emphasizes the condition and factors necessary for or contrasting to the occurrence of an event or condition.

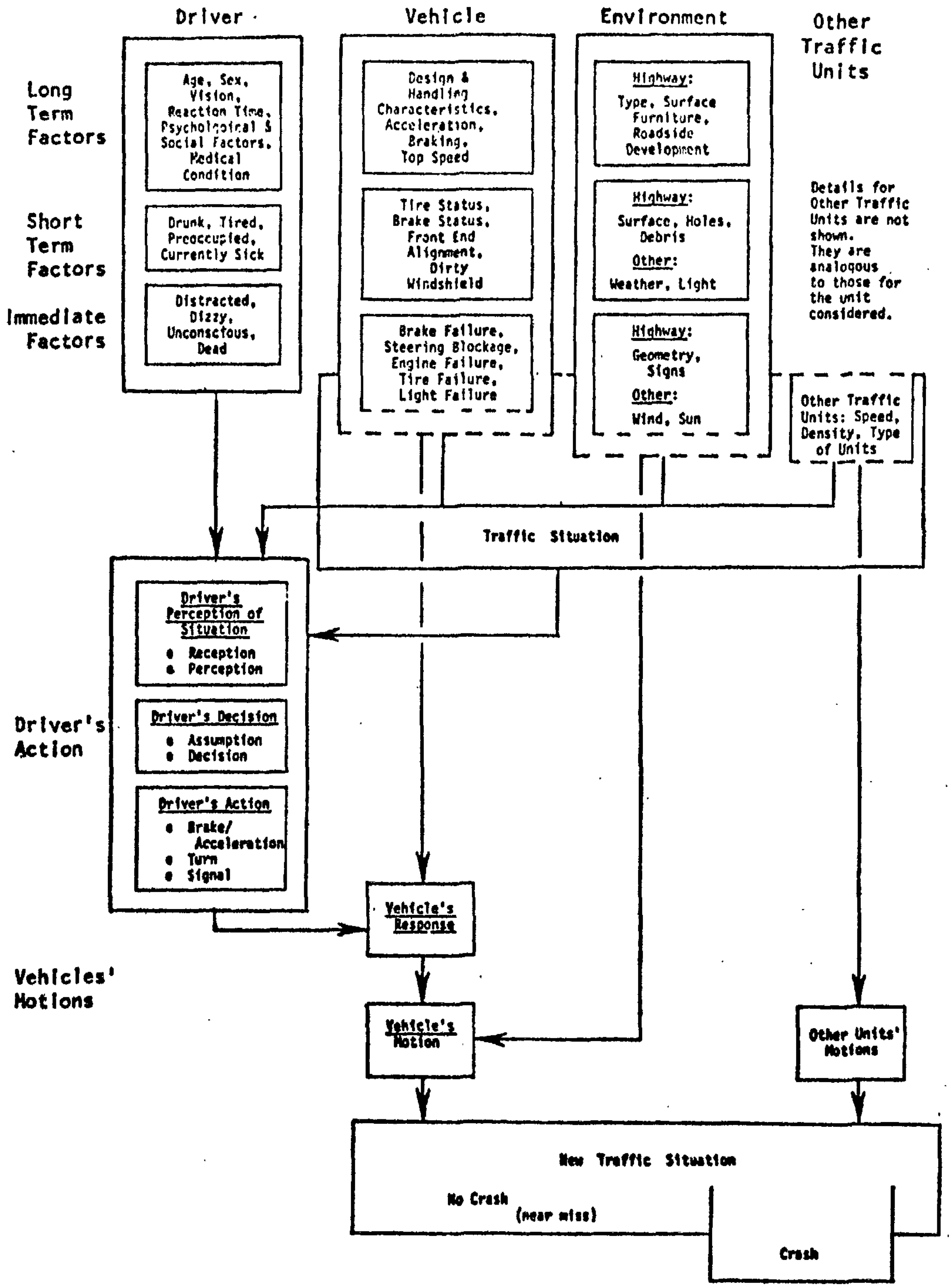


Figure 2-4. Modified Type II network which was used as a basis for developing the comprehensive network.

the first two. The present temporal structure goes from *long-term characteristics* of the major elements described above, which remain unchanged for at least days to possibly years, to the *current status or conditions* of those elements (which may last from a few seconds to hours, possibly days) to concern about the immediate traffic situation, which includes a description of the current *traffic configuration* and of sudden events or *disturbances*. These disturbances occur within fractions of a second to at most a few seconds (though they may last longer, as in the case of sudden death at the wheel), and are, therefore, precisely tied into a specific traffic situation. At this point the *driver/vehicle (re)action process* enters the temporal sequence. This process includes perception of information, decision-making, action-taking and vehicle response. Conceptually, this process is given a linear structure; however, in actuality these processes may go on in parallel, and there might be very short-term feedback loops. One can envision short-term feedback from vehicle to driver, as he encounters resistance to turning the wheel or depressing the brake, etc. The next network element is a description of the *vehicle motion*, which is a product of the interaction between the vehicle's mechanical response to driver actions, the vehicle contact with the highway, and the mechanical and handling characteristics of the vehicle. At this point, the time step between elements is extremely short with driver/vehicle (re)action and vehicle motion happening almost simultaneously. The *resultant traffic configuration* is a description of the new traffic situation in terms of vehicle positions and motions. At this point, the causal sequence can terminate with a crash or the cycle can repeat--the resultant traffic configuration becoming the initial traffic configuration of the next cycle. In addition to this main loop describing the ongoing driving experience, there is also another sort of feedback taking place. The ongoing driving experience gradually modifies the current driver and vehicle conditions, e.g., drivers become tired, anxious, frustrated, etc., the vehicle heats up, average speed changes, etc.

In considering the temporal sequence, one large element was the driver/vehicle (re)action process. Most of the other elements of the causal sequence of a crash can, at least in principle, be learned from physical evidence and from witnesses. The driver/vehicle (re)action, however, can normally only be inferred. Initially, we separated this process into four distinct groups: 1) the driver's perception of the situation; 2) his decision process; 3) his actions; and 4) the vehicle's reactions, and each of these again, as shown in Figure 2-2. A closer analysis of these activities, however, suggests a different aggregation under the aspects of obtainability and reliability of information. The first step in perceiving the situation is the physical reception of the information. In many cases, it can be established whether the driver could or could not receive a signal, considering his physical abilities, the properties of the car, the environment, etc. The second aspect,(perception of the situation), recognizing the important elements as such (e.g., a colored light as a traffic light) and perceiving the situation as a whole, is completely internal to the driver. In each individual case, one has to rely on the driver's statements. It might, however, be possible to infer something about perception for a class of drivers from statistical analyses of large data bases. The driver's decision process was originally divided into his assumptions and decisions. We concluded that a finer (but different) breakdown, presented in Section 3.0, is more appropriate. For details of this process in an accident, one has again to rely on information provided by the actual driver. Depending on his decision, he will activate the vehicle controls. In some cases, it might be possible to determine from physical evidence, or from observation of a vehicle occupant what the driver did. Usually, however, one will have to rely on the driver's statements, which may be objectively wrong, even when the driver makes a subjectively correct statement, if he is not aware that he did something different than he intended to do. Finally, the vehicle responds to the driver's actions. In some cases, the resulting response may be objectively determinable, but not whether this was a "normal" mechanical response to the specific driver's action. The vehicle's mechanical response, however, was later separated from its motion, which is the result of the interaction between its response and the highway surface and geometry. This motion can be observed and, in principle, reconstructed. In addition, Figure 2-5 indicates groupings of the elements. The initial traffic situation, and sudden disturbances which change it instantaneously are grouped together. The driver/vehicle (re)action sequence is grouped, because it appears more difficult to obtain information on these events than on other factors in the crash. Within this grouping, reception and vehicle response are separated from the other elements, because information on them is of a more objective nature than that on the other elements. Figure 2-5 presents the elements of the comprehensive causal network.

Another concept which has been applied in the construction of the causal network is that of traffic conflicts. Initially, we used it in the meaning developed by Stuart Perkins of the General Motors Corporation Research Laboratories to measure traffic accident potential.* According to the original definition a traffic conflict takes place when a driver takes on evasive action (brakes or weaves) to avoid a collision. Objective criteria for traffic conflicts were originally defined for over twenty specific accident patterns at intersections. When using the traffic conflict concept in the development of the causal network, we found that a different, broader definition was needed. Due to lack of a better term, however, we retained the name "traffic conflict" for the more general concept. Conceptually, a conflict situation will exist when two vehicles are on paths which, if they continue, will intersect at the same time. A conflict situation also exists if a single driver would have an accident if he did not actively guide his car, e.g., any curve is an objective conflict situation because the driver must do something to avoid running off the road. Many conflict situations can be created by legal driving maneuvers, e.g., turning left at a cross-type intersection, passing another vehicle on a two-lane highway, etc. Whether the conflict situation results in an accident depends on the driver/vehicle (re)action to the situation and the subsequent motion of the vehicles involved. In some cases, the time needed to perform an evasive maneuver is too long compared with the time in which the driver is able to recognize an objective conflict situation (e.g., a car hurtling out of a blind alley). Therefore, the concept of a conflict situation and an analysis of the time required to perform evasive action would help to establish when it is "too late" to do something in an accident sequence.

---

*Perkins, S.R., *GMR Traffic Conflicts Technique Procedures Manual.* Detroit, GM Research Publication GMR-895.

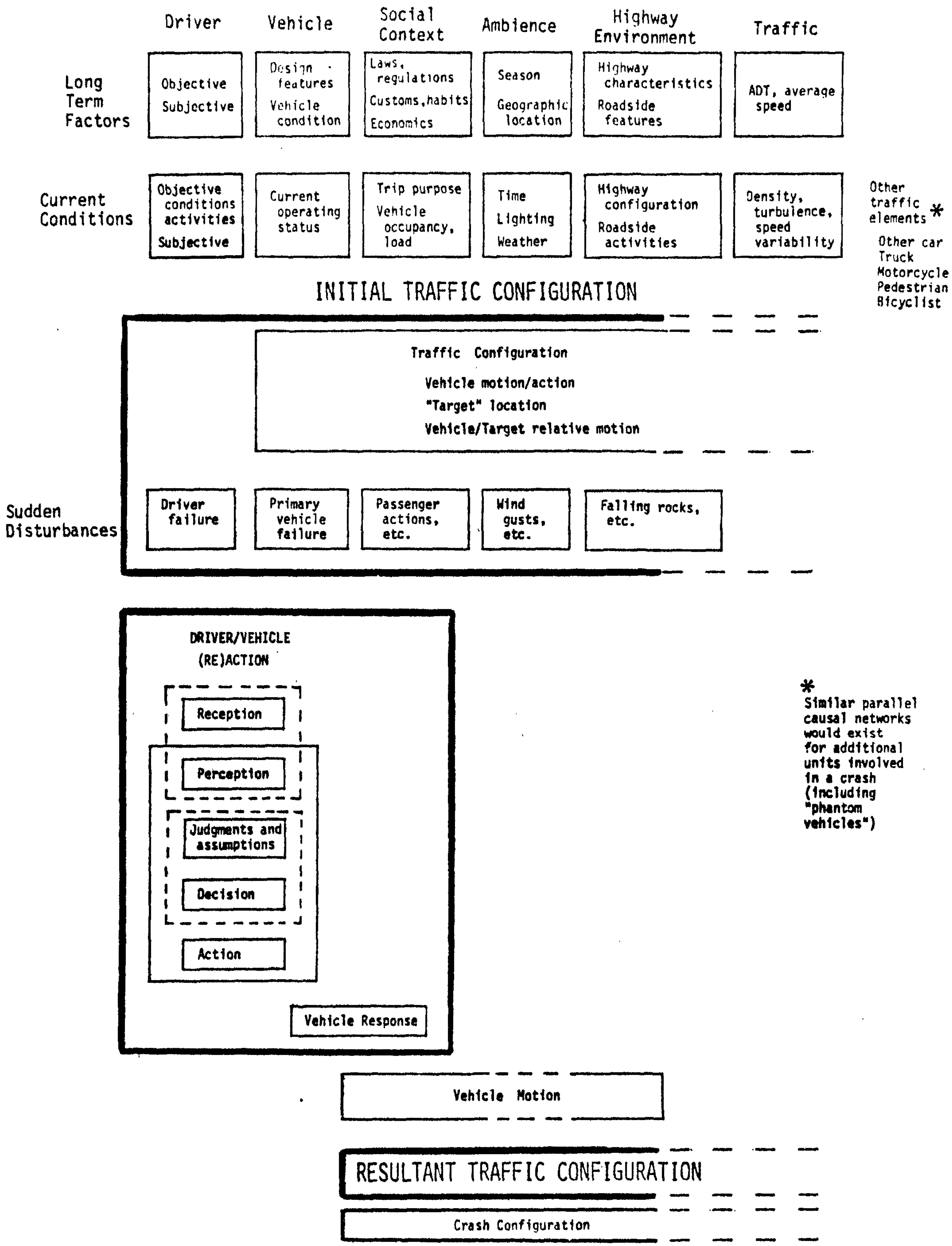


Figure 2-5. Major elements of the Comprehensive Causal Network. Causal links or chains are not shown.

In addition to the objective conflict situation, there are also potential accident situations which arise from simple driver compliance with the law. An example of this type of compliance conflict would be a lead car slowing for a stop sign or light. If the following car does not take action to "evade" the first car by slowing, there will be an accident. To distinguish this situation from one where the first driver slowed voluntarily for reasons of his own, we defined his situation as facing a "compliance conflict." In short, he would have violated a traffic (or other) law or regulation had he not taken action.

In studying how well actual or hypothetical accidents could fit into the framework of the network, we concluded that there are rather common situations where the simple cycle is not sufficient to describe the events, especially if more than one vehicle is involved. Therefore, we allowed the cycle initial traffic situation--driver/vehicle (re)action--resultant traffic situation to repeat once or several times. Similarly, we allowed several such networks to occur in parallel, to account for several driver/vehicle units involved in an accident.

Finally, we noticed that there are two different kinds of "links" in the network: one representing the "normal" flow of information and control, the other the "causal" factor. The first, for instance, identifies which information the driver receives, how he interprets this information, which specific decision he makes, etc. The other describes why a driver is not (or is delayed in) receiving certain information, why he does not perform the intended action, etc. A network containing the links of the first kind would become extremely complex, and most of its elements and connections would be irrelevant to the causation of the accident. Therefore, we concentrated on the second kind of link, those describing which factors caused or influenced "failures." In addition, however, we did retain the elements of the comprehensive network describing content, such as highway configuration, object seen (or not seen), etc. because certain kinds of failures may be associated with certain kinds of content. Figure 2-6 shows this distinction. Figure 2-7 illustrates using driver's reception as an example, to distinguish the factors influencing reception from what information is received.

"Failure," the key aspect of our network, had to be defined very broadly. It includes not only complete failure, but also delay (e.g., to see something) and also a failure of degree (e.g., to depress the brake pedal not as fast or as hard as intended). The inclusion of delays in the definition of failure, requires a time frame: the time from the origin of a conflict situation to the expected crash. Both the normal times of the (re)action cycle, and any delays have to be compared with this time horizon to assess their individual or joint contribution to the accident. The next section discusses the final version of the causal network in more detail.

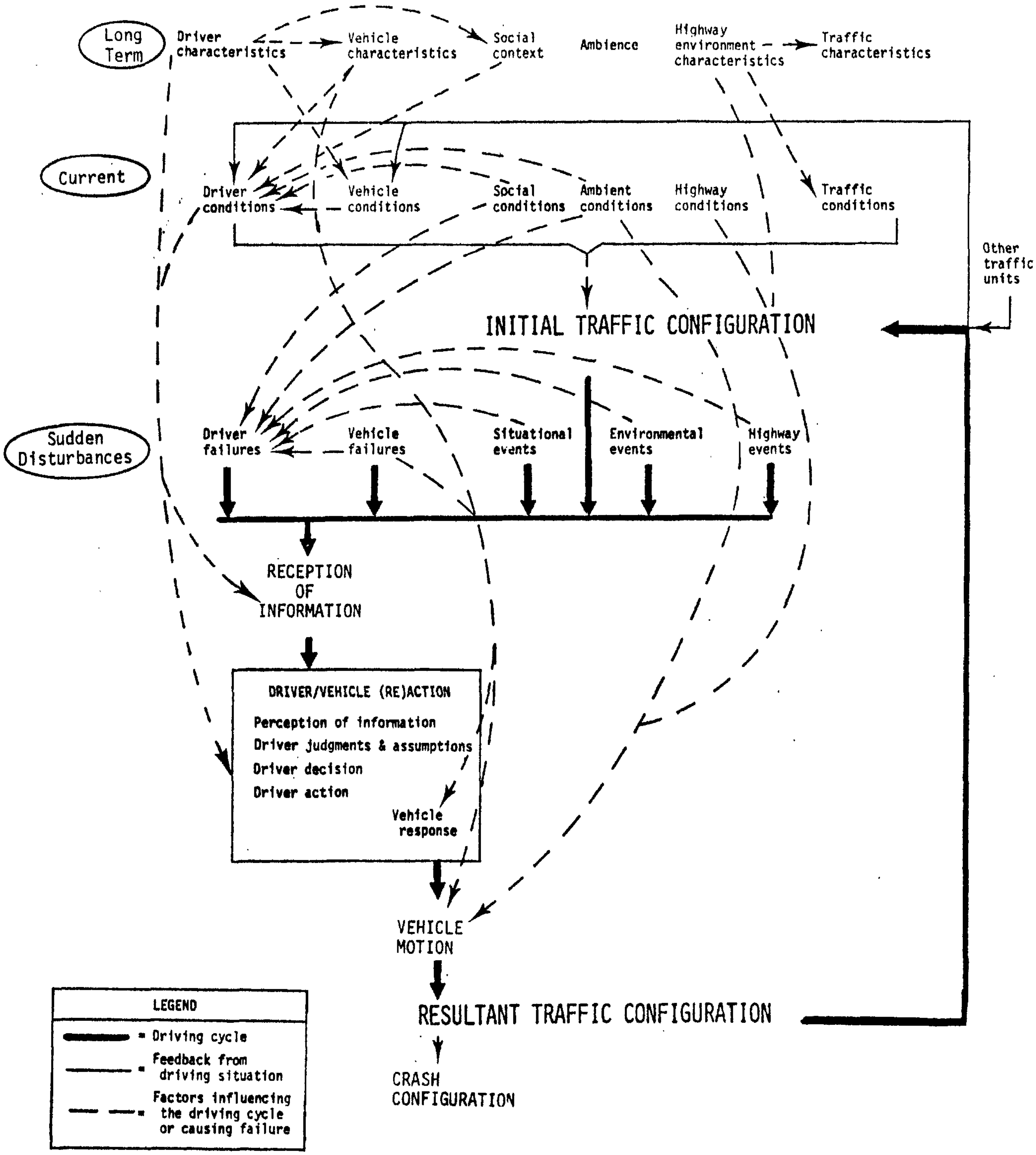


Figure 2-6. Causal network distinguishing the elements of the driving cycle and factors which influence or disturb it.

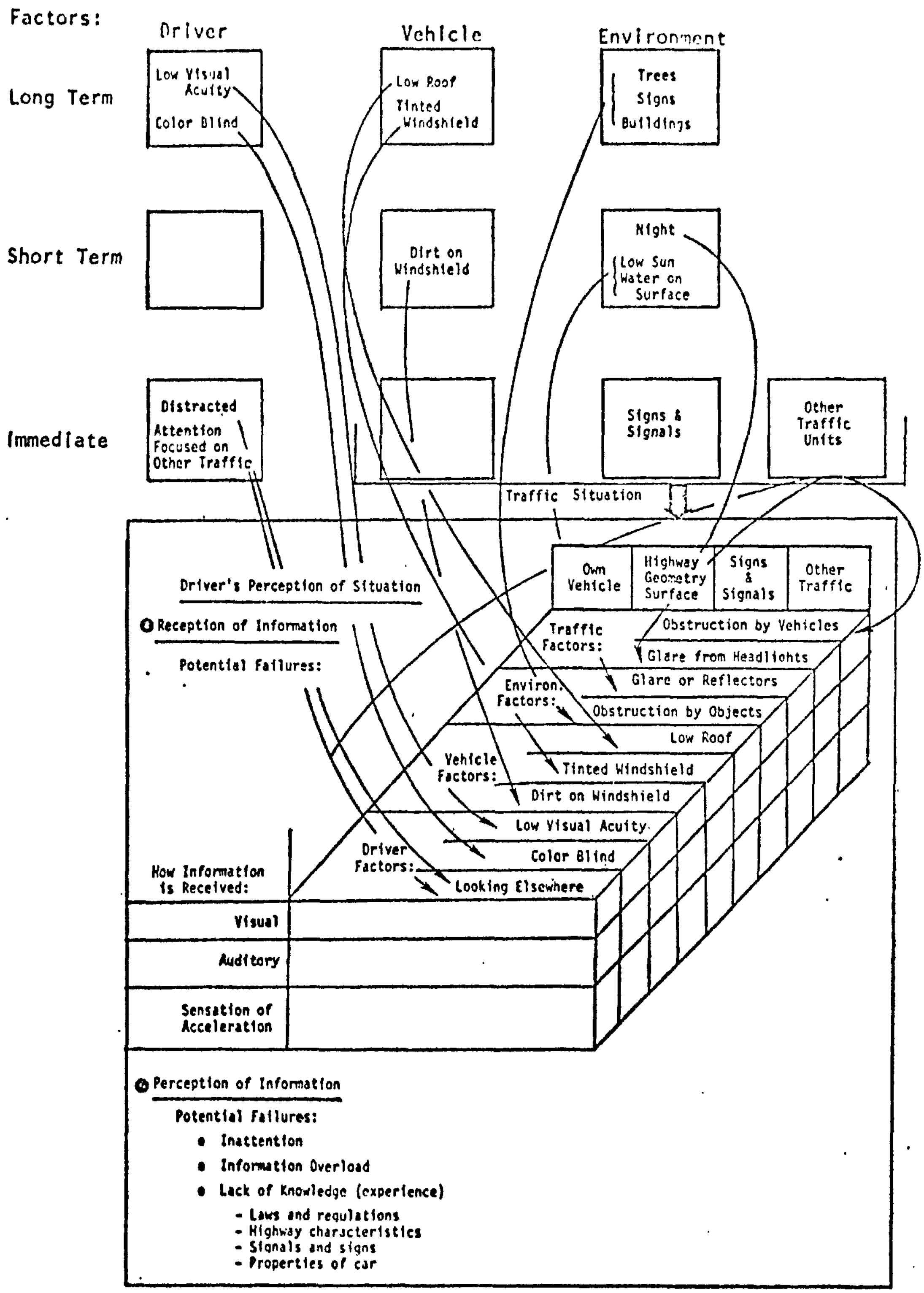


Figure 2-7. Illustration of the distribution of influencing factors and the content of activities, using the driver's reception as an example.

3.0 THE COMPREHENSIVE CAUSAL NETWORK

This section describes the comprehensive causal network at three levels:

- Section 3.1 presents the overall structure of the causal network.
- Section 3.2 contains the detailed structure both graphically and in several lists of causal factors.
- Section 3.3 presents an extensive list of causal factors and a coding scheme organizing them.

3.1 Overall Structure of the Network

To outline the overall structure of the network, we will

- show how the continuous processes ongoing in driving are organized into discrete cycles;
- describe the main elements of the network;
- introduce accident and conflict situations;
- describe how sequences of and parallel cycles are used in complex situations;
- define "failures"; and,
- discuss the time structure paralleling the sequence of events.

Many processes are going on in parallel when driving. The driver observes "continuously" (with occasional or frequent interruptions) the traffic scene; he makes "continuously" decisions (many of which are implicit, such as, continue the current course), and he controls the vehicle continuously. Thus, he may still steer his vehicle according to previous observations, while he is already deciding how to react to a new observation. Though this process, in principle, goes on continuously, it is helpful to think of it as occurring in a sequence (which is often actually the case): the driver will observe and react to the traffic situation, the vehicle will move, and a new traffic situation will result. This cycle repeats for the entire duration of the trip.

In addition to the actions of the driver and the reactions of the vehicle in the driving cycle, *sudden disturbances* can occur, such as a driver having a seizure, a tire failing, a rock falling from an embankment, etc. Such disturbances immediately create a new traffic situation. In addition to the continuously changing traffic situation, *"current" or "local" conditions* play a role, which are of a somewhat longer duration. A driver being drunk, a tire having low pressure, a wet pavement are examples of such conditions which influence the driving cycle. Other conditions remain unchanged over longer time: the driver's age and sex, many personality characteristics, a vehicle's design specification, its state of maintenance, wear and tear of tires, a highway's design. We call them *long term factors*. These are, in broad terms, the elements of the causal network; their relation is shown in Figure 3.1-1.

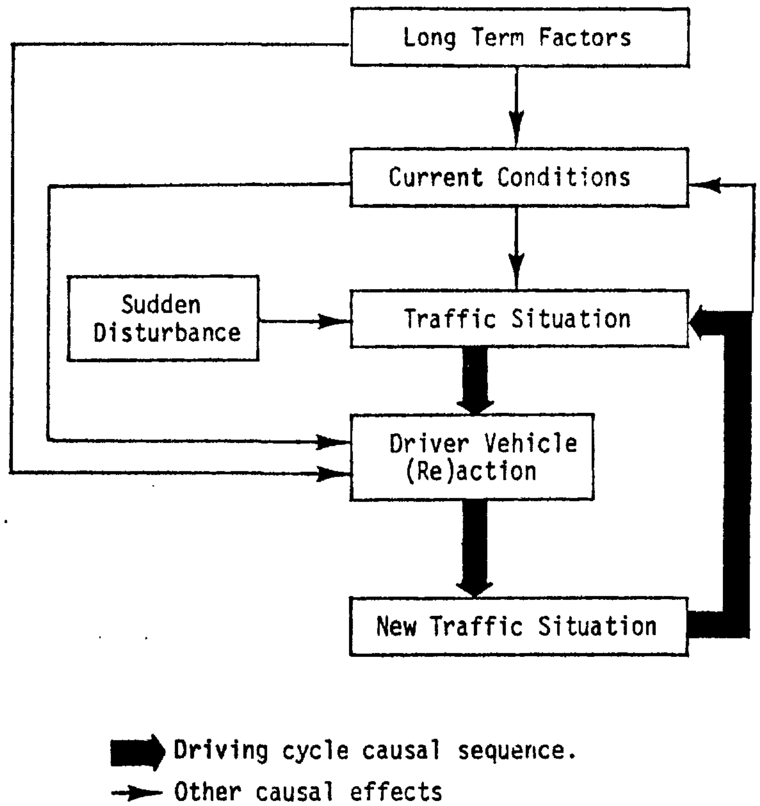


Figure 3.1-1. Main elements of the causal network and their relations.

In addition to the time oriented ordering of the major elements of the network as shown in Figure 3.1-1, it is helpful to organize it by the element affected: driver; vehicle; highway/environment, which includes the highway and the adjacent topography and man-made structures; ambience (weather, lighting, etc.); traffic; and "social context." The latter encompasses trip purpose, trip length, other vehicle occupants, and, by extension, vehicle cargo, as short term factors; and as long term factors laws and regulations, habits, economic factors such as payment per mile, etc. There is no natural order among these six aspects. They can be used to organize the elements of Figure 3.1-1 into "columns," as illustrated in Figure 3.1-2. This figure shows which elements refer to the driver only; that vehicle reaction concerns the vehicle only; that vehicle motion, however, is determined by the vehicle reaction and the highway jointly; and that the situation which the driver is facing contains factors of the vehicle, highway/environment, ambience, traffic and social context.

Our primary interest is in networks where the new traffic situation results in an accident. An accident can be precipitated by the driver/vehicle action immediately preceding; or it can also be the consequence of the preceding traffic situation (or the new situation created by an immediate disturbance), when the driver/vehicle unit does not or cannot perform a successful evasive maneuver. In the latter case, this unit faces a *conflict situation*, which is defined as a traffic situation which would be followed by a collision with another vehicle or object, running off the road, or overturning on the road, if the unit(s) involved would not change their course(s) or speed(s)*. Conflict

*This concept of conflict situation differs from the one developed by GM for assessing the accident potential of intersections.

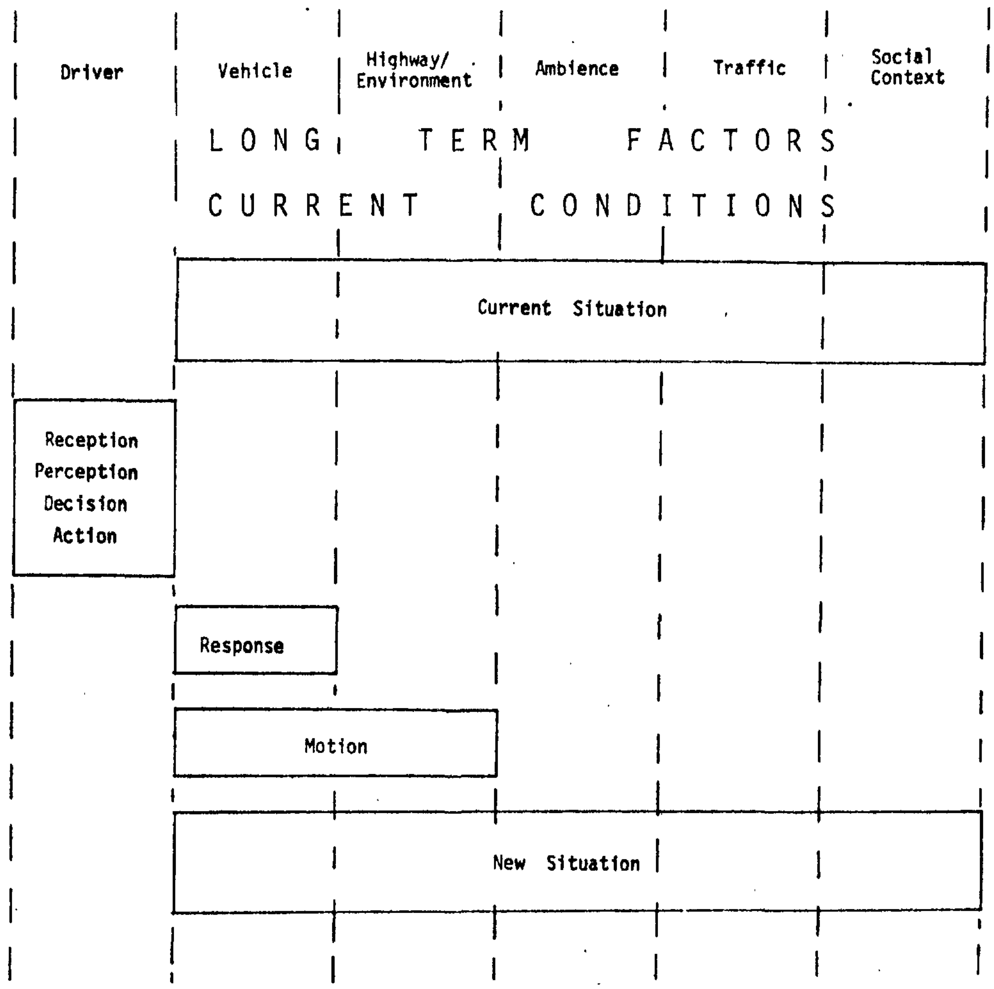


Figure 3.1-2. Organization of the elements of the network into six "columns" (this order is arbitrary).

situations occur commonly in normal driving, e.g., at intersections or if vehicles are following each other. In many cases, it would take a relatively long time before the collision would occur; the situation would change in the normal course of driving and the conflict may be removed long before the collision. Therefore, a time limit has to be imposed. We will not consider a situation a conflict situation if it would take more than a certain time--something more than about five seconds to at most one minute--until the collision would occur. The latter figure appears a reasonable upper limit; it is the time a car traveling at maximum legal speed would need to slide to a stop on an icy road.

If one driver's reaction precipitates an accident, this action also creates a conflict situation, which has to be considered separately from the accident, because another unit might react to it.

It also occurs that a driver involuntarily creates a conflict situation, e.g., to comply with a traffic signal, avoid trespassing on a private road, etc. To distinguish this case from that where the driver initiates a conflict on his own, we define the situation he faces as a *compliance conflict:* if he would not change his vehicle's course or speed, he would violate a --traffic or other--law. Compliance conflicts will be treated in the same way as other conflicts.

The network outlined in Figure 3.1-1 dealt with one unit and one cycle. Many crashes, however, involve several units, and they may also require a sequence of several cycles for adequate description of what went on. If several units are involved, several networks in parallel will be used to describe the crash. There may be some overlap of the conditions and factors, e.g., of the current ambience and highway/environmental features. Cycles can be repeated as often as necessary, though one or two cycles will probably suffice for most situations, and it is unlikely that more than three cycles will ever be needed. Figure 3.1-3 illustrates how networks can be combined and cycles repeated to describe such situations.

To describe an accident completely, the complete content of the information available to the drivers, their decision processes, their actions, and the motion of the vehicles would be needed, also a complete description of the current condition, and the long term factors which had some causal influence. A structure allowing inclusion of all of this would be unpracticably extensive and would also contain much information which is of little or no interest for studying accident causation. Therefore, we will concentrate on "failures"; those factors, conditions or events which were causally involved in the occurrence of the accident, and not just present. This concentration on failures limits the network to "accidents" in the literal sense. Intended collisions, as in the case of suicide or for other reasons, are excluded from consideration. We define *failure* in a very broad sense. First, it means complete failures, such as not seeing an approaching vehicle until the moment of the crash, complete failure of brakes, when activited, etc. Other *failures* are confusion, such as shifting into reverse instead of into a lower gear, turning off lights instead of activating the windshield wiper, etc. The right actions, but performed to a wrong degree, are also considered *failures*: braking too fast, turning the wheel too little, misperception of the speed of an approaching vehicle, etc.

The network concentrates on which failures occur in an accident, and which factors influenced the occurrence of these failures. Conditions, information or activities which are "normal" will nevertheless be retained to some extent in the network because they might be important for the design of countermeasures: some countermeasure may be more easily implementable on certain types of highways, to prevent certain maneuvers--e.g., left turns, might be simpler to prevent than a certain driver failure--though the maneuver in itself is not causal for the accident, etc.

A very frequent category of failures is characterized by descriptions such as "too late", "too fast", or "too close". Such terms are meaningful only, if they are judged against a quantitative scale, and an indication of what would not be too late, etc.

To solve this problem, we have to develop a time structure, which will be outside of the network proper, but related to it. Figure 3.1-4 shows this time structure. When a conflict situation arises, there is a time interval after which the vehicles would crash, if no change in its (their) motion occurs. We will call this *time-to-collision*, t_0. A time, t_1 may elapse until the driver can see (or hear) the situation, another time, t_2,

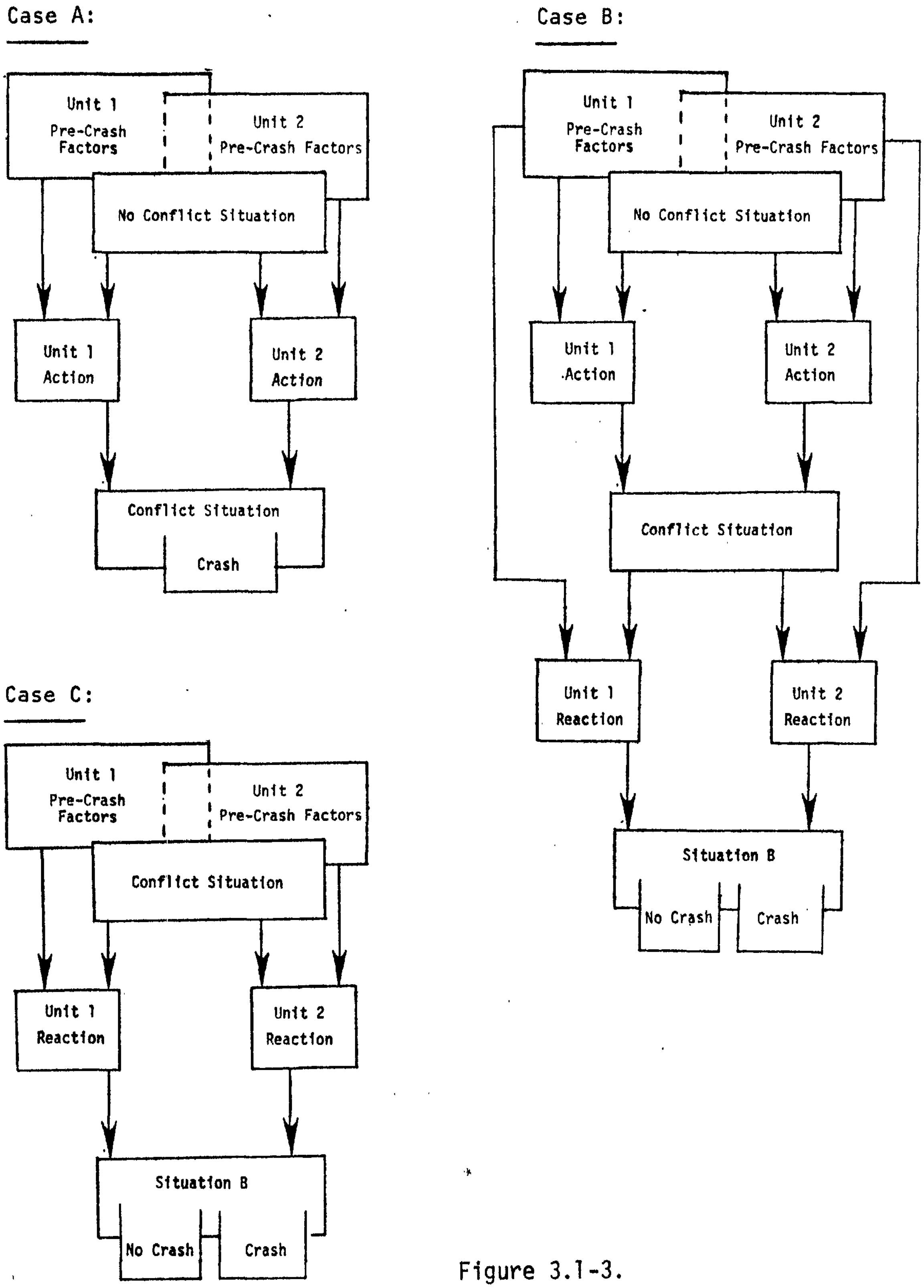


Figure 3.1-3.

Illustration of the combinations of units and cycles to describe complex accident processes. In Case A, the action of one unit, or the joint effects of both units' actions, precipitate a conflict situation which results without further reaction in a crash. Case B is initially the same, but the conflict situation leaves enough time for reactions. Depending on whether reactions occur, and whether they are successful, a crash occurs or the conflict is resolved. In Case C, initially a conflict exists and, depending on the units' reactions, and their success, the conflict is resolved or a crash occurs.

is needed to perceive the meaning of the situation, decision and action take another time, t_3. The mechanical response of the vehicle takes a time, t_4, and the actual change of motion takes additional time, t_5. Except if any single one of these times exceeds t_o, one can not apply the terms "too late", "too slow", etc., and identify any factor influencing such a delay on causes. Rather, it is the addition of all five times, each of which may be within "normal" limits, which "causes" the accident. Any factors which contribute to these delays, in addition to factors which cause or influence other kinds of failures have to be considered "causes" of the accident. To single out one factor is justified only under special circumstances.

The role of the physical motion changes is actually more complicated than adding an additional time, t_5. As the physical motion changes take place, the original time-to-collision, t_o, is changing; if the reaction is successful, the new t_o is increasing rapidly.

Figure 3.1-4 shows the time relations only for one driver and one cycle. In the case of several drivers and several cycles, the relations can become much more complicated. Since the time aspect is beyond the scope of the network proper, we did not develop it further. Also, its application to actual accidents requires much more detailed investigation and reconstruction of accidents than usually done. Nevertheless, this time aspect is a critical concept in defining accident causation.

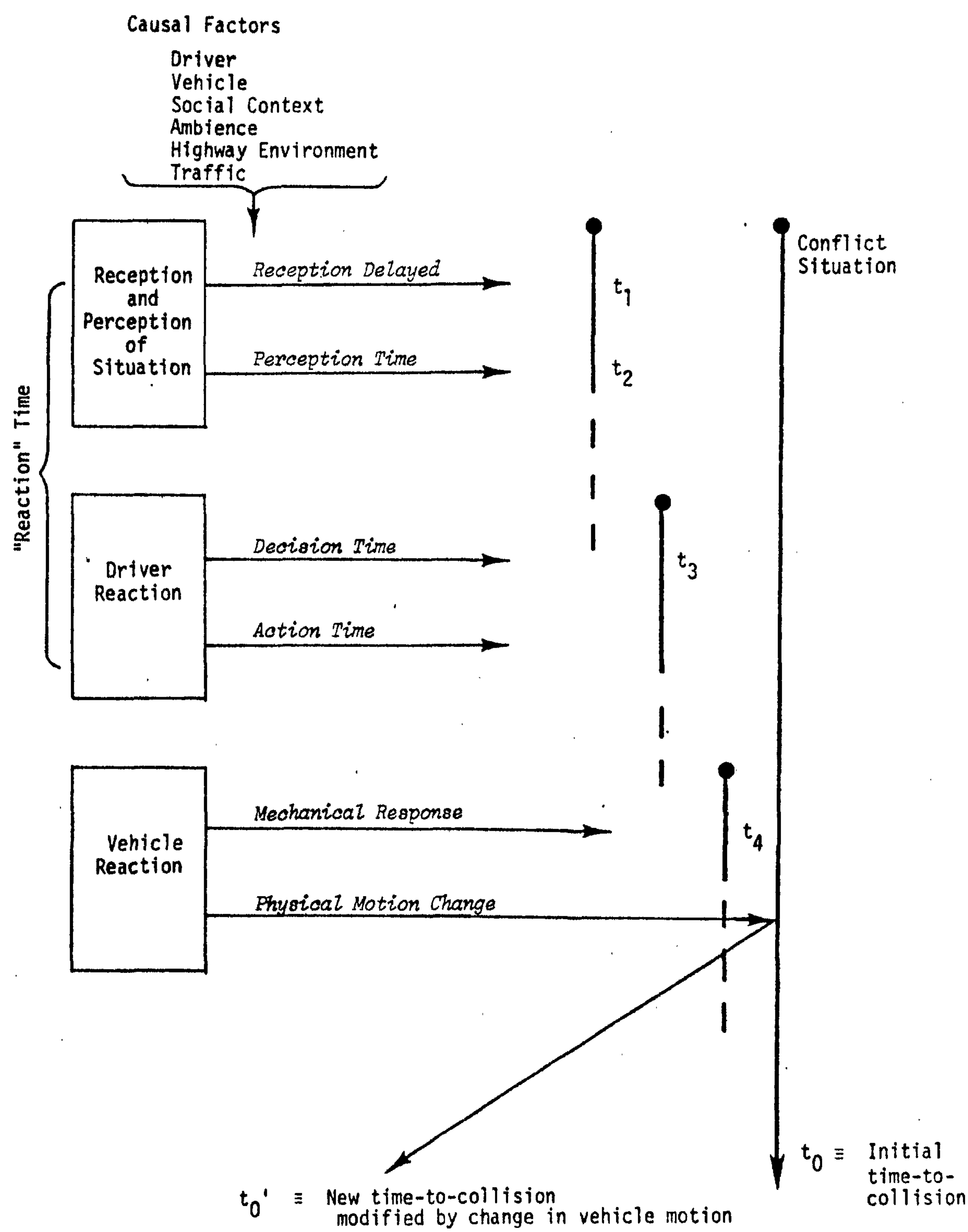


Figure 3.1-4. Relationship of time-to-collision with time delays.

3.2 Detailed Structure

The comprehensive network is presented at three levele:

- A graphical presentation in broad terms, and a list of causal factors in broad terms (Section 3.2.1).

- A graphical presentation of the detailed network in separate parts (Section 3.2.2).

- An extensive list of factors, including a coding scheme (Section 3.3).

3.2.1 The Elements of the Causal Network in Broad Terms

Figure 3.2.1-1 shows the elements of the causal network and the links describing the causal sequence in the normal driving cycle. Figure 3.2.1-2 shows the major links and causal chains leading to failure of elements in these cycles. (The effects of these failures can propagate further through subsequent normal links of the driving cycle.) Table 3.2.1-1 presents a more detailed list of causal factors.

Long-term driver factors cover the usual biographical data, psychological data, including the results of specific tests and self evaluation, driving history, physical disability etc. Some of them directly influence driver actions, or predispose to certain current conditions, e.g., though alcoholism does not "cause" a driver to be drunk at a certain time, it increases the probability of drunkenness. Current driver conditions can be objective, like being drunk, under medication, or subjective, e.g., being frustrated, angry, etc. Current activities, e.g., having one hand off the wheel and doing something non-driving-related are also included.

Sudden driver failures include death, cramps and seizures, but also such trivial events as violent sneezing.

Long-term vehicle factors include all design and manufacturing characteristics, but also normal wear and tear and status of maintenance. Current vehicle conditions include factors such as tire pressure, tire temperature, engine temperature, RPM and fogged or dirty windows. Primary sudden vehicle failures are those which have immediate effects (and do not become noticeable or occur only when the driver takes an action, e.g., depressing the brake pedal), such as blowing a tire or a broken steering element.

Long-term ambient factors are season of the year, geographical location, and the climatological conditions. Current ambient conditions include the weather, but also odors, blowing sand, and lighting. Due to lack of a better place, time of day will also be included (though under some aspects it may also fit under social context). Sudden ambient disturbances are the onset of hail and other severe weather, wind gusts, and failure of highway lighting.

The long-term social context contains laws, regulations and habits and customs. Inconsistencies and discrepancies between states, and also between the law and actual practice within a state can be causal factors. Economic aspects are also included, e.g., the system by which truck drivers are compensated (per

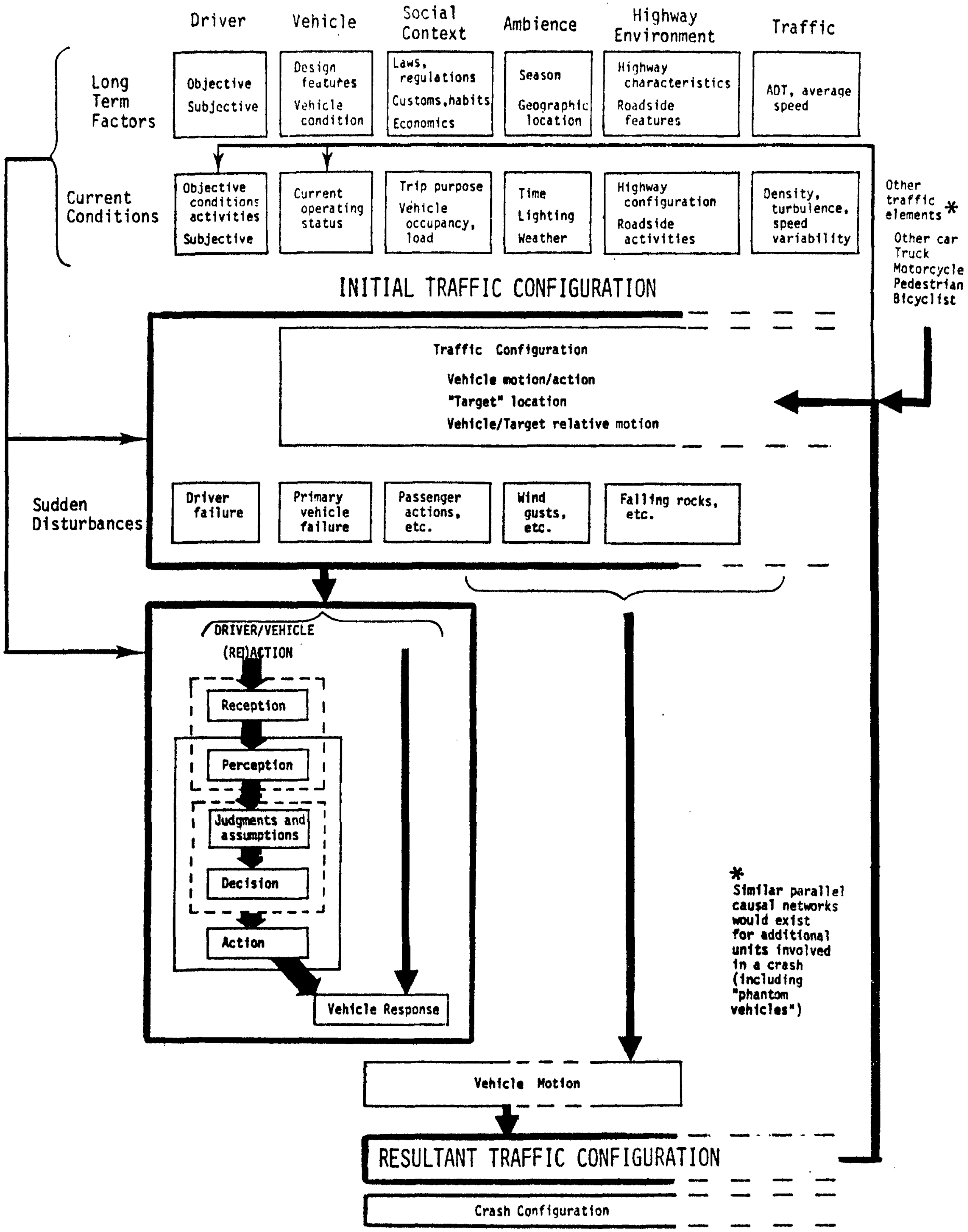


Figure 3.2.1-1. Major elements of the causal network and the causal links forming the normal driving cycle. The heavy arrows indicate very rapid processes, resulting in continuously changing situations. The narrow arrows indicate influences which affect the above changes.

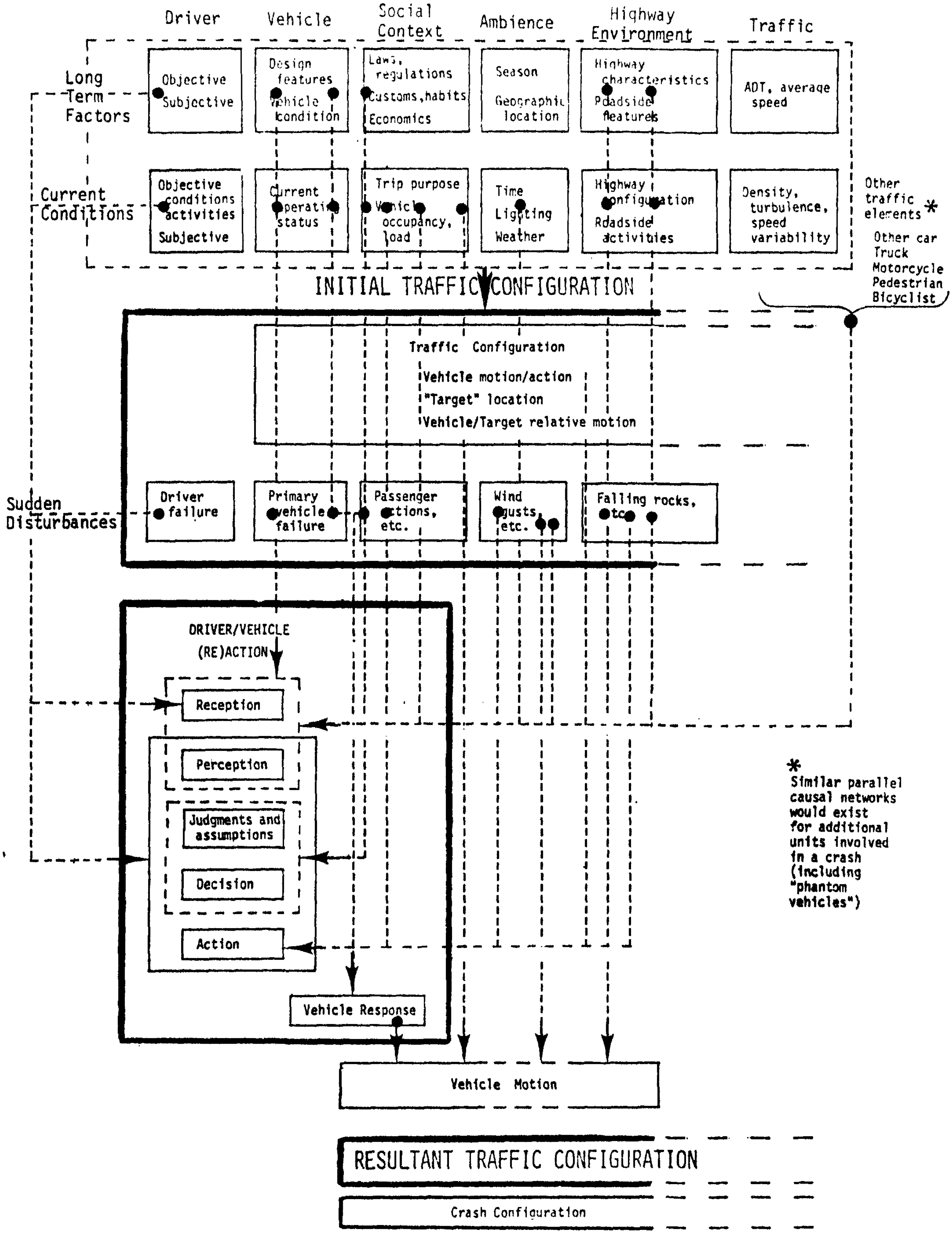


Figure 3.2.1-2. Major elements of the causal network and the major causal links and chains leading to failures in the normal driving cycle. Within the "box" with broken borders many causal and associated relations exist which are not shown to avoid clutter.

mile) or time schedules for bus and other drivers. The current social context includes trip purpose, the interpersonal relations with other drivers on the road (e.g., teenagers), vehicle occupants (cargo, trailer). Sudden social disturbances can originate from drivers, cargo, or accidents in the car.

The long-term highway/environment encompasses the type of highway, design characteristics, control devices, and off-road structures and topography, including land use. Current highway/environment conditions are surface conditions, objects or debris on the highway (including disabled vehicles from a previous accident), operating conditions of traffic signals, and also roadside activities. Sudden highway/environment disturbances are falling rocks, falling limbs, etc. However, if they cause only direct damage, this is not considered a traffic accident. Only if an accident occurs because a driver attempts to avoid falling (not fallen) rocks, or loses control as a consequence of being hit, is it a traffic accident in which the sudden disturbance was a factor.

Long-term traffic characteristics are ADT, average speed, peak volume and the variations of these quantities. Current traffic conditions are density, average speed and its variations, headway and its distribution, vehicle mix, frequency of weaving and merging.

The initial traffic situation is conceptually different from the other factors described. They dealt with the various aspects in isolation; the initial traffic situation, however, describes the position and motion of the case vehicle relative to the highway, and to other case vehicles, if any. Therefore, the description of the initial traffic situation tends to become complex, with the number of conceivable traffic situations being extremely large. Also, traffic situations change quickly and can be influenced only by preceding highway/environment or traffic conditions. Consequently, their usefulness for the study of countermeasures is limited, and only a very gross description of the initial traffic situation appears justified.

Sudden failures are included in the time sequence as simultaneous with the current traffic situation.

Between the initial traffic situation (which is, in principle, observable) and the vehicle motion leading to the crash (which can be reconstructed from the configuration immediately preceding the crash), lies the sequence of driver action and vehicle response. Because, in practice, the disaggregation into the elements is difficult if not impossible, we "boxed" this sequence in Figure 3.2-1. Within this "box," however, there are two elements on which information may be obtained more easily and reliably than on others: the driver's actual reception of information, and the vehicle's response to his actions. The remaining (more difficult to study) elements are again "boxed in." Of these, driver action may be observable by witnesses, or reconstructable from the vehicle's response. The study of the remaining steps of perception, judgment, assumption, and decision has to rely either on information given by the driver concerned, or on the statistical method, using large numbers of cases.

Reception failures can be due to blocking of the driver's view by vehicle parts, other traffic, roadside structures, etc. It can also be due to looking elsewhere for various reasons. The driver can also fail to receive acoustical or sensory information due to masking by "noise" of various kinds.

Perception failures consist of not recognizing the meaning of information received, e.g., a colored light as a traffic signal or lights as headlights of a car--and to incorrectly estimate distances and speeds. Some may be due to driver factors; others can be influenced by external factors, e.g., an overload of information. Also, limiting the reception of information (by a dirty windshield, for instance) can lead to reception failures.

Having perceived a situation, a driver has to make a decision. He has to judge the perceived situation in terms of risk. He may make explicit or implicit assumptions on unseen traffic units, or the behavior of other drivers; he has to consider alternative actions, and make a decision based on his judgment of the success probability of the actions and the values he attaches to the actions. "Failure" can occur by misjudging this risk of a situation or maneuver, making wrong assumptions, not considering all possible actions, and by attaching "faulty" values to certain actions (e.g., a negative value to slowing down in a risky situation, but a positive value to trying to evade it at high speed with a complicated maneuver).

A driver's action following a decision can fail for many reasons: the driver may physically be able to move his arms or legs as desired, his clothing may get caught in the controls, or he may confuse the controls in an unfamiliar vehicle.

The vehicle's response may fail completely, e.g., if the brake system fails when pressing the pedal, or it may respond more or less as he intended, e.g., the engine may accelerate with great delay if the accelerator is suddenly depressed,the steering may react imprecisely if the system has a lot of play, etc.

The vehicle motion is the result of the mechanical response of the vehicle and certain preconditions, primarily speed, road surface conditions and vehicle characteristics. There are two types of motion failure: skidding and rollover, but a variety of factors contributes to them.

The resultant traffic configuration contains the same categories as the initial traffic configuration: vehicle motion/action, "target" location, and "target" relative motion. The resultant configuration evolves from driver/vehicle actions. If the causal network were used like a simulation model, the resultant configuration would then become the initial traffic configuration at the beginning of each new cycle. A reasonable time step to use when thinking about the iterative nature of the driving cycle is about twice per second. In the event that the resultant traffic situation does not resolve the initial conflict, a crash will result. The crash configuration will closely match the resultant traffic configuration.

TABLE 3.2.1-1

LIST OF CAUSAL FACTORS (Level 2)

<u>LONG-TERM DRIVER CHARACTERISTICS</u>

- Objective
  - Personal
    - General
    - Family
    - Personal History
    - Driving-Related Personal History
    - Non-Vehicle Accidents
  - Socioeconomic
    - Education
    - Employment/Occupation
    - Residence
    - Activities
    - Achievement
    - Vehicle-Related
  - Driving Experience
    - General Driving History
    - Driving Record
    - Exposure
    - Simulator Responses
  - Physiological
    - Vision
    - Hearing
    - Reactions
    - Coordination
    - Chronic Disease/Condition
    - Recent Change in Physiological Condition
- Subjective (e.g., weight gain/loss)
  - Behavior
    - General
    - Driving-Related
  - Satisfaction
  - Attitudes
    - General
    - Driving-Related

<u>CURRENT DRIVER CONDITIONS</u>

- Objective
  - Physiological State
  - Familiarity
  - Activities
- Subjective
  - Emotional State

<u>IMMEDIATE DRIVER EVENTS</u>

- (Driver Failures)
  - Action Limiting
    - Internal
    - Externally Induced
  - Reception Limiting
    - Internal
    - Externally Induced

<u>LONG-TERM VEHICLE CHARACTERISTICS</u>

- General Characteristics
- Design Features of:
  - Mechanical Systems
  - Driver-Related Systems
- Use and Wear Status

<u>CURRENT VEHICLE CONDITIONS</u>

- Vehicle Operating Conditions
- Vehicle Speed

<u>IMMEDIATE VEHICLE EVENTS (PRIMARY FAILURES)</u>

- (Sudden Failure of the Systems Listed Above)

<u>LONG-TERM SOCIAL CONTEXT CHARACTERISTICS</u>

- Laws and Regulations
- Customs and Habits
- Economics

<u>CURRENT SOCIAL CONDITIONS</u>

- Trip Purpose
- Vehicle Occupancy and Load

<u>IMMEDIATE (SOCIAL) SITUATIONAL EVENTS</u>

- Actions by Passengers

<u>LONG-TERM AMBIENCE</u>

- Environmental Features
  - Season
  - Geographical Location

<u>CURRENT AMBIENT CONDITIONS</u>

- Meteorological Conditions
- Temporal
- Lighting

<u>SUDDEN AMBIENT CHANGES</u>

- (Examples: Wind gusts, lightning, etc.)

<u>HIGHWAY ENVIRONMENT CHARACTERISTICS</u>

- Road Characteristics
  - Location
  - Highway Class
  - Posted Speed
  - Geometry
  - Medians
  - Road Surface Type
  - Illumination Type
  - Traffic Control Devices
  - Traffic Flow Regulation
- Roadside Features and Structures
  - Highway Related
  - Non-Highway Related

<u>CURRENT HIGHWAY CONDITIONS</u>

- Highway Configuration
  - Road Surface Condition
  - Local Highway Geometry
  - Traffic Control Device Status
- Roadside Activities
  - Highway Related
  - Other

<u>SUDDEN HIGHWAY ENVIRONMENT EVENTS</u>

- (Example: Rockslides, etc.)

<u>LONG-TERM TRAFFIC CHARACTERISTICS</u>

- Highway Volume and Capacity
- Average Travel Speed

<u>CURRENT TRAFFIC CONDITIONS*</u>

- Traffic Density
- Turbulence/Traffic Flow
- Speed Variability

<u>INITIAL TRAFFIC SITUATION</u>

- Vehicle Motion/Action
  - Vehicle Control
  - Vehicle Motion
  - Vehicle Action
  - Vehicle Situation
  - Vehicle Signaling

Table 3.2.1-1 (Continued)

INITIAL TRAFFIC SITUATION (continued)
Target Location(s)
  Direction
  Distance
Target Relative Motion
  Direction
  Closing Speed
DRIVER RECEPTION
  Mode of Reception
    Visual
    Auditory
    Sense of Equilibrium/Acceleration
  Reception Failures
    Visual
    Auditory
    Sense of Equilibrium/Acceleration
DRIVER PERCEPTION
  Identification of Object
  Content of Information
    Meaning
    Position of Other Vehicles/Objects
    Direction of Motion
    Speed
    Immediately Reaction Producing
  Perception Failures
    Meaning
      Visual Information
      Auditory Information
      Sense of Equilibrium/Acceleration
    Position of Other Vehicles/Objects
    Direction of Travel (relative to Case Vehicle)
    Speed
	DRIVING JUDGMENTS AND ASSUMPTIONS
	  Subject of Driver Judgment and Assumptions
	    Highway
	    Other Drivers/Vehicles
	    Environment
	    Other
	  Basis of Judgments and Assumptions
	    Knowledge
	    Experience
	DRIVER DECISIONS
	  Range of Choice
	  Type of Decision
	    Character of Decision
	    Nature of Action
	    Values Involved
	DRIVER ACTION
	  Type of Action
	  Success of Action
	VEHICLE RESPONSE
	  Vehicle System Involved
	  Success of Response
	VEHICLE MOTION
	  Vehicle Control
	  Vehicle Speed/Direction
	RESULTANT TRAFFIC SITUATION
	  (Same Categories as Initial Traffic Situation)
	CRASH CONFIGURATION
	  Type of Accident
	  Impact Location

3.2.2 Detailed Subnetworks

One can conceive of a comprehensive network, showing all conceivable causal links and thereby allowing construction of all possible causal chains leading to failure. However, even a network showing only the most important causal links in an aggregate fashion is already cluttered, as Figure 3.2.1-2 shows. A really comprehensive network would be practically incomprehensible.

Therefore, we disaggregated the network into 15 subnetworks, which present the immediate causal links leading to failure in each of the 15 elements of the network. They are:

1. Driver conditions
2. Driver failures
3. Vehicle failures
4. Vehicle speed
5. Sudden social disturbances
6. Sudden ambience disturbances
7. Sudden highway/environment disturbances
8. Visual reception failures
9. Auditory reception failures
10. Failure to sense equilibrium/acceleration
11. Perception failures
12. Assumption/decision failures
13. Driver action failures
14. Vehicle response failures
15. Vehicle motion failures.

If possible, only the link immediately preceding a failure is shown, and links further removed can be traced by means of the other subnetworks. In many cases, however, the networks contain parts of causal chains, composed of two or three elements. Sometimes an indication of the importance or strength of a link is given by using broken lines instead of solid lines. Many factors lead directly to a failure, either with certainty or near certainty, or with a certain probability, completely or largely independent of other factors. In this case, a simple arrow is used. In other cases, the occurrence of a failure requires the presence of two or more factors, or the probability of a failure, or its degree depends on the interaction of two or more factors. In this case, two or more lines join a common "arrowhead."

In some cases the interaction of several factors can be identified by an intermediate factor which precedes a failure. For instance, the interaction between vehicle motion, tires and highway surface results in a friction force, which, combined with vehicle forces, determines whether skidding occurs.

The networks presented have been made as comprehensive as appeared meaningful, in our judgment. One can easily think of more causal factors, but we consider them to be of little numerical importance. On the other hand, some of the causal factors included and interactions shown may be actually of little or no practical relevance. These are questions of empirical knowledge which will be addressed in Section 4.0.

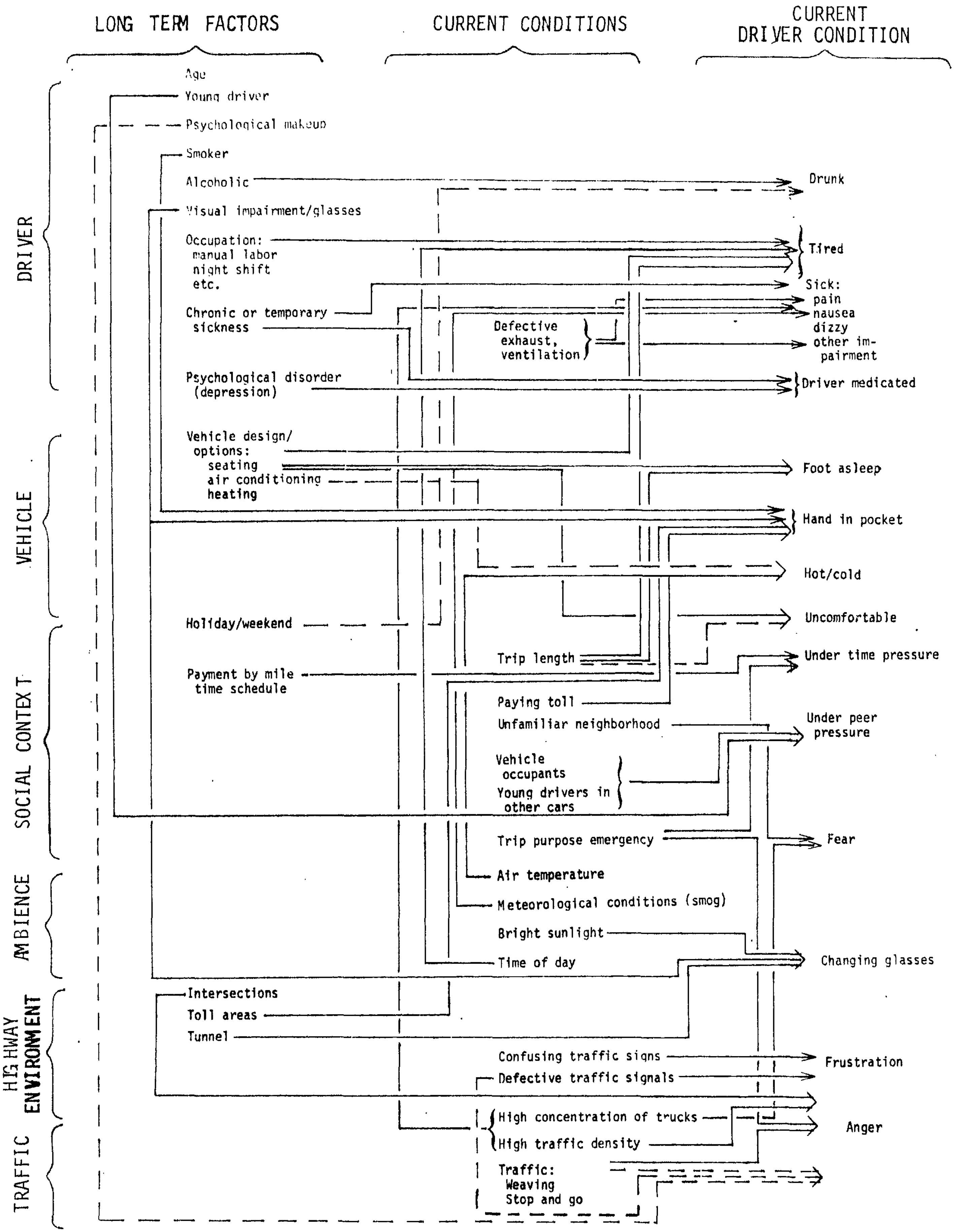


Figure 3.2.2-1. Current driver condition.

(1) Driver Conditions

The current driver condition is a particularly important element in accident causality as it integrates many long-term and current conditions and influences several step in the decision/action unit; feedback from the ongoing driving experience also affects the current driver condition.

The current driver condition can be broken down into three categories:

- Psychological conditions: frustrated, angry, hostile, depressed, elated, afraid, suicidal, carefree, nervous, pressured, etc.

- Physiological conditions: dizzy, drunk, tired, medicated, watery eyes, in pain, nauseous, suffering from specific temporary impairment, etc.

- Activities:
    - Driving related: searching for money for toll, passes, rolling down window to pay toll, etc.
    - Driver required: changing glasses, searching for handkerchief, etc.
    - Optional: eating, drinking, smoking, shaving, applying makeup, etc.

We can also break down the sources of psychological conditions into:

- Internal causes (non-driving related problems)
- Traffic induced (stop/go, weaving and merging, etc.)
- Highway induced (confusing/inconsistent signs and signals, etc.)

Some of the elements included in the driver condition network and subsequent networks are generic in nature and do not contain subcategories of detailed activities or states. For example, the trip purpose can significantly affect a given driver's reaction to difficult or slow driving conditions. Trip purpose can be divided into the following subcategories as given in *Automobile Facts and Figures* :

- Business
    - Commuting
    - Other business
- Family business
    - Shopping
    - Other; dentist, doctor, etc.
- Education, civic, religious
- Social and recreational
    - Vacations
    - Visiting friends and/or relatives
    - Pleasure rides
    - Other.

Relatively rare, but having a high accident potential, are emergency runs, not only by police, fire engines, and ambulances, but also by private drivers.

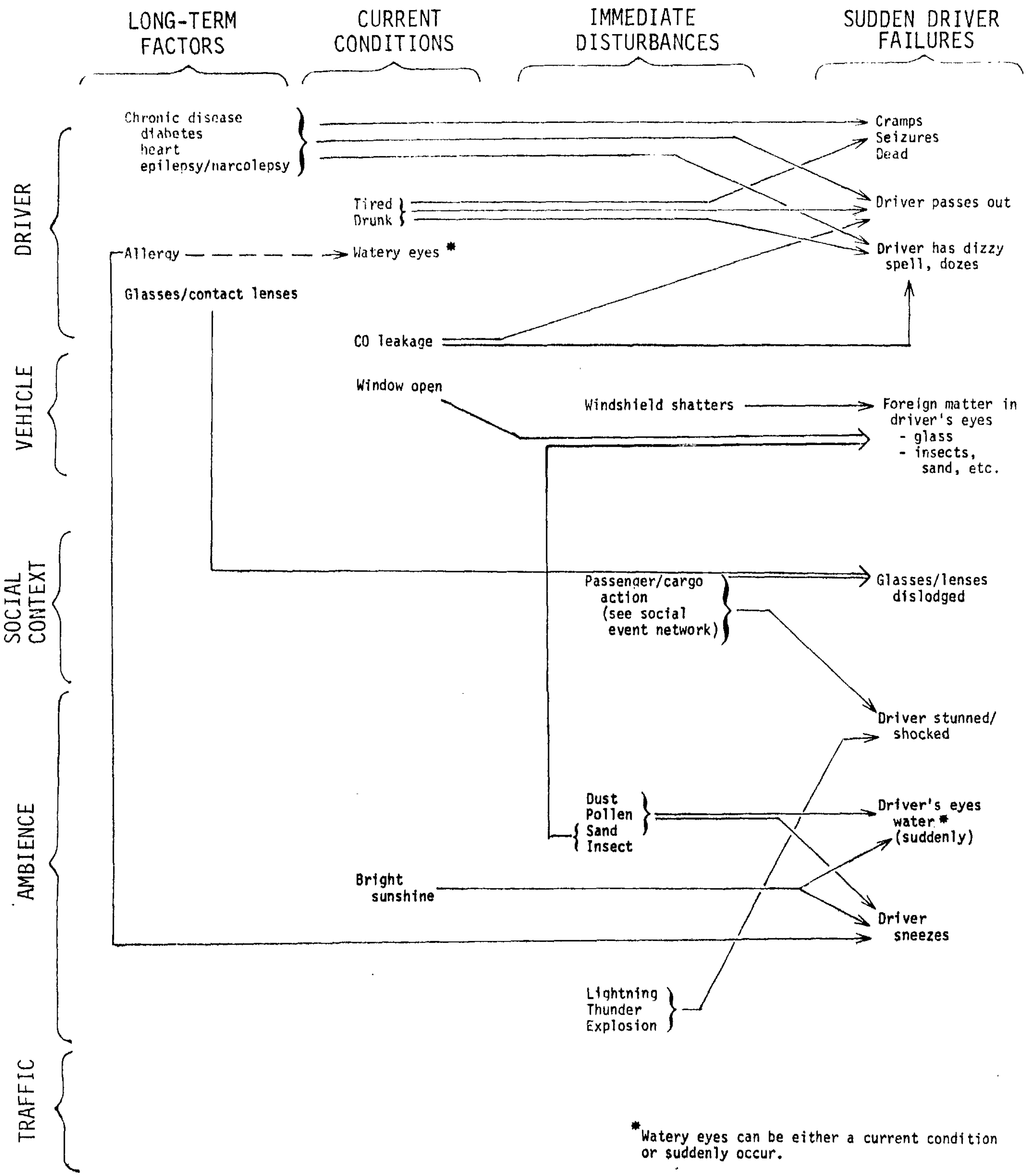


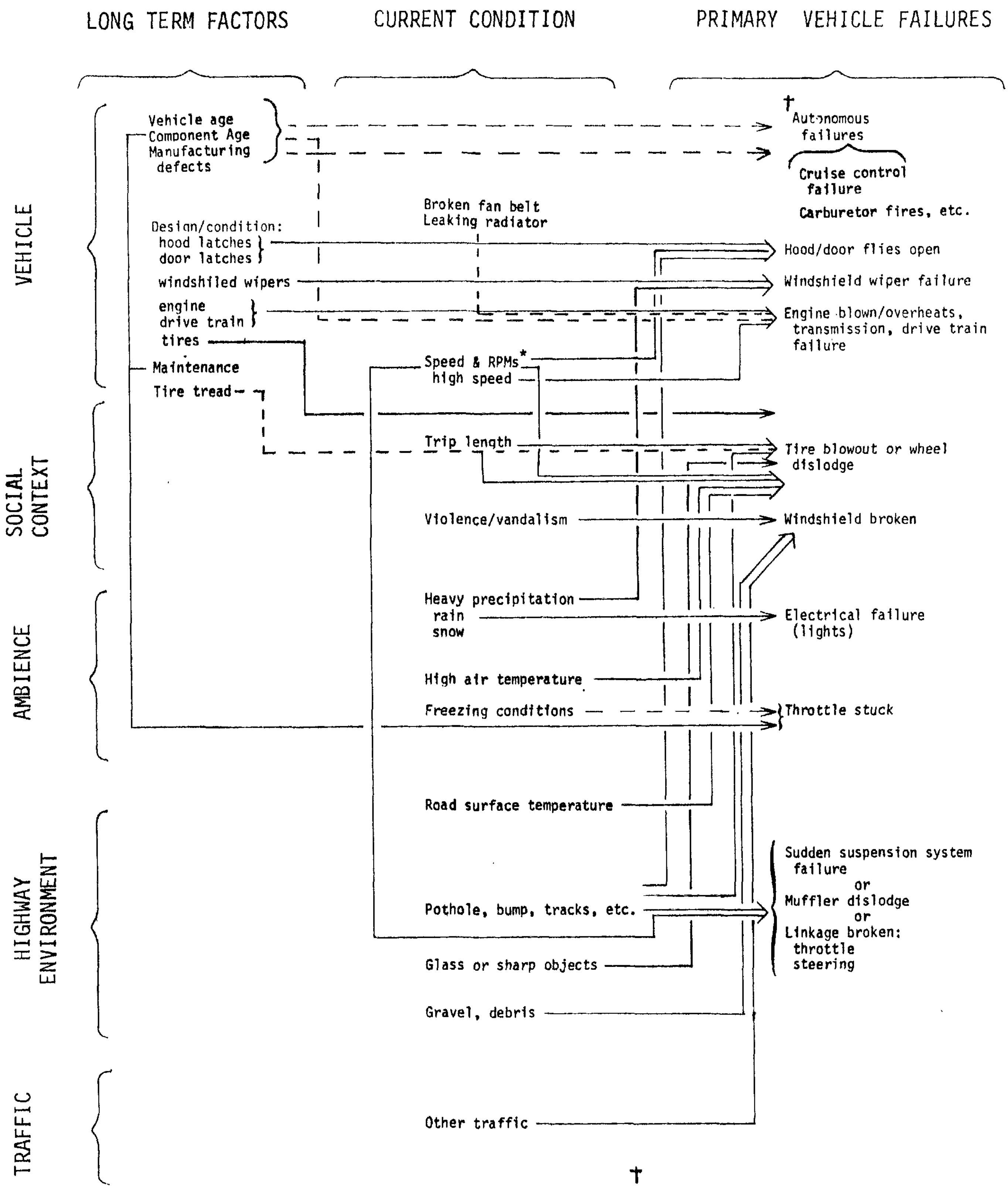
Figure 3.2.2-2. Sudden driver failures.

(2) Sudden Driver Failures

Sudden driver failures are either internally generated (cramps, dizziness, etc.) or externally induced (glasses dislodged, sneezing caused by cloud of dust or pollen, etc.). Many of the failures are partially limiting, such as a dizzy spell; however, some are absolute. Finally, some driver failures are action-limiting, such as cramps in an arm or leg, and some are reception-limiting, like glasses dislodged.

Many of the elements in the driver failures network have the potential for causing several types of driver failure. For example, the current driver condition of tired or drunk can be directly related to the driver failures of cramps or seizures, passing out or a dizzy spell. Similarly, many of the driver failures can be related by a number of causative factors acting independently or in concert. For example, a dizzy spell can result from a chronic disease, a current driver condition of tired or drunk, CO leakage in the vehicle, or noxious odors in the environment, most likely associated with truck traffic.

Unlike most of the 15 networks, only one causal chain is depicted in which the simultaneous presence of two or more elements is required for the resultant effect. When the driver's glasses are dislodged through his interaction with passengers or cargo in the vehicle, obviously it is required that both the driver wear glasses and the interaction takes place. All other elements shown can lead to a driver failure, independent of the presence of other factors. Clearly, some elements could be in effect simultaneously (e.g., chronic disease and tired and drunk), and might thereby considerably increase the probabilities of a factor, or its degree, but such interactions are not essential for a given driver failure.



*See vehicle speed network

† Autonomous failures can occur without any obvious cause beyond age or manufacturing defect. However, such autonomous failures can be contributors to other failures.

Figure 3.2.2-3. Primary sudden vehicle failures.

Primary Sudden Vehicle Failures

The primary vehicle failures are those which occur spontaneously, and not as a consequence of a driver action (or becomes noticeable when the driver attempts an action). Their occurrence can be strongly influenced by such current conditions as vehicle speed, or less strongly through long term factors like the maintenance practices of the driver. The Secondary vehicle failures which occur or become noticeable when the driver tries to do some maneuver are detailed in the vehicle response network. The primary vehicle failures can be autonomous (primarily age related) or they can be caused by the current situation, such as a bumpy road or high speeds, etc.

As might be anticipated most of the primary vehicle failures result from the interactive effects of a number of network elements. The likelihood of a tire blowout or wheel dislodgement will be affected by vehicle speed, trip length, air temperature and road surface temperature. The possibility that the engine hood or a side door will suddenly fly open is dependent on the design and condition of the hood latches and door latches, the vehicle speed and the road surface condition, especially the presence of potholes, bumps, or other surface irregularities.

Most elements in the network are very specific. An exception, violence/vandalism which results in a broken windshield, could be expanded as follows:

Violence/vandalism
- Riots
- Strikes
- Crime
- War
- Random impulses

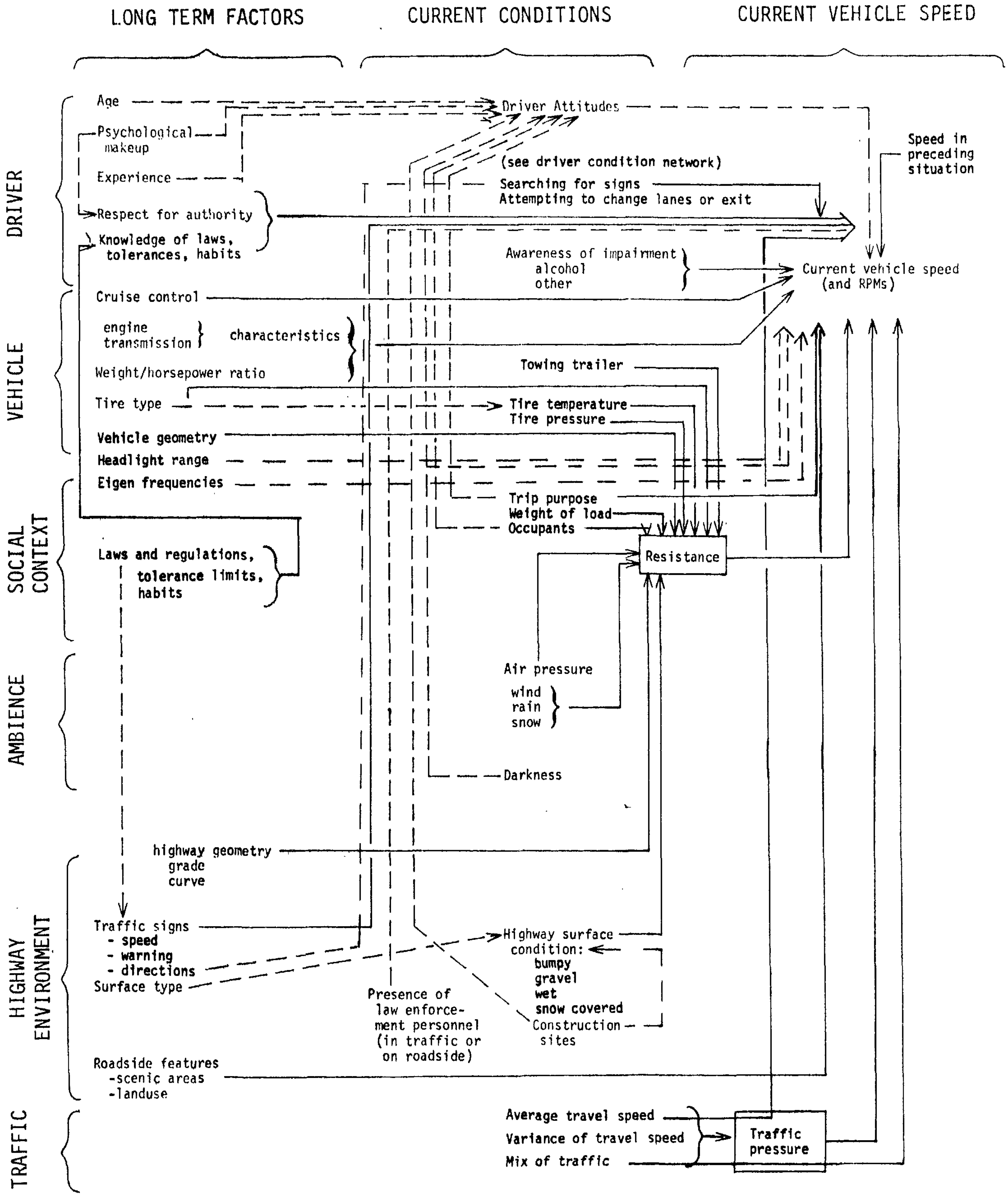


Figure 3.2.2-4 Current vehicle speed.

(4) Current Vehicle Speed

Vehicle speed enters the network at various places. It is a current condition which influences the operating conditions of the engine ; it constitutes an important part of the traffic situation, and thereby indirectly influences the driver's reception, perception and decision; it may influence the vehicle's reaction; and it is a key factor in determining the vehicle's motion.

Unlike most conditions, current speed is a result of a continuous feedback process which incorporates many factors relating the driver, vehicle, highway, ambience, social context and traffic. Some factors exert a direct physical influence, others impose physical limits. It might be possible to assess their influence to some extent. On the other hand, it appears impossible to quantify the absolute and relative impacts of all those factors which influence speed via the driver's largely implicit decisions. At best, what appears possible is to identify those factors which influence the average speed of all drivers in a certain situation, averaging out the specific factors which apply to individual drivers only. On the other hand, it might be easier to identify factors which influence a certain driver to considerably deviate from the average speed (or better, typical speed because the average is influenced by extreme speeds).

Such a concentration or deviation from the "typical" speed would conform to the attitude taken with regard to the rest of the network: to concentrate on "failures"--deviation from the normal or usual course of events--and to treat the normal factors as background information only.

Not all the factors which influence the current vehicle speed are shown in this network. The driver condition network has a lot of detail on what might influence driver attitudes, which influences speed as well as other driving parameters. The combination of trip purpose and roadside features is an illustrative example of how combinations of factors would influence current speed. Given scenic roadside areas and trip purpose being sightseeing, one would surely observe a slower vehicle speed. Another example might be searching for an address in an unfamiliar area.

Some of the elements in the current vehicle speed network that can obviously be considered in greater detail are given below:

Vehicle Geometry
- Dimensions
  - Length
  - Width
  - Height
- Weight
- Contour Characteristics
- Vehicle Load
  - Passengers
- Engine Tuneup Status
- Transmission Type

Tire Type
- Radials
- Non-radials
- Winter

Towing Conditions
- Trailer
- Boat
- Car

Surface Type
- Black top
- Concrete
- Dirt, gravel

Surface Conditions
- Wet
- Icy
- Snow covered
- Dirt covered
- Broken
- Joints, grills, etc.

Highway geometry
- Grades
- Curves
- Lane drops
- Lane markings
- Entering lanes: right, left
- Exit lanes: right, left
- Proximity of exits

Roadside Features
- Scenic areas
  - Mountains, hills
  - Valleys
  - Coastal
- Land use
  - Agricultural
  - Commercial
  - Residential
  - Forests/National Parks, etc.

Traffic
- Density
- Mix
  - Vehicle types
  - Trip purposes
  - Local/long-distance
  - Volume of entering and exiting traffic

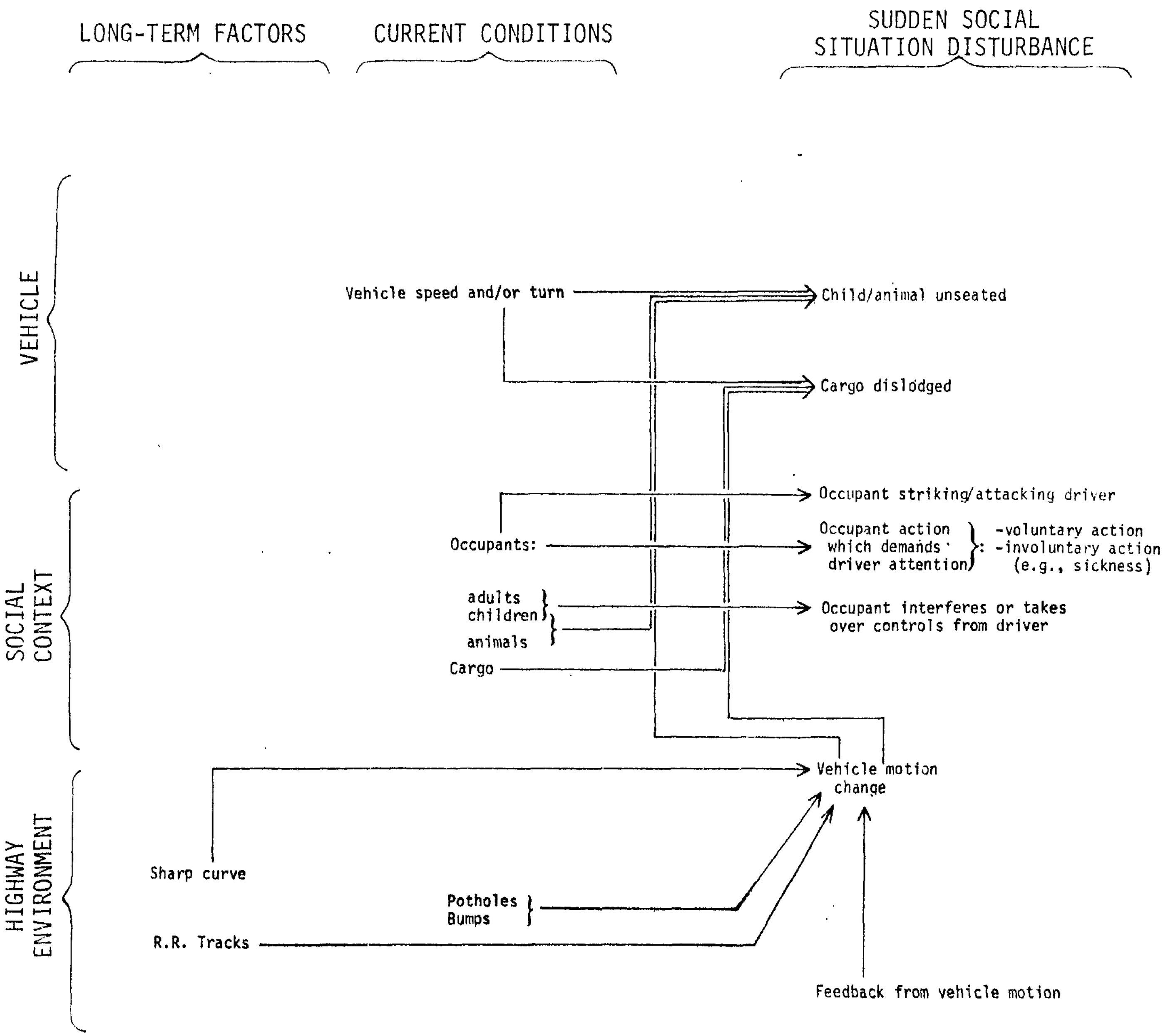


Figure 3.2.2-5. Sudden social situation disturbance.

(5) <u>Sudden Social Situation Disturbances</u>

Vehicle occupants or cargo are the elements of the social context which can have an immediate impact on the driver/vehicle unit. They can either cause the disturbance directly (striking driver, etc.) or they can be affected such that they create a disturbance (becoming dislodged from seat, etc.). These events mostly affect the driver's performance but one can conceive many situations in which the vehicle could be affected--glass being shattered, doors opened, controls blocked, etc.

A sudden change in vehicle motion can create or aggrevate a sudden social situation disturbance. The vehicle motion can be rather abruptly changed by surface irregularities such as potholes, bumps or railroad tracks, or by the driver's reaction to the situation, resulting in a sharp turn, sudden braking or combinations of such actions. The sudden motion change can dislodge cargo which could either strike a driver or distract him. Similarly, animal, children or even adults can become unseated due to sudden motion change and either bump the driver or cause a disturbance within the vehicle.

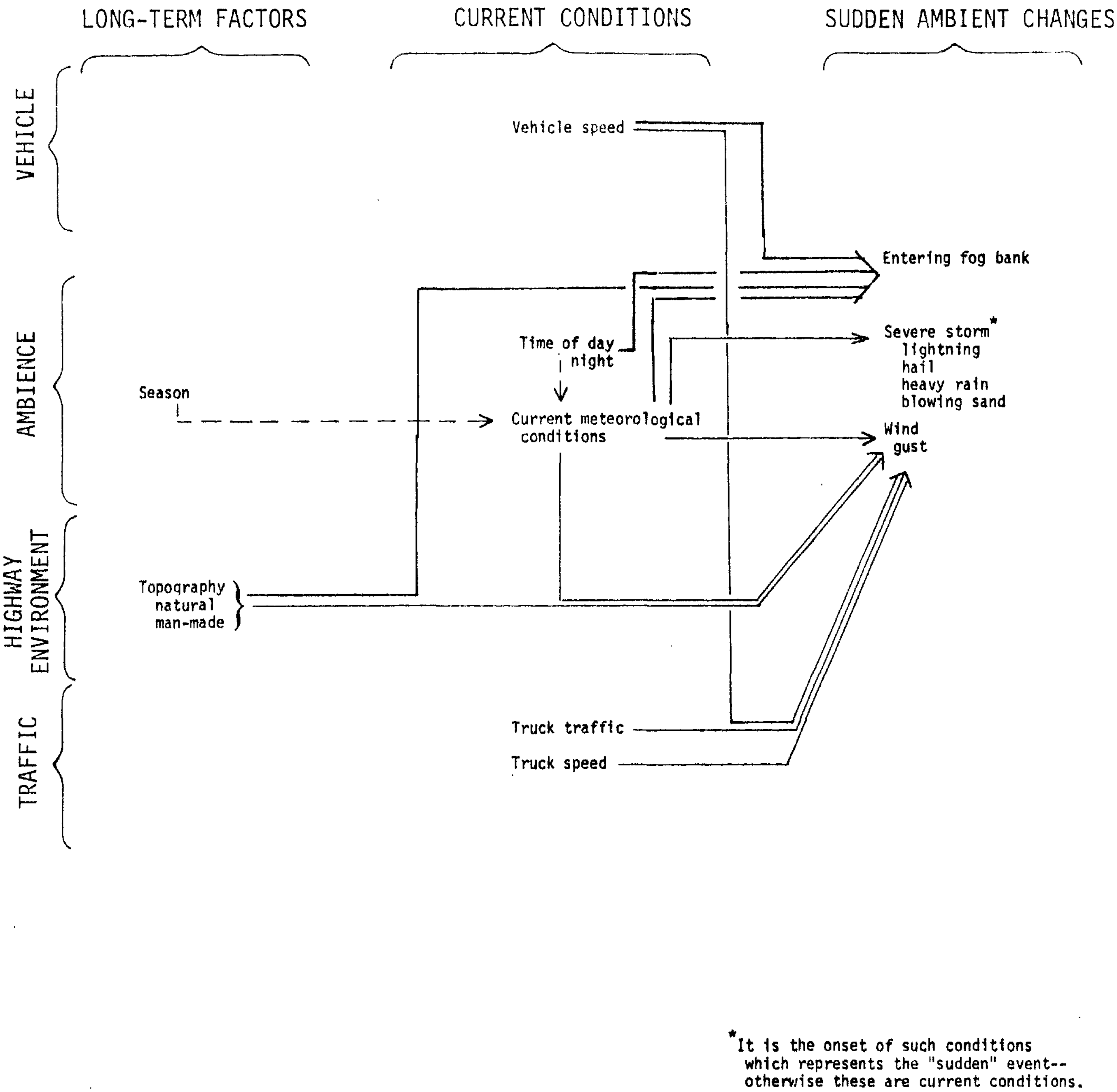


Figure 3.2.2-6. Sudden ambient changes.

(6) Sudden Ambient Disturbances

We have found only two types of sudden changes in ambient conditions. One is the *sudden* onset of meteorological events like severe storms. The suddenness and concentrated nature of these events can have a effect on the driver receiving information and even possibly create a panic situation if the driver is overwhelmed quickly. Wind gusts are the second. These factors can be influenced by both physical conditions and traffic conditions.

In this network, the elements season, topography and current meteorological conditions are generic in nature and could be considerably to include the following sub-categories:

Topography

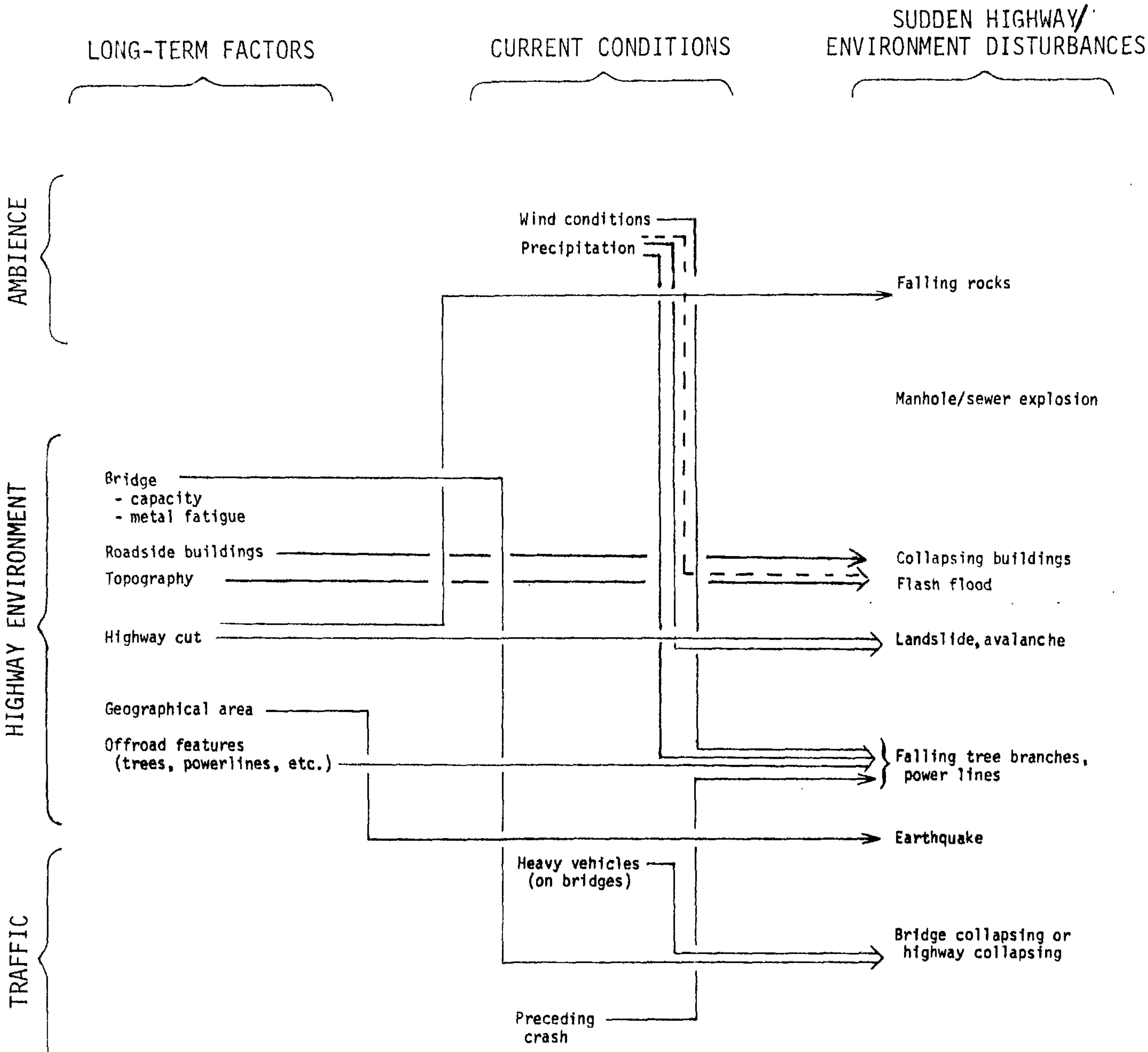
- Natural
  - Mountain, ridge, hill, crest
  - Valley, hollow, dingle
  - Proximate body of water: lake, pond, also bog
  - Orientation to prevailing wind direction
- Man-made
  - Bridge
  - Tunnel
  - Buildings
  - Embankment

Season

- Temperature/Arctic Climate
  - Winter
  - Spring
  - Summer
  - Fall
- Tropics
  - Wet
  - Dry

Current Meteorological Conditions

- Sky cover
  - Clear
  - Partly cloudy
  - Cloudy
- Visibility
  - Clear
  - Haze
  - Fog
  - Smog
- Precipitation
  - Rain/showers
  - Snow/snowflakes
  - Sleet
  - Thunderstorms
  - Hail
  - None
- Atmospheric Pressure
- Wind
  - Direction
  - Speed
- Air Temperature
- Humidity
  - Absolute
  - Relative



*If these events directly cause an accident, it is considered a non-traffic accident. They also can create a conflict situation, which may precede an accident.

Figure 3.2.2-7. Sudden highway environment disturbances.

(7) Sudden Highway/Environment Disturbances

The sudden highway environment disturbances are rather infrequent events which have a high degree of randomness to their occurrence (falling rocks, earthquakes, etc.) If an accident is caused by the direct action of the disturbance, e.g., a rock hitting a vehicle, a bridge collapsing under the weight of a vehicle, then the accident is a non-traffic accident. They can cause traffic accidents, however, if a driver tries to evade a falling rock, makes a panic stop when approaching a collapsing bridge, etc.

Not all rare, random sudden highway environment disturbances are shown in the network. Other examples include a manhole/sewer explosion or a catrostrophic event (explosion and fire) in industry or buildings in the immediate vicinity of the highway.

Some of the highway environment disturbances, while sudden, are much more likely to occur after persistent adverse atmospheric conditions. For example, the likelihood of a landslide or avalanche is enhanced by a fairly lengthy period of moderate or heavy precipitation. Problems with falling tree branches and broken power lines often occur during prolonged windy conditions with the occasional stronger gust that may precipitate the disturbance.

Some of the generic factors in the network that could be considerably expanded include bridge, geographical area, and off-road features. These are given below:

Geographical Area

- Coastal Plain
- Interior Plain/Plateau
- Hills/Lowlands
- Mountainous Region

Bridge

- Suspension
- Truss and Girder
- Concrete

Off-Road Features

- Adjacent Features
  - Highway furniture
    - Signs
    - Lamp post
    - Bridge abutements & supports
  - Non-Highway
    - Trees
    - Poles
    - Buildings
    - Shopping Centers, etc.
- Overhead Features
  - Highway furniture
    - Overhead signs
    - Overhead lights
    - Pedestrian crossings and bridges
  - Non-Highway
    - Tree branches
    - Transmission lines
- Topography
  - Cuts
  - Rivers, brooks

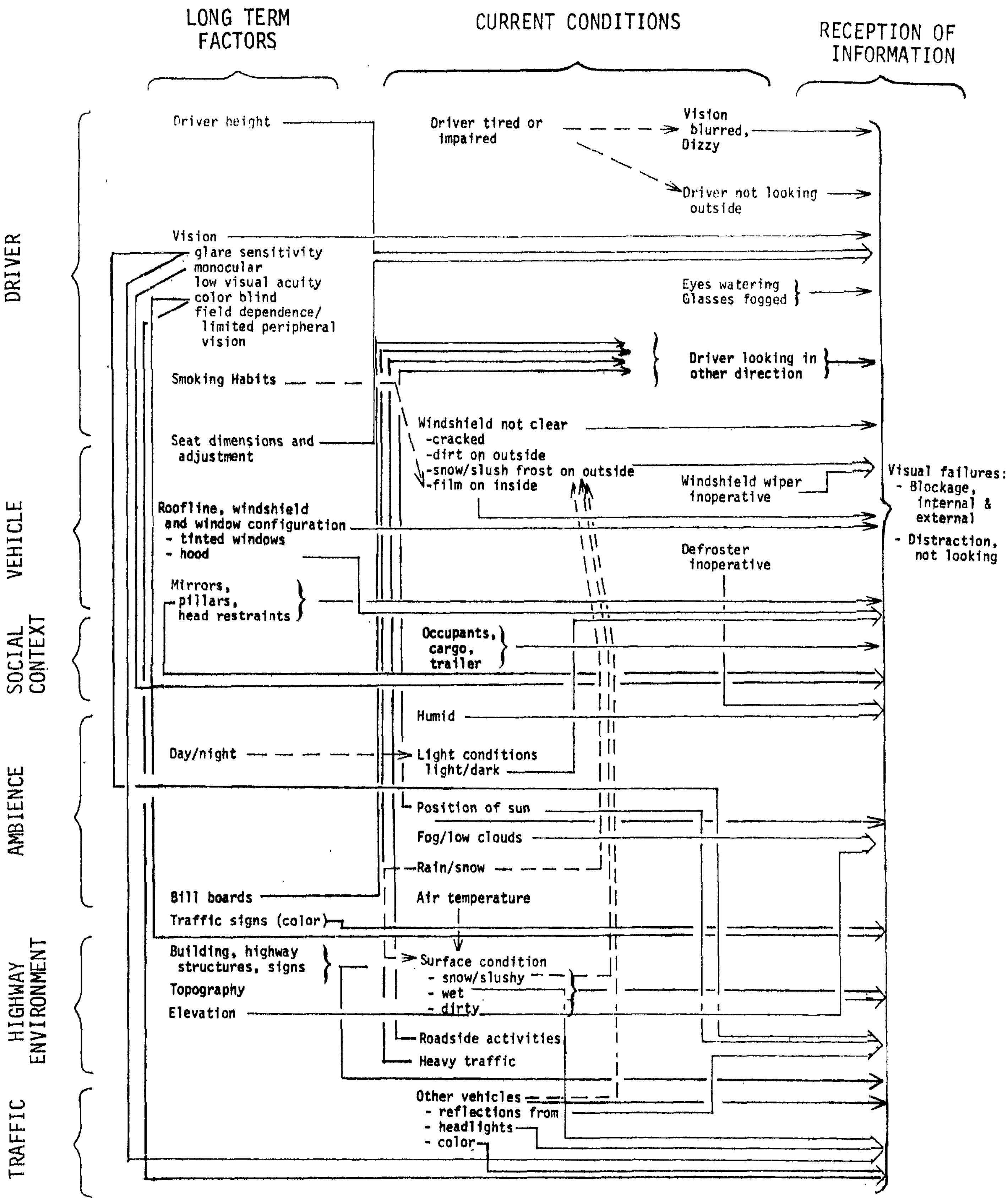


Figure 3.2.2-8. Reception of information: visual.

(8) Failure to Receive Visual Information

Reception of visual information may fail or be delayed due to blocking, or the driver looking elsewhere. The blockages can be due to driver incapacity vehicle limitations, or other elements. Normally, the blockage is total in the sense that a building or truck totally hides other objects or traffic units. However, many factors do not totally block the visual images, e.g., tinted glass at night may reduce the contrast between a sign and its background; by reducing the signal to noise ratio, they impede the perception of the signal (see network on perception failure).

A large number of factors can act alone in impeding or blocking the reception of information. In many cases, however, several factors have to act jointly to cause visual failures.

We have not attempted to exhaustively illustrate all conceivable interactive effects in what is already a rather complicated network. For example, obvious dirrect effects of monocularity can be aggravated by the configuration of windshield windows; the blocking effects of pillars will be more serious for a monocular driver, etc. Color blindness may have an interactive effect with a tinted windshield. The effects of color blindness also depend strongly on the color patterns of the object and observed and on the background, e.g., traffic signals or vehicles against vegetation or buildings, etc.

An important reason for not seeing something is looking elsewhere. This can be for an extended period of time, or just for brief moments, e.g., turning the head while taking a single brief look, or scanning a complex situation. There are many reasons for looking elsewhere. Traffic in general, or certain vehicles, may require special attention, such as traffic entering from an entrance lane, a vehicle approaching an uncontrolled intersection; being in the middle lane of a multilane highway in dense traffic requires extensive scanning, if one wants to change lanes, e.g., to go to an exit. Really complex traffic signals may require longer looking at them. Besides these "legitimate" reasons for looking elsewhere, there are many others. The driver may look at an occupant of his vehicle, the radio, etc.; he may look at other vehicles because of their type, color, cargo, occupants, etc., not because of their role in traffic; he may look at roadside features, buildings, activities, etc. In the case of billboards, the intent is specifically to "distract" the driver.

Objects of visual reception--relevant for driving--can be grossly classified as follows:

- Highway/Environment
  - Highway geometry
  - Lane controls
    - Stripes, arrows, reflectors, etc.
    - Cones, barriers
  - Traffic signs, signals
  - Objects on highway
  - Police officers and others directing traffic

- Traffic
  - Other vehicles
    - -- Drivers of other vehicles
    - -- Signals of other vehicles (especially emergency signals)
  - Pedestrians (including off road)
- Ambience
  - Fog, haze
  - Light conditions

Other objects can provide valuable information. Off-road structures, the topography, etc. can provide information on the highway alignment; buildings and other land use indications can suggest the presence of pedestrians, especially children or handicapped persons, etc.

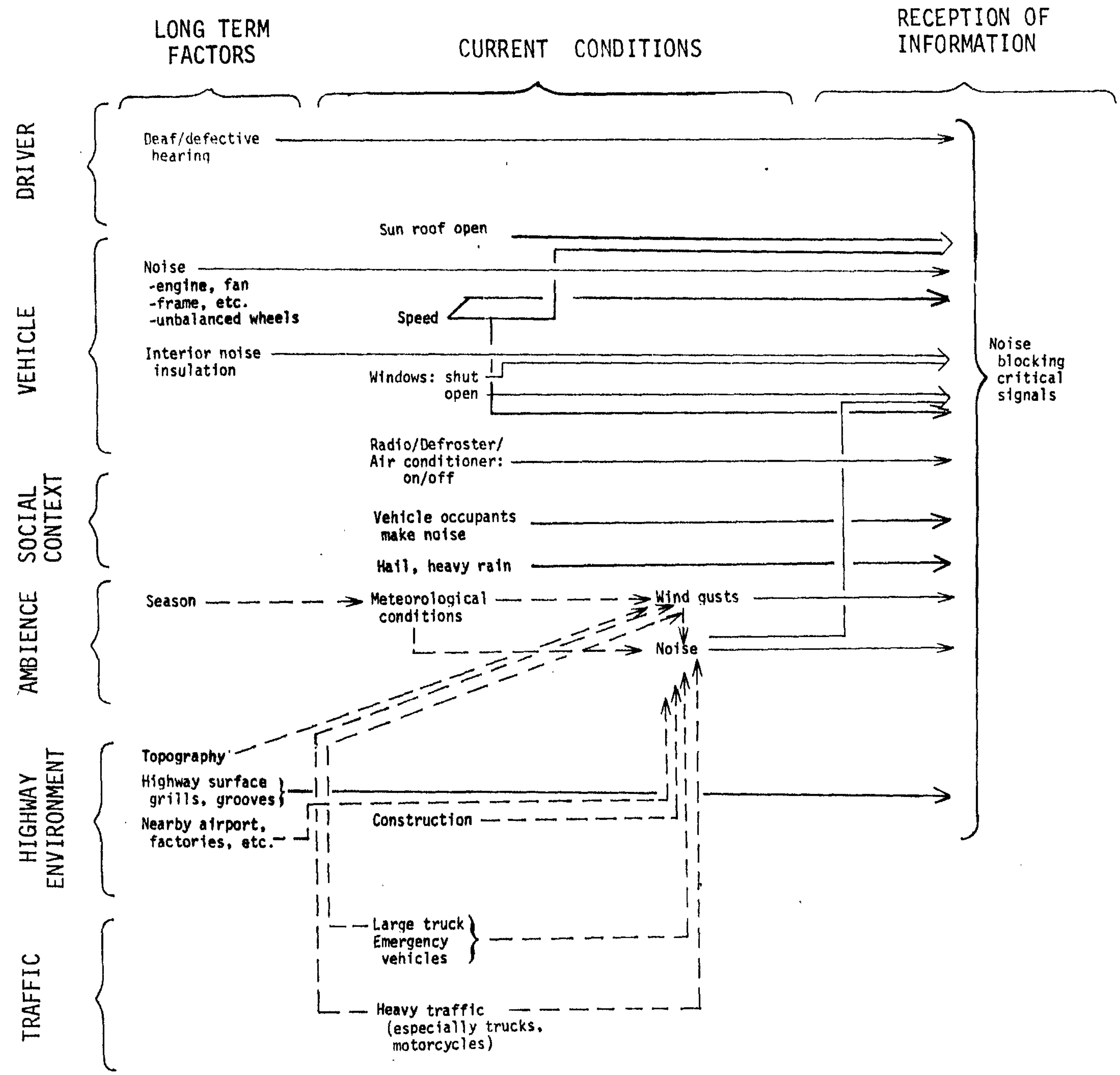


Figure 3.2.2-9. Reception of information: auditory.

(9) Failure to Receive Auditory Information

There are very few situations where sound is absolutely blocked--deaf driver, well insulated car, etc. In most cases it is a matter of signal to noise ratio with the message being overwhelmed by other noise sources. To a certain extent hearing is directional and reception can be affected by the direction of the source.

The driver can fail to hear several things which are important to driving:

- Sirens from police, fire, ambulance and other emergency vehicles.
- Police whistles and other attention getting signals.
- Horn signals from other vehicles.
- Bells at railroad crossings.
- The sound of other vehicles.
- Warnings and instructions from vehicle occupant.
- Noises indicating operating conditions or failures of his own car.

For drivers without defective hearing, the likelihood of receiving auditory information from an external source is most significantly affected by:

- Vehicle auditory insulation and whether the side windows are open or shut.
- Noise generated by the vehicle itself including both the operation of "optional" systems (radio, defroster, blower, air conditioner) and background noise (engine, tires, frame, etc.).
- Noise generated by the environment including both traffic sources and non-traffic sources such as wind, precipitation, airplanes, construction, etc.

Noise generated by the unit vehicle could be categorized as follows:

Vehicle Noise

- Engine, including fan, etc.
- Structure (frame)
- Tires
  - Type
    - -- Regular
    - -- Radials
    - -- Snow tires
  - Status
    - -- Balanced
    - -- Unbalanced
- Side Windows in connection with
  - Drivers side
  - Passengers side
- Glove Compartment
- Brakes (when activated or struck)
- Resonance of car interior, if sunroof or windows open

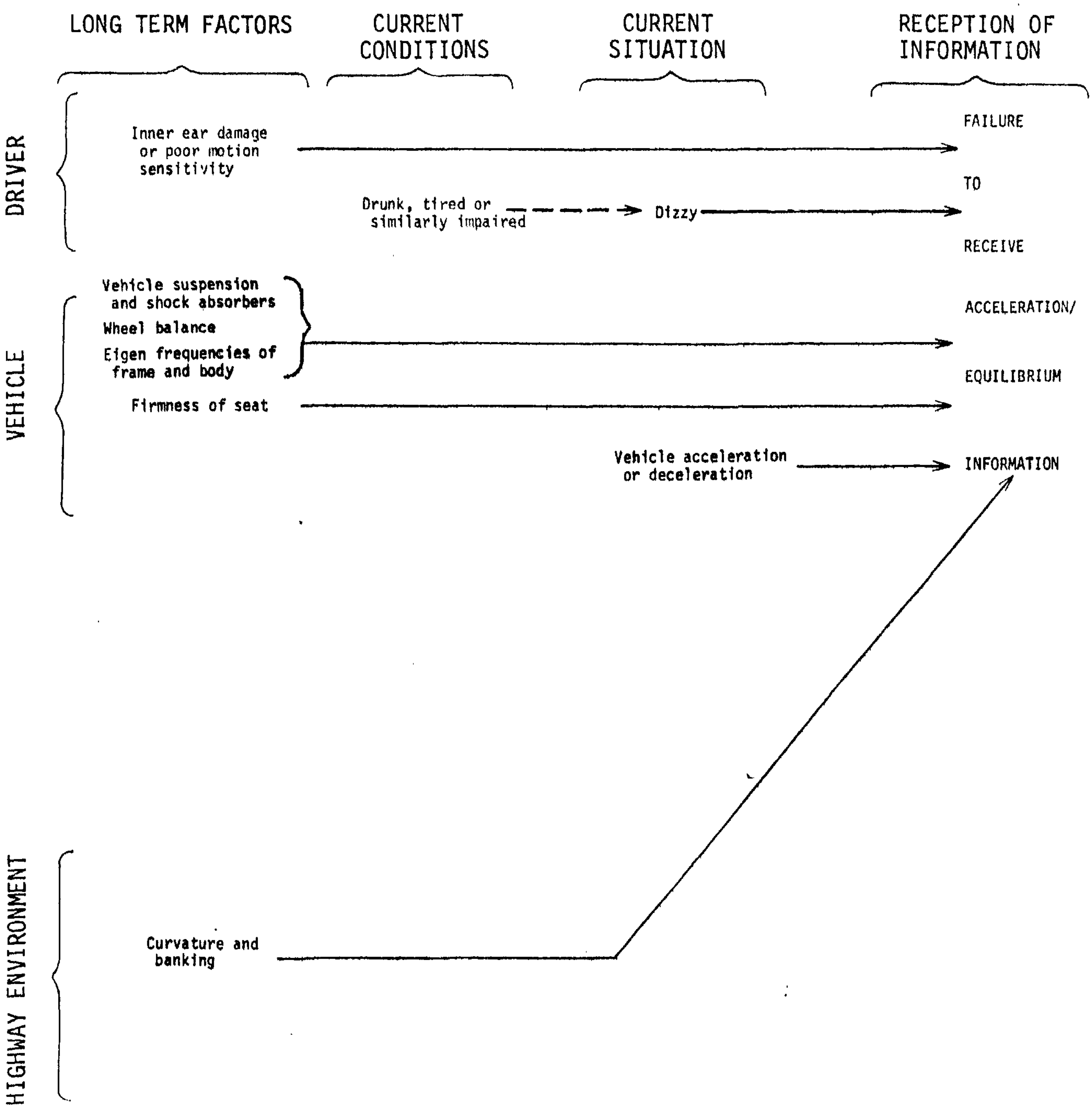


Figure 3.2.2-10. Reception of information: acceleration/deceleration.
(There is little difference between low frequency noise and vibration; therefore, such information may be received in different ways.)

(10) Failure to Receive Acceleration/Equilibrium Information

Specifying the role of sensing acceleration/equilibrium changes is difficult. This information often accompanies stronger visual or auditory cues. One important role of this information may be to directly feed back vehicle's response to the driver's action. The reception of this information may be very important in making small adjustments in vehicle manuevers such as turning a corner. The most critical items which may fail to be perceived in this way are the loss of traction and skidding.

"Speed bumps" or "rumble strips" are sometimes meant to alert the driver, and further information is usually provided by signs. Failure to feel a rough ride, or uneven ride, or other items will not likely have an immediate impact on accident causation but more likely will have a cumulative affect, lowering vehicle capabilities, as shocks go bad, wheels become unbalanced, etc., and it may mask the more important signals.

The reception of acceleration/equilibrium information can be adversely affected by two types of driver factors. A permanent or long-term situation of inner-ear damage or some other pathology leading to a lack of balance or poor motion sensitivity will impede the reception of accurate sensory cues by the driver. The transient or current condition of being drunk or similarly impaired can produce a dizziness or disorientation that can distort sensing information.

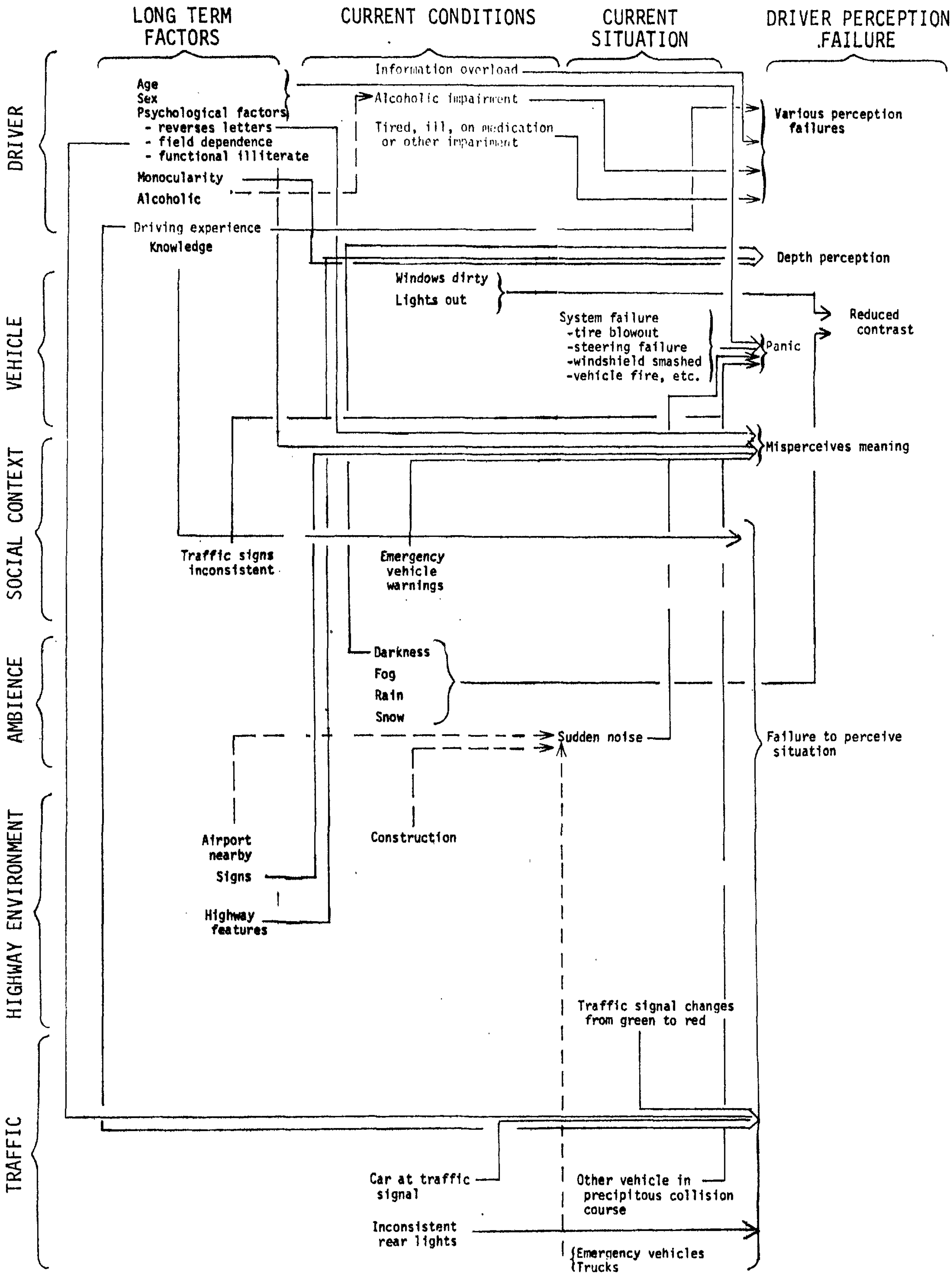


Figure 3.2.2-11. Driver perception failure.

(11) Perception

The distinction between reception failures and perception failures, given our definition, is not absolutely sharp: fog can completely prevent or delay reception of a visual signal, but often it only reduces contrasts and thereby affects perception. This situation is even more common with acoustical and sensory signals, where absolute reception failures are rare. Usually the failure consists of reducing a signal/noise ratio below a threshold of perception. A similar problem is reduced depth perception induced by monotonous highway features, darkness, or monocularity. To the extent possible, however, we will limit the term perception factor to those which are primarily the driver's failure to adequately process the information received. Perception of the traffic situation has essentially three aspects:

- Identification. The objects seen (or heard) have to be correctly identified, e.g., as the headlights or taillights of a vehicle, as a traffic light, a traffic sign, etc. Identifying elements of the traffic situation may fail because of reception problems (reduction of contrast) or because the driver does not recognize important patterns or configurations (shapes of signs, markings on road, etc.), or because they are partially hidden, or because of an overload of information.

- Perception of meaning. Once an object is identified as such, its meaning has to be determined. The driver may have identified an object as a traffic sign; then he has to determine the meaning of the sign. Lights may have been identified as the taillights of a vehicle; the next step required is to decode these as taillights, brake lights, or directional signals.

- Perception of position, velocity and direction. This third aspect requires processing of two binocular images, use of corollary information on the size of the object seen, and aggregation of data over time to determine position and motion.

In some situations, events occur so quickly that the driver panics because he perceives (correctly or not) an extremely dangerous situation. This perception is usually unstructured. Such a state of panic effectively short-circuits the driver decision process and leads directly to a reaction.

Identification failures can result from limited driving experience, information overload, or an impaired driver condition due to alcohol, medication or tiredness. Failure to perceive the meaning of information can result from a variety of causes. These include functional illiteracy and other reading impairments and a lack of knowledge of the driving situation or highway environment or his familiarity with local peculiarities of signs. The critical importance of functional literacy is emphasized if one considers the large variety of warning signs that must be correctly perceived:

Warning Sign

- Curve
- Hill
- Traffic Signal
- Speed Reduction
- Intersection
- Traffic Merge
- Trucks
- Lane Elimination
- Noise
- Construction
- Fog Area

The current change over to symbols rather than words in signs will probably reduce this problem.

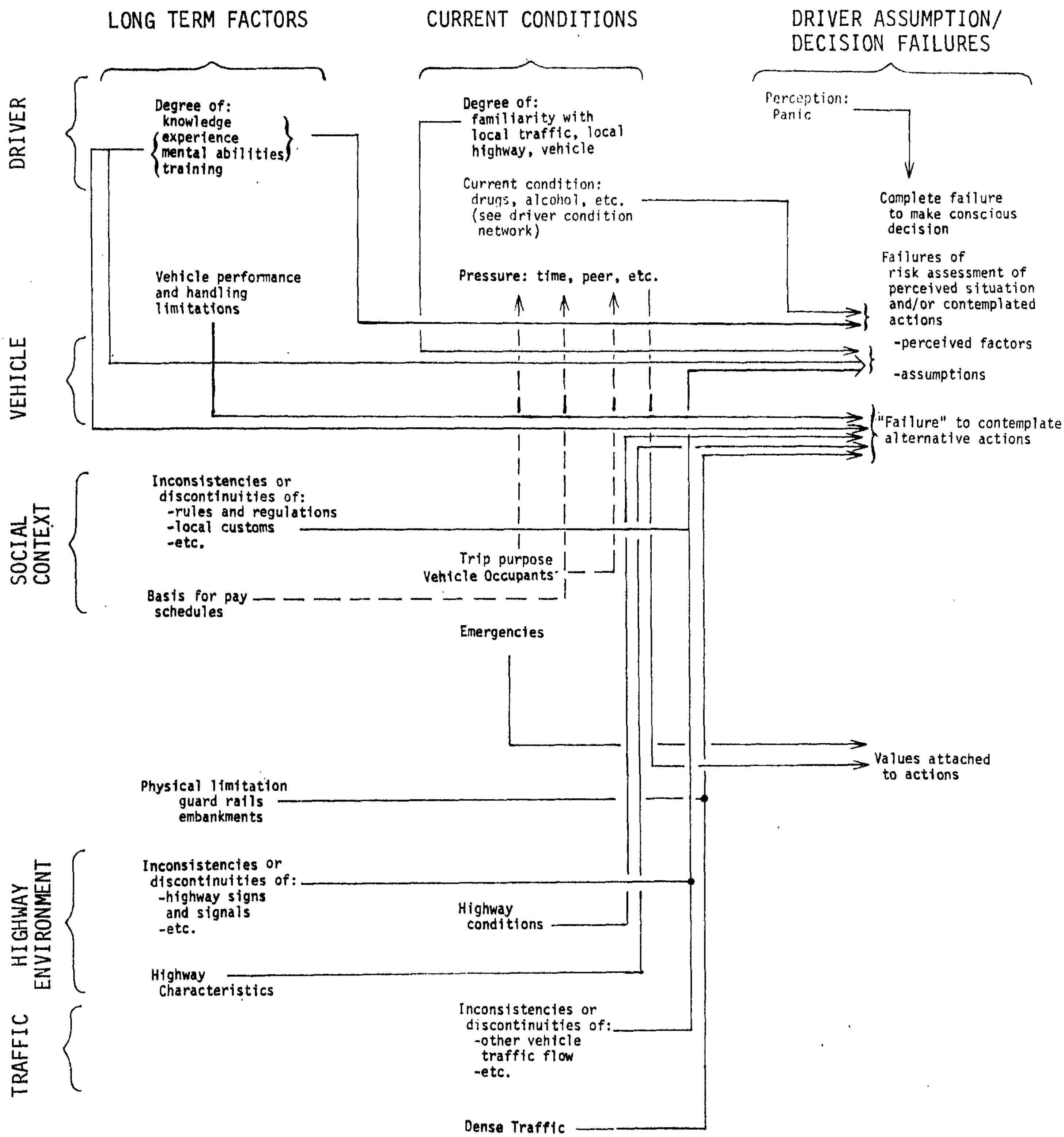


Figure 3.2.2-12. Driver assumption/decision failures.

(12) Driver Decisions

On a purely conceptual basis, a driver's decision process can be organized into the following steps:

- Assessing the perceived situation in terms of conflicts and risks;
- Identifying alternative actions he might take;
- Evaluate the alternatives in terms of
  - risks associated with them,
  - values and benefits associated with them,

  which results in a decision.

It is probably not possible to separate these steps in practice. Also, the same basic factors influence the assessment of the current situation, and the assessment of a contemplated action in terms of risk.

In assessing the risk of a situation or an action (maneuver) the basic failure categories are errors of judgment, and wrong assumptions. Errors of judgment concern perceived objects and characteristic, e.g., a misestimate when another car will enter an intersection, given its current speed and distance, or a misestimate of one's own capability to stop within a given distance. Assumptions have to be made (a) on objects which are not perceivable, and (b) on the behavior of other drivers. A common assumption of the first type is that a traffic light shows red to the crossing road if it shows green to one's own direction. Other assumptions of the same kind are that no car is approaching from a side street the view of which is blocked; that there is no car parked behind a curve which can not be fully viewed. Assumptions of the second kind are that a driver will stop at a red traffic signal, or that an on-coming driver will slow down or make an evasive maneuver to allow one to complete a passing maneuver.

Judgments and *assumptions* are based on one's knowledge, including that of local or temporary conditions, experience and mental abilities; they influence erroneous assessments and wrong assumptions. In addition, situations occur where a subjectively correct judgment or assumption is objectively wrong because of inconsistencies or discontinuities in the real world. A driver may base his judgment on experiences from his local area, or laws and regulations of his home state. His experience interacting with the inconsistency of laws and regulations can result in an assumption failure. Similarly, a driver may base assumptions on other drivers' behavior on local experience. Inconsistencies in local behavior together with his experiences cause assumption failures. Assumptions of continuity are commonly made, e.g., in night driving: that the highway continues straight or with a certain curvature beyond the reach of the headlights.

One failure in decision making is not to consider the full range of possible *alternative actions*. This failure is influenced by lack of knowledge, mental ability or training. In addition to the failure to consider all possible actions, another limitation exists: the highway furniture such as guard rails, embankments, etc., and also dense traffic, may physically limit the range of possible actions. Though not literally a decision failure, we will include such restrictions of the available options here, since there is no other place where they would better fit into the network.

The decision, i.e., the selection of one of the contemplated alternatives, is influenced not only by the estimated risk, but also by other positive or negative *values* attached to the alternatives. Loss of time is nearly always a negative value, especially if one is paid by the mile like many truck drivers, or has to keep a schedule. Certain drivers attach positive values to certain maneuvers, either to enjoy their own skill, or to impress others (this is sometimes interpreted as risk seeking; this point of view, however, appears too simplified; it is more likely that the driver is aware of some risk, but believes himself to be able to control it; proving his ability is a value in itself).

Values play an important role for drivers of emergency vehicles: police, fire engines, ambulances; but also drivers of private vehicles on an emergency run. Other values influence the decisions of drivers being pursued by the police. Hot pursuit accidents make a not insignificant contribution to the number of traffic deaths. Similar values enter the decisions of a driver who is being pursued by actual or suspected criminals, and to a lesser degree, by a driver who is "chased" by a heavy truck.

In addition to the situations where a driver makes a conscious decision, there is the *panic* situation: the driver perceives an imminent conflict situation, and he may react, but without any decision process which he would otherwise perform.

The decision made can be characterized in different ways:

(1) The strategic nature:

- Initiate a conflict situation
- Continue
- Take precautionary action, but mostly continue
- Take evasive action.

(2) The tactical nature (described by specific actions):

- Change speed
  - -slower
  - -faster
- Change direction
  - -left
  - -right
- Signal

Several of these actions may be performed simultaneously, and more complex maneuvers may require a specific sequence of these actions.

Various types of discontinuities and inconsistencies, together with the driver's knowledge or experience, can lead to decision failure. A list of the main types of discontinuation and inconsistencies follows:

Social Context

Inconsistency and discontinuity of:

- Rules and Regulations
  - State
  - County
  - Town (local)
- Local Customs
  - Speed observance
  - Merging Traffic: rotaries, etc.
  - Traffic signals
    - Running yellow light
    - Speed of start-up
    - Left turns

There can be inconsistencies between the rules and regulations of one state, town, etc., and those of different states, etc. There can also be discrepancies between laws or regulations and actual driving habits.

Traffic

Inconsistency and discontinuity of:

- Traffic flow
  - Speed
  - Continuity
- Other driver behavior
  - Signalling

A general assumption of continuity is that traffic speeds change slowly, in the absence of recognizable reasons for rapid changes. Also, it is usually assumed that if traffic is moving, there are no stopped vehicles on the pavement beyond a curve, or beyond the reach of headlights. Other common assumptions are that other drivers' signals and actions are consistent.

Highway Environment

Inconsistency and discontinuity of:

- Highway Signs
  - Warning signs
  - Speed signs
- Traffic Signals
  - Yellow caution light behavior
  - Leading green light
- Highway Markings and Characteristics
  - Markings for lane delineations
  - Length of acceleration and deceleration lanes
  - Lane width
  - Turning lanes
  - Highway surface

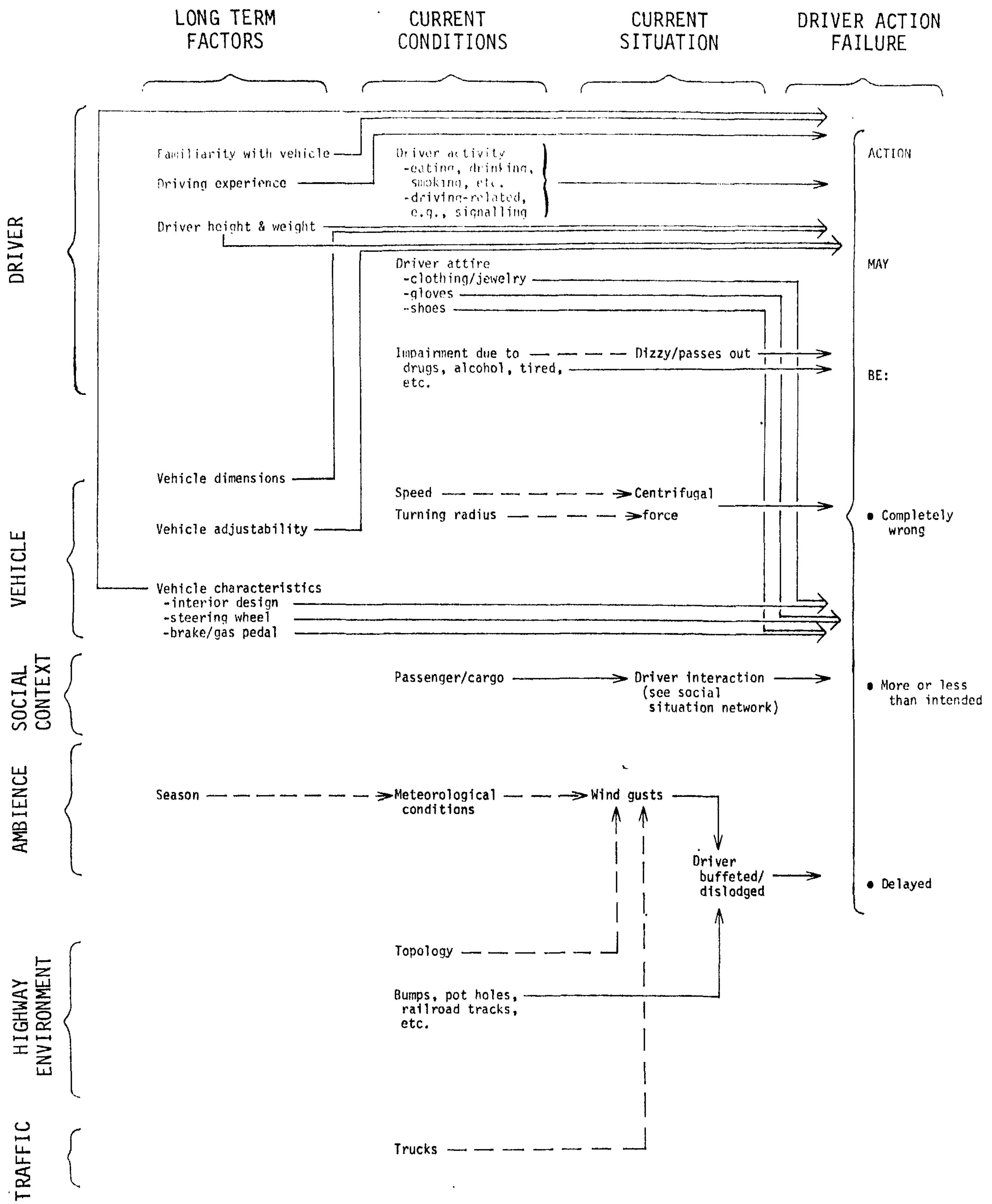


Figure 3.2.2-13. Driver action failure.

(13) Action Failure

A driver action can "fail" in one of the following ways:

- Completely wrong: The driver can be dizzy or confused and hit the wrong button or shift the car into the wrong gear.

- More or less than intended: This error is one of degree: pressing the brake or turning the wheel more than intended can easily happen if the vehicle goes over large bumps or potholes.

- Delayed: This type of error can also be caused by dizziness or confusion. Almost any action can suffer a delay failure.

The types of actions are listed below:

Actions Concerning	Operated With	
	Hands	Feet
Wheel	√	
Accelerator		√
Brake	(Emergency)	√
Clutch		√
Shift	√	
Horn	√	
Light Switch	√	
Dimming Switch	√ or	√
Wiper/Washer Switch	√	
Turn Signal	√	
Emergency Flasher	√	
Defroster/Defogger	√	

A large variety of current driver activities can influence the possibility of a driver action failure. These activities are enumerated below:

Driver Activity (current condition)

- Non-Driving Related Activity
  - Eating
  - Drinking
    - Temperature (hot/cold)
    - Type (alcoholic/non-alcoholic)
  - Smoking
    - Cigarette
    - Cigar
    - Pipe
  - Turning to passenger/animal
  - Disciplining child/animal
  - Reading (map, paper, etc.)
  - Closing/Opening glove compartment
  - Combing hair
  - Applying make-up
- Driving Related Activity
  - Manual signaling
  - Adjusting mirror

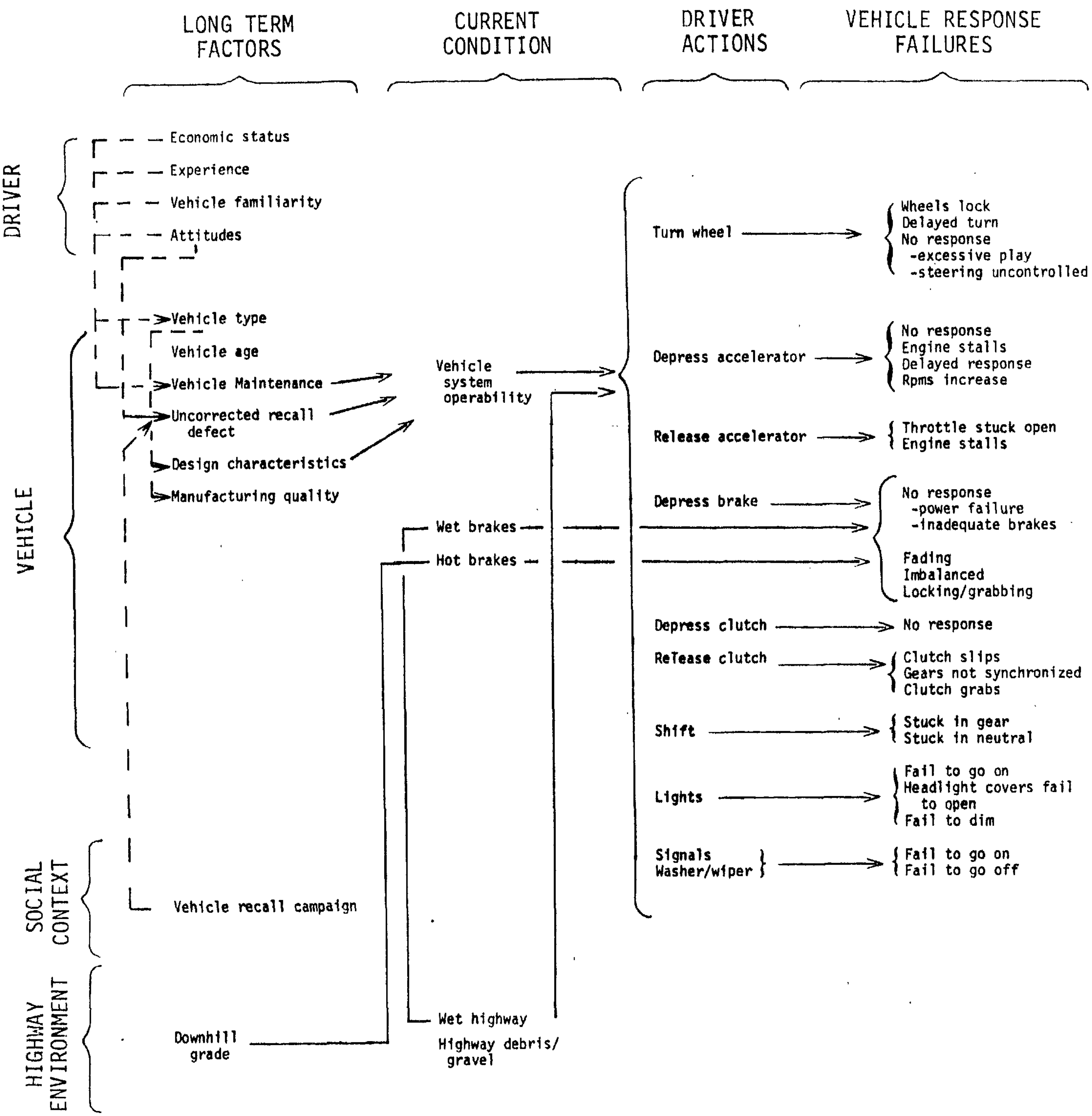


Figure 3.2.2-14. Vehicle response failures.

Vehicle Response Failures

Vehicle response failures can result from failures or poor operating condition in any of the following vehicle systems: (1) brakes, (2) drive train, (3) steering, (4) signals, (5) lights, and (6) wiper/washer. Clearly the likelihood of a system failure or partial inoperability will depend on the system design characteristics and wear, vehicle maintenance and vehicle age and use. The maintenance of the vehicle may in turn, be dependent on the economic status of the owner, his experience with cars and his familiarity with the vehicle in question. Given that many vehicles are subject to recall campaigns, the presence of identified but uncorrected defects is an important factor.

Some vehicle system response failures result directly from interaction with the highway environment. Wet brakes and a delayed braking action normally require the presence of puddles on the road surface. Sand and gravel and other objects on the road surface can be responsible for blockage in the steering system. Trucks are especially susceptible to brakes overheating on downhill grades.

The generic descriptions of vehicle response failures such as loss or total failure of brakes or power can be supplemented by a detailed description of which of the many individual components in the systems, i.e., the loss of power and resultant crashing can be due to failures in the transmission, drive shaft or universal joint. In general, such failures either freeze things in position or release them from control. Specific knowledge of the type of failure and the physical cause (materials defect, defect assembly, fatigue, overload, etc.) is important for the planning of countermeasures.

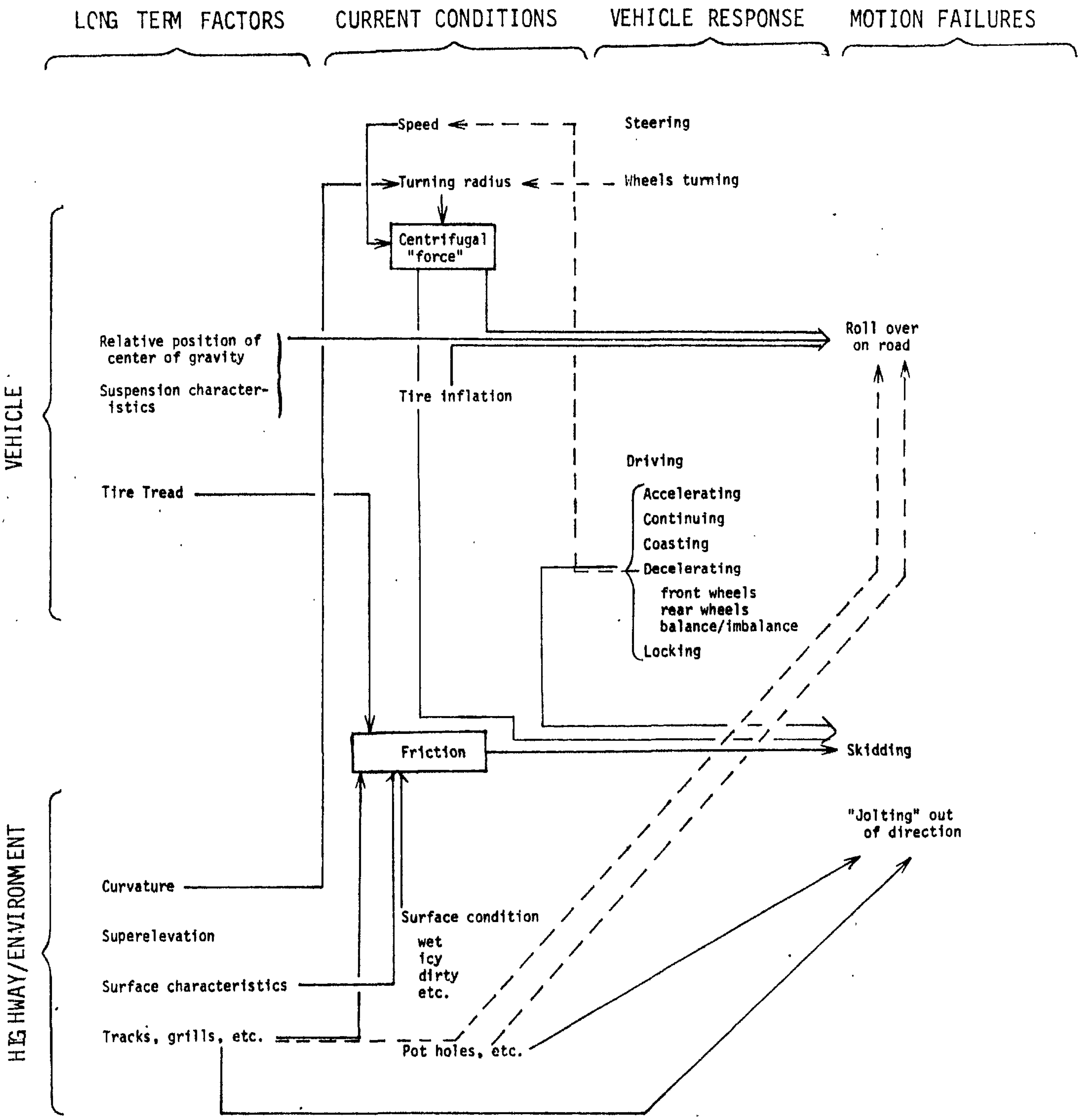


Figure 3.2.2.-15. Vehicle Motion Failure Network

(15) Vehicle Motion

Vehicle motion failures result from interactions between the vehicle's mechanical response and the highway. There are two types of failures:

Rollover in Road is usually the result of vehicle motion (turns), vehicle characteristics (position of center of gravity, suspension characteristics, tire inflation), and highway friction (including obstacles like potholes, etc.). Rollover occurring as a result of a collision are not to be included, neither should a rollover which occurs after a vehicle leaves the road.

Control failure is either momentary, e.g., a jolt from a pothole, tracks, etc., or of longer duration, *loss of control* or *skidding*. This results if the vehicle forces at the wheels exceed the friction forces. The latter are determined by the highway surface, both its permanent characteristics and its temporary condition (wet, icy, sandy, etc.), and the vehicle tires. The vehicle forces are determined by the forces in the tires accelerating or decelerating them in the direction of movement, and perpendicular centrifugal forces resulting from speed, turning radius, and superelevation. Friction can be affected by various conditions, e.g., such as a thin film of water mixed with road grease, or a thick layer of water causing hydroplaning.

Vehicle motions are broadly classified as:

- remaining in one lane
- leaving own lane
  - entering other lane
  - leaving road.

An independent characteristic of vehicle motion concerns direction and speed and whether they were as intended or not as intended. The severity of these failures depends on the subsequent motion of the vehicles as described above.

A wrong vehicle motion can result not only from a vehicle motion failure, but also from a vehicle response failure, and indirectly from preceding driver failures.

3.3 Coding Scheme

If one considers the causal network in a matrix structure, a coding scheme emerges quickly. Figure 3.3-1 shows one cycle of the causal network arranged in an x, y, z coordinate system. In the x-direction, the traffic unit involved is arranged; the y-direction lists the causal elements; and the z-direction follows the temporal sequence of elements (which may repeat). Some of the longer term elements apply to all the causal elements; traffic and crash configurations contain all aspects of the situation and all units. Some temporal elements only apply to one causal element, such as reception applying only to the driver. (However, at some time in the future when vehicles have radar controlled braking and other automated guidance systems, the reception of information may also apply to the vehicle.)

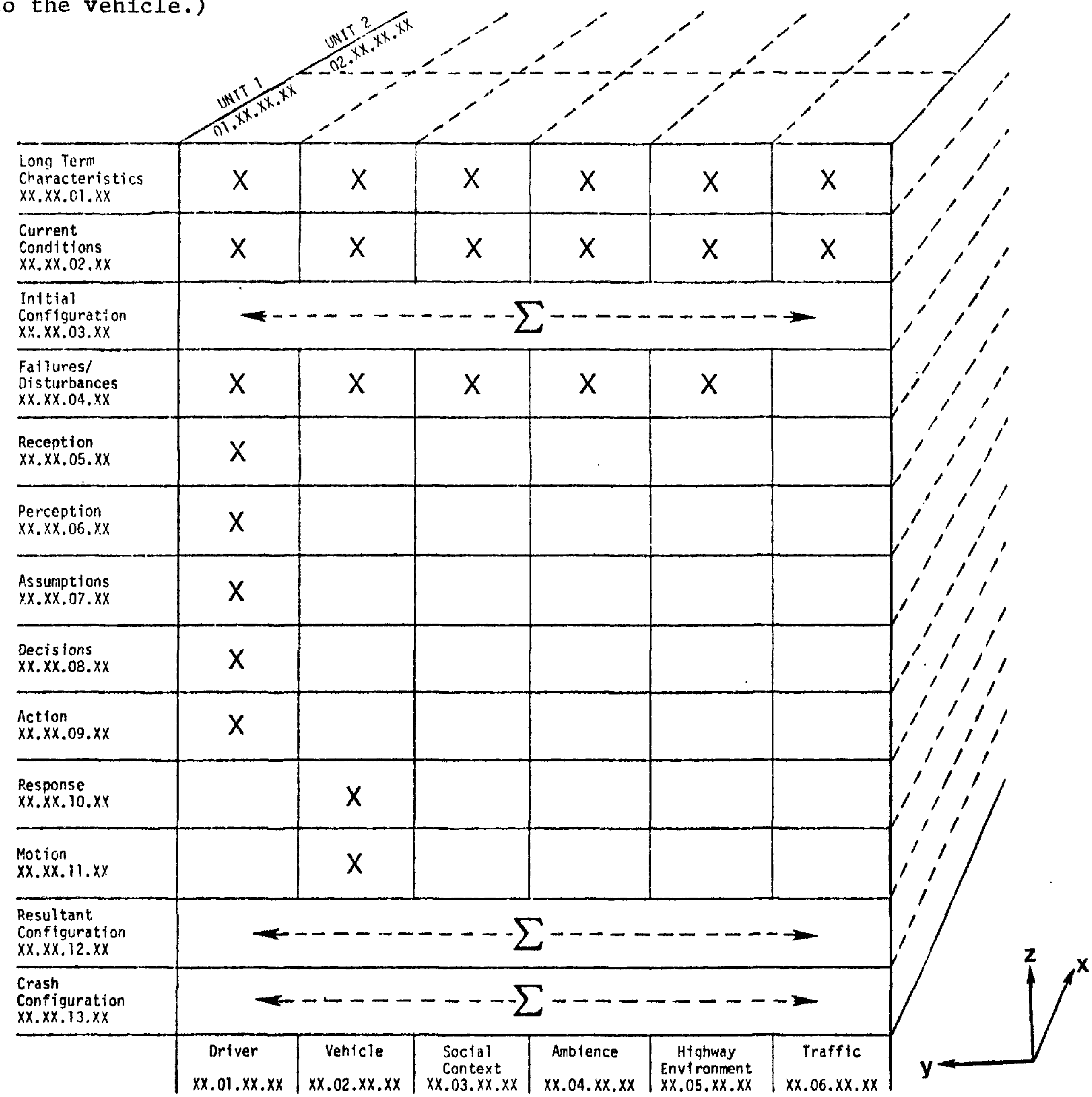


Figure 3.3-1. Arrangement of the elements of the causal network in matrix form. The x-dimension arranges the units involved; the y-division the causal elements; and the z-dimension the time sequence.

To be positioned in the matrix, therefore, requires four numbers--the unit number, the causal element number, the temporal element number, and the temporal cycle number. For example, the number 01.02.02.01- would indicate the first driver/vehicle unit, the current vehicle condition during the first cycle.*

A dash (-) follows the four pairs of digits which positions one in the network. This is used as a delimiter. Following this initial positioning, the coding of the detailed network varies for different elements, i.e., the hierarchy of factors describing long-term driver characteristics is considerably different from that describing the current vehicle conditions. Basically, the guiding principle in the coding of the detailed factors was the hierarchical structure. This concept is used so that an analyst might organize a wide range of data from different sources.

The pedestrian (and bicyclist) can be considered in the same sort of causal network as motor vehicle units. One can treat a pedestrian as the second "unit" in an accident; the same overall causal structure and specifications apply. Certain factors do not, however, apply to pedestrians or bicyclists; and there are factors influencing them which do not apply to motor vehicles. To accommodate these differences, the causal element number 07 is assigned to pedestrians, 08 to bicyclists, 09 to bicycles, etc. Table 3.3-2 lays out a detailed pedestrian network with codes. In those cases where the same factors as in the driver network apply, the details are not repeated.

The following list of factors runs to more than 25 pages. Even this level of detail is not totally exhaustive. However, before adding more detail we suggest some application of the network to concentrate the list of causal factors to those particularly important and to refine these, if necessary.

---

*Another feature of the causal network is the capability of describing an accident sequence through a series of maneuvers which are represented by different cycles of network. For instance, in a passing situation there are six distinct vehicle maneuvers: turning left into other lane, straightening out, accelerating past, turning right into original lane, straightening out, and slowing down (or perhaps continuing at high speed).

TABLE 3.3-1
DETAILED LIST OF CAUSAL FACTORS WITH CODING SCHEME

Code	Causal Factor
01.01.01.01-	LONG-TERM DRIVER CHARACTERISTICS
-01	SUBJECTIVE
-01.01	Behavior
-01.01.01	General
-01.01.01.01	Hostile
-01.01.01.02	Felt Like Smashing Something Recently (Note: Many of these factors are responses by the driver to questions and are self-evaluations.)
-01.01.02	Driving-Related
-01.01.02.01	Drives Recklessly
-01.01.02.02	Drives Worriedly
-01.01.02.03	Drives to Blow Off Steam
-01.01.02.04	Drives to Think About Problems
-01.01.02.05	Drives to Get Away
-01.01.02.06	Honks Horn at Others
-01.01.02.07	Missed Seeing Stop Sign Until Too Late
-01.02	Satisfaction
-01.02.01	With Living Quarters
-01.02.02	With Job
-01.02.03	With Financial Status
-01.02.04	With Spouse/Boy-Girl Friend
-01.02.05	With Life in General
-01.03	Attitude
-01.03.01	General
-01.03.01.01	Relations with Parents
-01.03.01.02	Relations with Teachers
-01.03.02	Driving-Related
-01.03.02.01	Towards Self
-01.03.02.01.01	Driving Confidence
-01.03.02.01.02	Effect of Accidents on Driving
-01.03.02.01.03	Enjoys Winding Roads
-01.03.02.01.04	Enjoys Driving
-01.03.02.01.05	California Inventory of Driver Attitudes & Opinions (CIDAO)
-01.03.02.02	Towards Others
-01.03.02.02.01	Elderly Drivers
-01.03.02.02.02	Middle-Aged Drivers
-01.03.02.03	Towards Law Enforcement
-01.03.02.04	Towards Alcohol and Marijuana
-01.04	Goals
-01.04.01	Educational
-01.04.02	Vacation
-01.04.03	For Satisfaction
-01.04.04	Driving-Related
-01.04.04.01	To Be a Racing Driver
-01.04.04.02	Other
-02	OBJECTIVE
-02.01	Personal
-02.01.01	General
-02.01.01.01	Age
-02.01.01.02	Sex
-02.01.01.03	Height
-02.01.01.04	Weight
-02.01.01.05	Race
-02.01.01.06	Birthplace
-02.01.02	Family
-02.01.02.01	Marital Status
-02.01.02.01.01	Married
-02.01.02.01.02	Single
-02.01.02.01.03	Divorced
-02.01.02.01.04	Recent Change
-02.01.02.02	Children (Number)
-02.01.02.03	Siblings
-02.01.02.03.01	Total
-02.01.02.03.02	Number of Brothers
-02.01.02.04	Parents
-02.01.02.04.01	Alive
-02.01.02.04.02	Married
-02.01.02.04.03	Occupation
-02.01.02.04.04	Other
-02.01.02.05	Parental Treatment
-02.01.02.05.01	Mother Babied
-02.01.02.05.02	Mother's Temper
-02.01.02.05.03	Approval of Friends
-02.01.02.05.04	Other

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.01.01.01-	(Driver Long-Term Characteristics continued)
-02.01.02.06	Parent-Child Inventory
-02.01.02.06.01	Parents' Use of Punishment
-02.01.02.06.02	Family Dissension
-02.01.02.06.03	Mother Rating
-02.01.02.06.04	Father Permissiveness Rating
-02.01.03	Personal History
-02.01.03.01	Smoking
-02.01.03.01.01	Yes/No
-02.01.03.01.02	Age Started
-02.01.03.01.03	Cigarettes (yes/no)
-02.01.03.01.04	Type of Cigarette
-02.01.03.01.05	Number per Day
-02.01.04	Non Traffic-Related Offenses
-02.01.04.01	Drinking
-02.01.04.02	Violent Crimes
-02.01.04.03	Social and Fraudulent Crimes
-02.01.04.04	Larceny and Miscellaneous Non-Violent Crimes
-02.01.04.05	Total Trouble with Police Since Age 20
-02.01.04.06	Gun Permit Application
-02.01.04.07	Armed Forces Service
-02.01.04.08	Age Started Dating
-02.01.04.09	Time Spent Drinking
-02.01.04.10	Time Spent Smoking Marijuana
-02.01.04.11	Drinking Habits
-02.01.04.11.01	Normally
-02.01.04.11.02	On Special Occasions
-02.01.04.12	Gordon Personality Profile
-02.01.04.12.01	Responsibility
-02.01.04.12.02	Emotional Stability
-02.01.04.12.03	Cautiousness
-02.01.04.12.04	Personal Relations
-02.01.04.13	Other
-02.01.05	Driving-Related Personal History
-02.01.05.01	Seat Belt Use
-02.01.05.01.01	On Long Trips
-02.01.05.01.02	On Short Trips
-02.01.05.02	Attended Car Races
-02.01.05.03	Other
-02.01.06	Non Vehicle Accidents
-02.01.06.01	Home-Related
-02.01.06.02	Other, not Related to Job, Sports, Home
-02.02	<u>Socioeconomic</u>
-02.02.01	Education
-02.02.01.01	Years
-02.02.01.02	Type of Degree
-02.02.01.03	Dropout
-02.02.01.04	Transfer
-02.02.01.05	GPA
-02.02.01.06	GPA Trend
-02.02.01.07	Citizenship Grade
-02.02.01.08	Absences
-02.02.01.09	Non-Language IQ
-02.02.01.10	Achievement Test
-02.02.01.11	IQ Discrepancy
-02.02.01.12	Achievement Index
-02.02.01.13	Rural School
-02.02.01.14	Played Hooky
-02.02.01.15	Vocabulary
-02.02.01.16	Other
-02.02.02	Employment/Occupation
-02.02.02.01	Full Time
-02.02.02.02	Part Time
-02.02.02.03	Unemployed
-02.02.02.04	Professional
-02.02.02.05	Operative
-02.02.02.06	Laborer
-02.02.02.07	Professional Driver
-02.02.02.08	Student
-02.02.02.09	Housewife
-02.02.02.10	Seniority
-02.02.02.11	Number of Job Changes
-02.02.02.12	Social Mobility Index

Code	Causal Factor
01.01.01.01-	<u>LONG-TERM DRIVER CHARACTERISTICS</u>
-02.02.03	Residence
-02.02.03.01	Location
-02.02.03.02	Local Traffic Density
-02.02.04	Activities
-02.02.04.01	Club Membership
-02.02.04.02	Religion
-02.02.04.03	Hobbies
-02.02.04.03.01	Indoor/Outdoor
-02.02.04.03.02	Group/Individual
-02.02.04.04	Academic
-02.02.04.05	Student
-02.02.04.06	Intramural
-02.02.04.07	Other
-02.02.05	Achievement
-02.02.05.01	Varsity Letters
-02.02.05.02	Non-Varsity Letters
-02.02.05.03	Other
-02.02.06	Vehicle-Related
-02.02.06.01	Ownership
-02.02.06.01.01	Type of Vehicle (motorcycle, car, etc.)
-02.02.06.01.02	Length of Ownership
-02.02.06.02	Type of Vehicle Driven (sports car, etc.)
-02.02.06.03	Accessories in Car
-02.02.06.03.01	Speed Accessories
-02.02.06.03.02	Customized
-02.03	<u>Driving Experience</u>
-02.03.01	General Driving History
-02.03.01.01	Age Licensed
-02.03.01.02	Length of License Gap
-02.03.01.03	Driver Education
-02.03.01.03.01	Commercial/School
-02.03.01.03.02	Grade
-02.03.01.03.03	Quality
-02.03.01.04	Licensing
-02.03.01.04.01	Number of Attempts
-02.03.01.04.02	Test Score
-02.03.01.04.03	Length of Instruction Permit
-02.03.02	Driving Record
-02.03.02.01	Accidents
-02.03.02.01.01	Total Number
-02.03.02.01.02	Fatal & Injury
-02.03.02.01.03	Property Damage
-02.03.02.01.04	Single Vehicle
-02.03.02.01.05	Drunk Driving
-02.03.02.01.06	Partially at Fault
-02.03.02.01.07	Hit and Run
-02.03.02.01.08	Cost
-02.03.02.01.09	Other
-02.03.02.02	Violations
-02.03.02.02.01	Total Number
-02.03.02.02.02	Sign/Signal
-02.03.02.02.03	Passing/Overtaking
-02.03.02.02.04	Right of Way
-02.03.02.02.05	Turning
-02.03.02.02.06	Speeding
-02.03.02.02.07	Alcohol/Drugs
-02.03.02.02.08	Other Countable
-02.03.02.02.09	Other Non-Countable
-02.03.02.02.10	Lane Placement (position)
-02.03.02.02.11	Following Too Closely
-02.03.02.02.12	Reckless Driving
-02.03.02.02.13	Driving While Suspended
-02.03.02.02.14	Equipment
-02.03.02.02.15	Miscellaneous Moving Violations
-02.03.02.02.16	Miscellaneous Non-Moving Violations
-02.03.02.02.17	Other
-02.03.02.03	Convictions
-02.03.02.03.01	Total Number
-02.03.02.03.02	Self-Reported
-02.03.02.03.03	Official Record - Spurious Conviction
-02.03.02.03.04	Official Record - Non-Spurious Conviction
-02.03.02.03.05	Failure to Appear/Failure to Pay
-02.03.02.03.06	Other

TABLE 3.3-1 (Continued)

Code	Causal Factors
01.01.01.01-	LONG TERM DRIVER CHARACTERISTICS
-02.03.03	Exposure
-02.03.03.01	Hours
-02.03.03.01.01	Continuous Hours
-02.03.03.01.02	Per Week
-02.03.03.01.03	Per Work Day
-02.03.03.01.04	Per Non Work Day
-02.03.03.01.05	Other
-02.03.03.02	Mileage
-02.03.03.02.01	Annual
-02.03.03.02.02	Last Two Years
-02.03.03.02.03	Monthly Mileage to Work
-02.03.03.02.04	Monthly Mileage for Errands
-02.03.03.02.05	Other Monthly Mileage
-02.03.03.02.06	Total Monthly Mileage
-02.03.03.02.07	Lifetime Mileage
-02.03.03.02.08	Number of 50-99 Mile Trips
-02.03.03.02.09	Number of 100-199 Mile Trips
-02.03.03.02.10	Percent Daytime Driving
-02.03.03.02.11	Percent Post-Midnight Driving
-02.03.03.02.12	Percent Heavy Traffic
-02.03.03.02.13	Percent Light Traffic
-02.03.03.02.14	Percent to and from Work
-02.03.03.02.15	Percent on the Job
-02.03.03.02.16	Percent on Pleasure Trips
-02.03.03.02.17	Percent on Most Frequent Route
-02.03.03.02.17.01	Total
-02.03.03.02.17.02	During rush hour
-02.03.03.02.17.03	After 6 P.M.
-02.03.03.02.18	Other
-02.03.04	Driving Simulator Responses
-02.03.04.01	Accelerator Reversals
-02.03.04.02	Steering Position
-02.03.04.03	Mean Speed
-02.03.04.04	Time to Brake Press
-02.03.04.05	Rate of Steering Change
-02.03.04.06	Other
-02.04	Physiological
-02.04.01	Vision
-02.04.01.01	Monocular
-02.04.01.02	Perception Time
-02.04.01.03	Glare Sensitivity
-02.04.01.04	Acuity
-02.04.01.05	Color Blindness
-02.04.01.06	Saccadic Fixation
-02.04.01.07	Perceptual Style (field dependence)
-02.04.01.08	Snellen Test Score
-02.04.02	Hearing
-02.04.03	Reactions
-02.04.03.01	Simple Reaction Time
-02.04.03.02	Complex Reaction Time
-02.04.04	Eye-Hand Coordination
-02.04.04.01	Simple Task Time
-02.04.04.02	Complex Task Time
-02.04.05	Chronic Diseases
-02.04.05.01	Cardiovascular
-02.04.05.02	Epilepsy
-02.04.05.03	Diabetes
-02.04.05.04	Alchoholism
-02.04.05.05	Mental Illness
-02.04.06	Recent Changes in Physiological Condition (e.g., weight gain/loss)

Code	Causal Factor
01.01.02.01-	CURRENT DRIVER CONDITIONS
-01	SUBJECTIVE
-01.01	Emotional State
-01.01.01	Frustrated
-01.01.02	Hostile/Angry
-01.01.03	Depressed
-01.01.04	Suicidal
-01.01.05	Elated/Carefree
-01.01.06	Nervous
-01.01.07	Other
-02	OBJECTIVE
-02.01	Physiological State
-02.01.01	Drunk
-02.01.02	Watery eyes
-02.01.03	Dizzy
-02.01.04	Taking Medication/Drugs
-02.01.05	Tired (physically/mentally)
-02.01.06	Diabetic Attack/Insulin Reaction
-02.02	Familiarity
-02.02.01	With Vehicle
-02.02.02	With Highway/Area
-02.03	Activities
-02.03.01	Driving Related
-02.03.01.01	Manual Signalling
-02.03.01.02	Paying Toll
-02.03.01.02.01	Groping for Money/Pass
-02.03.01.02.02	Rolling Window Down
-02.03.01.03	Reading Maps
-02.03.01.04	Adjusting Mirror
-02.03.02	Driver Required
-02.03.02.01	Putting on Glasses
-02.03.02.02	Searching for Handkerchief
-02.03.02.03	Scratching
-02.03.03	Optional
-02.03.03.01	Eating
-02.03.03.02	Drinking
-02.03.03.03	Smoking
-02.03.03.04	Shaving
-02.03.03.05	Applying Makeup
-02.03.03.06	Interacting with Passengers
-02.03.03.07	Reading
-02.03.03.08	Radio (Glove Compartment, etc.)
-02.03.03.09	Other
01.01.04.01-	IMMEDIATE DRIVER EVENTS/DISTURBANCES (DRIVER FAILURES)
-01	Action Limiting
-01.01	Internal
-01.01.01	Cramps
-01.01.02	Seizures
-01.01.03	Unconscious
-01.01.04	Dead
-01.02	Externally Induced
-01.02.01	Passenger Interference
-01.02.02	Cargo Interference
-02	Reception Limiting
-02.01	Internal
-02.01.01	Dizzy
-02.01.01	Sneeze
-02.01.02	Eyes Water (suddenly)
-02.01.03	Unconscious
-02.01.04	Dead
-02.02	Externally Induced
-02.02.01	Insect, Dust, Dirt in Eyes
-02.02.02	Passenger Interference
-02.02.03	Cargo Interference

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.02.01.01-	LONG-TERM VEHICLE CHARACTERISTICS
-01	General
-01.01	Model Year
-01.02	Type of Vehicle
-01.03	Make/Model
-01.04	Vehicle Recall
-01.05	Other
-02	Design Characteristics
-02.01	Mechanical Systems
-02.01.01	Wheels and Tires
-02.01.01.01	Magnesium Wheels
-02.01.01.02	Wire Wheels
-02.01.01.03	Regular Wheels
-02.01.01.04	Other Wheel Type
-02.01.01.05	Radial Tires
-02.01.01.06	Steel Belted
-02.01.01.07	Bias Ply
-02.01.01.08	Other Tire Type
-02.01.01.09	Width
-02.01.01.10	Tread Type
-02.01.01.10.01	Winter
-02.01.01.10.02	Regular
-02.01.01.10.03	High Speed
-02.01.01.10.04	Slicks
-02.01.01.10.05	Other
-02.01.01.11	Number of Wheels
-02.01.02	Brake System
-02.01.02.01	Power
-02.01.02.02	Front Disc Brakes
-02.01.02.03	Four Wheel Disc Brakes
-02.01.02.04	Air Brakes
-02.01.03	Steering System
-02.01.03.01	Power
-02.01.03.02	Number of Revolutions from Wheel Lock to Wheel Lock
-02.01.03.03	Turning Radius
-02.01.03.04	Rack and Pinion
-02.01.03.05	Other Steering System Characteristics
-02.01.04	Suspension System
-02.01.04.01	Height of Center of Gravity
-02.01.04.02	Helper Shocks
-02.01.04.03	Heavy Duty Suspension
-02.01.04.04	Other Suspension Characteristics
-02.01.05	Power Train and Exhaust
-02.01.05.01	Number of Cylinders
-02.01.05.02	Displacement
-02.01.05.03	Carburetion
-02.01.05.04	Transmission
-02.01.05.04.01	Automatic
-02.01.05.04.02	3 Speed
-02.01.05.04.03	4 Speed
-02.01.05.04.04	5 Speed
-02.01.05.05	Low Speed Rear Axle
-02.01.05.06	Four Wheel Drive
-02.01.05.07	Other Engine/Drive Train Chracteristics
-02.01.05.08	Number of Exhaust Pipes
-02.01.05.09	Catalytic Converter
-02.01.05.10	Special Modified Muffler
-02.01.06.11	Other Exhaust System Characteristics
-02.02	Driver-Related Systems
-02.02.01	Communications System
-02.02.01.01	Windows
-02.02.01.01.01	Windshield Tinted
-02.02.01.01.02	Windows Tinted
-02.02.01.01.03	Power Windows
-02.02.01.01.04	Window Area
-02.02.02	Driver Seating and Controls
-02.02.02.01	Type of Seats
-02.02.02.01.01	Bucket
-02.02.02.01.02	Bench
-02.02.02.01.03	Power Adjustable
-02.02.02.01.04	Head Restraints

TABLE 3.3-1 (Continued)

Code	Causal Factors
01.02.01.01-	(LONG-TERM VEHICLE CHARACTERISTICS)
-02.02.02.02	Position of Controls
-02.02.02.02.01	Wheel
-02.02.02.02.02	Accelerator
-02.02.02.02.03	Brake
-02.02.02.02.04	Clutch
-02.02.02.02.05	Shift
-02.02.02.02.06	Horn
-02.02.02.02.07	Light Switch
-02.02.02.02.08	Dimming Switch
-02.02.02.02.09	Wiper/Washer Switch
-02.02.02.02.10	Turn Signal
-02.02.02.02.11	Emergency Flasher
-02.02.02.02.12	Defroster/Defogger
-02.02.02.02.13	Other
-02.02.03	Body, Doors, and Other Vehicular Features
-02.02.03.01	Door Locks
-02.02.03.02	Hood Latches
-02.02.03.03	Other
-03	Use and Wear Characteristics
-03.01	Mechanical Systems
-03.01.01	Wheels and Tires
-03.01.01.01	Tire Tread Depth
-03.01.01.02	Matching Tire Types
-03.01.01.03	Inflation Pressure
-03.01.01.04	Balance
-03.01.01.05	Other
-03.01.02	Brake System
-03.01.02.01	Brake Fluid Level
-03.01.02.02	Brake Shoe Thickness
-03.01.02.03	Disc Brake Pad Thickness
-03.01.02.04	Emergency Brake Linkage
-03.01.02.05	Other
-03.01.03	Steering System
-03.01.03.01	Wheel Play
-03.01.03.02	Hydraulic Fluid Level
-03.01.03.03	Other
-03.01.04	Suspension System
-03.01.04.01	Shocks
-03.01.04.02	Springs
-03.01.04.03	Engine Mounts
-03.01.04.04	Other
-03.01.05	Power Train and Exhaust
-03.01.05.01	Compression/Torque
-03.01.05.02	Tuning
-03.01.05.03	Clutch Slippage
-03.01.05.04	Automatic Transmission Fluid Level
-03.01.05.05	Gear Synchronization/Slippage
-03.01.05.06	Exhaust System Anchorage
-03.01.05.07	Other
-03.02	Driver-Related Systems
-03.02.01	Communication System
-03.02.01.01	Windshield Pitted/Scratched
-03.02.01.02	Windshield Obstructed by Stickers, etc.
-03.02.01.03	Lights Burned Out
-03.02.01.04	Other
-03.02.02	Driver Seating and Controls
-03.02.02.01	Seating Loose
-03.02.02.02	Seating Sprung
-03.02.02.03	Controls Inoperable
-03.02.02.04	Other
-03.02.03	Body, Doors, and Other Vehicular Systems
-03.02.03.01	Unrepaired Damage to Door
-03.02.03.02	Unrepaired Damage to Hood
-03.02.03.03	Other

TABLE 3.3-1 (Continued)

Code	Causal Factors
01.02.02.01-	CURRENT VEHICLE CONDITION
-01	Vehicle Speed
-01.01	Speed
-01.02	RPMs
-02	Vehicle Operating Conditions
-02.01	Mechanical Systems
-02.01.01	Wheels and Tires
-02.01.01.01	Tire Temperature
-02.01.01.02	Other
-02.01.02	Brake System
-02.01.02.01	Brake Temperature
-02.01.02.02	Air/Hydraulic Pressure
-02.01.02.03	Other
-02.01.03	Steering System
-02.01.03.01	Power Steering Fluid Pressure
-02.01.03.02	Steering Binding
-02.01.03.03	Other
-02.01.04	Suspension System
-02.01.04.01	Pressure in Air Shocks
-02.01.04.02	Other
-02.01.05	Power Train and Exhaust System
-02.01.05.01	Engine Cold/Hot
-02.01.05.02	Engine Flooded
-02.01.05.03	Carburetor Clogged
-02.01.05.04	Automatic Transmission Fluid Pressure
-02.01.05.05	Other
-02.02	Driver Related Systems
-02.02.01	Communication System
-02.02.01.01	Windshield Fogged (Inside)
-02.02.01.02	Windshield Dirty/Ice
-02.02.01.03	Lights Dirty
-02.02.01.04	Other
-02.02.02	Driver Seating and Controls
-02.02.02.01	Vibration from Wheel
-02.02.02.02	Other
-02.02.03	Body, Doors, and Other Vehicular Features
-02.02.03.01	Noise, Rattles
-02.02.03.02	Other
01.02.04.01-	IMMEDIATE VEHICLE EVENTS (Primary Failures)
-01	Mechanical Systems
-01.01	Wheels and Tires
-01.01.01	Blowout
-01.01.02	Wheel Falls Off
-01.01.03	Other
-01.02	Brake System
-01.02.01	Brakes Lock/Jam
-01.02.02	Anti-Skid Device Failure
-01.02.03	Brakes Fail During Braking
-01.02.04	Other
-01.03	Steering System
-01.03.01	Total Failure
-01.03.02	Freezing or Locking
-01.03.03	Other
-01.04	Suspension System
-01.04.01	Sudden Failure of Springs
-01.04.02	Other
-01.05	Power Train and Exhaust System
-01.05.01	Power Loss
-01.05.02	Intermittent Power/Slippage
-01.05.03	Transmission Failure
-01.05.04	Exhaust System Dislodgement
-01.05.05	Exhaust System Back Fire
-01.05.06	Other

TABLE 3.3-1 (Continued)

Code	Causal Factors
01.02.04.01-	(IMMEDIATE VEHICLE EVENTS)
-02	Driver-Related Systems
-02.01	Communication System
-02.01.01	Lights/Signals Fail
-02.01.02	Window/Windshield Breaks
-02.01.03	Wipers Fail
-02.01.04	Other
-02.02	Driver Seating and Controls
-02.02.01	Control Device Breaks
-02.02.02	Driver Seat Moves
-02.02.03	Other
-02.03	Body, Door, and Other Vehicular Features
-02.03.01	Door Opens
-02.03.02	Hood Opens
-02.03.03	Trunk Opens
-02.03.04	Other
01.03.01.01-	LONG-TERM SOCIAL CONTEXT CHARACTERISTICS
-01	Laws and Regulations
-01.01	Signalling
-01.02	Passing
-01.03	Speed Limit
-01.04	Vehicle Regulations
-01.05	Driver Requirements
-01.05.01	Age
-01.05.02	Tests
-01.05.02.01	Driving
-01.05.02.02	Written
-01.05.02.03	Visual
-01.05.02.03	Other
-01.05.03	Other Qualifications
-01.06	Right-of-Way
-01.07	Right-Turn-On-Red
-01.08	Legal Blood-Alcohol Content
-01.09	Other
-02	Customs and Habits
-02.01	Yellow Light Behavior
-02.02	Exceeding Posted Speed
-02.03	Tolerance of Speeding
-02.04	Tolerance of Driving under the Influence
-02.05	Observance of Pedestrian Rights
-02.06	Other
01.03.02.01-	CURRENT SOCIAL CONDITIONS
-01	Trip Purpose
-01.01	Business
-01.01.01	Commuting
-01.01.02	Business-related
-01.02	Family Business
-01.02.01	Shopping
-01.02.02	Other: Dentist, Doctor, Etc.
-01.03	Education, Civic, Religious
-01.04	Social and Recreational
-01.04.01	Vacations
-01.04.02	Visiting Friends/Relatives
-01.04.03	Pleasure Rides
-01.04.04	Other

TABLE 3.3-1 (Continued)

Code	Causal Factors
01.03.02.01-	(CURRENT SOCIAL CONDITIONS)
-02	Vehicle Occupancy and Load
-02.01	Occupants
-02.01.01	Number and Position of Adults
-02.01.02	Number and Position of Children
-02.01.03	Age of Occupants
-02.01.04	Pets, Type and Number
-02.02	Load
-02.02.01	Position of Load
-02.02.02	Type of Load (Groceries, etc.)
-02.02.03	Other
01.03.04.01-	IMMEDIATE SOCIAL SITUATION EVENTS
-01	Actions by Occupants
-01.01	Involuntary
-01.01.01	Child Falls from Seat
-01.01.02	Animal Falls from Seat
-01.01.03	Passenger Becomes Ill
-01.01.04	Other
-01.02	Volitional
-01.02.01	Passenger Performs Distracting Act (Shouts, Points, etc.)
-01.02.02	Passenger Interferes with Driver
-01.02.02.01	Strikes Driver
-01.02.02.02	Holds Driver
-01.02.02.03	Takes Controls from Driver
-01.02.02.04	Other Passenger Action
-01.02.03	Animal Interferes with Driver
-01.02.04	Other
-02	Cargo Movement
-02.01	Cargo Movement Distracts Driver
-02.02	Cargo Movement Restricts Driver
-02.03	Cargo Strikes Driver
-02.04	Cargo Strikes Controls
-02.05	Cargo Damages Other Vehicle Parts
-02.06	Other

Code	Causal Factors
01.04.01.01-	LONG-TERM AMBIENCE CHARACTERISTICS
-01	TIME
-01.01	Year
-01.02	Month
-01.03	Day
-01.04	Hour
-01.05	Minute
-02	SEASON
-02.01	Temperate Regions
-02.01.01	Winter
-02.01.02	Spring
-02.01.03	Fall
-02.01.04	Summer
-02.02	Tropic Regions
-02.02.01	Wet Season
-02.02.02	Dry Season
-03	CLIMATOLOGY
-03.01	Average Cloudiness
-03.02	Percent Sunshine
-03.03	Annual Precipitation
-03.04	Annual Snowfall
-03.05	Annual Number of Thunderstorms
-03.06	Average Wind Speed
-03.07	Average Visibility
-03.08	Average Temperature
-03.09	Average Humidity
-03.10	Average Air Quality
-03.11	Average Salt Content
-04	DAY/NIGHT
-04.01	Dawn
-04.02	Day
-04.03	Dusk
-04.04	Night
01.04.02.01-	CURRENT AMBIENCE CONDITIONS
-01	METEOROLOGICAL CONDITIONS
-01.01	Sky Cover
-01.01.01	Total Cloud Amount
-01.01.02	Low Cloud Amount
-01.01.03	Low Cloud Type
-01.02	Precipitation
-01.02.01	Amount
-01.02.01.01	Previous Hour
-01.02.01.02	Previous 3-hours
-01.02.01.03	Previous 24-hours
-01.02.02	Type
-01.02.02.01	Rain
-01.02.02.02	Snow and Snow Flurries
-01.02.02.03	Sleet
-01.02.02.04	Showers and Thunderstorms
-01.02.02.05	Hail
-01.02.02.06	None
-01.03	Atmospheric Pressure
-01.04	Visibility
-01.04.01	Extent
-01.04.02	Restrictions to Visibility
-01.04.02.01	Haze
-01.04.02.02	Fog
-01.04.02.03	Smog
-01.04.02.04	None
-01.05	Air Temperature
-01.05.01	Below Freezing
-01.05.02	Above 90°F
-01.06	Wind
-01.06.01	Wind Direction
-01.06.02	Wind Speed
-01.07	Humidity
-01.07.01	Relative Humidity
-01.07.02	Absolute Humidity

Code	Causal Factors
	CURRENT AMBIENCE CONDITIONS (Continued)
-02	SUN CONDITIONS
-02.01	Current Solar Radiation Hourly Rate
-02.02	Position of Sun
-02.02.01	Azimuth Angle
-02.02.02	Elevation Angle
-03	LIGHT CONDITIONS
-03.01	Type
-03.01.01	Natural
-03.01.01.01	Dawn
-03.01.01.02	Full Daylight
-03.01.01.03	Dusk
-03.01.01.04	Night
-03.01.02	Artificial
-03.01.02.01	Type
-03.01.02.02	Amount
-04	NOISE CONDITIONS
-04.01	Source
-04.01.01	Traffic
-04.01.02	Emergency Vehicle
-04.01.03	Construction
-04.01.04	Airplace/Airport
-04.01.05	Other
-04.02	Amount
-04.02.01	Subjective
-04.02.01.01	Insignificant
-04.02.01.02	Annoying
-04.02.01.03	Loud
-04.02.01.04	Deafening
-04.02.01.05	Painful
-04.02.02	Objective - Decibels
-05	ODOR CONDITIONS
-05.01	Source
-05.01.01	Traffic
-05.01.02	General Air Pollution
-05.01.03	Sanitary Disposal Area
-05.01.04	General Water Pollution
-05.01.05	Other
-06	FOREIGN MATTER - NATURAL
-06.01	Sand
-06.02	Dust
-06.03	Pollen
-06.04	Insects
01.04.04.01-	SUDDEN AMBIENCE DISTURBANCE
-01	Onset of Meteorological Event
-01.01	Precipitation
-01.01.01	Heavy Rain
-01.01.02	Heavy Snow/Sleet
-01.01.03	Hail
-01.02	Wind Gust
-01.02.01	Direction
-01.02.02	Speed
-01.03	Severe Storm
-01.03.01	Thunderstorm
-01.03.01.01	Lightning
-01.03.01.02	Thunder
-01.03.02	Tornado
-01.03.03	Other
-02	Onset of Change in Air Quality
-02.01	Sand
-02.02	Dust
-02.03	Pollen
-02.04	Insects
-03	Sudden Noise - Non-Meteorological
-03.01	Emergency Vehicles
-03.02	Trucks
-03.03	Horns from Other Vehicles
-03.04	Construction
-03.05	

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.05.01.01-	LONG-TERM HIGHWAY ENVIRONMENT CHARACTERISTICS
-01	HIGHWAY LOCATION
-01.01	General Location
-01.01.01	Location Characteristics
-01.01.01.01	Urban
-01.01.01.02	Rural
-01.01.02	Population
-01.01.02.01	Distribution
-01.01.02.02	Density
-01.01.03	Geographical Area
-01.01.03.01	Coastal Plain
-01.01.03.02	Interior Plain/Plateau
-01.01.03.03	Hills/Lowlands
-01.01.03.04	Mountainous Region
-01.01.03.04.01	Non-Fault Area
-01.01.03.04.02	Fault Area
-01.01.03.04.02.01	Inactive
-01.01.03.04.02.02	Potentially Active
-01.02	Specific Location
-01.02.01	Country
-01.02.02	State (Province, Territory, etc.)
-01.02.03	County
-01.02.04	City (or Town)
-01.02.05	Borough or Local Region
-01.02.06	Street/Highway- Name/Number
-01.02.07	Street Number/Highway Section
-02	TOPOGRAPHY IN VICINITY
-02.01	Natural
-02.01.01	Feature
-02.01.01.01	Mountain
-02.01.01.02	Ridge
-02.01.01.03	Hill
-02.01.01.04	Valley
-02.01.01.05	Hollow, Dingle
-02.01.01.06	Water in Vicinity
-02.01.01.06.01	Pond
-02.01.01.06.02	Lake
-02.01.01.06.03	River
-02.01.01.06.04	Sound (Inlet)
-02.01.01.06.05	Ocean
-02.01.01.07	Flat
-02.01.02	Orientation to Prevailing Wind.
-02.01.02.01	Feature Approximately Parallel to Wind
-02.01.02.02	Feature Approximately Perpendicular to Wind
-02.01.02.03	Feature Approximately at Angle to Wind
-02.01.03	Elevation of Feature
-02.01.04	Type of Rock Face of Feature (if applicable)
-02.01.05	Highway Cut Angle (if appropriate)
-02.02	Man-Made
-02.02.01	Embankment
-02.02.02	Buildings
-02.02.03	Bridge
-02.02.03.01	Type
-02.02.03.01.01	Suspension
-02.02.03.01.02	Truss and Girder
-02.02.03.01.03	Concrete
-02.02.03.02	Toll
-02.02.03.02.01	Toll Collected
-02.02.03.02.02	Non-Toll
-02.02.04	Tunnel
-02.02.04.01	Toll
-02.02.04.02	Non-Toll
-02.02.05	Airport in Vicinity
-02.02.06	Other
-03	HIGHWAY CLASSIFICATION AND SPEED
-03.01	Highway Classification
-03.01.01	Interstate System
-03.01.02	U.S. Route Numbered
-03.01.03	State Route Numbered
-03.01.04	County Road
-03.01.05	City Street
-03.01.06	Other
-03.02	Speed
-03.02.01	Automobiles
-03.02.01.01	Maximum Speed
-03.02.01.02	Minimum Speed
-03.02.02	Trucks
-03.02.02.01	Maximum Speed
-03.02.02.02	Minimum Speed
-03.02.03	Variations in Posted Speed

TABLE 3.3-1 (Continued)

Code	Causal Factor
	LONG-TERM HIGHWAY ENVIRONMENT CHARACTERISTICS (Continued)
-04	ROAD CHARACTERISTICS
-04.01	Geometry
-04.01.01	Lanes
-04.01.01.01	Number
-04.01.01.02	Width
-04.01.01.03	Shoulder Width
-04.01.02	Horizontal Alignment
-04.01.02.01	Magnitude of Curvature
-04.01.02.02	Frequency of Directional Changes
-04.01.03	Vertical Alignment
-04.01.03.01	Grade
-04.01.03.02	Frequency of Crests/Hollows
-04.01.04	Elevation
-04.01.05	Cross Slope
-04.02	Medians
-04.02.01	Barrier Type
-04.02.01.01	Rigid
-04.02.01.02	Semi-Rigid
-04.02.01.03	Flexible
-04.02.02	Barrier Dimensions
-04.02.02.01	Width
-04.02.02.02	Height
-04.02.03	Openings
-04.02.03.01	Frequency
-04.02.03.02	Length
-04.02.03.03	Other
-04.03	Road Surface
-04.03.01	Type
-04.03.01.01	Concrete
-04.03.01.02	Asphalt
-04.03.01.03	Gravel
-04.03.01.04	Dirt
-04.03.01.05	Other
-04.03.02	Semi-Permanent Irregularity
-02.03.02.01	Railroad Tracks
-02.03.02.02	Grills
-02.03.02.03	Other
-04.04	Artificial Illumination
-04.04.01	Type of Lamp
-04.04.02	Frequency of Lamp
-04.05	Roadside Features
-04.05.01	General Extent of Development
-04.05.01.01	Continuous
-04.05.01.02	Intermittent
-04.05.01.03	Absent
-04.05.02	General Land Use
-04.05.02.01	Commercial
-04.05.02.02	Residential
-04.05.02.03	Agricultural
-04.05.02.04	Unused--Forests/National Parks, etc.
-04.05.03	Adjacent Features
-04.05.03.01	Highway Furniture
-04.05.03.01.01	Signs
-04.05.03.01.02	Lamp Post
-04.05.03.01.03	Bridge Abutments and Supports
-04.05.03.01.04	Other
-04.05.03.02	Non-Highway
-04.05.03.02.01	Trees
-04.05.03.02.02	Poles
-04.05.03.02.03	Buildings
-04.05.03.02.04	Shopping Centers
-04.05.03.02.05	Parking Lots
-04.05.03.02.06	Drive-In Movie
-04.05.03.02.07	Homes
-04.05.03.02.08	Other
-04.05.04	Overhead Features
-04.05.04.01	Highway Furniture
-04.05.04.01.01	Overhead Signs
-04.05.04.01.02	Overhead Lights
-04.05.04.01.03	Pedestrian Crossings and Bridges
-04.05.04.01.04	Other
-04.05.04.02	Non-Highway
-04.05.04.02.01	Tree Branches
-04.05.04.02.02	Transmission Lines
-04.05.04.02.03	Other

TABLE 3.3-1 (Continued)

Code	Causal Factor
	LONG-TERM HIGHWAY ENVIRONMENT CHARACTERISTICS (Continued)
-05	ROAD ACCESS AND CONTROL
-05.01	Traffic Signals
-05.01.01	Length of Green Phase
-05.01.02	Length of Red Phase
-05.01.03	Length of Yellow Phase
-05.01.04	Leading Green Light
-05.01.04.01	With Green Arrow
-05.01.04.02	Without Green Arrow
-05.01.05	Flashing Yellow
-05.01.06	Flashing Red
-05.01.07	Other
-05.02	Traffic Signal Sequencing
-05.02.01	Non-Sequencing
-05.02.02	Sequencing with Speed Limit
-05.02.03	Other
-05.03	Traffic Signs
-05.03.01	Speed
-05.03.01.01	Maximum
-05.03.01.02	Minimum
-05.03.02	Directional
-05.03.03	Warning
-05.03.03.01	Speed Reduction
-05.03.03.02	Traffic Signal
-05.03.03.03	Intersection
-05.03.03.04	Curve
-05.03.03.05	Hill
-05.03.03.06	Trucks
-05.03.03.07	Noise
-05.03.03.08	Construction
-05.03.03.09	Lane Ending
-05.03.03.10	Traffic Merge
-05.03.03.11	Fog Area
-05.03.03.12	Other
-05.04	Traffic Flow Regulations
-05.04.01	Intersections
-05.04.01.01	Vehicular
-05.04.01.02	Railroads
-05.04.01.03	Other
-05.04.02	One-Way Streets
-05.04.03	Driveways
-05.04.04	Parking
-05.04.05	Special Turn Lanes
-05.04.06	Other
-05.05	Highway Access
-05.05.01	Ramp
-05.05.01.01	Type
-05.05.01.01.01	Diamond
-05.05.01.01.02	Trumpet
-05.05.01.01.03	Cloverleaf Ramps with Distributor Road
-05.05.01.01.04	Cloverleaf Ramps without Distributor Road
-05.05.01.01.05	Loops without Distributor Road
-05.05.01.01.06	Cloverleaf with Distributor Road
-05.05.01.01.07	Left Side
-05.05.01.01.08	Direct Connections
-05.05.01.01.09	Buttonhook
-05.05.01.01.10	Scissors
-05.05.01.02	Curvature
-05.05.01.02.01	None
-05.05.01.02.02	Small
-05.05.01.02.03	Large
-05.05.01.03	Direction Relative to Main Highway
-05.05.02.	Speed Change Lanes
-05.05.02.01	Acceleration Lane
-05.05.02.01.01	Length
-05.05.02.01.02	Width
-05.05.02.02	Deceleration Lane
-05.05.02.02.01	Length
-05.05.02.02.02	Width
-05.05.02.03	Weaving Lane
-05.05.02.03.01	Length
-05.05.02.03.02	Width

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.05.02.01-	SHORT-TERM HIGHWAY ENVIRONMENT CHARACTERISTICS
-01	HIGHWAY SURFACE
-01.01	Traction Condition
-01.01.01	Dry
-01.01.02	Wet
-01.01.03	Snow-Covered
-01.01.04	Slush-Covered
-01.01.05	Icy Patches
-01.01.06	Puddles
-01.01.06.01	Scattered
-01.01.06.02	Highway Flooded
-01.02	Surface Temperature
-01.03	Surface Defects
-01.03.01	Potholes
-01.03.02	Bumps
-01.03.03	Road Collapsed
-01.03.04	Other
-01.04	Objects on Surface
-01.04.01	Glass, Sharp Objects
-01.04.02	Sand, Gravel
-01.04.03	Grease, Oil
-01.04.04	Debris
-01.04.04.01	From Other Vehicle
-01.04.04.02	Fallen Objects, Tree Limbs
-01.04.04.03	Other
-02	CONSTRUCTION
-02.01	Off-Road
-02.02	On-Road
-03	TRAFFIC SIGNAL/SIGN FAILURE
-03.01	Traffic Signal Failure
-03.01.01	Off
-03.01.01.01	Power Failure
-03.01.01.02	Bulb Failure
-03.01.02	Frozen
-03.01.02.01	Green
-03.01.02.02	Red
-03.01.02.03	Yellow
-03.02.03	Flashing
-03.02.03.01	Red
-03.02.03.02	Yellow
-03.02	Traffic Sign Failure
-03.02.01	Knocked Down
-03.02.02	Altered Illegally (Vandalism)
-03.02.03	Bent or Twisted
-03.02.04	Other
-04	ARTIFICIAL ILLUMINATION FAILURE
01.05.04.01-	SUDDEN HIGHWAY ENVIRONMENT DISTURBANCE
-01	EARTHQUAKE
-02	FALLING ROCKS
-03	LANDSLIDE
-04	SNOW AVALANCHE
-05	ROAD COLLAPSES
-05.01	Bridge
-05.02	Tunnel
-05.03	Elevated Highway
-05.04	Other

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.06.01.01-	<u>LONG-TERM TRAFFIC CHARACTERISTICS</u>
-01	Highway Volume and Capacity
-01.01	Average Daily Traffic (Seasonal)
-01.02	Maximum Hourly Traffic Flow
-01.03	Variation in Average Daily Traffic
-01.04	Variation in Hourly Traffic Volume
-01.05	Other
-02	Average Travel Speed
-02.01	Daytime
-02.02	Nightime
-02.03	Seasonal
-02.04	Distribution of Travel Speed
-02.05	Other
01.06.02.01-	<u>CURRENT TRAFFIC CONDITIONS</u>
-01	Traffic Density
-01.01	Vehicles per Highway Mile
-01.02	Average Vehicle Gap
-01.03	Vehicle Mix
-01.04	Other
-02	Turbulence/Traffic Flow
-02.01	Special Changes
-02.02	Weaving, Merging Maneuvers
-02.03	Other
-03	Speed Variability
-03.01	Distribution of Vehicle Speeds
-03.02	Other

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.00.03.01-	INITIAL TRAFFIC CONFIGURATION
-01	VEHICLE MOTION/ACTION
-01.01	Vehicle Control
-01.01.01	Deliberate/Controlled
-01.01.02	Reactive/Controllable
-01.01.03	Out of Control
-01.01.03.01	Skidding
-01.01.03.02	No Steering
-01.01.03.03	No Brakes
-01.01.03.04	Other
-01.02	Vehicle Motion
-01.02.01	Faster
-01.02.01.01	Engine Accelerating
-01.02.01.02	Rolling Downhill
-01.02.02	Slower
-01.02.02.01	Braking with Engine
-01.02.02.02	Slowing with Brakes
-01.02.02.03	Going Uphill
-01.02.02.04	Rolling, No Engine
-01.02.02.05	Other
-01.02.03	Turning
-01.02.03.01	Left
-01.02.03.02	Right
-01.02.04	Veering
-01.02.04.01	Left
-01.02.04.02	Right
-01.02.05	Continuing
-01.02.05.01	Same Speed
-01.02.05.02	Same Direction
-01.03	Vehicle Situation
-01.03.01	Passing
-01.03.01.01	On Left
-01.03.01.02	On Right
-01.03.02	Being Passed
-01.03.02.01	On Left
-01.03.02.02	On Right
-01.03.03	Crossing Traffic
-01.03.04	Entering Traffic
-01.03.04.01	From Left
-01.03.04.02	From Right
-01.03.05	Exiting Traffic
-01.03.05.01	To Left
-01.03.05.02	To Right
-01.03.06	Merging, Weaving
-01.03.07	Continuing in Same Lane
-01.03.08	Stopping
-01.03.08.01	On Highway
-01.03.08.02	Off Highway
-01.03.08.02.01	To Left
-01.03.08.02.02	To Right

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.00.03.01-	(INITIAL TRAFFIC CONFIGURATION)
-01.04	Vehicle Signalling
-01.04.01	Turn Signals
-01.04.01.01	Left
-01.04.01.02	Right
-01.04.02	Manual Signals
-01.04.02.01	Left
-01.04.02.02	Right
-01.04.02.03	Stop
-01.04.03	Horn
-01.04.04	Brake Lights
-01.04.05	Headlights
-01.04.06	Flashers
-02	TARGET LOCATION
-02.01	Direction (Clock direction relative to driver/vehicle unit)
-02.02	Distance
-03	TARGET RELATIVE MOTION
-03.01	Direction
-03.01.01	Same
-03.01.02	To Left
-03.01.03	To Right
-03.01.04	Opposite
-03.02	Closing Speed
-03.02.01	Velocity
-03.02.02	Time to Collision

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.01.05.01-	RECEPTION OF INFORMATION
-01	Mode of Reception
-01.01	Visual
-01.02	Auditory
-01.03	Sense of Equilibrium/Acceleration
-02	Reception Failures
-02.01	Visual
-02.01.01	Highway
-02.01.01.01	Curve
-02.01.01.02	Exit/Entrance
-02.01.01.03	Driveway
-02.01.01.04	Signs
-02.01.01.05	Signals
-02.01.01.06	Markings
-02.01.01.07	Barriers
-02.01.01.08	Potholes
-02.01.01.09	Surface Condition
-02.01.01.10	Other
-02.01.02	Traffic
-02.01.02.01	Other Vehicle
-02.01.02.02	Vehicle Signal
-02.01.02.03	Other
-02.01.03	Ambience
-02.01.03.01	Precipitation
-02.01.03.02	Other
-02.02	Auditory
-02.02.01	Traffic
-02.02.01.01	Police, Fire, Ambulance Siren
-02.02.01.02	Police Whistle
-02.02.01.03	Horn Signals
-02.02.01.04	Road Noise and Other Traffic
-02.02.01.05	Other
-02.02.02	Ambience
-02.02.02.01	Fire Alarm
-02.02.02.02	Other
-02.03	Sense of Equilibrium/Acceleration
-02.03.01	Highway
-02.03.01.01	Lane Markers
-02.03.01.02	Toll Warning Areas
-02.03.01.03	Curve (due to banking)
-02.03.01.04	Shoulder
-02.03.01.05	Other
-02.03.02	Vehicle
-02.03.02.01	Vibration
-02.03.02.02	Response
-02.03.02.02.01	Acceleration
-02.03.02.02.02	Braking
-02.03.02.02.03	Turning

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.01.06.01-	<u>PERCEPTION OF INFORMATION</u>
-01	<u>Identification of Items</u>
-02	<u>Content of Information</u>
-02.01	Meaning
-02.02	Situation
-02.02.01	Position
-02.02.02	Direction of Travel
-02.02.03	Speed
-02.03	Panic Producing
-03	<u>Perception Failures</u>
-03.01	Meaning
-03.01.01	Visual
-03.01.01.01	Vehicle
-03.01.01.02	Highway
-03.01.01.03	Traffic
-03.01.01.04	Other
-03.01.02	Auditory
-03.01.02.01	Traffic
-03.01.02.02	Ambience
-03.01.02.03	Other
-03.01.03	Sense of Equilibrium/Acceleration
-03.01.03.01	Highway
-03.01.03.02	Vehicle
-03.01.03.03	Other
-03.02	Situation
-03.02.01	Position of Other Vehicles/Objects
-03.02.01.01	Clock Direction
-03.02.01.02	Distance
-03.02.02	Direction of Travel Relative to Case Vehicle
-03.02.02.01	Same
-03.02.02.02	To Left
-03.02.02.03	To Right
-03.02.02.04	Opposite
-03.02.03	Speed
-03.02.03.01	Velocity
-03.02.03.02	Time
-03.02.04	Other
01.01.07.01-	<u>DRIVER ASSUMPTIONS</u>
-01	<u>Subject of Assumptions</u>
-01.01	Highway Environment
-01.02	Other Driver/Vehicle Units
-02	<u>Basis of Assumptions</u>
-02.01	Knowledge
-02.02	Experience
01.01.08.01	<u>DRIVER DECISIONS</u>
-01	Type of Decision
-01.01	Deliberate
-01.01.01	Action
-01.01.02	No Action
-01.02	Panic/Reactive
-01.03	Too Late
-02	Nature of Action
-02.01	Strategic
-02.01.01	Initiate Conflict Situation
-02.01.02	Continue
-02.01.03	Take Precautionary Action
-02.01.04	Take Evasive Action
-02.02	Tactical
-02.02.01	Change Speed
-02.02.02	Change Direction
-02.02.03	Signal

NOTE: The sequence of actions may be an important factor in complex manuevers. Therefore, additional descriptions could be added.

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.01.09.01-	DRIVER ACTION
-01	Type of Action
-01.01	Throttle
-01.01.01	No Change
-01.01.02	Depress
-01.01.03	Release
-01.02	Brake
-01.02.01	No Action
-01.02.02	Depress
-01.02.03	Release
-01.03	Clutch
-01.03.01	No Action
-01.03.02	Depress
-01.03.03	Release
-01.04	Shift
-01.05	Signal
-01.05.01	Left
-01.05.02	Right
-01.05.03	Horn
-01.06	Lights
-01.07	Steering
-01.07.01	Continue
-01.07.02	Left
-01.07.03	Right
-01.08	Other
-02	Success of Action
-02.01	As Intended
-02.02	Distorted
-02.02.01	Too Much
-02.02.02	Too Little
-02.03	Wrong

TABLE 3.3-1 (Continued)

Code	Causal Factor
01.02.10.01-	VEHICLE RESPONSE
-01	Vehicle System
-01.01	Wheels and Tires
-01.02	Brake System
-01.03	Steering System
-01.04	Suspension System
-01.05	Power Train and Exhaust
-01.06	Communication System
-01.07	Driver Seating and Controls
-01.08	Body, Door and Other Vehicular Features
-02	Success of Response *
-02.01	As Expected
-02.02	Distorted
-02.02.01	Too Much
-02.02.02	Too Little
-02.02.03	Delayed
-02.02.04	Unbalanced
-02.02.05	Other
-02.03	No Response
01.02.11.01-	VEHICLE MOTION
-01	Vehicle Control
-01.01	Out of Control
-01.01.01	Skidding
-01.01.02	Jolted (momentary)
-01.01.03	Rolling Over
-01.01.04	Other
-01.02	Deliberate/Controlled
-01.03	Reactive/Controllable
-02	Vehicle Speed/Direction
-02.01	Speed
-02.01.01	Same
-02.01.02	Faster
-02.01.03	Slower
-02.01.04	Stopped
-02.02	Direction
-02.02.01	Same
-02.02.02	To Left
-02.02.03	To Right
-02.02.04	Reverse
-02.03	Lane Position
-02.03.01	Continuing in Same Lane
-02.03.02	Leaving Own Lane
-02.03.02.01	Entering Other Lane
-02.03.02.02	Leaving Road

*Since one can consider several systems being involved simultaneously, one would have to allow several "positions" to indicate how each of the systems succeeded (or failed).

TABLE 3.3-1 (Concluded)

Code	Causal Factor
01.00.13.01-	CRASH CONFIGURATION
-01	TYPE OF ACCIDENT
-01.01	Single Vehicle (with)
-01.01.01	Stationary Object
-01.01.01.01	Guard Rail
-01.01.01.02	Bridge Rail
-01.01.01.03	Median Barrier
-01.01.01.04	Pole
-01.01.01.05	Impact Attenuator
-01.01.01.06	Bridge Structure
-01.01.01.07	Tree
-01.01.01.08	Ditch/Canal
-01.01.01.09	Fence
-01.01.01.10	Embankment
-01.01.01.11	Culvert
-01.01.01.12	Building
-01.01.01.13	Other
-01.01.02	Non-Stationary Object
-01.01.03	Ran Off Road
-01.01.04	Overturned in Road
-01.01.05	Other
-01.02	Two Vehicle (with)
-01.02.01	Other Passenger Car
-01.02.02	Truck
-01.02.03	Bus
-01.02.04	Motorcycle
-01.02.05	Other
-01.03	Vehicle - Non-Motor Vehicle
-01.03.01	Pedestrian
-01.03.02	Bicylist
-01.03.03	Train
-01.03.04	Animal
-01.03.05	Non-Motor Vehicle
-01.03.06	Other
-02	IMPACT LOCATION
-02.01	Primary Vehicle
-02.01.01	Front
-02.01.01.01	Full Front
-02.01.01.02	Left Front
-02.01.01.03	Right Front
-02.01.01.04	Specific Location Unknown
-02.01.02	Left Side
-02.01.02.01	Front Quarter Panel
-02.01.02.02	Passenger Compartment
-02.01.02.03	Rear Quarter Panel
-02.01.02.04	Side Swipe
-02.01.02.05	Specific Location Unknown
-02.01.03	Right Side
-02.01.03.01	Front Quarter Panel
-02.01.03.02	Passenger Compartment
-02.01.03.03	Rear Quarter Panel
-02.01.03.04	Side Swipe
-02.01.03.05	Specific Location Unknown
-02.01.04	Rear
-02.01.04.01	Full Rear
-02.01.04.02	Left Rear
-02.01.04.03	Right Rear
-02.01.04.04	Specific Location Unknown
-02.01.05	Top
-02.01.06	Undercarriage
-02.02	Secondary Vehicle (if applicable)
-02.02.01	Front
-02.02.02	Left Side
-02.02.03	Right Side
-02.02.04	Rear
-02.02.05	Top
-02.02.06	Undercarriage

TABLE 3.3-2

PEDESTRIAN NETWORK

Code	Causal Factor
02.07.01.01-	LONG TERM PEDESTRIAN CHARACTERISTICS (Pedestrian as the second unit)
-01	OBJECTIVE
-01.01	Personal
-01.01.01	General
-01.01.01.01	Age
-01.01.01.02	Sex
-01.01.01.03	Height
-01.01.01.04	Weight
-01.01.01.05	Race
-01.01.01.06	Other
-01.01.02	Family
-01.01.03	Personal History
-01.01.04	Driving-Related Personal History
-01.01.04.01	Not a Driver
-01.01.04.02	Other
-01.01.05	Non-Vehicle Accidents
-01.02	Socioeconomic
-01.02.01	Education
-01.02.02	Employment/Education
-01.02.03	Residence
-01.02.04	Activities
-01.02.05	Achievement
-01.03	Driving Experience
-01.03.01	General Driving History
-01.03.02	Driving Record
-01.03.03	Exposure
-01.03.04	Simulator Responses
-01.04	Physiological
-01.04.01	Vision
-01.04.02	Hearing
-01.04.03	Reactions
-01.04.04	Coordination
-01.04.05	Chronic Disease/Condition
-01.04.06	Recent Change in Physiological Condition
-02	SUBJECTIVE
-02.01	Behavior
-02.02	Satisfaction
-02.03	Attitudes
-02.04	Goals
02.07.02.01-	CURRENT PEDESTRIAN CONDITIONS
-01	OBJECTIVE
-01.01	Physiological State
-01.02	Familiarity
-01.03	Activities
-01.03.01	Standing
-01.03.01.01	In Road
-01.03.01.02	On Shoulder
-01.03.01.03	On Sidewalk
-01.03.01.04	Other
-01.03.02	Walking
-01.03.02.01	Across Road
-01.03.02.02	With Traffic
-01.03.02.03	Against Traffic
-01.04	Dress
-01.04.01	Color
-01.04.02	Reflectivity
-02	SUBJECTIVE
-02.01	Emotional State

TABLE 3.3-2 (Continued)

Code	Causal Factor
02.07.04.01-	<u>*IMMEDIATE PEDESTRIAN EVENTS/DISTURBANCES*</u>
-01	<u>Action Limiting</u>
-01.01	Internal
-01.02	Externally Induced
-01.02.01	Interference from Other Pedestrians
-01.02.02	Interference from Animals
-01.02.03	Interference from Motor Vehicles
-01.02.04	Interference from Highway-Related Objects
-01.02.05	Interference from Other Objects
-01.02.06	Interference from Pedestrian Load
-02	<u>Reception Limiting</u>
-02.01	Internal
-02.02	Externally Induced
-02.02.01	Ambience
-02.02.02	Pedestrians
-02.02.03	Other Objects
02.03.01.01-	<u>LONG TERM SOCIAL CONTEXT CHARACTERISTICS</u>
-01	<u>Laws and Regulations</u>
-01.01	Pedestrian Rights
-01.02	Other
-02	<u>Customs and Habits</u>
-02.01	Pedestrian Behavior
-02.01.01	Crossing at Cross Walks
-02.01.02	Jaywalking
-02.01.03	Playing in Roadway
-02.01.04	Other
-02.02	Driver Behavior (toward pedestrians)
02.03.02.01-	<u>CURRENT SOCIAL CONDITIONS</u>
-01	<u>Activity Purpose</u>
-01.01	Work
-01.02	Play
-01.03	Trip
-01.03.01	Pleasure
-01.03.02	Business
-01.04	Disruption (strike, riot, etc.)
-01.05	Stranded Motorist
-01.06	Other
-02	<u>Company</u>
-02.01	Friends
-02.01.01	Adults
-02.01.02	Children
-02.02	Strangers
-02.02.01	Adults
-02.02.02	Children
-02.03	Animals
-02.03.01	Leashed
-02.03.02	Free
02.03.04.01-	<u>IMMEDIATE SOCIAL SITUATION EVENTS</u>
-01	<u>Actions by Company</u>
-01.01	Distracting Actions by Company
-01.02	Company Restricts Pedestrian Action
-01.03	Company Restricts Pedestrian Vision
-01.04	Pedestrain Struck/Attacked by Company

TABLE 3.3-2 (Continued)

Code	Causal Factor
02.04.01.01-	<u>LONG TERM AMBIENCE</u>
	(Same as Driver Network)
02.04.02.01-	<u>CURRENT AMBIENT CONDITIONS</u>
	(Same as Driver Network)
02.04.04.01-	<u>SUDDEN AMBIENT CHANGES</u>
	(Same as Driver Network)
02.05.01.01-	<u>LONG TERM HIGHWAY ENVIRONMENT CHARACTERISTICS</u>
	(Same as Driver Network plus detail on Sidewalk and Crossing Control)
02.05.02.01-	<u>CURRENT HIGHWAY ENVIRONMENT CONDITIONS</u>
	(Same as Driver Network plus Condition of Sidewalks and Crossing Signals)
02.05.04.01-	<u>SUDDEN HIGHWAY ENVIRONMENT CHANGES</u>
	(Same as Driver Network)
02.00.03.01-	<u>INITIAL TRAFFIC CONFIGURATION</u>
-01	<u>Pedestrian Motion</u>
-01.01	Speed
-01.01.01	Still
-01.01.02	Walking
-01.01.03	Running
-01.02	Direction
-01.02.01	With Traffic
-01.02.02	Against Traffic
-01.02.03	Across Traffic
-02	<u>Pedestrian Position</u>
-02.01	On Highway
-02.02	On Shoulder
-02.03	On Sidewalk/Off Highway
-03	<u>Vehicle Motion Relative to Pedestrian</u>
-03.01	Direction
-03.01.01	From Left
-03.01.02	From Right
-03.01.03	From Front
-03.01.04	From Rear
-03.02	Speed
-03.03	Distance to Pedestrian
-03.03.01	Absolute
-03.03.02	From Line of Travel (Offset)
-04	<u>Pedestrian Action</u>
-04.01	Deliberate/Controlled
-04.01.01	Traffic Related
-04.01.02	Non-Traffic Related
-04.02	Unintentional/Uncontrolled
-04.02.01	Lack of Internal Controls
-04.02.02	Externally Induced

TABLE 3.3-2 (Concluded)

Code	Causal Factor
02.07.05.01-	RECEPTION OF INFORMATION
-01	Mode of Reception
-02	Reception Failures
	(Same as Driver Network with more emphasis on signs, signals, markings, and traffic)
02.07.06.01-	PERCEPTION OF INFORMATION
-01	Identification of Items
-02	Content of Information
-03	Perception Failures
	(Same as Driver Network)
02.07.07.01-	PEDESTRIAN ASSUMPTIONS
-01	Subject of Assumptions
-02	Basis of Assumptions
02.07.08.01-	PEDESTRIAN DECISIONS
-01	Type of Decision
-02	Nature of Decision
-02.01	Strategic
-02.02	Tactical* (*One can consider pedestrians stepping from the curb and waiting as a signal of their intention to cross)
02.07.09.01	PEDESTRIAN ACTION
-01	Type of Action
-01.01	Change Speed
-01.01.01	Run
-01.01.02	Walk
-01.01.03	Stop
-01.02	Change Direction
-01.02.01	Go Forward (across)
-01.02.02	Reverse
-01.02.03	Diagonal
-01.02.04	With Traffic
-01.02.05	Against Traffic
-02	Success of Action
-02.01	As Intended
-02.02	Distorted
-02.02.01	Too Soon
-02.02.02	Too Late
-02.02.03	Slip/Trip
-02.03	Wrong
02.07.10.01-	(RESPONSE does not apply to the Pedestrian Network)
02.07.11.01-	(MOTION does not apply--ACTION describes pedestrian motion)
02.00.12.01-	RESULTANT TRAFFIC CONFIGURATION
	(Same as Initial Traffic Configuration)
02.00.13.01	CRASH CONFIGURATION
	(Same as Driver Network)

4.0 INFORMATION REQUIREMENTS AND AVAILABILITY

4.1 Existing Accident Causation Information

According to the initial plan, the quantitative information on accident causation collected in Phase II of the study should serve as a basis for developing the causal network. Therefore, the network developed in Phase III would naturally have had at least a partially quantitative basis.

The detailed results of the Phase II literature review are given in a separate appendix (Volume 2 of this report). We found a vast amount of information on accident related factors, some of it very detailed, some of it derived by very sophisticated methods, some showing very clear relations, and some directly useful for the planning and design of accident countermeasures. However, we found only one study* which implicitly used the concept of a causal sequence in a sophisticated structure of accident factors. But the quantitative analysis presented used only very limited aspects of this structure.

Most studies dealt only with a limited number of factors, usually long term factors or current conditions. Overall, however there was considerable overlapping between the factors used by the different studies, so we hoped to be able to combine the results from the various studies. Our attempts to do this failed for various reasons. Some reasons are of a relatively simple technical nature, e.g., different definitions used, different populations, differences in the nature of the populations: in some cases accidents, in others, drivers or highway miles. To combine studies, some exposure information is needed. More important, however, is that usually only pre-crash factors were available, and that only the presence (or the value) of a factor was established, but not its causal nature.

There are a few studies where we found some elements of causal chains. A study of tire disablements** allowed one to trace the influences of vehicle age, tread depth, trip length and ambient temperature on tire disablement. And secondly, the influence of driver age and sex on the occurrance of an accident, once tire disablement has occurred. Some of these factors are, however, considered only at two levels, and this study was limited to high speed roads. Thus, the results cannot be generalized.

---

*K. Perchonok, *Accident Causation Analysis* (final report), Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y., July 1972, DOT-HS-800 716.

**J. S. Baker, G. D. McIlraith, "Tire Disablements and Accidents on High-speed Roads." *Highway Research Record*, no. 272, 1969: 24-38.

The data presented in two studies* allow one to trace the effects of driver age, sex, and highway class and "drinking hour" (weekday day versus weekday night and weekend) upon sobriety and upon the speed preceeding an accident. The speed ranges are not exhaustive and no directly causal factor is used. Though the results do not allow one to partially quantify more than a very small part of the causal network, one can make some interesting observations: drunk drivers did drive faster than sober drivers before the accident, and the difference is greater for female drivers than for male drivers, and for older drivers (over 24) greater than for young drivers (but older drunk drivers only drove as fast as sober young drivers).

Relations between chronic medical conditions and driver errors--as reflected by citations, not through accident investigations--are presented by Waller and Goo.** Some of the relations, e.g., that alcholic drivers have 5.3 times as many citations for excessive speed for conditions as the average driver, or 11 times as many for being on the wrong side of the road when not passing, are plausible causal relations. That drivers with cardiovascular disease have 3.3 times as many citations as average drivers for following too closely, does not reflect an obvious causal relationship. It appears more plausible that other factors related to cardiovascular disease, and to following too closely, play a role.

Another source of information on driving errors, as reflected by citations, is a study by Harrington and McBride.*** It shows that the rate (per 100 million miles of travel) of speeding violations decreases with age, but that turning, passing, right of way and traffic sign violation rates are lowest for the 26-65 age group, and higher for older and for younger drivers. For the latter four types of violations, old female drivers have a higher rate than the young ones. For male drivers, this holds only for turning and right-of-way violations; for passing and sign violations, young drivers have higher rates than old drivers. Observing that 18% of the right-of-way violations involved an accident, compared with 9% of the passing violations, 5% of the speeding, 3% of the turning and less than 2% of the sign violations, one might conclude that right-of-way violations are especially hazardous. One has to consider that right-of-way violations require the presence of another vehicle, therefore, the probability of an accident is necessarily greater than in the other case where no other vehicle must be present. Again, this study gives an insight into one link in the causal chain. Age and sex influence certain driving habits. However, this link cannot be connected with others.

---

*Research Triangle Institute, *Some Characteristics of North Carolina Accident Involved Drivers Relative to the Estimated Speed Prior to the Accident.* Raleigh, N.C., Governor's Highway Safety Program, Jan. 1971.

S. B. White, C. A. Clayton, "Some Effects of Alcohol, Age of Driver, and Estimated Speed on the Likelihood of Driver Injury." *Accident Analysis and Precaution*, v. 4, no. 1, March 1972: pp. 59-66.

** _____,"Highway Crash and Citation Patterns and Chronic Medical Conditions," *Journal of Safety Research*, v. 1, no. 3, March 1969, pp. 13-27.

*** _____, "Traffic Violation by Type, Age, Sex, and Marital Status," *Accident Analysis and Prevention*, v. 2, no. 1, May 1970, pp. 67-79.

A very clear-cut case is the monocular driver.* At crossroads, monocular drivers have 6 times as many accidents where the other vehicle is approaching on the blind side than on the other side, as one would intuitively expect. Consequently monocular drivers should have a higher accident rate than binocular drivers. There are indeed 4 times as many monocular drivers among drivers with multiple crashes than monocular persons among patients seen for eye care--which is not an ideal control group.

The most extensive and thorough investigations of accident causation have been performed by the Institute for Research in Public Safety of Indiana University**. We have not been able to reconcile the causation structure they used with the concepts of a causal chain or a causal network. They classified causal factors as human,vehicular and environmental, each of these classes if further subdivided, and so on, in a hierarchical fashion. The results presented show with which frequencies the various factors, at different levels of confidence, were contributing to the accidents investigated. A summary tabulation shows also how frequently human and environmental, human, vehicular and environmental, and other combinations of factors were involved. However, there is no detailed presentation of the actual combinations of the factors. From our point of view, some of the conclusions immediately raise questions which lead to the concept of a causal chain. For example, speed excessive for road design (without regard to weather or traffic conditions) is considered a human factor, rather than an interaction between a human and a highway factor (and possibly vehicle factors). The most frequent environmental factors found as accident causes were view obstructions (especially by parked cars), and slippery roads. Again, we would raise the question to what extent speed, perhaps also tire and brake design characteristics (as distinct from defects) also had to be involved for the accident to occur.

A later study contains cluster analyses of accidents. Several different clusters of accidents were identified. However, the assignment of causes were made as described above, and the variables found to distinguish the clusters are pre-crash factors; thus, no causal chains were identified.

---

*R. L. Bleakly, *The Monocular Driver* (final report). Federal Highway Administration, Bureau of Motor Carrier Safety, Feb. 1974.

A. N. Keeny, "Significances of Visual Problems in Pennsylvania Drivers," *Pennsylvania Medicine*, v. 77, Aug. 1974, 49-51.

** _____, *Study to Determine the Relationship Between Vehicle Defects and Failures and Vehicle Crashes*, (final report), v. 1, May 1973, DOT-HS-800-850, v. 2, May 1973, DOT-HS-800-851, Summary of Final Report, Aug. 1973, DOT-HS-800-902.

_____, *Tri-Level Study of the Causes of Traffic Accidents: Interim Report I, Volume I - Research Findings*, (final report), January 1974, DOT-HS-801-334.

_____, *Interim Report II. Volume III: Interim Report on Driver Vision and Knowledge Testing, and Other Special Study Topics*, March 1975, DOT-HS-034-3-535.

_____, *An Analysis of Emergency Actions, Manuevers, and Driver Behavior in Accident Avoidance*, Falls Church, Va., URA/,atrix Co., Feb. 1975.

Our conclusion was that the results of the IRPS studies could not contribute to the construction of a causal network, even if they were published in greater detail. This was primarily due to the explicit, and even more, the implicit definitions of causation--which may be due to their initial emphasis on "vehicle defects."

On the basis of these findings we had to conclude that the currently published studies of accident causation provide no basis for even a partial quantification of a causal network.

4.2 Information Requirements

Since we found practically no quantitative information which could be used in the construction of the network, we have not only to indicate on which aspects of the network additional information is needed, but we have also to state the information requirements in generic terms.

The primary requirement is not that data on accidents are collected in an ordered manner -- such as entering the various factors or quantities in the spaces provided on a form -- but that their causal and temporal sequence is retained. Typically, this is done in the narrative part of accident reports, and in sketches or diagrams which show the sequence of the vehicles' positions during the crash process, and even the various impact points, etc. What enters these unstructured descriptions of an accident, contrasting with the structured information collected on the form, depends to a large extent on the subjective judgement of the investigator, and on the breadth or narrowness of his concept of causation. The following may illustrate this point: a car enters a curve on a rainy night; the curvature of the road is not clearly recognizable; the vehicle skids out of control when the driver tries to slow down in the curve. An investigator may indicate that speed was too high for conditions. Another may conclude that the driver did not properly apply the brakes; however, one also has to consider that the delineation of the curve might have been inadequate; and if one takes a very broad concept of causation, then the absence of skid control devices was a causal factor. The minimum which is required is to present this entire sequence: listing all factors which lead to the last one -- skidding -- which immediately preceded the accident. Desirable however, is further analysis which estimates, and preferably quantifies, the impact of the various factors. If the investigation shows that even if the road had been well marked so that the driver could have recognized its curvature or that even with skilled braking or skid control devices the driver could not have slowed down to avoid running off the road or skidding, then, high speed could indeed be identified as *the* cause of this accident (and, of course, those pre-crash factors which influenced the driver to travel at this speed). In all other cases, however, all factors together have to be considered as causal, except, of course, if it was determined that the driver would not have slowed down earlier even if he had recognized the degree of curvature of the road. Only then would the inadequate markings be eliminated as a causal factor. To assign "weights" or other measures of importance to the several factors appears to be extremely difficult, if possible at all.

An important point is to distinguish the presence of a "causal" factor from its actual involvement in the causal chain. For example, a wet pavement may be present, but it may have been in no way connected with the occurrence of the accident; in this case, it is quite likely that this will be correctly recognized in a description of the event. In the case of alcohol, however, its presence could probably be considered at least as a contributing factor to a more specific failure of the driver. For a correct evaluation, however, this has to be established. One study which we found showed that alcohol had only little effect on reaction time up to fairly high BAC levels, though it had strong effects on other driving related factors.

This discussion illustrates that what is needed is a description of accidents in terms of causal chains. To make these causal chains compatible so that they can be combined and analyses performed and overall conclusions be drawn, it is necessary that common factors are used, e.g., by following an extensive list of factors, such as the one presented in Section 3.3 and that the causal chains possibly follow a common pattern, e.g., as outlined in Section 3.2. However, it may be necessary to introduce new links into these networks, if unanticipated causal mechanisms occurred.

It is unrealistic to expect that in the near future sufficient accident data will become available to develop a network of the level of detail described in Section 3. Therefore, it may be necessary to initially develop a more aggregated network. An important practical problem is that certain factors cannot easily, if at all, be reliably assessed, e.g., whether a driver did not see a car or whether he chose to ignore it is very difficult, if not impossible, to establish. The distance at which one car followed another, and their absolute speeds will be nearly impossible to reconstruct, but their braking capabilities are easily determinable. Thus, one has to make a compromise between what is conceptually desirable and what is practicably obtainable. Currently, it appears that all factors which are internal to the driver during the crash process should be summarily treated in an initial network.

4.3 Potentially Usable Information

There are two ways of obtaining information for actually quantifying a causal network:

- Re-analysis of existing data files
- Collection of new information.

The second way is being considered by NHTSA as evidenced by the request for proposal, "Accident Causation Methodology Development for the National Accident Sampling System." It will take some time, however, until such a program is implemented and results obtained. Therefore, a re-analysis of existing data files might be worthwhile.

The most extensive accident investigations under the aspect of causation have been conducted by the Institute for Research in Public Safety of Indiana University. The hardcopy original reports, however, were destroyed. Only information coded in a standard format is still available. Another study of accident causation conducted by CALSPAN used data from several quite different files, but it used a more general causation structure than IRPS. The multidisciplinary accident investigations provide detailed verbal and also coded, descriptions of accidents. Overall, these three sources contain about 10,000 cases.

A potentially valuable source of some causal information is available in the North Carolina accident data files, which begin in 1966, for which the verbal description of the accident has been coded. Thus, in principle, it is possible to computer process this large information base. However, it is not obvious that is is practically possible to write computer programs which extract from the highly diverse accident descriptions written by policy officers the causal chains in a standardized format.

The State of Connecticut has a very detailed scheme for coding accident reports from the verbal description of the accident. This scheme allows one to describe several hundred pre-crash maneuvers. We do not know, however, to what extent these possibilities are actually used.

An initial analysis of such existing sources could, if not actually produce a quantified network, suggest what level of detail can be realistically obtained, and also suggest what the more, and less, important parts of the network are.

5.0 USES OF THE NETWORK

The uses of the network at the present conceptual level are limited; once it has been--fully or partially--quantified, additional uses are possible. The main areas of use are:

- For the current conceptual network:
  - Guiding the planning, execution and analysis of accident investigations and reconstructions,
  - Providing a framework for planning and coordinating analytical and simulation studies of accident processes.

- For a quantified network:
  - Organizing and analyzing accident statistics
  - Providing a basis for planning and evaluating accident countermeasures.

5.1 Accident Investigations

Current accident investigations typically result in a form, partially for quantitative entries, partially a checklist of precrash factors, a sketch of the accident process, and a narrative description. Some of this information is obtainable with a high degree of reliability, some is based on the statements of casual observers or interested parties, and what went on is often intuitively inferred from the available information. In special investigations, the motions of the vehicles may be reconstructed by computer programs like SMAC or CRASH.

Though the results of an accident investigation may be "correct" in a narrow sense--meaning that the information reported is correct--they may be misleading because of the omission of information, either because it was not requested on the form, or because its relevance was not appreciated. A few examples may illustrate this. Assume two cars approaching an intersection at a right angle. One driver faces a red light, but continues at unchanged speed. The other driver, facing green, continues at his speed, although he sees the other vehicle. He fails to correctly assess that the other vehicle cannot (or only with difficulty) stop in time, and a collision occurs. Most accident reports will consider only the one driver's running of a red light the cause of the accident. A thorough analysis, using the network concept, would have to determine whether the one driver did see the red light or not. If not, what prevented him from seeing it; if yes, why did he not attempt to stop. For the second driver, one would have to establish why he did not recognize the inability of the other driver's vehicle unit to stop, given the speed; did he perceive the speed incorrectly or did he overestimate the braking capability of the other car.

For a more complex situation, make the same initial assumption, except that the driver of the second vehicle assumes that the first one is not going to stop at the intersection, and, therefore, makes an emergency stop. A third following vehicle has a driver who notices the second vehicle stopping, and also brakes, but hits the second vehicle in the rear. In this situation, the first vehicle will usually be gone--if its driver notices the accident at all--when the accident is investigated, and will be classified as a "phantom" vehicle. Some information on it and its actions can be obtained, but with very low reliability. Nevertheless, it is an important element in the chain of events leading to the crash. For the collision between the second and third car, one has to determine whether the driver of the third car did see the first vehicle at all; if not, why; if he did, when (and why later than the driver of the first vehicle) and why he did not reach the same conclusion as the driver of the second vehicle. If he did reach the same conclusion, why did the collision occur? Was his braking delayed, were his car's brakes less effective than those of the first car, did his car skid, or was it just that the relation between the headway when the first car braked, the speeds of the two cars and their braking capabilities was such that a collision could not be avoided? The latter is usually lumped under the label, "following too closely," but this is a vacuous term if the factors mentioned above are not determined, or at least estimated. Actually, "following too closely" already judges the possibility of evasion under the aspect of one single implied countermeasure, namely to increase the distance between the cars.

These examples illustrate one use of the network in investigating accidents: to trace "all" causal chains to make sure that no causal factor which influences the occurrence of an accident was overlooked. The network and the list of factors also show which factors should be obtained or reconstructed in order to obtain a full understanding of the accident process.

As we have shown in Section 3.1, not only are causal sequences important, but also the interactions of independent factors, each of which causes a delay, reduces friction etc., so that none of the individual factors contributes enough to cause an accident. Indeed, the summation or interaction of all or several factors may make a parameter exceed a critical value and, thereby, "cause" an accident. Our network incorporates functional interactions to the extent that we recognized them and judged them to be important. We could not naturally incorporate temporal interaction into the network; this has to be done by means of an adjacent structure as shown in Figure 3.1-4.

An investigation of accidents along the lines described here exceeds by far what is currently being done. In some respects it may even exceed what is practicable within the foreseeable future. Therefore, it will be necessary to make compromises between the comprehensiveness of the network's aims and the practical aspects of obtaining information on a sufficiently large number of accidents.

5.2 Analytical and Simulation Studies of Accident Processes

To obtain insight into the processes which occur in accidents, one can design analytical or simulation models for special aspects of the accident process. It is, for example, relatively easy to develop an analytical model which connects the various factors influencing skidding,so that one can determine how changes in certain parameters of vehicles or highways would influence the occurrence of skidding. Simple models exist to determine the length of the line of sight as it depends on highway, vehicle and driver characteristics. Studies of driver's eye motions when driving have been made, showing what attracts their view; they could be used to model delays in recognition time. On a more ambitious level, one can imagine models incorporating the dynamic aspects of a CRASH or SMAC to be used for simulating the effects of hypothetical emergency maneuvers. This would go a long step beyond the IRPS studies of avoidance maneuvers, and of the potential effects of a hypothetical radar brake, where essentially subjective judgments were used to assess the potential effects.

The causal network will not be a direct part of such models which have to consist of equations or algorithms. However, a comprehensive causal network can provide guidance as to which factors and interactions to include, and also in which sequence to enter the factors into the model, and to perform the operation.

5.3 Organizing and Analyzing Accident Statistics

Most summaries of accident data consist of one-, two-, and (rarely) three- or more dimensional tabulations; sometimes they give statistical relations between the parameters of the accident. Usually, only the presence or absence of a factor is considered, not its involvement in the causal chain. "Causes" are usually identified within the legal framework of the police accident investigation. Sometimes these causes are related to other factors, primarily driver factors. Only a few studies deal with "causes" defined in a broader manner and established by a more thorough investigation.

The causal network can be used to organize and analyze accident data more thoroughly. The first step is to consider causal links connecting factors, and entire causal chains as new elements which will be treated separately. For instance, the influence of alcohol would not be considered in isolation. Rather, the specific failure which was influenced by the presence of alcohol would be considered, in conjunction with the presence of alcohol. To complement this, however, "all" (or at least the most frequently occurring) combinations of these factors with other preceding factors, e.g., being tired, being inexperienced, etc. would have to be considered. An obvious consequence is that since the number of links in the causal chain is much larger than the number of factors, tabulations will have to be much more extensive than at present, where only individual factors are used. This problem can be alleviated to some extent by concentrating on the most important chains.

An aggregate manner of presenting the causal relations is a matrix which provides both rows and columns for "all" relevant factors. Thus, one could show how a factor is (directly or indirectly) related to preceding factors, and to subsequent factors. This relation could be expressed in various ways: by the relative frequencies with which these factors occur, (given that the factor under consideration applied), by a measure of strength or importance of the relation, and, possibly, by other measures, e.g., the minimal number of intermediate factors.

The most extensive use of the network would be in organizing accident data in a "tree" format. A complete "tree" would be too extensive, but it is possible to limit the presentation of the tree to those aspects which are of interest in any given context.

5.4 Planning and Evaluating Countermeasures

Accident countermeasures are intended to interrupt the causal chain by changing specific factors. Their overall effect depends on two characteristics: 1) how much they affect the occurrence of this factor; and 2) how removing or changing this factor affects accidents. The first characteristic has two components, extent and degree. An alcohol countermeasure program may concentrate on a few "problem drinkers," or it may be aimed at the majority of drivers who drink and drive occasionally; this describes the extent of the program's impact.

The degree of its impact is whether it diminishes driving under the influence of alcohol for those individuals who are reached by the program, or whether it reduces the alcohol level to an "acceptable" limit. An analysis of the impact of a program upon the factors of the network is beyond the scope of the network analysis; this has to be developed as part of the program development and planning. However, it may be performed in several feedback cycles, using the network between the cycles.

Having identified the impact of a countermeasure on a specific causal factor, the network enables one to "trace" its effect, and to estimate the impact of the countermeasure upon the overall accident occurrence.

Though the effect of a countermeasure on a specific factor may be high, it might not be recognizable as a change in total accident numbers, because it affects only a fraction of all accidents. In this situation, the network can help to identify which specific accident situations are most influenced by the countermeasure, and which ones are not, thus allowing the selection of an "experimental" and a "control" group for evaluating the effects of a specific countermeasure. It also would allow the determination of which other factors might influence the experimental and the control groups of accidents differently, and would thus enable one to assess whether the control group can actually be used as a control group or whether the influence of other factors might have to be accounted for also.

Finally, the network can help to plan the implementation of various countermeasures. Several countermeasures which initially influence different causal factors may (in the causal chain) finally influence the same factor, thereby making their effects less than additive. On the other hand, countermeasures which affect completely different links on the causal chain have additive effects.

Figure 5.4-1 shows where the major countermeasures as grouped by the Highway and Motor Vehicle Safety Standards, directly affect the causal network. Figure 5.4-2 shows for one countermeasure (driver education) how this influence spreads by means of the causal chain.

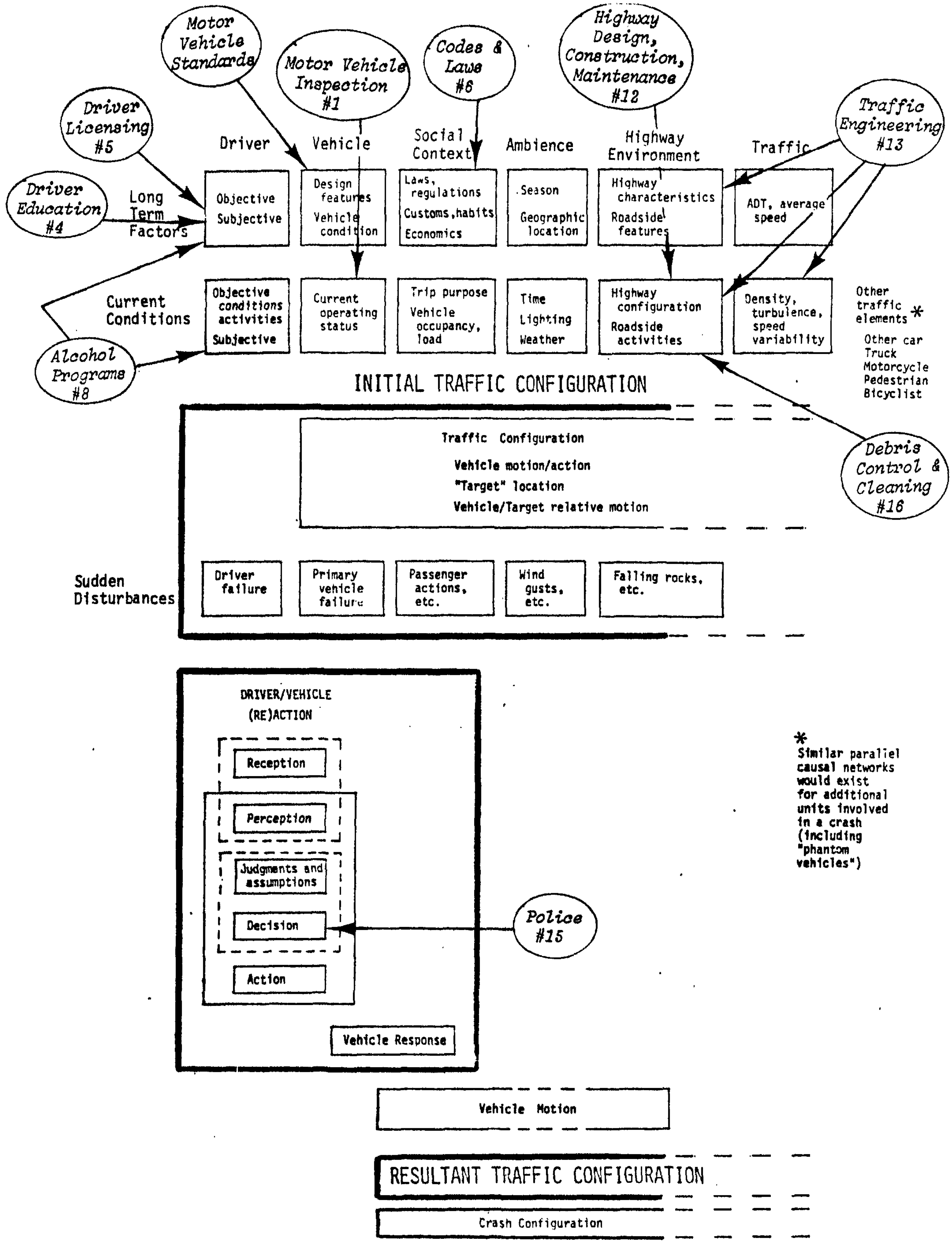


Figure 5.4-1. The direct effect of highway and Motor Vehicle Safety Standards on the elements of the causal network. The effect of the following programs cannot be directly shown in the network: MV registration (#2), motorcycle safety (#3), identification of accident location (#9), traffic records (#10), accident investigation and reporting (#18), pedestrian safety (#19).

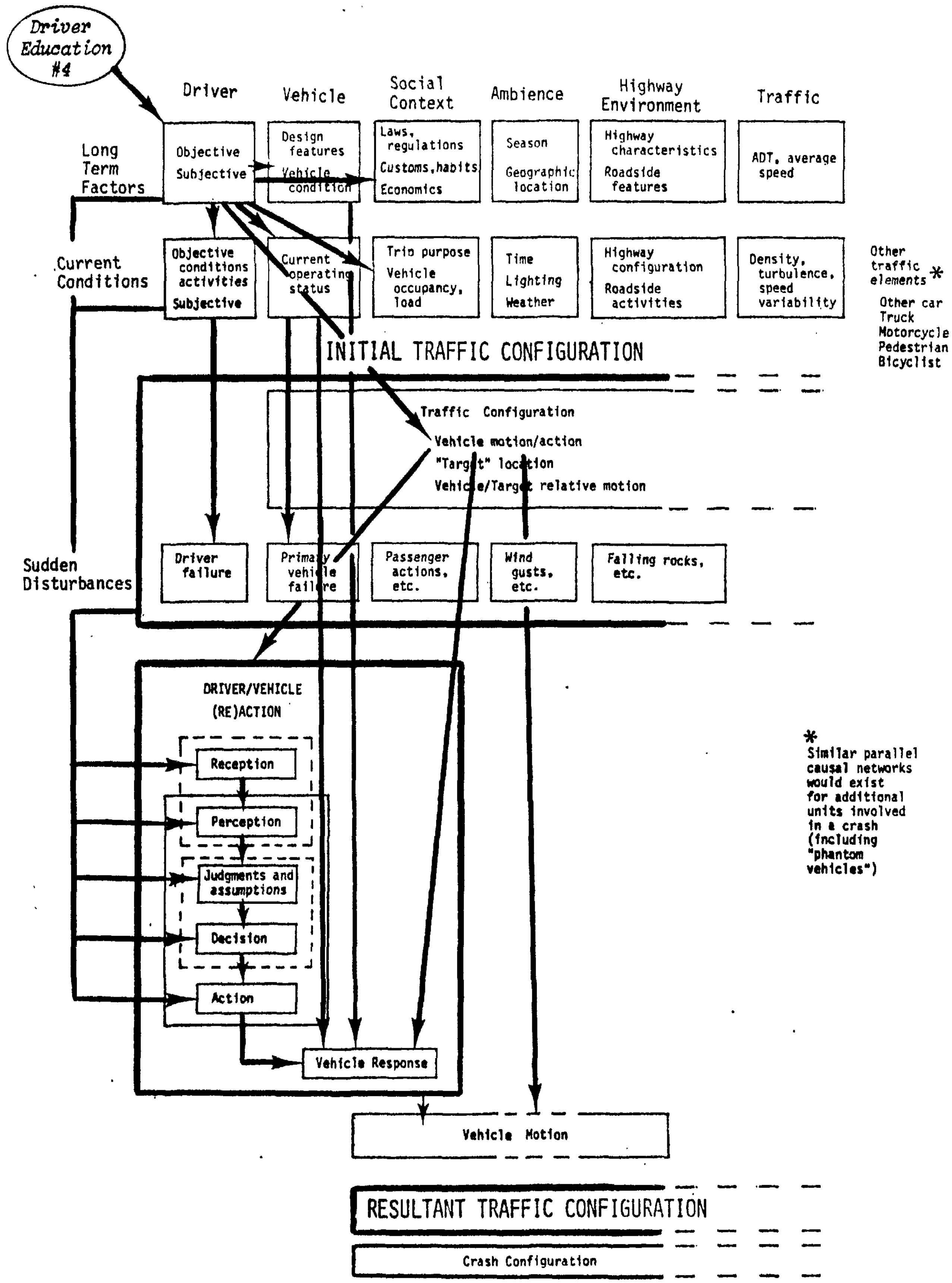


Figure 5.4-2. Illustration of the direct and indirect (via the links of the causal network) effects of driver education.

6.0 RECOMMENDATIONS

We recommend future work in the following areas:

- Quantifying the network with existing accident data.
- Reviewing the possibilities for obtaining additional data from new accident investigations.
- Studying methods to quantify interactions of accident factors.
- Studying the time structure of accident events.
- Reviewing the concept of exposure measurement.
- Developing specifications for countermeasure program plans.

Quantifying the network. Existing detailed accident investigation data descriptions and analyses should be studied to obtain an overall quantification of the causal network. It should also be determined which information is adequately collected at present and which information is missing.

Reviewing data obtainability. It should be determined, in cooperation with accident investigators and analysts, which of the factors included in the causal network can be determined by accident investigations, the effort involved, and the reliability to be expected.

Quantifying interactions of accident factors. It should be determined to what extent mathematical models can be developed which quantify the interactions of the factors of the network, on physical, engineering, or empirical bases. A cimple example is the interaction of the factors which have to interact to lead to "loss of control" (skidding), and the numerous factors which may contribute to this.

Studying the time structure. A similar problem is how to quantify the interactions (in this case, addition) of the various normal performance times and delays which together make an action "too late" to be successful. A critical aspect of this is the examination of the statistical properties of the available times to avoid a collision, which may not be exceeded by the time to perform the various steps of reacting. A great difficulty is that such situations are created by the actions or reactions of drivers.

Exploring appropriate exposure measures. Currently used exposure measures (typically, vehicle miles of travel) are of a highly aggregate nature. To define accident risk, more sophisticated exposure measures are needed. For instance, what is the proper exposure base to define the risk involved in following another car at a certain distance (to quantify the violation "following too closely")? Is it vehicle miles of travel, is it seconds, or is it a count of such situations without regard to their duration? A very thorough analysis of the concept, and also of the possibilities of actually measuring exposure is needed to obtain a meaningful basis for accident risk.

Specifying countermeasure program plans. To assess the potential effects of implemented countermeasures, a detailed description of them, in terms of the elements of the causal network which they affect, is needed. It is also desirable to quantify these effects: the degree to which a countermeasure, implemented with a certain intensity, modifies the affected factors.

APPENDIX A: BIBLIOGRPAHY FOR VOLUME 1

1. Goeller, B. F. *Modelling the Traffic-Safety System.* Santa Monica, Calif., The Rand Corp., April 1968. 66 p.

2. Hall, William K. and James O'Day. "Causal chain approaches to the evaluation of highway safety countermeasures," *Journal of Safety Research*, v. 3, no. 1, March 1971: 9-20.

3. Kontratos, Anthony N. "A systems analysis of the problem of road casualties," *Accident Analysis and Prevention*, v. 6, no. 3/4, Dec. 1974: 223-242.

4. Fell, James. C. *A Motor Vehicle Accident Causal System: The Human Element.* Springfield, Va., National Technical Information Service, July 1974. 28 p.

5. Kurvcz, Charles N. and Bertan W. Morrow. *A Causal Model for Single Vehicle Accidents.* Coral Gables, Florida, University of Miami (n.d.) 13 p.

6. Wilde, Gerald S. "Social interaction patterns in driver behavior: an introductory review," *Human Factors*, v. 18, no. 5, Oct. 1976. 477-492.

7. Perkins, Stuart R. *GMR Traffic Conflicts Techniques Procedures Manual.* Detroit, Mich., GM Research Publication GMR-895, August 1969. 25 p.

8. Perchonok, K. *Accident Cause Analysis.* Buffalo, N.Y., Cornell University Laboratory, Inc., July 1972. 72 p.