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TRANSPORTATION RESEARCH RECORD 909

Motor Vehicle Technology Assessment; and Motorcycle, Moped, and Bicycle Use

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TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL
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Potential of the Bicycle as a Substitute for Other Modes of Transportation

WERNER BRÖG AND ERHARD ERL

Without a doubt, the bicycle is the most ecologically acceptable mode of transportation. Nonetheless, for a long time, it had been almost ignored in transportation planning. Only very recently has this changed. However, some uncertainty still exists concerning the extent to which the bicycle can substitute for other modes of transportation in urban areas. This question is investigated by first observing the development of transportation in recent years in selected areas of the Federal Republic of Germany, in which use of the bicycle has been on the increase. This makes it possible to identify those changes in modal choice that have brought about this increase in the use of bicycles. The changes in modal split in favor of bicycles reflect individual reorientations that have led to substitution processes. Further potential of the bicycle as a substitute for other modes of transportation will depend on policymaking. Social scientific behavioral studies based on the concept of the situational approach make it possible to give reliable estimates of the order of magnitude of change to be expected and to predict the extent to which bicycles can become a substitute for private motor vehicles.

Since the 1950s, an increasing trend toward motorization has been observed in the Federal Republic of Germany. The use of private motor vehicles reached its peak in the mid-1970s. Use of nonmotorized modes of transportation was considered to be inconsequential, especially by transport planners, whose ideal it was to design cities suited to the needs of motorists.

Thus, it is not surprising that the first federal German survey on travel behavior (KONTIV) (1), in order to record all movements from one place to another place (including walking trips and trips made by bicycle), relied on methodological arguments and not arguments that had to do with content (2).

With regard to bicycle use, the results of the study were interesting for two reasons:

1. Bicycles were used to make 10 percent (3) of the total number of trips; thus, bicycle use turned out to be much more important than transport planners had generally assumed;
2. A number of arguments that had been used to determine whether the bicycle was a serious mode of transportation (e.g., a mode to be used only in good weather or by youngsters) were proved to be false.

These insights would not have had such a broad influence if car use had not been viewed with increasing scepticism, primarily due to the energy crisis and increasing awareness of the need to protect the environment, which had caused people to think more of the bicycle. This started a trend of increasing bicycle use in the Federal Republic of Germany, a trend that could be noticed "with the naked eye" (4).

These trends suggest new questions, which may easily tempt us to propose premature answers and evaluations, for instance, the following:

1. Is cycling a passing fad or is it an indication of a change in the behavior pattern?
2. Was one mode actually used to substitute for another mode or did changes occur only in such external factors as sociodemographic structures?
3. Is there a further potential for change to bicycle use?

Depending on their attitude, people may answer these questions differently--and often prematurely. Since the list of such questions, and of possible answers, can be extended indefinitely, it is especially difficult to design and implement policies intended to influence the use of bicycles.

It is the goal of this paper to present some findings on the current increase in bicycle use and to study the extent to which the bicycle has potential as a substitute for other modes of transportation.

CHANGES IN MODAL CHOICE

The considerations in this section are based on time-series data similar to the data reported in the national KONTIV study referred to above. Since then, numerous regional surveys that used a comparable design were performed in the early 1980s (5). The results were based on independent, representative random samples. The samples were large enough to make it possible to at least identify basic trends. Data were corrected when differences in the methodology (weighting) were present.

In order to show changes taking place as precisely as possible, an index was constructed, which starts from the 1980-1981 value as a base and permits calculation of the corresponding value for 1975-1976 (6):

Index of change = [(value for 1975-1976)/(comparable value for 1980-1981)] x 100.

When the calculated index exceeds 100, the 1975-1976 value is greater than the 1980-1981 value, which implies a retrogressive tendency; if it is less than 100, this value shows an ascending trend.

Transportation planners in the 1960s and 1970s frequently referred to increasing mobility because mobility was (incorrectly) equated with the use of motorized modes of transportation. However, when all possible ways of getting from one place to another are considered, there was never a very large increase in mobility (7,8) but only a change from the use of nonmotorized modes to motorized modes of transportation. In the communities discussed in this paper for which figures are available, mobility increased very slightly, as one might expect. Most increases in mobility were caused by the fact that those who were mobile increased the average number of trips they made by making complicated trip chains that resulted from a combination of various activities (see Table 1).

CHANGES IN MODE CHOICE

Modal split varied considerably in the different communities studied. In particular, the percentage of cyclists fluctuated radically, although topographical drawbacks to cycling were an important factor in only one instance. One should also note that the nonmotorized modes seem to strike a kind of balance with each other. Thus, changes in behavior are relatively insignificant when one analyzes the extended modal split. However, even here, certain trends can be observed (Table 2). Use of private motor vehicles decreased with only three exceptions; use of public transportation increased in urban areas (when the public transportation supply had noticeably improved) and decreased in smaller com-

Table 1. Mobility.

Variable	Index of Change: Detmold	Rosenheim	Landshut	Offenburg	Hannover[a]: Region	City
Out-of-house share	100	100	100	100	100	99
Trips per mobile person	98	98	98	97	100	98
Trips per person	98	99	98	98	100	97

[a]These figures are not available for the other survey in a German metropolitan area.

Table 2. Modal split and mode choice.

Item	Index of Change: Detmold	Rosenheim	Landshut	Offenburg	Hannover: Region	City	Large German City[a]: Region	City
Extended modal split:								
Nonmotorized mode	68	117	91	107	100	86	101	100
Motorized individual mode	117	83	112	91	106	135	100	108
Public transportation	171	87	108	131	85	80	97	85
Mode choice:								
Walk	82	180	135	134	117	94	102	103
Bicycle	41	50	45	73	81	68	99	63
Motorized one-axle vehicle	30	26	39	19	100	120	72	44
Car								
Driver	133	85	125	103	103	136	104	116
Passenger	75	93	95	82	119	132	93	91
Public transportation	171	87	108	131	85	80	97	85

[a]Survey results of a large German city. Since these results have not yet been published, the city remains anonymous.

munities beyond the range of the population centers. The use of nonmotorized modes of travel developed erratically.

The differences disappear if one considers all the modes usually used (Table 2). One can observe that bicycle use is increasing in all the areas studied, although at different rates. However, sometimes the increase in cycling occurs solely at the cost of pedestrian travel. This shows that one should view the increase in bicycle use, which is so frequently noted with joy, somewhat sceptically. Only rarely can one assume that a noteworthy change from motorized modes to cycling took place. Quite frequently, on the other hand, the bicycle is now used for trips that were previously made on foot. Nonetheless, this gets people used to riding bicycles, which might ultimately increase the potential for further, more effective changes in behavior.

When studying the changes in modal choice, one should not forget to take the initial situation into consideration. As Figure 1 shows, the bicycle share in 1975-1976 was above average in the four areas studied. In Offenburg and the region of Hannover, where the bicycle share in 1975-1976 was particularly high, the increase in the number of trips made by bicycle is less than in areas in which the bicycle share was smaller to begin with. One exception here is Hannover. Hannover shows a relatively small increase in the use of bicycles, although the share of cyclists in 1975-1976 was not particularly high.

It is possible to theorize that the bicycle fad progresses according to certain generally valid principles, i.e., independent of specific regional differences (communal "cycling climate," bicycle infrastructure, degree of motorization, topography, etc.), and that changes occur at different rates. This could mean that a development that took place in the region of Hannover and Offenburg in 1975-1976 took place at a later time in Rosenheim and Landshut. This would imply that the two latter cities will be able to maintain their existing very high bicycle share only with very great effort, although an increase in the bicycle share still seems to be possible in Detmold. In other words, bicycle planning should not only aim at increasing the percentage of trips made by bicycle but also try to stabilize those trips now made by bicycle.

Changes in modal choice also depend on local conditions. Thus, general behavioral trends do not always apply in specific areas. Since it is impossible to deal with the different areas studied here in depth, given the limitations of this paper, the variance in different communities will be shown by using the example of bicycle use according to different age groups. (We have figures for four different communities here.) Table 3 shows that the bicycle share according to age develops differently in different areas. In Offenburg, for example, younger persons, and in Detmold older persons, made relatively fewer trips by bicycle than they did in 1975. All in all, one can say that the increases for younger persons have been less than average, and indices showing changes for the middle age groups (30-49 years of age) more or less reflect the general trend.

INTRAPERSONAL CHANGES IN MODAL CHOICE

The changes depicted above were based on the results of samples obtained at two different times. In order to attain further qualitative insights into the trends taking place, explorative in-depth interviews were done in the two cities of Detmold and Rosenheim. These were two of the cities included in the project city for cyclists (9). A sample of 50 households and 100 persons was selected for these explorative in-depth interviews. A special questionnaire was designed to deal with this difficult empirical task. The questionnaire included external factors such as neighborhood, place of work, and status as well as mode choice related to trip purpose; the average week was used as a basis. If

Figure 1. Development of bicycle traffic.

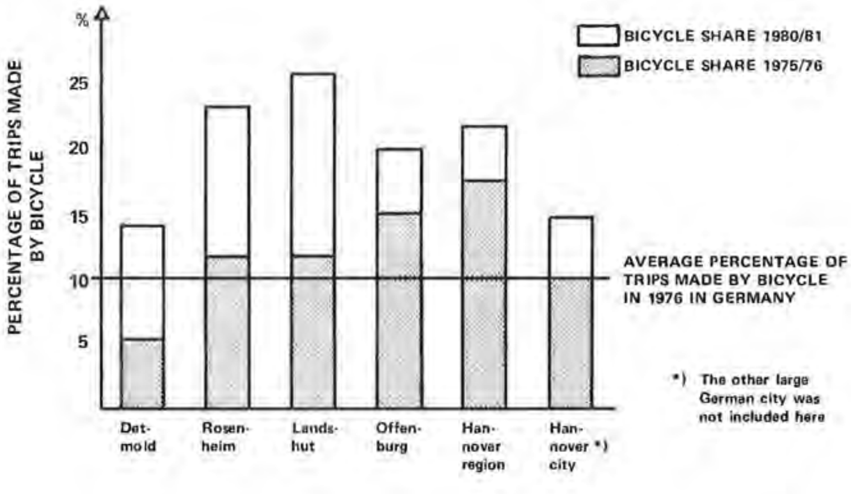

Table 3. Bicycle use by age.

Age Group	Index of Change of Bicycle Share[a]			
	Detmold	Rosenheim	Landshut	Offenburg
10-17	52	69	61	104
18-29	8	65	40	70
30-49	43	57	47	72
50-64	44	28	31	52
65+	117	37	55	24
All ages	41	50	45	73

[a] For the large cities these qualifications are not available.

changes in the behavior pattern occurred, reasons causing these changes were studied.

Changed travel behavior is rarely the result of external factors. With the exception of those who move to a new neighborhood, only 5 percent of the respondents or less were affected by changing external conditions. About 40 percent of the respondents moved within the period of observation; more than half of these moved to a new community. Although moves within the same community do not usually affect modal choice, it is different when people move to new communities. Since moves to new communities are usually accompanied by major changes in living conditions, changes in the entire personal activity pattern frequently occur. Other factors dealing with the social environment turned out to be relatively insignificant in a quantitative way. A major determining factor in modal choice is the availability of certain modes of transportation. In this paper, cars and bicycles are of central interest; other modes will not be dealt with further here.

Among the populations studied, the number of cars increased by 26 percent, whereas the number of bicycles increased by 55 percent between 1975 and 1981. Increased car ownership led to a greater percentage of households that had access to cars; in Rosenheim especially, the percentage of households with two cars and more doubled. The increase in bicycle ownership had a similar but more pronounced effect.

Increases in bicycle ownership correlated positively with the increased use of bicycles. This was not so for cars. The increase in car ownership (which was less than the increase in bicycle ownership) is paired with opposite trends in car use. Although the proportional increase in car ownership was similar in both areas studied, there was a noticeable decrease in car use in Detmold and a slight increase in Rosenheim. One possible explanation for this is the fact that in the last seven years in Rosenheim, cars were increasingly purchased by households that did not own a car previously. For the time being, we conclude that the availability of different vehicles is more closely related to changes in traffic patterns than to the external factors that had been considered first.

Most of the respondents in both areas perceive the changes in the general traffic situation to be the result of a general increase in the volume of traffic. As a second characteristic, however, we mention the increase in bicycle use. The differences in the two areas are interesting here. Although the rate of increase is comparable in both areas, this phenomenon is more noticeable in Rosenheim than in Detmold.

This is perhaps due to the fact that the percentage of persons who use bicycles to travel is noticeably higher in Rosenheim and can therefore not be overlooked. A considerable number of respondents also claimed that it had become more dangerous to use bicycles. This is probably related to the fact that many respondents also observed that compared with seven years ago, car drivers have become less considerate. However, certain differences can be observed between Detmold and Rosenheim. The complaint that drivers are less considerate is one that can be heard more frequently in Rosenheim, where the volume of car traffic has actually increased, than in Detmold. However, the increasing danger of using bicycles in Detmold is emphasized somewhat more than in Rosenheim. Perhaps this shows that cyclists perceive danger as being inversely related to the proportion of bicycles in the total traffic volume, which is, as has been mentioned, higher in Rosenheim.

In a self-evaluation of changes in their personal choice of travel modes, more than half the respondents in each area claimed that nothing had changed. In both of the areas studied, 27 percent of the target persons claimed to use bicycles more frequently; this contributes to the fact that the share of bicycles in relation to the total traffic volume has doubled. A further noteworthy peculiarity, however, is that 4 percent of the respondents made fewer trips by bicycle than seven years ago. This can be explained by the fact that older persons use bicycles less, for safety reasons. The most striking fact here, however, is that 15 percent of the respondents in Detmold and 21 percent in Rosenheim claim to use their cars less. In Detmold, this agrees with the reduction in the car share, whereas in Rosenheim, one can assume that the increase in car use is due to new car ownership by those who previously did not own their own cars.

There are many different reasons why changes in modal choice occur. In both towns, an increase in bicycle use is attributed primarily to cost consciousness and ecological awareness. In Detmold, health reasons were frequently quoted, and in Rosenheim, one frequently hears that the increase in traffic volume has resulted in parking problems but also that persons are using bicycles more than previously because they simply enjoy riding bicycles. The most important reason mentioned in Detmold for increasing car use is comfort, whereas this does not seem to play a role in Rosenheim. Reduced use of cars is generally a result of financial considerations, but this might also result from substitutions of walking trips or simply from not making certain trips at all.

Those persons who made fewer trips by bicycle than they used to claimed that it has become increasingly dangerous to use bicycles. Although this is sometimes simply related to the fact that older persons feel less safe using bicycles, it shows an aspect of bicycle use that could be relevant for planning. This brings us back to external reasons for not using bicycles. These external factors may also play a minor role in subjective reasons for changing modal choice.

To summarize the results of these explorative interviews, at least for the respondents (and we feel that these results can be generalized), the following statements can be made:

1. An increase in the number of trips made by bicycle is the result of a substitution process;
2. Increased use of bicycles reflects individuals' changes in behavior as the result of motivated reorientations;
3. An attractive bicycle infrastructure is not cited as being the reason for using bicycles;
4. Some persons show a tendency to use bicycles less frequently; this fact is easily hidden by the general increase in the use of bicycles; adequate planning of bicycle paths could serve to be a stabilizing influence here;
5. The fact that it is "in" to ride bicycles plays a certain role in influencing behavior; and
6. External factors, which take a macroscopic view of travel behavior, play only a minor role in behavioral changes.

It is important to emphasize the fact here that the greatest percentage of trips made by bicycle is to be found among younger persons; i.e., as the age structure of the population changes, this will be reflected in the number of trips made by bicycle. In the Federal Republic of Germany, this means that the drastic reduction in the birth rate in the 1970s will eventually be reflected in a considerably smaller contribution to bicycle use by the members of the bicycle-oriented younger generation.

BICYCLE AS SUBSTITUTE FOR OTHER MODES

It is generally agreed that the use of bicycles has considerably increased in recent years in the Federal Republic of Germany. Although this partly reflects permanent changes in behavior as regards modal choice, it is also partly the result of a currently friendly climate toward bicycle use. If one wishes to influence modal choice in favor of bicycle use, these findings mean that the current situation is favorable but that existing behavior patterns are deceptive. In other words, considerable planning is needed if the currently positive climate is to be used to influence long-range changes in behavior. It has already been shown elsewhere that besides those who have already changed to bicycle use, there is still a sufficient potential to be considered and a variety of integrated measures will be needed in order to attain this potential (10).

It has also been shown how much behavior varies if one views it on a local level. This variability characterizes not only the local traffic conditions but also the patterns of change or the ways in which they are influenced. This means, however, that only detailed knowledge of local traffic conditions gives one the prerequisites needed to plan effectively. The analysis of general behavior tendencies is insufficient for such planning. On the contrary, the danger that the bicycle is used only as an alternative to walking trips or trips made with public transportation is great.

Simultaneously, one should note here that not only does the traffic infrastructure serve to fulfill our traffic needs safely but it represents, in addition, a major element forming our environment. This becomes clear if one considers persons not only as tripmakers but also as the people who actually live in the environment; i.e., a person lives in a neighborhood that has a given infrastructure.

Since the early to mid-1970s, it has been found more and more important to better plan and design the areas in which we live. The most important factors here to improve the quality of life (11) are

1. Less traffic-generated noise and air pollution,
2. More green and recreational areas directly surrounding residential areas,
3. More room to move about on safer streets,
4. More consideration for disadvantaged groups (such as children, older persons, and the handicapped),
5. Appropriate consideration of nonmotorized modes of transportation, and
6. Rediscovery of streets as places of communication and living areas.

These factors have become increasingly important as criteria in the evaluation of different neighborhoods, but there has frequently been dissatisfaction with the degree to which these requirements have been fulfilled. On the other hand, as early as 1976, it was felt that a satisfactory traffic situation had been more than fulfilled [Table 4 (12)].

All these factors considered, one has to assume that there are other tendencies to reevaluate the use of private motor vehicles for daily travel than the definite trend to use bicycles more.

Table 4. Evaluation of characteristics pertaining to neighborhood in planning regions with urban structure.

Characteristic	Importance[a]	Contentment[b]	Degree to Which Fulfilled
Neighborhood, area surrounding residence	1.73	2.34	-
Residence (cost, size, furnishings)	2.10	2.49	-
Protection against pollution and noise caused by traffic	2.32	3.20	--
Shopping possibilities in area	2.33	2.40	0
Accessibility by			
Public transportation	3.16	2.63	+
Private motor vehicle	3.24	1.83	++

[a]The scale reaches from 1.00 = most important to 6.00 = least important (N = 2455).
[b]The scale reaches from 1.00 = very contented to 6.00 = very discontented (N = 2455).

Table 5. Possible increase in use of bicycles.

Dimension	Measure	Acceptance Index (AI)[a] Per Dimension When Isolated Measures Used	In Pro-Bicycle Community Climates per Measure in Other Dimensions	In Pro-Bicycle Community Climates and Realistic Perception of Bicycle Use for Development of Bicycle Infrastructure
Current trend	None	1.03		
Subjective willingness	Community climate	1.20		
Perception of bicycle use	Public relations work	1.19	1.50	
Perception of route	Infrastructure planning	1.17	1.36	1.66
Constraints	Transporting baggage, weather protection	1.26	1.51	
Objective option	Bicycle rental	1.15	1.41	

[a]AI: 1.00 = current bicycle share remains same; 2.00 = current bicycle share doubled.

Table 6. Possible reduction in use of private motor vehicles.

Dimension	Measure	Reduction Index (RI)[a] Per Dimension When Isolated Measures Used	In Pro-Bicycle Community Climates per Measure in Other Dimensions	In Pro-Bicycle Community Climates and Realistic Perception of Bicycle Use for Development of Bicycle Infrastructure
Current trend	None	0.99		
Subjective willingness	Community climate	0.98		
Perception of bicycle use	Public relations work	0.96	0.91	
Perception of route	Infrastructure planning	0.97	0.95	0.89
Constraints	Transporting baggage, weather protection	0.93	0.90	
Objective option	Bicycle rental	0.98	0.95	

[a]RI: 1.00 = current share of private motor vehicles remains same; 0.50 = current share of private motor vehicles reduced by one-half.

POTENTIAL OF BICYCLE AS SUBSTITUTE FOR TRIPS WITH PRIVATE MOTOR VEHICLES

To summarize these insights, one can say that although we have become more aware of the environment, other external conditions also appear to influence modal choice in favor of bicycles. A study must be done of the conditions under which those persons currently using private motor vehicles would be willing to use and would actually use bicycles.

Due to the limits of most research methods (which has already been explained elsewhere) (13), it is relatively difficult to do such a study. However, the situational approach, which has been tested frequently in recent years (14), is very promising when used together with the new empirical survey techniques (15). This method is currently being used to study the general potential that exists for switching to bicycle use (16) (without taking specific private motor vehicles into consideration); the results are available for those who are interested (10).

In this study, the different factors (so-called dimensions) that influence modal choice were differentiated. It is possible to influence these dimensions by implementing certain types of policies. The dimensions are shown below:

Dimension	Description
Objective option of using bicycle	Bicycle available, trip < 15 km
Constraints against using bicycle or requiring use of specific mode	Baggage transport needed, weather conditions, health reasons, car needed at work
Perception of route	No bicycle paths, too many hills, dangerous intersections
Perception of bicycle use	Too slow, too tiring, clothes get dirty
Subjective willingness	Personally willing to use bicycle mode

To influence these dimensions, the following measures were considered:

1. Objective option: influence basic availability of bicycles (e.g., make it possible to rent bicycles),
2. Constraints: only constraints pertaining to the bicycle itself (baggage transport needed, weather conditions) are referred to here, since other constraints (e.g., passengers, car needed at work, complex trip chains) cannot be dealt with by the measures discussed in this paper,
3. Route: improve the bicycle infrastructure,
4. Bicycle use: do public relations work geared at clarifying misconceptions and incorrect perceptions, and
5. Subjective willingness: increase the number of persons willing to change to use of bicycle by creating a climate of opinion in the community favorably disposed to bicycles.

A so-called "acceptance index" was used to better describe the probable behavioral changes. This index indicated the extent to which current bicycle use could be increased maximally if measures pertaining to the different dimensions were to be implemented. An index of 1.00 means that the current bicycle share remains the same, whereas an index of 2.00 means that the share of persons using bicycles doubled. This shows that if the bicycle infrastructure is improved but nothing else is done to encourage cycling, only relatively few persons can be expected to switch to bicycle use. However, if an integrated group of measures is used in which efforts are made to influence subjective areas, one can expect a considerable increase in the use of bicycles (Table 5).

If one wishes to determine the extent to which the increase in bicycle use is the result of persons who switch to bicycles from private motor vehicles, and thus the degree to which the use of private motor vehicles has declined, not only must one make a special evaluation of persons changing from one mode to another mode according to the type of transportation used, but one also needs another indication of the results. We have decided to use a reduction index per dimension and measure, which is similar to the acceptance index. A reduction index of 1.00 indicates that the use of private motor vehicles would stay the same if a certain policy were implemented, whereas a reduction index of 0.50 would indicate that it would be reduced by a maximum of 0.5.

The individual reduction indexes, which can be compared with those in Table 5, show that if bicycle use is encouraged by using the right policies, the use of private motor vehicles can be somewhat curtailed (Table 6). However, one should not forget that in the communities studied (population of 80 000 or less) in the Federal Republic of Germany, the percentage of trips made with private motor vehicles was 55 percent, or more than three times as high as the percentage of trips made by bicycle (16 percent). Therefore, a 1 percent reduction in the former results in a 3.5 percent increase in the latter. In order to reduce the number of trips made with private motor vehicles and to increase the number made by bicycle, it has been shown that measures dealing with both subjective attitudes (counteracting prejudices and negative opinions) and technical problems (transporting luggage and weather protection, etc.) play an important role, whereas (isolated) measures to improve the infrastructure are much less effective.

It should be emphasized that only the potential for changing to other modes has been studied here. If a person has started to use a bicycle and discovered that the bicycle infrastructure is inadequate, it is very likely that he or she will revert to the use of the former mode. Thus, a good infrastructure does not create an increased demand for bicycle use but ensures that the persons dependent on this infrastructure will continue to use bicycles. Thus, if one wishes to encourage bicycle use, it is not enough to simply build bicycle paths. If no other measures are taken, only a small additional incentive is created, especially to induce those persons who now use motor vehicles to change to bicycles. However, it is precisely this latter group that is of greatest interest to transport planners. Integrated groups of measures are needed in order to reinforce the currently positive trend to use bicycles.

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Analysis of Insurance Claims to Determine Effects of 1980 Bumpers on Crash Damage

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The effectiveness of the crash-protecting automobile bumpers required by the 1980 version of the Federal Motor Vehicle Safety Standard, Part 581—Exterior Protection, Passenger Cars, was evaluated through an analysis of insurance claims filed with the State Farm Insurance Company. Data for the 1980 model year are compared with both 1972 and 1979 data to determine whether vehicles conforming to the 1980 version of the standard exhibit any significant changes in claim proportions or average claim cost for bumper-related incidents. The relationship of bumper type and bumper design to the two measures of effectiveness is also examined. Pairwise statistical comparisons were performed for the three model years by using hypothesis tests for differences in claim proportions and differences between mean costs stratified by market class and impact point. Findings indicate that the 1980 data continue current trends in which the actual proportion of bumper-involved claims has been decreasing, whereas average claim costs adjusted for inflation have been increasing.

In 1971, NHTSA issued Federal Motor Vehicle Safety Standard 215 (FMVSS-215), Exterior Protection, Passenger Cars, for the performance of automobile bumpers. The standards required bumpers to meet requirements for the protection of safety-related parts in low-speed collisions starting with model year 1973 passenger cars. Over the years, various versions of the standards have been implemented with the intent to offer increased protection to the automobile and cost savings to consumers. Effective with 1979 model year passenger cars, Part 581 incorporated FMVSS-215 and added requirements for bumper protection of nonsafety items.

Research (1) is described that extends the results of two previous studies (2,3) that compared insurance-claim data on proportions and average cost of bumper-involved claims for automobile model year periods corresponding to various versions of FMVSS-215. In those studies, prestandard period, 1972 model year vehicles were compared with 1973, 1974-1978, and 1979 model year vehicles to assess the impact of the crash-protecting bumper standard. The latter model year periods corresponded to potentially significant changes in the standard. The general requirements of each successive version of the bumper standards are listed below:

Standard	Model Year	Requirement
FMVSS-215	1973	5-mph front and 2.5-mph rear impact with barrier Limited damage to lamps and reflectors; hood, trunk, and doors; fuel, cooling, and exhaust systems
FMVSS-215	1974-1978	5-mph front and rear impacts with barrier and pendulum; 3-mph corner impact with pendulum Limited damage to same items as earlier test and propulsion, suspension, steering, and braking systems; pendulum test established bumper height between 16 and 20 in
Part 581, incorporating FMVSS-215	1979	All of above Exterior surfaces shall not be damaged or have permanent deviations except for damage to bumper face bar and components and fasteners that attach bar to chassis frame
As above	1980	All of 1973-1978 requirements and exterior surfaces shall not be damaged or have permanent deviations except for face bars, which can have no permanent deviation greater than 3/4 in from its original contour relative to vehicle frame and no permanent surface deviation greater than 3/8 in from original contour on areas of contact with test devices

In this study, 1980 model year data were compared with 1972 and 1979 data to determine whether the 1980 period exhibits any significant changes in claim proportions or average cost of these claims for bumper-related incidents. The primary emphasis of this work was on the changes observed between the 1979 and 1980 model year data.

The study also examined the relationship of bumper type and bumper design as reflected by the data of different manufacturers on the two measures of effectiveness. This was done to detect any differences in the proportion of bumper claims and their average cost that may exist between bumpers of different materials and designs. This analysis could thereby identify preferred bumper materials and design from a cost-effectiveness point of view. As with the previous studies, State Farm insurance-claim data obtained from their claim service centers constituted the data base for this study.

EXPERIMENTAL DESIGN

The analysis of 1972, 1979, and 1980 bumper claim data obtained from the State Farm Insurance Company was organized into two experiments. In experiment 1, all claims involving one-year-old vehicles, where bumpers were either repaired or replaced, were stratified by market class and by impact point. The proportion of property-damage claims involving the bumper and the average repair cost of these claims were the measures of effectiveness used to compare three model-year periods statistically. The pairwise comparisons were 1972 versus 1979 model year, 1972 versus 1980 model year, and 1979 versus 1980 model year. They were made by using the hypothesis tests for the difference between proportions and for the difference between means. Each comparison was stratified into four vehicle classes--compact, subcompact, intermediate, and full-size vehicles--and two impact points--front and rear. The vehicle classes were defined by the following criteria:

Market Class	Wheelbase (WB) (in)
Subcompact	$WB \leq 101$
Compact	$101 < WB \leq 111$
Intermediate	$111 < WB \leq 120$
Full size	$WB > 120$

Results of these comparisons were summarized to identify the existence of significant trends that may be attributable to the influence of the bumper

Table 1. Analysis of bumper-related insurance claims for one-year-old vehicles by model year.

Market Class	Model Year	Percentage of All Claims by Impact Point: Front	Rear	Total Bumper Related	Avg Repair Costs at 10 Percent Inflation Rate by Impact Point ($1980): Front	Rear	Avg, All Bumper Related
Subcompact	1972	37	23	60	771	556	689
	1979	26[a]	15[a]	41[a]	925[b]	620	812[b]
	1980	21[c]	12[c]	33[c]	1141[d]	730[b]	996[d]
Compact	1972	35	21	56	894	599	782
	1979	23[a]	14[a]	37[a]	1145[b]	785[b]	1008[b]
	1980	21[a]	15[a]	36[a]	1128[b]	706	957[b]
Intermediate	1972	33	20	53	819	620	744
	1979	22	21	42[a]	907	689	800
	1980	26[a]	14[c]	40[a]	1078[b]	758	962[d]
Full size	1972	31	21	53	840	652	764
	1979	25	21	45[a]	1010	686	862
	1980	23[a]	22	45	1638	1038	1348[d]
All sizes	1972	34	21	55	830	611	746
	1979	24[a]	16[a]	40[a]	1001[b]	690	877[b]
	1980	22[c]	13[c]	35[c]	1146[b]	741	994[d]

[a]Reduction in claims relative to 1972 is significant at 5 percent level.
[b]Cost increase relative to 1972 is significant at 5 percent level.
[c]Further reduction between 1979 and 1980 is significant at 5 percent level.
[d]Further increase between 1979 and 1980 is significant at 5 percent level.

Table 2. Sample sizes for analysis in Table 1.

Year	Total No. of Claims in State Farm Data Base	Claims by Market Class: Subcompact: Bumper	Subcompact: Total	Compact: Bumper	Compact: Total	Intermediate: Bumper	Intermediate: Total	Full Size: Bumper	Full Size: Total
1972	8275	1039	1722	967	1734	1171	2218	1375	2601
1979	3368	615	1492	433	1165	226	532	81	179
1980	4631	893	2730	486	1341	169	423	62	137

standards in 1979 and 1980. The main thrust of the analysis was to determine whether there were significant differences in observed claim experience between the 1979 and 1980 data.

Experiment 2 consisted of two parts. In the first, the proportion of property-damage claims and average cost of these claims were analyzed by bumper type. Three types--steel, aluminum, and hybrid--were compared. The pairwise model year comparisons were made only for compact and subcompact market classes due to the lack of data for intermediate or full-size market classes.

In the second part of the experiment, an analysis by bumper manufacturer (General Motors, Ford, Chrysler) was made. Both proportion and cost data were evaluated.

The two parts of experiment 2 were intended to ascertain whether differences in bumper design or material affect the proportion or average cost of bumper-involved claims. Summaries of these results are presented and interpreted.

Experiment 1

Experiment 1 examined all claims involving one-year-old vehicles where bumpers were repaired or replaced to determine whether there were significant differences in the proportion of property-damage claims and average cost of these claims between model years.

Methodology

For the proportion analysis, the number of front and rear bumper claims was aggregated for each market size class and for each model year period. The proportion of these claims relative to the total of all property-damage claims for that market class was computed for each model year. No totaled vehicles were in the State Farm data, although both collision and liability claims were included. For each of the time-period comparisons--1972 versus 1979, 1972 versus 1980, and 1979 versus 1980--the hypothesis test for differences in proportions was computed for each combination of market class and impact point. These comparisons are shown in Table 1.

Table 1 also displays the cost analysis, in which the average cost of the claims in each combination of market class and impact point was computed for each of the three model year periods. For each model year comparison, the differences between these average costs were statistically tested by using the hypothesis test for the difference between means at the 5 percent level of significance.

The sample sizes available for this experiment are given in Table 2.

Proportion-Analysis Summary

As can been seen in Table 1, the 1979 model year period exhibits significant reductions in the proportion of bumper-involved claims for each market class when compared with 1972. These reductions are largely due to reductions in the proportion of front-impact claims. The market-class differences in proportions range from about 8 percent for full-size vehicles to 19 percent for subcompacts. For the overall mix of vehicles, the 1979 model year proportion of bumper claims is 40 percent as compared with 55 percent for the 1972 period--a difference of 15 percent. In the 1979-1980 comparison, few proportions are significantly reduced within each market class, subcompact cars excepted; however, the proportion of all bumper claims was reduced from 40 to 35 percent. This decrease of 5 percent is statistically significant. Thus, in the 1979 to 1980 model years, a further decrease in the proportion of bumper-involved claims occurred for the total vehicle mix, primarily due to further significant decreases for subcompact vehicles.

Cost-Analysis Summary

Cost comparisons can be summarized from Table 1 by noting that from 1972 to 1979, average claim costs for bumper claims increased for all vehicle classes and impact points; statistically significant increases occurred particularly in the case of subcompacts and compacts. Between 1979 and 1980, all market classes with the exception of compact vehicles showed statistically significant increases. Average repair costs for compacts appear to decrease between 1979 and 1980. However, this reducton is not statistically significant.

It should be noted that the total sample sizes for 1979 and 1980 are about one-half of the 1972 sample. However, with the possible exception of full-size vehicles, these sample sizes are adequate for inferential purposes for this experiment.

Experiment 2

Experiment 2 was divided into two parts:

1. Analysis of bumper types--steel, aluminum, hybrid; and
2. Analysis by bumper manufacturer--General Motors, Chrysler, Ford.

Although both proportion and average cost comparisons were made in each analysis, the available data created special restrictions and limitations in each case. The specific constraints and conditions for each study will be treated separately.

Part 1: Analysis of Bumper Types

The bumper types compared were steel, aluminum, and hybrid. Since no data were available for intermediate or full-size market classes, the analysis was restricted to subcompact (Table 3) and compact (Table 4) market classes. Furthermore, there were no aluminum or hybrid bumpers for the 1972 model year data. The three model year comparisons--1972 versus 1979, 1972 versus 1980, and 1979 versus 1980--are presented for each of the two market classes. However, comparisons with 1972 involve only steel bumpers. The following sample sizes were available for the bumper-type analysis:

	Claims by Bumper Type					
	Steel		Aluminum		Hybrid	
Model Year	Bumper	Total	Bumper	Total	Bumper	Total
1972	2027	3506	-	-	-	-
1979	844	1986	82	210	87	390
1980	1176	3286	86	229	118	561

The analysis was intended to determine whether either of the measures of effectiveness is a function of bumper type. Hypothesis tests for the differences between proportions and means were applied as in experiment 1.

Table 3. Analysis of bumper-related insurance claims for one-year-old subcompacts by bumper type.

		Percentage of All Claims by Impact Point			Avg Repair Costs at 10 Percent Inflation Rate by Impact Point ($1980)		
Bumper Type	Model Year	Front	Rear	Total Bumper Related	Front	Rear	Avg, All Bumper Related
Steel	1972	37	23	60	772	557	690
	1979	26[a]	16[a]	42[a]	931[b]	636	818[b]
	1980	22[c]	12[c]	34[c]	1149[d]	755[b]	1025[d]
Aluminum	1972	NA	NA	NA	NA	NA	NA
	1979	31	10	41	818	530	747
	1980	15[a]	17	32	884	624	748
Hybrid	1972	NA	NA	NA	NA	NA	NA
	1979	13	7	21	1189	423	914
	1980	12	10	22	1273	633	989

Note: NA = no data available.

[a]Reduction in claims proportion relative to 1972 is significant at 5 percent level.
[b]Cost increase relative to 1972 is significant at 5 percent level.
[c]Further reduction between 1979 and 1980 is significant at 5 percent level.
[d]Further increase between 1979 and 1980 is significant at 5 percent level.

Table 4. Analysis of bumper-related insurance claims for one-year-old compacts by bumper type.

		Percentage of All Claims by Impact Point			Avg Repair Costs at 10 Percent Inflation Rate by Impact Point ($1980)		
Bumper Type	Model Year	Front	Rear	Total Bumper Related	Front	Rear	Avg, All Bumper Related
Steel	1972	34	21	55	896	596	782
	1979	27[a]	15[a]	42[a]	1142[b]	832[b]	1029[b]
	1980	25[a]	15[a]	40[a]	1121[b]	740	975[b]
Aluminum	1972	NA	NA	NA	NA	NA	NA
	1979	19	17	36	1123	685	913
	1980	22	25	47	1020	595	797
Hybrid	1972	NA	NA	NA	NA	NA	NA
	1979	14	9	23	1106	656	924
	1980	11	9	20	1154	606	897

Note: NA = no data available.

[a]Reduction in claims proportion relative to 1972 is significant at 5 percent level.
[b]Cost increase relative to 1972 is significant at 5 percent level.

Proportion-Analysis Summary for Bumper Types

Due primarily to inadequate data on aluminum and hybrid bumpers even for the 1979-1980 comparison, no significant findings relative to these types emerged. The overwhelming presence of steel bumpers leads to the conclusion that the observed reduction in the proportion of bumper claims for subcompact and compact vehicles from 1972 to 1979 and from 1972 to 1980 is due to reductions in claims involving steel bumpers. Similarly, the reduction in claims for subcompact vehicles from 1979 to 1980 is due to reductions in such claims.

Cost-Analysis Summary for Bumper Types

As in the proportion analysis, only data for steel bumpers were available for model year 1972. Results observed here are similar to those seen in experiment 1. Between 1972 and 1979, the average repair costs for bumpers (adjusted for inflation) increased significantly for both subcompact and compact vehicles. Between 1979 and 1980, further significant cost increases were observed for subcompact vehicles with steel bumpers, whereas costs for aluminum and hybrid systems remained relatively unchanged.

Again, compact vehicles appeared to experience a reduction in average repair costs between 1979 and 1980, although this reduction is not significant. As seen in Table 4, this experiment indicates that the cost reduction from 1979 to 1980 is noticeable for each of the three bumper types.

In the comparison of bumper types, aluminum systems on average appear to involve the lowest average repair costs regardless of the model year and applicable version of the standard. Hybrid systems are second lowest, and steel systems are consistently the most expensive to repair. When specific impact points are examined, these rankings do fluctuate.

Part 2: Analysis by Bumper Manufacturer

General Motors (GM), Ford, and Chrysler were the three manufacturers analyzed to determine whether any significantly different experiences in bumper claim proportions or average costs exist as a function of the manufacturer. This was intended to serve as a surrogate measure for bumper design and therefore as a means for isolating a design that may exhibit enhanced performance relative to the stated measures of effectiveness.

Within each pairwise model year comparison, for both proportions and average cost, each manufacturer was analyzed separately. The number of claims by manufacturer available for this analysis was as follows:

	Claims by Manufacturer					
	GM		Ford		Chrysler	
Year	Bumper	Total	Bumper	Total	Bumper	Total
1972	1878	3398	1464	2652	551	1155
1979	629	1545	226	617	191	565
1980	678	1841	199	622	107	324

The model-year comparisons are shown in Tables 5-7. These tables summarize the comparisons within manufacturer for GM, Ford, and Chrysler, respectively. Very few comparisons are statistically significant; however, in the hope of identifying design-related effects, some potentially interesting results are noted.

Proportion-Analysis Summary by Bumper Manufacturer

Between 1972 and 1979, each manufacturer's overall fleet of vehicles exhibited statistically significant reductions in bumper claim proportions. During this period, both GM and Ford showed statistically significant reductions in their subcompact and compact classes. The two manufacturers differed in the performance of the larger classes. GM demonstrated a significant reduction in the proportion of bumper-involved claims for its intermediate vehicles, whereas its full-size vehicles showed a slight increase. On the other hand, Ford showed significant reductions for its full-size vehicles but a slight (not significant) decrease for its intermediate vehicles. Chrysler samples sizes were too small to make any inferences on the basis of market class.

From 1979 to 1980, both GM and Ford subcompacts exhibited further significant reductions in the proportions of bumper-involved claims. In addition, claims for rear collisions of GM intermediate vehicles were also significantly reduced, which led to an overall reduction for the total GM fleet. Counter to this trend was the performance of the front bumpers of GM intermediate vehicles, which exhibited a significant increase between 1979 and 1980. Chrysler showed no change between 1979 and 1980.

The results of these comparisons should be considered as recommendations for further investigation, since the 1979 sample sizes need to be enlarged to permit definitive conclusions. However, one observation obtained from the 1979-1980 comparison is that of the three manufacturers, only GM exhibited statistically significant reductions in bumper-claim proportions. This may reflect that the corresponding bumper designs are responsible for the observed differences.

Cost-Analysis Summary by Bumper Manufacturer

Between 1972 and 1979, average repair costs for both the GM and the Ford fleets adjusted for inflation increased $120 to the same figure of about $875. Undoubtedly, due to the sample sizes, the GM increase was noted as significant, whereas Ford's was not. Although these increases were apparent in all market classes, increases for compacts were statistically significant for both these two manufacturers. During the same period, Chrysler showed overall increases of only $21.

From 1979 to 1980, all manufacturers showed continued increases in average repair costs of $21, $63, and $115 for Ford, GM, and Chrysler, respectively. However, none of these increases was found to be significant. In the case of Chrysler, this is likely to be due to the small sample size. The most notable increases over this period were for GM intermediate and full-size vehicles.

STUDY RESULTS

Experiment 1 analyzed the variations in bumper claim proportions and average costs for the model years 1972, 1979, and 1980. The analysis sought to determine whether any significant changes have occurred in these two measures of effectiveness, particularly for the 1979-1980 time period, and thus to assess the effectiveness and impact of the current version of the bumper standard. The major conclusions were as follows:

1. The proportion of bumper-involved claims for 1979 for each market class has decreased significantly when compared with that for 1972.
2. The reduction in proportion noted from 1972 to 1979 is largely due to reduction in the proportion of front-impact claims.
3. From 1979 to 1980, a further decrease in the proportion of bumper-involved claims occurred for

Table 5. Analysis of bumper-related insurance claims for one-year-old GM vehicles.

		Percentage of All Claims by Impact Point			Avg Repair Costs at 10 Percent Inflation Rate by Impact Point ($1980)		
Market Class	Model Year	Front	Rear	Total Bumper Related	Front	Rear	Avg, All Bumper Related
Subcompact	1972	38	24	62	771	681	737
	1979	28[a]	16[a]	45[a]	864	675	795
	1980	24[a]	13[a]	36[b]	933	703	853[c]
Compact	1972	35	25	60	891	625	782
	1979	24[a]	14[a]	38[a]	1016	789	937[c]
	1980	21[a]	15[a]	35[a]	1065	643	890[c]
Intermediate	1972	37	21	57	817	669	764
	1979	20[a]	22	42[a]	868	749	805
	1980	28[d]	13[b]	41[a]	1101[c]	719	980[e]
Full size	1972	27	23	50	858	626	749
	1979	29	23	52	931	649	804
	1980	19	26	45	1993	1357[c]	1629[e]
All sizes	1972	33	23	55	838	645	759
	1979	24[a]	17[a]	41[a]	954	749	874[c]
	1980	23[a]	14[b]	37[b]	1071	724	937[c]

[a]Reduction in claims proportion relative to 1972 is significant at 5 percent level.
[b]Further reduction between 1979 and 1980 is significant at 5 percent level.
[c]Cost increase relative to 1972 is significant at 5 percent level.
[d]Increase in claim proportion between 1979 and 1980 is significant at 5 percent level.
[e]Further increase between 1979 and 1980 is significant at 5 percent level.

Table 6. Analysis of bumper-related insurance claims for one-year-old Ford vehicles.

		Percentage of All Claims by Impact Point			Avg Repair Costs at 10 Percent Inflation Rate by Impact Point ($1980)		
Market Class	Model Year	Front	Rear	Total Bumper Related	Front	Rear	Avg, All Bumper Related
Subcompact	1972	35	23	58	773	537	679
	1979	20[a]	11[a]	31[a]	844	520	730
	1980	13[b]	11[a]	24[a]	1217	601	944
Compact	1972	34	21	55	874	630	779
	1979	23[a]	15	38[a]	1260[c]	773	1068[c]
	1980	22[a]	16	38[a]	997	611	835
Intermediate	1972	28	21	50	832	594	730
	1979	28	18	46	NA	NA	NA
	1980	NA	NA	NA	NA	NA	NA
Full size	1972	38	19	57	819	719	786
	1979	22[a]	18	39[a]	1091	753	929
	1980	29	17	46	1325	401	983
All sizes	1972	34	21	55	827	639	756
	1979	22[a]	14[a]	37[a]	1031	639	876
	1980	18[a]	14[a]	32[a]	1104	619	897

Note: NA = insufficient data available.

[a]Reduction in claim proportion relative to 1972 is significant at 5 percent level.
[b]Further reduction between 1979 and 1980 is significant at 5 percent level.
[c]Cost increase relative to 1972 is significant at 5 percent level.

Table 7. Analysis of bumper-related insurance claims for one-year-old Chrysler vehicles.

		Percentage of All Claims by Impact Point			Avg Repair Costs at 10 Percent Inflation Rate by Impact Point ($1980)		
Market Class	Model Year	Front	Rear	Total Bumper Related	Front	Rear	Avg, All Bumper Related
Subcompact	1972	NA	NA	NA	NA	NA	NA
	1979	22	7	29	NA	NA	NA
	1980	17	14	31	NA	NA	NA
Compact	1972	NA	NA	NA	914	537	792
	1979	19	17	36	1231	470	868
	1980	27	12	39	1172	915	1094
Intermediate	1972	28	16	44	823	499	707
	1979	21[a]	19	39	887	582	741
	1980	17	21	38	1097	741	897
Full size	1972	NA	NA	NA	NA	NA	NA
	1979	NA	NA	NA	NA	NA	NA
	1980	NA	NA	NA	NA	NA	NA
All sizes	1972	31	17	48	871	525	749
	1979	21[a]	12[a]	34[a]	879	581	770
	1980	19	14	33	1006	725	885

Note: NA = insufficient data available.

[a]Reduction in claim proportion relative to 1972 is significant at 5 percent level.

the total mix of vehicle market classes, primarily due to further significant decreases for subcompact vehicles.

4. Average claim costs, adjusted for inflation, for bumper claims increased for all vehicle classes and all impact points from 1972 to 1979; the significant increases occurred particularly for subcompacts and compacts.

5. From 1979 to 1980, significant increases in average costs occurred for all market classes except compact vehicles, which showed a slight reduction in average repair costs.

Thus, the proportion of bumper claims has decreased from 1979 to 1980; however, average costs increased for the total vehicle mix. This is a continuation of the pattern found in the earlier years of the standard. However, the decrease in costs for compacts is a departure from the earlier pattern.

In the first part of experiment 2, bumper types were compared to determine whether steel, aluminum, or hybrid bumpers exhibit different performance characteristics as measured by the proportions and average cost of bumper claims. The major results were the following:

1. No significant differences in proportion of bumper claims emerged for aluminum and hybrid types;
2. Most of the reductions in the proportion of bumper claims involved steel bumpers, due to their predominance in the sample;
3. On average, claims involving aluminum bumpers appear to involve lower average costs than do the other types; and
4. Bumper type does not appear to be as significant as vehicle class in its relation to average cost.

The second part of experiment 2 compared the bumper manufacturers--GM, Ford, and Chrysler. Major results are listed below:

1. Between 1979 and 1980, GM was the only one of the three manufacturers studied to indicate an overall significant decrease in claim proportions; and
2. Between 1979 and 1980, none of the manufacturers showed any significant overall change in average repair costs.

CONCLUSIONS

It is intended that this analysis be used to interpret the effectiveness of the 1980 bumper standards. The two surrogate measures of effectiveness used in this evaluation, namely, claim proportion and average repair costs, yielded conflicting results. Although it was demonstrated that the actual proportion of bumper-involved claims was decreasing, average claim costs adjusted for inflation were steadily increasing. This raises several additional questions to illuminate the picture fully:

1. What factors contributed to the increases in repair costs?
2. Were any of these factors directly related to the bumper standards themselves and, if so, how?
3. If it is found that factors outside the standards themselves were at work to increase costs, would average repair costs be even higher if the bumper standards were not in effect?
4. Why do compacts run counter to the trend and show a decrease in average claim costs between 1979 and 1980?
5. Although claim proportions were more directly influenced by the bumper standards than were average claim costs, is it possible that the reductions indicated were part of some general trend independent of the bumper standard and evident in non-bumper-related accidents?

There are several possible explanations, which are recommended as avenues for further investigation:

1. Significant automotive design changes have occurred since 1978, which include unitized bumpers and many other changes unrelated to bumpers, such as rectangular headlamps, front-drive McPherson-type suspensions, and the wider applications of plastics. These changes may influence repair costs significantly.
2. In general, deductibles are not increased to match inflation; therefore, it is possible that the proportion of collision claims made with higher deductible amounts has increased. This, or a change in the mix of policy claim type (liability and collision), would increase the cost of the average claim without an actual increase in bumper repair costs.
3. Since it was beyond the scope of this study to investigate non-bumper-related claims, it remains unknown whether the decrease in claim proportions attributed to the bumper standard is also evident in non-bumper-related claims. Because of the conflicting results of this evaluation, this is an important area for further investigation. It is necessary to ascertain the extent to which claim-proportion reductions are attributable to the standards themselves, independent of other factors. It is recommended that the analysis procedure used in this study for claim proportions and costs be applied also to non-bumper-related claims. It would then be possible to compare results for both types of claims to provide the perspective needed to evaluate the influence of the bumper standards. Using non-bumper-related claims as an additional control group would be useful in understanding both the proportion and the average cost results.

The State Farm Insurance Company suggested that the following conditions be understood in drawing conclusions from their data base:

1. Damage estimates in the data base were taken in service centers that provided a disproportionately metropolitan sample.
2. A bumper-involved crash is defined by State Farm as one in which there is repair or replacement of the bumper face bar. Where a soft face is damaged, without repair or replacement of the bumper face bar, this definition may or may not be appropriate, depending on the inference one is trying to draw. Changing designs since 1972, including the emergence of soft-face technology, greatly complicate the problem of defining bumper involvement.
3. Observed insurance claim frequencies vary from year to year and are affected by many other factors besides the bumper standard. These other factors include the weather, the economy, price and availability of gasoline, condition of roads and highways, and changes in traffic laws and the quality of enforcement. For this reason, and also because it is impossible to define the group of cars that produced the claims in this data base, conclusions about overall effect on insurance costs would have to rely on estimated changes in claim frequency determined inferentially from changes in the distribution of bumper-involved and non-bumper-involved claims. This is made more difficult by the change in designs, as explained above.
4. To the extent that improved bumpers perform their function of eliminating relatively low-cost

claims, the remaining claims are, on the average, larger. This basic point is necessary to an understanding of these data.

ACKNOWLEDGMENT

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Acceleration Characteristics of Late-Model Automobiles

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In response to federal mandates and consumer demand for more fuel-efficient automobiles, the American automobile industry is currently producing markedly smaller and lighter automobiles than it was 10 years ago. As fuel prices rise, one can only anticipate that this trend will continue. Many of the changes made in the newer automobiles to promote fuel economy adversely affect acceleration capability. Therefore, this study was conducted to examine acceleration characteristics and determine the extent to which the acceleration capability of passenger vehicles has deteriorated over the past decade. Data were collected from automotive reports in popular magazines for two acceleration maneuvers. The first maneuver, the time required to accelerate from 45 to 65 mph, increased an average of 18 percent between 1971 and 1979. The second maneuver, the acceleration time required for a speed change from 0 to 60 mph, increased an average of 22 percent between 1971 and 1979. The results of the acceleration-data analysis were used to investigate design criteria involving vehicular acceleration rates. In all cases the current automobiles were found to accelerate more quickly than those used when the original acceleration tests were performed in the 1930s. Although there has been some deterioration in acceleration capability over the past decade, it has not occurred to the point where the design criteria exceed the current capability and thus pose a safety hazard.

Over the past decade the average American automobile has changed significantly in response to oil embargoes and the rising cost of gasoline. In 1970 a typical standard-sized car weighed 4000 lb and was probably powered by a V-8 engine with a displacement of at least 350 in^3. In 1980 the average American car weighed some 3300 lb and was probably equipped with a six-cylinder engine that had less than 250 in^3 of displacement. Hence, a marked trend has evolved in which new automobiles have become smaller and lighter from year to year.

The predominant reasons for the current automotive trend are the federal mandates and consumer demand for improved fuel economy. One step taken in achieving these aims has been to use more fuel-efficient components in the drive train of the automobile, such as smaller-displacement engines and higher rear-axle ratios. Although such components are superior for fuel economy, they are generally not better in terms of vehicle acceleration and performance. Other considerations, such as reducing weight and improving aerodynamics, can be said to enhance both fuel economy and performance. Therefore, there is considerable question whether the acceleration capabilities of cars manufactured today are on a par with those of a decade ago.

The tests conducted to determine the acceleration capabilities of passenger vehicles were performed in the 1930s and 1940s. Design criteria derived from these tests appear in A Policy on Geometric Design of Rural Highways (1), hereafter referred to as the AASHO Blue Book. Naturally, many improvements in automotive technology followed during the postwar period, such as the automatic transmission and the high-compression V-8 engine. The design criteria derived from the early tests remained applicable during the 1950s and 1960s, with an added safety factor. However, in light of recent changes that are detrimental to automotive performance, it seems appropriate to also investigate applicable design criteria and assess their relevance to present-day automobile performance.

PURPOSE AND OBJECTIVES

The primary purpose of this study was to examine vehicle acceleration characteristics and determine whether there has been a significant change in the acceleration capabilities of passenger vehicles over the past decade. Factors that affect the acceleration rates will also be discussed. The objectives of this study were to analyze design criteria involving vehicular acceleration rates recommended in the AASHO Blue Book and evaluate their relevance to current passenger-car performance trends.

METHOD OF STUDY

The test data for this study were obtained from popular magazines that regularly report automotive test data. Data extracted from these magazines include acceleration times from 0 to 60 mph and from 45 to 65 mph, rated engine horsepower, and curb weight.

The data obtained are used to analyze trends in automobile acceleration characteristics over the past decade. One measure of performance is the ability of a vehicle to perform a certain passing maneuver that was initially described in the literature (2-5) during the 1950s and 1960s. Another measure of performance analyzed is the trend in weight-to-horsepower ratio during the past decade and its significant relationship with the acceleration capability for the vehicle.

By using the current test data, comparisons are made with design criteria in the AASHO Blue Book that involve vehicular acceleration rates. The three design areas analyzed were (a) passing sight distance, (b) lengths of acceleration lanes, and (c) sight distance at intersections.

ANALYSIS OF ACCELERATION CHARACTERISTICS

Vehicle characteristics of significant importance in highway design include acceleration, fuel economy, braking deceleration, and physical dimensions. This study is concerned only with the acceleration characteristics of passenger vehicles, namely, the capacity to accelerate between a range of speeds that would likely be found in certain maneuvers involved in typical traffic operations.

Many variables affect the acceleration characteristics of an automobile. Malliaris, Hsia, and Gould (6) stated that the most appropriate parameter used to estimate acceleration capabilities was the horsepower-to-weight ratio. The test data used in this study were obtained from popular magazines, each of which has its own test control criteria and reporting standards. Therefore, considerable effort was made to select data that were believed to be reliable and representative of the particular model being tested. Special-production automobiles and cars equipped with high-performance engines were not included in the test data for this study.

Data Collection

The trend toward smaller vehicles with lighter curb weights and lower-powered engines raises the question of whether or not modern automobiles accelerate as well as cars manufactured a decade ago. To analyze this question, vehicle acceleration data from popular magazines (Consumer Reports, Motor Trend, and Car and Driver) were recorded for selected model years during the past decade. Using data reported in these automotive tests has several advantages. One of these is that all cars were tested when they were new. This procedure eliminates any decline in acceleration capability that may develop as an automobile ages. A second advantage is that a wide assortment of models are tested and reported in the magazines during any particular model year. Therefore, it is possible to select a group of models that is a representative sample of all automobiles manufactured during that year.

Acceleration times were recorded for automobile model years 1971, 1973, 1975, 1977, and 1979 for two maneuvers: (a) acceleration from 45 to 65 mph and (b) acceleration from 0 to 60 mph. The first maneuver is typical of a change of speed involved in a highway passing maneuver and will be used to compute a full acceleration rate that is representative of speeds in this range. The second maneuver, acceleration from 0 to 60 mph, is the most commonly reported acceleration maneuver and is a measure of full acceleration through the range of gears in the transmission of the test vehicle.

Weighting factors based on the relative sales volumes were developed for each model (7). Instead of calculating the arithmetic mean of the acceleration times achieved for a particular maneuver in various vehicles, the weighting factor is incorporated to more adequately represent the car population for a model year. The weighting factor is necessary because different vehicle models have widely variable annual sales volumes. Therefore, the weighting factor permits popular vehicle models to be weighted more heavily in computing the acceleration characteristics of the average new vehicle in the traffic stream during each model year.

The weighting factor was obtained by dividing the fractional part of the sales of a particular model by the total domestic automobile sales for a given year. In many cases, test data were not available for all models produced during a certain year. The procedure adopted to adjust for this situation was that sales for any omitted model were added to a model for which test data were available. Such substitution practices were almost always limited to automobiles of the same size and produced by the same manufacturer. Many such automobiles, often referred to as corporate twins, are manufactured on the same assembly line and are virtually identical except for minor exterior differences. One example of such a pair is the subcompacts from the Chrysler Corporation, the Plymouth Horizon and the Dodge Omni.

Horsepower ratings as claimed by the manufacturer were used for all calculations. Before 1972, the ratings reflect gross horsepower. Beginning with the model year 1972, the ratings are a measure of net horsepower. The test weight is the curb weight plus 300 lb to allow for an average on-board loading (weight of driver and fuel). These variables are used to calculate the weight-to-horsepower ratio, the magnitude of which is often used as a basis for estimating the acceleration capability of a vehicle. Generally, as the weight-to-horsepower ratio increases, the acceleration capability decreases.

Passing Distance

One test performed during several model years and reported in the literature (2-5) provides information on automobile acceleration capabilities by determining the time and distance required to safely complete a passing maneuver. A typical passing maneuver is shown schematically in Figure 1. Car A passes car B on a two-lane highway and must return to the right lane before encountering oncoming car C. Three car lengths (60 ft) between cars A and B and 200 ft between cars A and C are assumed as minimum safe clearance distances. All cars are assumed to be traveling at 40 mph, and car A accelerates at its full rate while overtaking car B.

An analysis of the ability of cars to perform this passing maneuver during the selected study years may reflect a trend in automobile acceleration characteristics. The value assumed for acceleration is the full rate from 45 to 65 mph that was obtained for each test vehicle. The weighted average times for all test vehicles of each model year under study are given below:

Year	Time (s)	Avg Acceleration Rate (fps^2)
1971	8.4	3.49
1973	9.4	3.12
1975	9.4	3.12
1977	10.1	2.90
1979	9.9	2.96

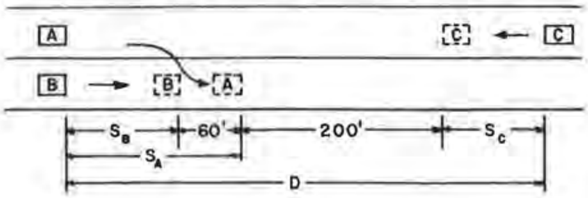
The weighted average time (t_a) for any one year is calculated by the following equation:

$$t_a = w_1 t_1 + w_2 t_2 + w_3 t_3 + \ldots + w_n t_n \quad (1)$$

where

w = weighting factor,
t = time required for acceleration maneuver, and
n = number of test cars observed.

Figure 1. Schematic diagram of typical passing maneuver.



The passing distance (S) required for the maneuver depicted in Figure 1 is computed by using the general dynamics formula for accelerated motion as follows:

$$S = at^2 + v_i t \quad (2)$$

where

a = rate of acceleration,
t = time of accelerated motion, and
v_i = initial velocity.

With reference to the dimensions in Figure 1, the following expressions can be obtained:

$$S_B + 60 = S_A \quad (3)$$

$$D = S_A + 200 + S_C \quad (4)$$

where S_A, S_B, and S_C are the distances in feet traveled by cars A, B, and C, respectively. Substitution of Equation 2 into Equations 3 and 4 and simplification leads to the following formulas:

$$at^2 = 120 \quad (5)$$

$$D = 0.5at^2 + 117.3t + 200 \quad (6)$$

where a is the acceleration rate of car A in feet per second per second and t is the time for car A to overtake and gain 60 ft on car B in seconds.

With the acceleration rate (a) known, it is possible to solve directly for time (t) by using Equation 5. Substitution of these values into Equation 6 will yield the total passing distance (D). The results of the computations performed to calculate the passing times and distances are presented below. (These values could be considered a little conservative, since in the passing maneuver the passing vehicle is initially traveling at 40 rather than 45 mph.)

Year	Passing Time (s)	Distance (ft)
1971	5.87	949
1973	6.20	988
1975	6.20	988
1977	6.43	1015
1979	6.36	1007

The passing times and distances given above increased somewhat for each consecutive test year until that trend was reversed in 1979. The largest difference between any two years occurred between 1971 and 1973, with an increase from 949 to 988 ft.

Stonex (4) determined passing distances for automobiles during the 1950s. For the year 1952, a value of 944 ft was obtained, and for 1957, the value was 790 ft. These values are less than the values obtained in this study. This result may not be that surprising when it is recalled that the average of advertised horsepower reached a maximum in 1958 (8). Thus, the values obtained in this study for the 1970s may result from a decline in performance, the use of conservative acceleration rates, or a combination of these two factors.

Acceleration Time from 0 to 60 Mph

Another test widely reported in automotive literature is the time to accelerate from 0 to 60 mph. This parameter is the most commonly reported performance criterion because it is a measure of full acceleration through the range of gears in the transmission of the test vehicle. The time required for this maneuver was recorded for each test vehicle and then weighted based on volume of sales for each vehicle for the selected model year.

The average times as determined by this analysis are given below:

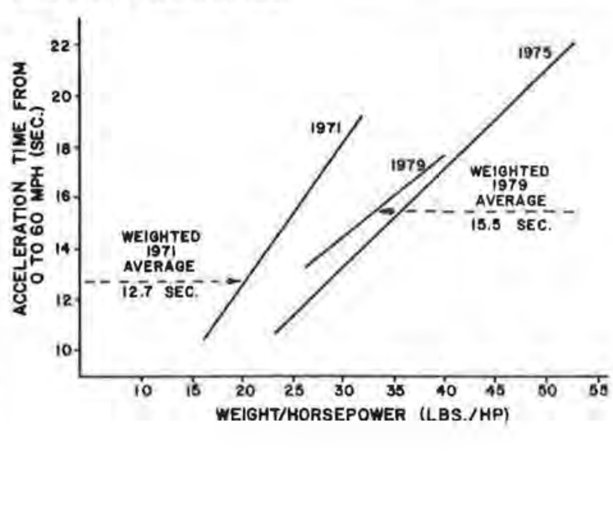
Year	Time (s)
1971	12.7
1973	14.1
1975	14.8
1977	15.5
1979	15.5

During the study period, it is readily apparent that the time required for this acceleration maneuver has increased more than 20 percent, whereas it remained unchanged between 1977 and 1979.

It has been reported that the horsepower-to-weight ratio of a particular vehicle is the simplest and most convenient means of relating a physical characteristic of the vehicle to its 0-to-60-mph acceleration time (6). The relationship between these two variables is inversely proportional; values for one variable increase as those for the other decrease, and vice versa. By inversion of the horsepower-to-weight ratio, a directly proportional relationship is made possible to compare the 0-to-60-mph acceleration time with the weight-to-horsepower ratio. This procedure was followed in analyzing the test data for selected model years because it is often more convenient to analyze a positive linear relationship than a negative one.

By using simple linear regression, an analysis of 0-to-60-mph acceleration time (ordinate) versus weight-to-horsepower ratio (abscissa) was performed for the years 1971, 1975, and 1979. The best-fitting lines with these data appear in Figure 2. Values of the correlation coefficient (r) obtained were 0.95, 0.92, and 0.71 for 1971, 1975, and 1979, respectively. Corresponding values of the coefficient of determination (r^2) were 0.89, 0.85, and 0.50, respectively. One noticeable feature is that the

Figure 2. Simple linear regression analysis of 0-to-60-mph acceleration time versus weight-to-horsepower ratio.



line that represents 1971 is considerably removed from the 1975 and 1979 lines. One possible explanation for this occurrence is the definition of advertised horsepower used in each case. Prior to 1972, advertised horsepower was described as gross horsepower, or that which was developed by an engine without any load on it. Since 1972, horsepower ratings have been a measure of net horsepower, or that which is developed by an engine under loadings imposed on it as installed in a vehicle.

From Figure 2, one important observation noted is that the range of values in the independent and dependent variables is not so great for 1979 as that for the two earlier years. Therefore, there is a trend toward more uniformity in weight-to-horsepower ratios and acceleration times. This finding is in agreement with a study (9) conducted by Glauz, Harwood, and St. John, which concluded that the size and performance of future vehicles will be more homogeneous than those of present and past vehicles. Another important observation to be made is that the weighted average of acceleration time increased from 12.7 s in 1971 to 15.5 s in 1979. Accordingly, it is reasonable to conclude that automotive performance deteriorated slightly during the 1970s.

EVALUATION OF DESIGN CRITERIA

Many of the design criteria in the AASHO Blue Book are related to the physical dimensions and operating characteristics of motor vehicles. The acceleration capability of a vehicle must be considered in three particular areas of highway design: passing sight distance, length of acceleration lanes, and sight distance at intersections.

Design calculations generally make use of normal rates of acceleration, or rates that would be typical of an average driver. Weinberg and Tharp (10) state that there is some level or narrow band of acceleration above which drivers will experience discomfort. Acceleration rates that exceed this level are of little or no importance in traffic operations because many drivers would be hesitant to accelerate so rapidly. Any design criteria to be based on acceleration rates should use the rate that the average driver perceives as a reasonable or typical value.

For the purpose of this study, however, it is convenient to compare full rates of acceleration determined from previous tests to the values determined from current tests. One reason is that full acceleration rates are less susceptible to variation from driver to driver but more dependent on the capabilities of the particular test vehicle. Should current full rates reflect inferior vehicle performance when compared with rates from the past, it is logical to conclude that a decline in automotive acceleration performance has occurred. Once the relationship between the full rates from the original and current tests has been established, it is then appropriate to evaluate the relevance of the design values of the normal acceleration rates from the original tests to the present time.

Passing Sight Distance

Passing sight distance on two-lane highways for design purposes is determined on the basis of the length necessary to complete a normal passing maneuver safely. The passing driver must be able to see enough of the highway ahead so that the vehicle can pass and return to the right traffic lane before it encounters oncoming traffic.

Four elements are considered in the determination of passing sight distance: initial maneuver distance, distance traveled during occupation of the left lane, clearance length, and distance traveled by the opposing vehicle.

The acceleration capability of the passing automobile is incorporated in the calculation of the first element of safe passing sight distance, the initial maneuver distance. This distance is traveled while a driver accelerates and encroaches on the left lane. From the AASHO Blue Book, the distance (d) traveled during the initial maneuver is

$$d = 1.47t(v - m + at/2) \tag{7}$$

where

t = time of initial maneuver (s),
a = average acceleration rate (mph/s),
v = average speed of passing vehicle (mph), and
m = difference in speed between passing vehicle and passed vehicle (mph).

Field studies of vehicle passing practices were conducted by the Public Roads Administration from 1938 to 1941 (11). Their results for vehicle acceleration rates during the initial maneuver period, as presented in the AASHO Blue Book, are given below:

	Speed (mph)			
Item	30-40	40-50	50-60	60-70
Avg passing speed (mph)	34.9	43.8	52.6	62.0
Avg acceleration (mph/s)	1.40	1.43	1.47	1.50
Time t (s)	3.6	4.0	4.3	4.5
Initial maneuver distance d (ft)	145	215	290	370
Total passing sight distance (ft)	1035	1460	1915	2380

As shown above, the distances traveled during the initial maneuver period are only about 15 percent of the total passing sight distances, which incorporate three additional elements. Nevertheless, acceleration capability is important in ensuring that a vehicle achieves the average passing speed during its occupation of the left lane. The distance traveled during occupation of the left lane is the single largest element of the total passing sight distance and is calculated by assuming a constant average passing speed. Therefore, no acceleration rate is included.

Comparison of the acceleration rates given above with full rates from 1937 (below) and those from the present should provide a measure of the adequacy of the design values. Full rates for 1937 are listed below:

Speed (mph)	Distance (ft)
0-30	222
30-40	226
40-50	364
50-60	575
60-70	908

Full rates for the present for a typical 1979 automobile and data collected for a poorly performing 1981 automobile whose acceleration capability was the poorest observed are given below:

	Typical 1979 Automobile			Poorly Performing 1981 Automobile	
Speed (mph)	Time (s)	Rate (mph/s)	Distance (ft)	Time (s)	Rate (mph/s)
0-30	4.4	6.82	97	5.8	5.17
30-40	2.5	4.00	128	3.3	3.03
40-50	3.7	2.70	244	4.4	2.27
50-60	4.9	2.04	395	5.8	1.72
60-70	7.4	1.35	705	8.2	1.22

Figure 3. Normal and full acceleration rates for range of speeds.

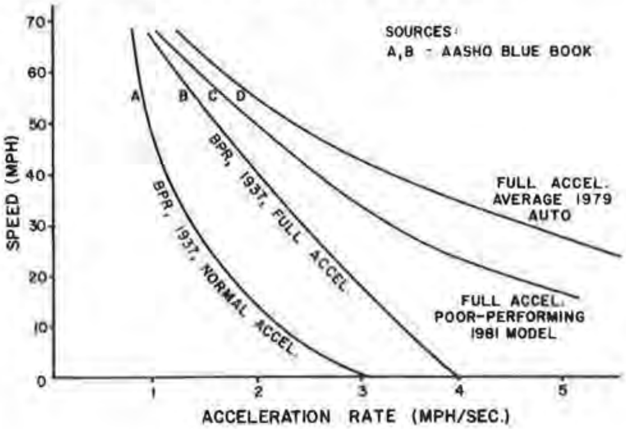
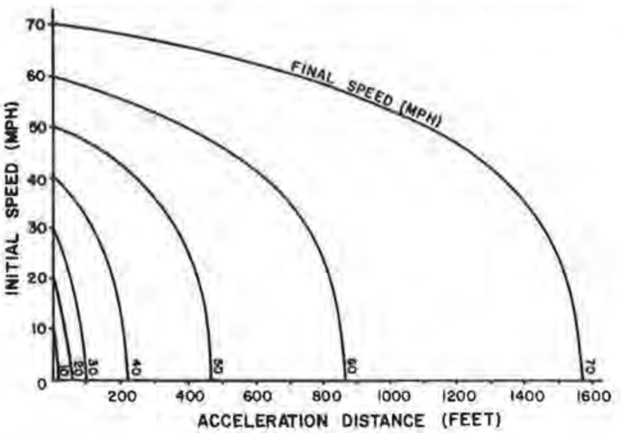


Figure 4. Distances traveled during full acceleration for range of speeds for average 1979 automobile.



For example, maximum acceleration rates of 1.5 mph/s could be exceeded up to a speed of approximately 52 mph in the 1937 full-acceleration design test, as shown in Figure 3. However, a typical 1979 automobile could exceed this acceleration rate until around 64 mph and a poorly performing 1981 car exceeded the rate until reaching 60 mph. Consequently, the ability of these automobiles to maintain a given acceleration rate at a higher speed when compared with those used in the original tests has introduced an added safety factor in the passing-sight-distance design values.

Length of Acceleration Lane

The length of an acceleration lane is based on several related factors. These factors include the speed at which drivers enter the acceleration lane, the speed at which drivers merge into the main traffic stream, and the distance required to accelerate between these two speeds. The distance is a function of the acceleration capability of the automobile and the extent to which its driver makes use of that capability.

The recommended lengths of acceleration lanes were determined by using test data that were compiled by the Bureau of Public Roads in 1937 (12). The data used for design purposes are normal acceleration rates since full acceleration rates are seldom used by drivers in any particular situation. Nevertheless, the adequacy of the design criteria may be tested by comparing the distances traveled under full acceleration rates then and now. If recent acceleration lengths are shorter than those determined by using 1937 data, the conclusion may be reached that the distances traveled under normal acceleration would be adequate and contain an additional safety factor. However, should lengths based on current data be greater than the lengths used for design purposes, it would be necessary to consider adjustment of the design data.

The distances traveled under full acceleration over a range of speeds as determined by the Bureau of Public Roads (12) were shown above.

Full acceleration distances for an average 1979 automobile, based on collected data, are presented above and in Figure 4.

If we compare data from the two previous tabulations, it is evident that the average 1979 automobile accelerates to a particular speed in a much shorter distance than the average 1937 vehicle. For the speed change from 0 to 70 mph, the total distance is in fact about 32 percent shorter for the 1979 automobile than for the 1937 vehicle. Since these data reflect a considerable relative improvement in performance for the more recent automobile, it is reasonable to conclude that the distances under normal acceleration used for design purposes are sufficiently large.

Trucks and buses require longer distances to accelerate than do passenger cars. Pignataro (13, pp. 15-16) stated that the rate of acceleration for trucks is only 2-3 ft/s^2 as compared with 6-9 ft/s^2 for passenger cars. Wright and Paquette (14, p. 64) give a typical full acceleration rate of 1.5 ft/s^2 for tractor-trailer trucks between 0 and 30 mph. Therefore, to base acceleration-lane lengths in most cases on the rates for trucks is inappropriate, because the lengths required would be inordinately great. Nevertheless, in places where there is a large percentage of truck traffic, it may be suitable to lengthen the acceleration lane as a traffic safety measure.

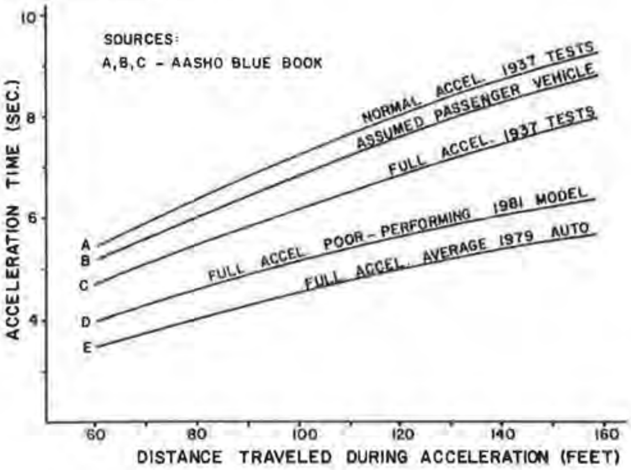
Sight Distance at Intersections

An important design criterion involving acceleration rates must be considered at intersections controlled by stop signs. The driver of a stopped vehicle must have sufficient sight distance along the through highway so that the driver is able to accelerate and clear the intersection before a vehicle on the through highway arrives at the intersection. The distance that must be traversed by the crossing vehicle is the sum of the distance from the front of the stopped vehicle to the near edge of the pavement plus the width of the through highway plus the overall length of the crossing vehicle.

The crossing time used in design calculations is the sum of the time required to accelerate across the intersection plus driver perception-reaction time. From the AASHO Blue Book, a perception-reaction time of 2 s is assumed. The acceleration time varies with the individual driver and vehicle. However, under no circumstances should the time required to traverse the intersection under full vehicle acceleration be more than the time necessary for a vehicle to cover the minimum sight distance along the through highway.

The tests used in the AASHO Blue Book involving vehicle acceleration rates were conducted by the Bureau of Public Roads in 1937. The time-distance relationships as determined in its tests for both normal and full acceleration (curves A and C) are presented in Figure 5. As shown here for a given distance, acceleration times are approximately 15 percent shorter under full acceleration than under

Figure 5. Relationship between accelerated time and distance traveled during normal and full acceleration.



normal acceleration. As noted in the AASHO Blue Book, most drivers accelerate at a rate faster than normal, although few drivers operate at the maximum capability of their automobiles. Therefore, the relation used in design calculations (curve B) incorporates a slightly higher acceleration rate than normal. Hence, the design curve lies between the normal and full acceleration curves.

Curves representing full acceleration for a poorly performing 1981 model (curve D) and a typical 1979 automobile (curve E) are also included in Figure 5. These curves were computed by using the test data from selected magazines and the general-dynamics formula for accelerated motion (Equation 2). It is evident that acceleration times under full throttle for both of these models are shorter than those from the 1937 tests. Furthermore, acceleration times are 33 percent shorter for the typical 1979 automobile over a given distance than for the assumed design passenger vehicle. Even for the poorly performing 1981 model, acceleration times are approximately 23 percent shorter than for the design vehicle.

Consequently, since the full acceleration capability is greater for a typical 1979 automobile and a poorly performing 1981 model than for the design vehicle, it follows that the assumed curve for the design passenger vehicle is appropriate. If either of the recent curves had shown inferior performance when compared with the 1937 full-acceleration curve, a further investigation and possible revision of the design curve would have been appropriate.

Accordingly, it is not recommended that the curve be upgraded to reflect an acceleration rate that is faster than the one currently used for design. Because of their relatively poor acceleration capabilities, single-unit and tractor-trailer trucks, which are part of almost any traffic stream, must also be considered. Ivey (15) stated that the percentage of trucks in the traffic stream is expected to increase from 17 percent in 1978 to 34 percent in 1990. Therefore, it would be inappropriate to institute an upgraded design curve that would not be consistent with the projected increase in trucks on the highways.

In summary, the existing AASHO design criteria involving acceleration rates were found to be adequate for current design use. Although there has been some deterioration in automotive acceleration performance during the past decade, it has not occurred to the extent that the design criteria exceed current vehicle capability and thus pose a safety hazard. In fact, the AASHO design criteria remain adequate because they are based on data prior to the 1950s, a period distinguished by significant advancements in automotive technology and vehicle performance.

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to determine whether the acceleration capability of passenger vehicles had changed significantly over the past decade. The objectives of this study were to analyze AASHO Blue Book design criteria that involved acceleration rates and evaluate their relevance to current performance trends.

The average American automobile has undergone significant changes in recent years. Sales of compact and subcompact automobiles now exceed those of full-sized automobiles. Six-cylinder engines have now replaced V-8 engines as the most popular engine choice. Many other innovations have recently been incorporated into new automobiles, mostly in an effort to meet federal mandates and consumer demand for more fuel-efficient automobiles.

The test data used in this study were extracted from popular magazines that regularly report automotive performance data. A special effort was made to select data for vehicles that were believed to be equipped in a typical manner for each of the particular models being tested. Weighting factors were calculated based on model sales in an attempt to give emphasis to the most popular car models during a given year. The acceleration data were collected and weighted for two maneuvers: (a) acceleration from 45 to 65 mph and (b) acceleration from 0 to 60 mph.

From the analysis of the data collected in this study, the following conclusions can be made:

1. Acceleration times required for two speed-change maneuvers increased between 1971 and 1979. The time required for acceleration from 45 to 65 mph increased 18 percent, from 8.4 s in 1971 to 9.9 s in 1979. The time required to accelerate from 0 to 60 mph increased from 12.7 s in 1971 to 15.5 s in 1979. Consequently, there has been a definite reduction in the acceleration capability of the average passenger vehicle during the past decade.
2. The simple linear regression analysis showed that there was a significant relationship between acceleration time and the weight-to-horsepower ratio. For model year 1979, there was a narrower range in these two variables than for 1971 or 1975. Therefore, it is reasonable to conclude that a trend toward more uniformly performing automobiles has emerged. This trend could possibly be attributed to the virtual disappearance of fast, high-performance automobiles.
3. Full acceleration rates at any given speed were greater for an average 1979 automobile and a poorly performing 1981 automobile than for the average of several models tested in 1937. Therefore, the acceleration rates used in calculating minimum passing sight distances are still adequate. The passing sight distance criteria of AASHO remain applicable to the current conditions.
4. Distance traveled under full acceleration by an average 1979 automobile was 32 percent shorter for a speed change of 0-70 mph than for the 1937 design passenger vehicle. The greater acceleration capability of the modern automobile indicates that the distances traveled under normal acceleration in 1937 are amply large. Hence, the AASHO acceleration-lane design criteria are still applicable to current vehicle performance characteristics.

5. The time required to travel a fixed distance under full acceleration was shorter for an average 1979 automobile and a poorly performing 1981 model than for the assumed 1937 design passenger vehicle. Over a given distance, the times were 33 percent shorter for the 1979 automobile and 23 percent shorter for the 1981 model than for the design passenger vehicle. Thus, modern automobiles can accelerate across and clear an intersection in less time than the 1937 automobile. Consequently, the intersection sight distance criteria given in the AASHO Blue Book remain appropriate for current use. However, the acceleration capability of new cars should be monitored at regular intervals in the future should vehicles powered by alternative fuels or energy sources become as popular as it has been widely projected.

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Federal Government and Integrated Vehicle Development: U.S. Experience

R. K. WHITFORD

Three integrated vehicle-development programs sponsored by civilian mission agencies in the federal government are critically reviewed. A brief historical background and some critical reflections are provided for the Transbus, Experimental Safety Vehicle, and Near-Term Electric Vehicle programs. The purpose of the assessment was to determine the lessons learned that might be applied in future programs. Funding limitations, relationships with industry, overly stringent specifications, lack of planning, competition (parallel contracts), international participation, and government involvement in commercialization are factors that are examined. Although all are important, planning the project following an in-depth requirements analysis and carrying it through under a cooperative partnership with industry appear to be the most important for future programs.

Vehicle research and development (R&D) programs initiated by the federal government are sometimes viewed by the private sector with alarm and doubt. Three recent U.S. vehicle programs are critically examined in this paper in order to assess our success in the programs and to determine from the experience what lessons might be applied to future programs. Each vehicle program chosen reflects government response to a different perceived public requirement or need.

1. The Transbus program was initiated to generally improve bus aesthetics, passsenger amenities, and the special mobility needs of the elderly and handicapped by developing a bus with lower overall floor height and improved boarding and discharge capability. Because the government grants a significant percentage of the capital for new bus purchases (50-80 percent), it was planned to improve buses by using the federal grant power to aggregate the market demand and by requiring grant recipients to purchase buses according to Transbus specifications.

2. The Experimental Safety Vehicle (ESV) program and its follow-up program, the Research Safety Vehicle (RSV), had as their primary goal the support of automobile safety rulemaking. Basically, the program was initiated to determine whether crashworthiness could be improved through integrated vehicle design and, if so, at what cost. The initial program dealt with large cars; the following program, with small vehicles (less than 3000 lb). The latter program also dealt with concerns for reduced emissions and enhanced fuel economy.

3. The Near-Term Electric Vehicle program was to be one of several developments that, if successful, would help the U.S. citizen retain a high level of personal mobility and simultaneously meet the national goal of reducing petroleum use. Gasoline price control and perceived high technological risk kept commercial electric-vehicle R&D at a low ebb until Congress initiated a program in 1976 to push electric vehicles. The Near-Term Electric Vehicle program was one major portion of that R&D effort.

The major results of this assessment are found in the concluding section of the paper, entitled Lessons Learned. These lessons should be taken into account in planning any new program of vehicle R&D leading to commercialization and public use.

ROLE OF GOVERNMENT IN R&D

The goals of R&D expenditures in the federal sector are considered here. Expenditures for near-term technology can be evaluated by standard benefit/cost methods. In contrast, longer-term R&D is less amenable to quantitative evaluation and depends on political values and insights at the time of authorization and appropriation. Furthermore, such programs in the civilian mission agencies are often funded on a year-to-year basis and must compete in each budget cycle with other priority programs, often new ones resulting from changes in political leadership.

Federally financed R&D programs are usually designed to meet one of five basic government functions (1, pp. 305-333):

1. They are intended to support operational activities that are the direct responsibility of the federal government, e.g., national defense, surveillance of the seacoast, and air traffic control.

2. They support the regulatory process, either in determining the cost and effectiveness of promulgation or in developing the procedures, tools, and instruments (such as the ESV) needed for effective enforcement. The studies and experimental measurements made before the automotive fuel economy regulation or aircraft noise regulation were essential; compliance test procedures were necessary for the enforcement of automobile emission control regulation.

3. They undergird grants made to state and local governments by providing research and data to aid decisionmaking or by stimulating industry to provide needed developments. One example is the highway research carried out by states under the National Cooperative Highway Research Program (also the Transbus program).

4. They augment private-sector investments to spur R&D in particular areas of national concern; e.g., recent direct investments in energy R&D and individual tax incentives for solar heating that created a market (also electric-vehicle research).

5. They help meet general economic and social needs in areas where the major responsibility lies with the government and where the private sector lacks sufficient incentive and/or resources to make adequate investment. The U.S. space program and basic and applied research programs that support scientific and engineering activities in universities are examples.

The government uses a variety of mechanisms to achieve the desired result in each of these categories; basically these are contracts, usually fully funded, with full government specifications and with the R&D results made available to all who wish to use them. Some contracts, however, are of a cost-sharing variety and allow for protection of proprietary development depending on the sharing arrangement. For basic research, the government often grants the money to be used in a more discretionary way. In addition, the government may also attempt to subsidize (often through tax structures) some R&D by rewarding the commercialization of a product or products.

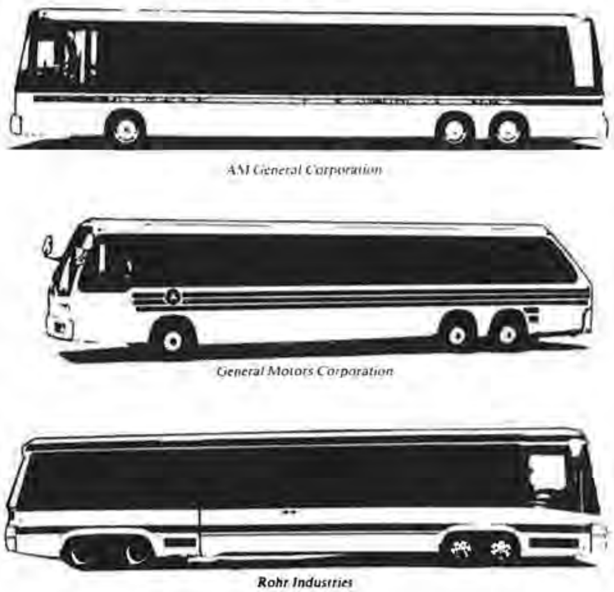
TRANSBUS

Background

Transbus, an UMTA R&D program, was initiated in 1971 with the stated purpose to (a) improve passenger comfort and ride quality, (b) reduce operating and maintenance costs, and (c) provide special features to facilitate its use by the elderly and handicapped. The special features to be developed were a low floor, two-step entry, kneeling capability, ramp or lift to provide for wheelchair entry, increase in front door width, and provisions for wheelchair locks and turnaround. Other system-level improvements included service life, curb visibility, and fire resistance. The desires of the transit agencies were communicated to UMTA through the Bus Technology Committee of the American Public Transit Association. [Before 1965, General Motors Corporation (GMC) had a virtual lock on the bus market--an 85 percent share. GMC's main competition, Flxible, accounted for the remaining 15 percent. Following a U.S. Department of Justice suit in 1965, GMC agreed to allow other companies to buy major bus components at interdivisional rates. AM General entered the bus-manufacture business in 1971.] Three contracts were awarded (to GMC, Flxible, and AM General) in 1972 for the development of a prototype Transbus to be followed by 100 preproduction models for service testing. Nine prototypes (three from each manufacturer), as shown in Figure 1, were delivered in 1974; demonstrations were held around the country in 1975. There followed a month-long demonstration in revenue service in each of four cities. The purchase of the 100 preproduction units was canceled in 1975 when UMTA announced that, in lieu of design specifications, it would develop a performance specification for low-floor urban buses that would have performance requirements related to safety, accessibility for the elderly and handicapped, low maintenance, high performance, and economical operation. Hearings were held and specifications developed from 1976 to 1978.

In 1977, the Secretary of Transportation issued a Transbus mandate that all full-sized buses purchased with federal aid after September 1979 were to comply with Transbus specifications. In early 1979, three cities formed a consortium to obtain purchase bids on 530 buses to be built to meet Transbus procurement specifications. [The Transbus Consortium included the Southern California Rapid Transit District (Los Angeles), Metropolitan Dade County (Miami), and Southeastern Pennsylvania Transportation Authority (Philadelphia). Unfortunately, each transit authority had so many individual requirements that many potential advantages of the multiple

Figure 1. Prototypes for Transbus program.



bid were nullified (2).] No bids were received by May 1979, the bidding deadline. In August, a delay in the effective date for compliance with Transbus procurement specifications was issued. At this time, the Transbus Procurement Request has been permanently shelved.

Although some costs are unknown, for example, those spent by industry in response to the mandate or in preparing for competition, about $30 million was spent by the federal government on the development project for the nine buses.

Reflections

The Transbus program (3, p. 21) was for a vehicle design stimulated by the government in an attempt to solve a dual mandate of improved bus performance and improved accessibility for the elderly and the handicapped. The first goal was already being considered by GMC and Flxible, which were in the process of introducing improvements in their existing "new-look" bus designs. They were also involved (encouraged by UMTA) in an evolutionary product design called the advanced-design bus (ADB).

The major departure in Transbus over the ADB was the low floor, which created potential problems in the technology of axle and drive-train design, tire design and wear, and obstruction clearance. In addition, the estimated Transbus cost represented a 60 percent increase in purchase price over the "new-look" bus and 50 percent over the estimates for the ADB, which in fact incorporated many of the passenger amenities and safety and operating capabilities desired in the Transbus. Relative to the ADB, Transbus as specified has one or two fewer seats, is about 2 percent less fuel efficient, and costs more to buy, operate, and maintain (4, p. 10).

The Transbus procurement request specified the use of several unproved, risky technologies. These, coupled with onerous warranty terms for which the bidders had to assume all the risk and including guarantee of service life and performance, were key reasons for the lack of bids. No doubt the unproved provision for the elderly and handicapped, which suggested the steep ramp design or lift operation, presented potential product liability. (To provide reasonable egress, the ramps had to be either too long or too steep.) Foreign competition was also kept out of the bidding because of the buy-American policies that existed at that time. Finally, there was no indication that any advantage was taken of European experience with low-floor, low-entrance buses.

The orderly process from prototype to production of a new product takes a predictably long time, especially when some development and extensive testing of key subsystems and components are needed. If adequate tests are not planned early in the R&D phase of the program or are not carried out, the price must be paid in the operational phase. In Transbus, for example, the cancellation of a second phase, i.e., the purchase and extensive testing of 100 preproduction models, caused a major gap in the orderly movement from R&D to production.

In addition, the timing was inopportune in that the Transbus program occurred just at the time major manufacturers had completed, and were attempting to absorb, investments in their ADB product. These circumstances, coupled with uncertainty about several changes in U.S. Department of Transportation (DOT) leadership, government regulations, and the nature of the bus business in general, provided a poor climate for any significant additional investment.

Another inhibiting item was the relationship of the product to the real needs of the elderly and handicapped. Other potential alternatives did not provide for mainstream access for those of the elderly and handicapped not already using transit. Later market studies indicated that the Transbus capability did not guarantee the use of the system. Bus-stop waiting, fear of crime, and nonbus movement from bus stop to other destinations were equally significant deterrents to potential elderly and handicapped users. One study showed that the additional users of the system would represent only 4 to 6 percent of the elderly and handicapped market. There was also political pressure. At one point, when UMTA stated that a low-floor bus could be introduced on an evolutionary basis, litigation was initiated by representatives of the elderly and handicapped lobby to reverse the decision. Apparently missing at the outset was a valid study assessing the usefulness and cost-effectiveness of a variety of alternative ways to enhance the mobility of the elderly and handicapped.

INTEGRATED SAFETY VEHICLES

Integrated-vehicle R&D with specific safety requirements was initiated in 1968 under the ESV program. R&D continued through the late 1970s for a second vehicle, the RSV. Sponsored by NHTSA and its predecessor agency, the National Highway Safety Board (NHSB) (NHSB became NHTSA in 1970), the primary goal of both programs was to evaluate improved safety concepts, especially crashworthiness and occupant-protection systems.

Until 1962 safety standards for automobiles were not part of federal statutes. In 1962 and 1963 federal standards were enacted for brake fluids and seat belts, respectively. These were followed by a more complete set of standards. (Known as the Roberts Law, PL 88-515 resulted in 17 standards established by the General Services Administration for government-purchased automobiles.) In 1966 PL 89-563 enabled NHSB to issue standards for all motor vehicles. Twenty-two Federal Motor Vehicle Safety Standards (FMVSS) were issued, to be effective in 1968. The law included a series of studies aimed at developing a research data base to support further rulemaking efforts. The vehicle program that was established was called the Family Sedan Experimental

Safety Vehicle program (better known as ESV). The four basic objectives of the ESV program were (5, p. A-7; 6)

1. To determine the technical feasibility of making significant "quantum jump" advancements in automotive safety performance;
2. To stimulate public awareness of the injury reduction potential and associated economic advantages of advanced automotive safety;
3. To encourage the automotive industry, both domestic and foreign, to increase its level and effort in motor vehicle safety research, and to accelerate the integration of advanced safety systems into production vehicles; and
4. To establish a technical base for the development of improved motor vehicle safety standards.

The ESV program, which spanned the years 1968-1974, included the following significant developments:

1. Four U.S. companies provided family sedan prototype cars designed to meet stringent safety specifications, especially 50-mph front-barrier and rear-crash and 70-mph rollover protection. Major automobile companies, GM and Ford, provided ESVs for a contract cost of $1. Chrysler was a subcontractor to Fairchild.
2. These vehicles underwent extensive testing in order to evaluate crash injury-reduction systems (without active restraints) and accident-avoidance technologies such as improved braking, handling, and visibility.
3. Because all cars required a 20 to 30 percent weight penalty to meet the specification, NHTSA was able to develop an improved understanding of the relationship of safety increases to fuel consumption and vehicle costs.
4. As a result of the fuel embargo, which occurred during the ESV program, there was an increasing interest in smaller, lighter cars as well as major concern about the safety of such cars. As a result, a shift from the family sedan ESV to the RSV (3000 lb or less) occurred in 1974.
5. A series of international agreements for mutual cooperation were instituted between 1970 and 1972 with Germany, Japan, the United Kingdom, Italy, France, and Sweden. International ESV conferences were held beginning in January 1971. In parallel with the U.S. program, some 14 foreign ESV-type models were built by companies in the six participating countries, often to less stringent specifications but with considerably improved safety. Several countries also invested significant resources in test tracks and test facilities for evaluating safety performance. The cost of the international program has been estimated at $150 million (7, pp. 2.0-28 through 2.0-30).
6. An estimated $25 to $30 million was spent in the United States, about half in public funds and half in private funds.

The RSV program was initiated in 1974. It was to be R&D relevant to the cars of the 1980s and to retain and expand the positive features of the ESV program. Practicality of design (exercised through mandatory weight limitation) was stressed. The early involvement and participation of the automobile industry, both domestic and foreign, was also to be sought.

Its goals, similar to but broader than those for the ESV, included enhanced fuel economy, reduced emissions, and consumer consideration. They were based on a more thorough initial study of traffic accident causation and characterization. Studies also included a review of aggressiveness in collisions and pedestrian/cyclist accidents. Engineering data from the evaluation and test of the RSV were to be used to assist in the development of FMVSS for the mid-1980s.

Five companies received contracts to provide phase-1 data characterizing traffic projection and preliminary design for a range of possible vehicles (3000-lb maximum) to meet such traffic conditions. Two companies with vastly differing approaches were selected to design and fabricate models in the 3000-lb range. One approach was more conservative and evolutionary (the Calspan/Chrysler team), whereas the other involved more innovative features (minicars). The overall RSV program cost about $30 million.

Ten models of each vehicle have been delivered and have undergone or are undergoing testing. Unfortunately, no summary report is available at this time. The minicar approach resulted in a car weighing about 2200 lb and showed many unique advantages and safety approaches in the use of very lightweight materials and design innovations. In addition, NHTSA had a six-passenger family sedan built that used essentially GM styling. That one prototype was used to attempt to stimulate the industry by showing what could be done with innovative technologies.

Although the program had an overall negative result (that is, meeting the 50-mph crash-barrier capability necessitated severe weight penalties), the initial ESV program achieved the major benefit of focusing the automotive industry, both American and foreign, on a broad set of safety concerns. The expenditure of more than $30 million has resulted in much improvement in vehicle safety and hence a reduced loss of lives. Although not due solely to the ESV program, since 1967 there has been a dramatic improvement in automobile-occupant protection as shown by the sharp reduction in fatalities per accident per vehicle mile traveled (Figure 2).

The RSV work added a new dimension, namely, the trade-off between safety and fuel consumption, particularly in smaller, lighter-weight cars. It is not clear, however, that the effort had much to do with rulemaking as such, except to show that there was at least one technology available where fuel economy improvements could be incorporated in cars that would have a higher degree of crashworthiness.

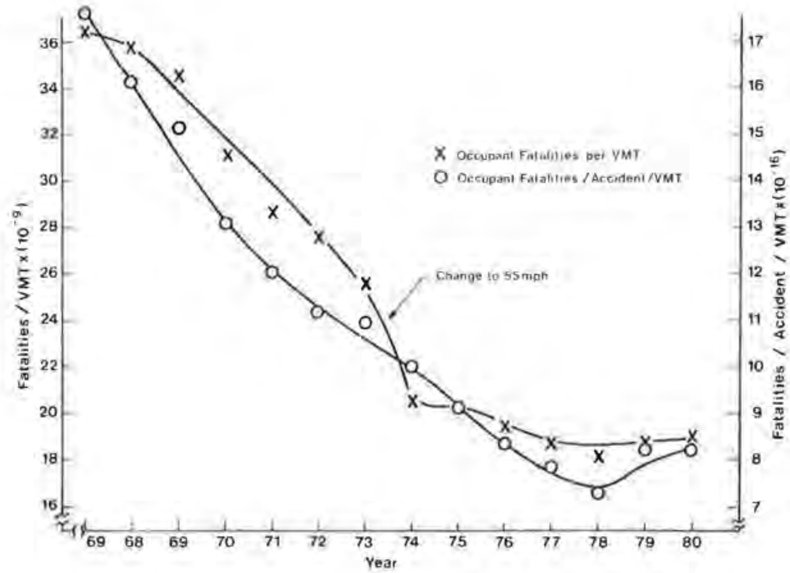
The six-passenger lightweight vehicle, which used the minicar design, was apparently constructed primarily for political purposes. It was used as an attempt to prod the automobile manufacturers. Industry's reaction to that approach probably helped to spell doom for the program in the current administration. At this time there is no further budget for the integrated-vehicle R&D program. Unfortunately, the elimination of this program occurs at a time when such integrated-vehicle R&D could be important to improve the safety potential of very small cars, especially in light of their poor safety performance (8). Only an integrated, total-vehicle approach will improve understanding of how to build maximum passive safety capability into a small car.

The ESV/RSV program was unique in that no previous single program had done more to advance automobile safety on an international basis. This is especially important when one considers the worldwide construction of test facilities and test vehicles that ensued.

ELECTRIC AND HYBRID VEHICLES

In September 1976, Congress enacted Public Law

Figure 2. Safety data related to occupant fatalities.



94-413, the Electric and Hybrid Vehicle Research Development and Demonstration Act of 1976. The act was to accelerate the development and to demonstrate the commercial feasibility of electric and hybrid vehicles through government-sponsored R&D, demonstrations, and financial incentives. A major portion of the program was the Near-Term Electric Vehicle Program, whose goals were to (9)

1. Determine optimum overall electric-vehicle design,
2. Assist industry in accelerating advancements in electric-vehicle technologies,
3. Provide analytical and test methodologies and tools for application by industry to electric-vehicle system technology,
4. Identify areas requiring increased R&D attention, and
5. Provide a national data base to enable determination of technology and standards of performance.

Two contracts were placed for integrated test vehicles. Each contract brought together the three different disciplines of vehicle design, electric drive-train design, and electronic control. One major role of this program was the integration of these disciplines into an effective overall electric-vehicle system design.

Vehicles were to include increased range between battery charges (50 percent over existing electric cars), meet existing U.S. safety standards, show contemporary styling, and have generally peppy performance equivalent to that of subcompact cars. The vehicles, ETV-1 and ETV-2, were delivered in 1978 and 1979, respectively. ETV-1 was built by a team consisting of the General Electric Company and the Chrysler Corporation (vehicle) and Glove Union (battery). The Garret/Budd team (ETV-2) included Garret Air Research, the Budd Company (body), Eagle-Picher Industries, Inc. (battery), Dynamic Science Inc. (safety), the Brubaker Group (styling), and All American Racers (supervision and brakes).

Several advances in technology were demonstrated. The aerodynamic design of ETV-1 was tested in the wind tunnel and showed some of the best overall aerodynamic characteristics of cars of its size tested to date (10). Significantly improved battery and electric-system control capability, drive-train performance, load leveling, and integrated structure were also demonstrated. The General Electric/Chrysler entry (Figure 3) was based on the existing Omni-Horizon body design and achieved recognition as a practical design, with potential for the mid-1980s provided battery capability and cost problems could be solved. This car has been extensively tested and is now serving as a test bed for advanced battery concepts. The Garret/Budd entry, which was implemented with 1990 technology, is a hybrid electric with a mechanical flywheel and battery (11). The flywheel, in effect, provides load leveling for the battery, reduces power demands, and thereby increases effective range between charges. During the R&D phase, significant advancements were made both in flywheel design and control and in integrated vehicle structures.

Before the building of ETV-1, the electric car was perceived as a small, golf-cart-type car, too small and too slow for use on the same road with gasoline-powered cars. ETV-1, by using existing technology for the most part, clearly changed that image. Its development showed that it was possible to build an authentic, market-responsive vehicle, provided the battery energy capacity or life (cost) problems or both could be solved. Its speed, handling, and safety tests were proof that a regular car could be propelled with all-electric energy.

It also proved that the engineers from the disciplines of power-train engineering, vehicle technology, and electronics could become an effective team involved in optimizing a design that would have market potential.

ETV-1 and ETV-2 have provided a technology data base that was unavailable by other means. They have indicated the R&D needed at the component and subsystem level for future electric vehicles (12,13). The automobile companies have reviewed the technology used in the model, and the analytical work has been made available for their use.

Except for the battery and control system and for drive-train packaging, the technologies used for improving aerodynamics, reducing rolling resistance, and reducing weight are equally applicable to internal-combustion cars. This means that the drive-train efficiency and cost for future vehicles can be compared on a subsystem basis. (Spinoffs from vehicle R&D are not always as obvious as they are in ETV-1. The perfection of a low-cost, high-powered switching transistor was accomplished and is now used by General Electric in other product lines.)

Motor Trend, a magazine that is often critical of

Figure 3. GE/Chrysler near-term electric vehicle (ETV-1).

government programs, especially those involving automobiles, had this to say about the ETV (Feb. 1980): "This project is one of the best uses of federal tax money in the field of energy, emissions and vehicle design.... The ETV-1 is not only an eye catcher, it is a working mule, and it works well."

VEHICLE RESULTS

The following tentative conclusions regarding integrated-vehicle R&D at the federal level have been developed from this brief examination of three government programs.

Transbus

The real needs of the elderly and the handicapped are better understood because of the Transbus program. The failure of industry to respond to the specification for purchase of 530 buses opened the eyes of many government officials to the real need for better government understanding of the financial risks and planning horizons of major businesses, particularly those in the automotive sector.

Safety Vehicles

Although it is difficult to separate the impacts of the specific parts of the NHTSA program, the ESV has probably done as much for integrating safety concerns for both domestic and foreign producers of automobiles as any of these. The international participation by six countries and the development of elaborate testing facilities in several countries speak to that success. The ESV "weight problem" was a learning experience that caused considerable effort to be spent in system studies before the RSV program was begun. The results of the Calspan/Chrysler effort suggest that some of the RSV safety features have found their way into the Omni/Horizon and probably into other cars as well. The minicar design has demonstrated the possibility of combining a very lightweight with a highly crashworthy structure for the automobile of the future.

Electric Vehicles

The electric-vehicle program did a tremendous amount to alter the image of the electric car from an advanced golf cart to a potentially stylish, peppy electric car that many of us would be willing to own (if the price were right). The program, however, has done little to improve the system infrastructure or to determine the real service and use demand for an electric vehicle.

LESSONS LEARNED

A major reason for this assessment was to develop an understanding of both the good and bad points of those lessons that were learned. Such lessons should be considered in any future vehicle program, as well as in other programs where commercialization and public use are the intended end result.

There is insufficient political staying power (funding) to cover the span of adequate vehicle R&D. Vehicle programs never achieve the preproduction models needed to ensure commercialization. Early prototypes shown to Congress and demonstrated to the consumers and media lead to overselling the readiness of the product. This kind of result further exacerbates the funding problems created by changing priorities or political leadership. Precious R&D money is often the only money quickly available to fund new program initiatives. For example, the omission of preproduction bus manufacture and the service testing of 100 prototype vehicles in the Transbus program reorientation left many unsolved technical problems and was a major reason companies chose not to bid. The RSV program today would be ready to tackle the most important question of very small car safety had it not been recently eliminated because of political initiatives in the safety program.

Good relations and involvement with industry are necessary during the program. No government R&D program for vehicle development can be suitably initiated and carried on without considerable participation by the industry that will eventually put the vehicle or its improvements on the market. All programs suffered from the absence of industry interest or government and industry teamwork pledged to completion. By itself, participation in the program does not commit the corporation to commercialization. Companies have often participated in programs, as appears to be the case with the Transbus and the ESV programs, not because the companies agree with the program or even with its specifications, but because it is a corporate defensive strategy.

To a certain extent, the lightweight RSV was used to prod U.S. automobile manufacturers into looking at new concepts, a fact that annoyed the industry. On the other hand, Calspan's work with Chrysler apparently caused some new safety ideas to be integrated directly into the Omni/Horizon. The data from near-term electric vehicles built by GE/Chrysler and Garret/Budd have been given to industry. Low battery capability and high overall cost are still the major drawbacks to commercialization. However, the program showed that adequate performance could be obtained from existing batteries and improved design of controllers.

Government specifications are often too constraining. Wide-ranging social and political pressures often lead to overspecification, which causes the product to be more expensive and, perhaps, to be engineered in a way less suitable for eventual movement into the marketplace. The rear-barrier crash at 50 mph, side-pole crashworthiness at 30 mph, and rollover at 70 mph contributed significantly to the battle-tank weights of the ESV family sedan. The low-floor, step-design, and axle-weight requirements of the Transbus, because they were too constraining, required a new bus design rather than an evolutionary one.

Planning, including the early establishment of program requirements, is crucial. In evaluating these three programs, it became apparent that the planning and requirements analysis was not always adequate. More preliminary study of alternatives for the elderly and handicapped could have created a different and more evolutionary Transbus program. Realistic safety requirements could have made the ESV more like a 1972 family sedan than tank.

Competition is important. Conversations with participants in all programs revealed that the competitive nature of the program was important. In the electric-vehicle and RSV programs, the chosen contractors (two for each program) explored different technologies; one looked at innovative approaches whereas the other looked at a more evolutionary or nearer-term approach.

International participation is important. The failure to seek international expertise for the Transbus was a negative factor. On the other hand, safety vehicle work has been greatly enriched by extensive foreign interest and heavy participation. The near-term electric vehicle program has enriched U.S. participation in international electric-vehicle conference and technical interchanges.

The government's knowledge of the market and what it takes to stimulate it are lacking. Market studies by government are usually contrary to policy and thus any efforts toward commercialization are seldom handled well. Since the government is often the purchaser of large numbers of vehicles, it could become a catalyst for commercialization in integrated-vehicle programs. Thus it could share the risk and be involved in gathering important data on new-vehicle maintenance, operations, durability, and so forth. Unfortunately, for the three examples here, no such government involvement was devised and/or implemented.

In summary, vehicle R&D programs, although seldom funded adequately enough to achieve commercialization, frequently have value in identifying critical R&D needs in the subsystem or component area. Two of the programs succeeded in showing that technology is available to accomplish some major program goals. It appears clear that public-sector involvement should be stimulatory and at the same time one of partnership with industry. If the desire is to move technology and innovation at the fastest rate in order to achieve national goals, established industry is in a better position to meet such goals and with products that will satisfy the marketplace. The poor but mixed results of our government programs underscore this need.

A strong requirement analysis at the outset and government cooperation with industry as partners are fundamental to future programs. Where international experience and cooperation are available, they should be integrated into the program if for no other reason than to improve cost-effectiveness.

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Moped Use by Visitors to Hawaii

C. S. PAPACOSTAS AND WAYNE Y. YOSHIOKA

The current definition of mopeds and the rules and regulations governing their ownership and operation as enacted by the 1978 Hawaii Legislature are presented. The results of a study that determined the characteristics of an important segment of the local rental market, i.e., visitors to Hawaii, and the attributes of their recreational excursions are also presented. The major findings obtained from an analysis of traffic accidents involving mopeds and reported by the Honolulu Police Department are included.

The 1978 Hawaii Legislature defined the term "moped" and created a new section in the Hawaii Revised Statutes pertaining to special rules governing moped ownership and operation. A conference committee report (1) issued at the time stated that "because of the increased popularity and use of mopeds, regulation and control is necessary in the interest of safety and traffic efficiency."

The committee report claimed that the majority of moped accidents involved rented equipment. For this reason, additional requirements "of maintaining in effect certain minimum amounts of property damage and liability insurance coverage" (1) were placed on moped rental firms.

This paper presents the major findings of a study (2) that

1. Investigated the legislative background of moped use in Hawaii,
2. Examined the trip attributes and the characteristics of visitors to Hawaii who rented mopeds, and
3. Compared the patterns of traffic accidents involving rented and privately owned mopeds.

LEGISLATION

Definitions

The 1977 Hawaii Revised Statutes made no reference to the term "moped." However, a "device propelled by ... motor power of one and one-half horsepower or less upon which any person may ride, having two tandem wheels sixteen inches in diameter or greater" constituted one of three types of devices covered by the generic term "bicycle," which was excluded from the definition of motor vehicle.

A motor-driven cycle, on the other hand, was defined as a motor vehicle and included "every motorcycle, including every motor scooter, with a motor which produces not to exceed five brake horsepower, and every bicycle with motor attached, but excluding such bicycle with motor of one and one-half horsepower or less."

Thus, devices with a motor less than 1.5 hp were defined as bicycles, whereas those with more than 1.5 but less than or equal to 5 hp were defined as motor-driven cycles and were classified as motor vehicles. The former were generally covered by statutes pertaining to bicycles, although there were certain differences between them and other types of bicycles. In such cases, they were referred to as motorized bicycles or bicycles equipped with a motor, but it remained unclear whether these terms also covered motor-driven cycles.

The current definitions set forth by the 1978 Hawaii Legislature provide for a new classification for the moped that is distinct from the bicycle and the motor scooter. The old definition for motor-driven cycle was deleted and a new one for the motor scooter was added. The following definitions are currently in force:

1. Bicycle: "Every device propelled solely by human power upon which any person may ride, having two tandem wheels sixteen inches in diameter or greater, and including any device generally recognized as a bicycle though equipped with two front or two rear wheels."
2. Moped: "A device upon which a person may ride which has two or three wheels in contact with the ground, a motor having a maximum power output capability measured at the motor output shaft, in accordance with the Society of Automotive Engineers standards, of one and one-half horsepower (one thousand, one hundred and 19 watts) or less and, if it is a combustion engine, a maximum displacement of 3.05 cubic inches (fifty cubic centimeters) and which will propel the device, unassisted, on a level surface at a maximum speed no greater than thirty-five miles per hour; and a direct or automatic power drive system which requires no clutch or gear shift operation by the moped driver after the drive system is engaged with the power unit."
3. Motor scooter: "Every motorcycle which produces not more than five horsepower, and excludes a moped."

Licensing Requirement

A provision that was not applicable to the old class of bicycles equipped with a motor was added in 1978; henceforth, a valid driver's license of any category became mandatory. At this time, there exist 10 such categories in Hawaii; the lowest three are driver's licenses for motor scooters, motorcycles and scooters, and cars and trucks 10 000 lb or less gross vehicle weight.

An earlier provision prohibiting any person under 15 years of age from driving a bicycle equipped with a motor was deleted, and the rule amended to refer to mopeds was added.

Liability

Parents or guardians of minors who operate a moped and cause damage through negligence or misconduct are held jointly and severally liable. In addition, rental firms are required to carry minimum liability insurance coverage of $10 000 per person and $20 000 per accident.

Use of Bikeways

The basic provisions of the 1977 statutes relating to the use of bikeways were twofold:

1. No motor vehicle can use a bikeway unless it is executing a legal turn or is specifically permitted to do so (e.g., an official vehicle while on official duty); and
2. Vehicles in the vicinity of the bikeway must in some instances yield the right-of-way to bikeway users (e.g., a right-turning vehicle with a bikeway between it and the curb).

Regarding the use of bikeways by bicycles, it was required that "whenever a usable path for bicycles has been provided adjacent to or on a roadway ... bicyclists shall use the path and no other portion of the roadway." An exception to this rule allowed counties with a population of at least 100 000 to post certain bikeways to prevent bicycles equipped with a motor from using them. Of the four counties that make up the state of Hawaii, only one qualifies for this exception.

The 1978 legislation left the above rules intact. However, because of the distinction made between bicycles and mopeds, it was necessary to delete all references to bicycles equipped with a motor and to create a new section entitled Special Rules for Mopeds, which require moped drivers to use bicycle paths and empower the director of the state department of transportation and the counties to restrict or prohibit the use of bicycle paths by mopeds.

Other Rules

Other rules applying to mopeds include the following:

1. Prohibition of driving on sidewalks;
2. Prohibition of passengers;
3. Establishment of a maximum operating speed of 35 mph;
4. Requirement that mopeds be driven in single file; and
5. Requirement that unless performing a legal maneuver or otherwise allowed, mopeds must ride as near to the right side of a roadway as practicable. In the case of one-way roadways with two or more lanes, riding on the left-hand side is also permitted.

VISITOR USE AND ACCIDENT PATTERNS

Visitors to Hawaii constitute a significant segment of the local moped rental market. Because questions relating to rented mopeds played a prominent role in the legislative debate discussed above, a study was conducted to examine the characteristics of these renters and the attributes of their trips. An investigation of the patterns of traffic accidents involving mopeds was also undertaken. The study drew on the following data sources:

1. A user survey,
2. A sample of rental agreements,
3. A volume-count and movement survey,
4. Available moped accident reports, and
5. State of Hawaii Data Book (3).

The first four of these sources are described below.

User Survey

A questionnaire was administered to renters over a period of three weeks in February 1978. The survey was conducted on the premises of a moped rental firm located in the Waikiki district of Honolulu, the major visitor destination in the state. The survey instrument was prepared in both English and Japanese and was structured in four parts as follows:

1. Questions about the users, including age, sex, and place of residence;
2. Questions about their visit to Hawaii, such as the type of travel arrangements and whether they were return visitors;
3. Questions about their use of mopeds, including the duration of rental, size of renting group, places visited, traffic violations, and warnings or citations issued to them, and other questions such as car rental, bus use, and foregone activities; and
4. Two open-ended questions, one asking about problems encountered by the renter and the other seeking suggestions for the improvement of the street system.

Rental Agreements

The agreements between renters and the moped rental firm for an entire month were made available to the researchers. From these contracts, the following data were obtained: number of mopeds per agreement, place of residence of renters, and number and type of road trouble calls.

Volume-Count and Movement Survey

An observer located at a fixed point in the Waikiki district conducted an 8-h volume-count and movement survey. The area visible from the observer's vantage point is shown in Figure 1. Each roadway lane, crosswalk, and sidewalk was uniquely coded as shown, and a number of special locations, such as a hotel parking lot entrance, were also identified. The coding system was used to specify the movement of mopeds within the observation area. The information thus obtained included the number of mopeds in each observed group, the sex of the operator, their movement paths, and the maximum number of mopeds abreast for each group. A convenient method of logging the above information was devised as follows:

$M/F/Z_1D_1 - \ldots - Z_nD_n/S/W,$

where

M = number of male drivers in a group;
F = number of female drivers in a group;
Z_i = lane, sidewalk, or crosswalk code;
D_i = direction of movement;
S = stop location, if any; and
W = maximum observed number of mopeds.

Thus, an entry of 2/2/3E-4E-6N/H/2 means that a group of four mopeds driven by two males and two females entered the area under observation on Kalakaua Aveneue in lane 3 moving east (see Figure 1), changed to lane 4, made a left turn into Liliuokalani, and entered the hotel parking lot. The maximum phalanx width observed was two mopeds.

This complete description of movements facilitated the analysis of the data and also made possible the enumeration of any violations of the rules governing the operation of mopeds.

Moped Accident Reports

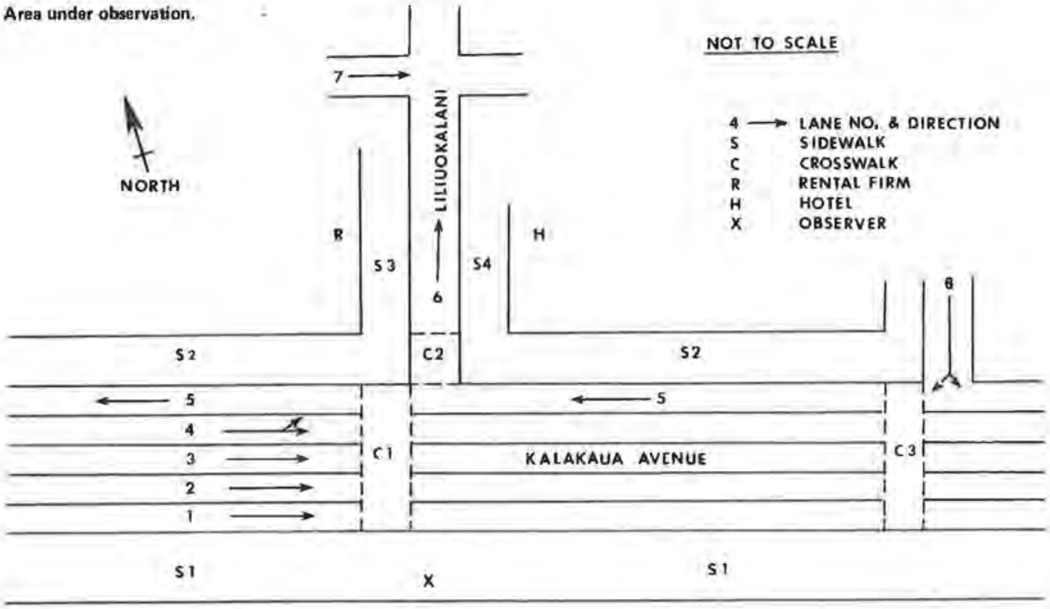
Seventy-one accident reports were obtained from the files of the Honolulu Police Department (HPD) that covered the period from October 1975 to June 1977. Hard copies of the reports are filed by HPD in chronological order and are identified by an accident report number. The contents of these reports are partly computerized by the Hawaii Department of Transportation (HDOT) (4-6), but because the data items in the computer files were limited, it was decided to obtain copies of the actual reports. Normally, because of problems in the definition of terms, this would have entailed many difficulties, especially when we attempted to identify from the computerized files those accidents that involved mopeds. Fortunately, the Motor Vehicle Safety Office of HDOT had compiled a list of moped accident report numbers, dates, and locations. Photocopies of these reports were obtained from HPD at a rate of about 15 reports per week. Data from these reports were coded and analyzed by using the Statistical Package for the Social Sciences (7).

STUDY FINDINGS

User Profiles

The sex profiles of the respondents to the user sur-

Figure 1. Area under observation.



vey and of those observed during the volume-count session are presented below:

Survey	Men (%)	Women (%)
User	64	36
Volume-count	74	26

In both cases, men outnumber women, but there appear to be differences in the proportions corresponding to the two samples. An explanation may be found in the fact that the moped users observed on the street were not drawn exclusively from the rental segment but also included individuals belonging to other categories of moped users. The volume-count proportions are almost identical to those exhibited by University of Hawaii moped users as reported in a paper by Papacostas in this Record.

With regard to age, the user survey revealed an average age of 27 for men and 22 for women; the corresponding medians were 25 and 21, respectively.

Shown below is the distribution by country of residence of the visitors who responded to the user survey. Also shown is the distribution for party heads (excluding Hawaii residents) obtained from the sample of rental agreements and the overall split by country of origin of all visitors to Hawaii as reported by the Hawaii Visitors' Bureau (3).

	Country of Residence (%)			
Sample	United States	Japan	Canada	Other
Use survey	70	9	17	4
Rental agreements	59	7	32	2
Visitors' Bureau (3)	69	14	8	9

A general conclusion can be drawn from this table: a higher proportion of Canadians is found among the moped renters as compared with their representation in the total visitor population. On the other hand, Japanese and other foreign visitors are underrepresented.

The results of the user survey also showed that two-thirds of the renters had never operated a moped before the day on which they were interviewed and that only 17 percent of the renters previously had visited Hawaii compared to the 40 percent return visitors claimed by the Hawaii Visitors' Bureau (3). Thus, for most renters the use of a moped constituted a novel experience in an unfamiliar setting.

Trip Characteristics

The average duration of moped rentals was estimated to be about 6 h, or a good part of the day's activity. It was also possible to infer from the responses to the questionnaire that about one-third of the renters confined their journeys to the immediate Waikiki district. The majority of the remaining longer excursions involved travel along major arterial streets. Most trips were taken for sight-seeing or joy-riding; only about 10 percent of the respondents indicated that they undertook other recreational activities, such as swimming.

About half of the respondents said that they would not have visited the same places if a moped had not been available to them. Of the rest, about half cited the city bus system, 20 percent a rented car, 20 percent walking, and 10 percent hitchhiking as the mode they would use in lieu of a moped. Interestingly, about 80 percent of those citing the bus as their alternative mode of travel had actually used the Honolulu bus system before, whereas the same proportion of those who cited other means of travel had not.

One-fourth of the moped renters said that they had either rented a car or were planning to do so sometime during their stay in Hawaii. About 40 percent had no plans to rent a car. The rest were not sure.

When asked to identify any safety problems they encountered, respondents to the user survey cited inadequate bikeway facilities, poorly maintained roadway surfaces, and inconsiderate motorists as the major sources of concern.

Violations and Enforcement

Thirty-five percent of the respondents said that they had ridden on a sidewalk for some portion of their trips; no one indicated receiving either a warning or a citation from the police. This level of tolerance of moped rule violations was also borne out from the volume-count and movement survey, during which no rule breaker received the attention of the police. Ten percent of the observed moped users rode on a sidewalk, 8 percent drove in the wrong direction of one-way streets, 16 percent of the total sample (or 26 percent of those traveling in groups) rode two or more abreast, and 22 percent of those not executing a left turn were seen in a lane other than the prescribed right-hand lane. However, it should be pointed out that whether strict conformance to the rules governing the operation of mopeds in Hawaii would improve or worsen their safety record is largely an open question and needs careful examination.

Accident Patterns

It should be made clear that the following findings relating to accidents involving mopeds were based on the accident-number method; the researchers were faced with the, unfortunately, all-too-common problem of inadequate exposure data for either moped users as a group or for the various moped user categories.

Because it was claimed during the legislative debate on moped regulation that the majority of moped accidents in Hawaii involve rented devices, the study tried to compare the accident patterns of rented versus privately owned mopeds.

Of the 71 accidents analyzed, only 56 clearly identified the owner of the device involved. Contrary to the aforementioned claim, 43 of these (or 77 percent) involved privately owned and not a rented moped. Moreover, with one exception, chi-square comparisons at the 0.05 level of significance disclosed no differences between the characteristics of accidents involving privately owned mopeds and those with rented mopeds. The only exception was that renters were less likely than owners to be involved in accidents occurring on multilane divided highways.

With respect to accidents, five levels of which (ranging from no injury to fatality) are reported in Hawaii, the majority of the accidents analyzed were of the minor-visible-injury type. There was one fatality. No-injury cases were found to be infrequent, but this may be due to low reporting rates for these accidents.

There was a noticeable lack of head-on collisions and a very small number involving a parked car. The remaining collision patterns were similarly represented; side-swipe and left-turn accidents showed a slight edge over rear-end, right-angle, and right-turn collisions.

Regarding the age of moped drivers, the most vulnerable group, in terms of total accidents, was between the ages of 16 and 20 years.

Finally, it is of interest to note that only one accident report indicated roadway defects at the accident site. It we consider that moped users consistently identify roadway defects as one of their major complaints, this finding may carry the implication that those who do not use mopeds, including members of the police force and perhaps transportation planners, tend to view and evaluate the prevailing roadway conditions from the perspective of the motorist rather than the moped user. If true, this perspective may have as a consequence the unwillingness on the part of planners to consider seriously the investment of funds for the improvement of special facilities used by mopeds.

SUMMARY

The 1978 Hawaii Legislature defined the term "moped" as constituting a new category of devices that are distinct from bicycles and motor vehicles. A limitation of 1.5 hp measured at the motor output shaft and a maximum engine displacement of 50 cc were imposed. Earlier rules pertaining to a now-eliminated category of bicycles equipped with a motor were updated and consolidated into a special section of the Hawaii Revised Statutes. According to current provisions of the state law, moped drivers must have a valid driver's license and must be at least 15 years old. Parents and guardians are considered to be jointly liable with minors, and moped rental firms are required to carry minimum damage and liability insurance coverage.

Based on a user survey, a volume-count and movement survey conducted in the Waikiki area of Honolulu, and a sample of rental agreements, the study described here determined the characteristics of visitors to Hawaii who rented a moped and the attributes of their moped excursions. The study also analyzed a number of traffic accidents involving mopeds as reported by HPD.

The majority of the renters surveyed were found to be visitors from the rest of the United States. Canadians were more likely, whereas Japanese and other foreign visitors were less likely, to rent a moped as compared with their proportions in the overall visitor population. Male renters outnumbered females and were somewhat older.

The average duration per rental was about 6 h. Almost all excursions were made exclusively for sight-seeing and joy-riding. Approximately 10 percent of the trips involved another recreational activity such as swimming. About one-third of the renters confined their trips to the immediate Waikiki area.

Approximately 25 percent of the renters indicated that they either had rented a car or were planning to do so during their stay in Hawaii. About 40 percent said they had no such plans and the rest were not sure.

The renters identified as major problem areas the need for more and better bikeways, the need for better maintenance of roadways, and inconsiderate motorists.

Based on total accidents, the study showed that a legislative finding that the majority of moped accidents in Hawaii involve rented devices was not accurate. With a single exception, no significant differences were found in the accident patterns of renters versus owners of mopeds. The majority of the reported accidents involved minor visible injuries and there was one fatality. The most vulnerable age bracket was between 16 and 20 years.

Traffic violations by moped users are generally tolerated by the police, but the safety implications of this are unknown at this time.

Finally, a significant difference in the perception of roadway conditions was found between moped users and police officers who completed the accident reports. Hence, a better awareness of special problems encountered by moped users is needed.

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Motorcycle Trade Press Exposure Study

CLINTON H. SIMPSON, JR.

To determine nationwide motorcycle rider characteristics, training, protective gear use, and riding patterns, the Motorcycle Safety Foundation conducted a questionnaire survey in cooperation with the motorcycle trade press. Seven motorcycle magazines ran the full-page questionnaire in their January 1981 issue: American Motorcyclist, Biker, Cycle, Cycle Guide, Cycle World, Road Rider, and Touring Bike. In addition, a New England motorcycle club newsletter reprinted the form. A total of 16 339 forms were returned and analyzed. These national exposure data replicate the findings from an earlier observational exposure study by Hurt in such areas as motorcycle brand, engine size, motorcycle and helmet color, and respondent's sex and education.

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RIDING PATTERNS

Mileage Last Month

The questionnaire appeared in the January 1981 issue of the trade press magazines. It appears that the magazines were received in December, because many respondents noted that their answers were for November. Therefore, half the responses for "last month" probably represent November and half December.

Twenty-six percent of the respondents said they had ridden zero miles; only 8 percent claimed more than 1000 miles. The mean was 410 miles and the median was 200 miles. The highest mileage claimed was 8500 and only 55 respondents claimed more than 3000 miles. The data from the question about distance ridden last month are as follows:

No. of Miles	Percent of Respondents	No. of Miles	Percent of Respondents
0	26.1	701-800	3.9
1-100	10.9	801-900	1.5
101-200	15.2	901-1000	5.8
201-300	8.5	1001-2000	6.7
301-400	6.2	2001-3000	0.8
401-500	8.3	3001-4000	0.2
501-600	3.7	4001-5000	0.05
601-700	2.1	5000+	0.07

Annual Mileage

Less than 1 percent of the respondents stated that they had not ridden last year, and 26 percent claimed 10 000 miles or more. The average number of miles ridden was 7110; the median was 6000 miles. The highest mileage reported was 85 000, although only 60 respondents claimed more than 30 000 miles (85 000 miles at an average of 50 mph is 1700 h--there are only 8760 h in a year). Mileage last year is summarized below (zero-mileage responses excluded):

No. of Miles	Percent of Respondents	No. of Miles	Percent of Respondents
0	0.9	6001-7000	6.5
1-1000	5.5	7001-8000	7.1
1001-2000	10.3	8001-9000	4.1
2001-3000	10.0	9001-10 000	7.1
3001-4000	9.9	10 001-20 000	16.9
4001-5000	10.4	20 001-30 000	1.9
5001-6000	9.0	30 001+	0.4

By Manufacturer

The number of miles that respondents reported riding last year by manufacturer differed substantially only for BMW. As the table below shows, BMW owners reported an average of 2500 miles more than that reported by owners of the Harley-Davidson:

Avg No. of Miles	Manufacturer
9940	BMW
7440	Harley-Davidson
7090	Honda
7070	Suzuki
6490	Yamaha
6410	Kawasaki

By Engine Size

The number of miles last year reported for various sizes of bikes increased with larger engine sizes. Motorcycles with engines less than 400 cc traveled only about 3000 miles last year compared with those that had 1100-cc engines, which averaged close to 10 000 miles. Although the average number of miles reported last year was 7110, bikes with engines 1000 cc and larger, which made up more than one-fourth of the bikes, had a reported annual mileage of more than 9000 miles. The number of miles ridden last year by engine size is shown below:

Engine Size (cc)	No. of Miles	Engine Size (cc)	No. of Miles
1-100	2850	801-900	8000
101-200	3230	901-1000	9270
201-300	3720	1001-1100	9860
301-400	4920	1101-1200	7540
401-500	6220	1201-1300	9080
501-600	6650	1301-1400	7800
601-700	6470	1401+	9270
701-800	7290	Unknown	5130

By Age

Comparing the miles ridden per year by different ages shows a slight trend of increased mileage for older riders up to 60 years; then the annual mileage tapers off.

Lending support to the quality of the data was the reported mileage for riders under 16, which was just 2680 miles; this figure is substantially lower than that for older riders, as would be expected.

By State

The highest reported mileage for a state was that for Arizona, in which the respondents indicated an average of 9200 miles; the second highest was that for California, 9050 miles. The area with the lowest mileage was not Alaska (the 31 Alaskan respondents averaged 5130 miles) but Washington, D.C., which reported 4210 miles. Average mileage by state is summarized in Table 1.

Those who took a rider-training course reported about 1000 more miles ridden last year than those who learned on their own--7920 miles as opposed to 6970 miles.

Months Ridden Last Year

One-third of the respondents said that they ride all 12 months. Only 10.7 percent listed 5 or fewer months. The average was 8.94 months (8 months, 28 days, 14 h). But if zero-mileage riders are excluded, the average comes up to 9.14 months. The median was 9 months and the most common response was all 12 months. The responses are summarized below:

No. of Months	Percent of Respondents	No. of Months	Percent of Respondents
0	2.2	7	10.3
1	0.5	8	11.7
2	0.6	9	11.2
3	1.4	10	8.9
4	2.2	11	4.1
5	3.8	12	33.4
6	9.7		

The five major motorcycle brands were all ridden about the same number of months. (They were within one week of each other.) Only BMW differed, with almost an additional month more than the others.

The months ridden by the size of the motorcycle showed the same trend as the annual mileage; the smaller bikes were ridden for slightly fewer months than the larger ones.

The number of months ridden by cyclists of various ages has a similar pattern--the older the cyclists, the more months they ride up to about 60 years of age.

Although cyclists who own helmets might be expected to ride more months of the year by using the helmet for protection from the elements, this is not the case. The number of months ridden last year is almost identical for helmet owners and nonowners (8.9 months for helmet owners, and 8.8 months for nonowners).

Puerto Rico has the longest reported riding season, which averages 11.5 months; Hawaii's is next longest--11.08 months. The shortest riding season was not that of Alaska (which reported 7.23 months of riding) but that of North Dakota, which reported only 6.61 months of riding last year (Table 1).

Daylight Riding

More than 97 percent of the respondents indicated that they ride in daylight half or more than half of the time.

The respondents' average daylight riding was 79.2 percent of the time; the median was 80 percent. Only 21.3 percent ride during the day more than 90 percent of the time:

Percentage of Time in Daylight	Respondents	Percentage of Time in Daylight	Respondents
0	0.5	51-60	6.4
1-10	0.4	61-70	9.8
11-20	0.3	71-80	28.3
21-30	0.6	81-90	25.0
31-40	1.2	91-100	21.3
41-50	6.2		

City Riding

The average amount of time spent in city riding was 30.7 percent; the median was 25 percent. Only 1.2 percent always ride in the city. A total of 15.9 percent of the respondents indicated that 50 percent or more of their riding was in the city:

Percentage of City Riding	Respondents	Percentage of City Riding	Respondents
0	3.8	51-60	4.6
1-10	24.4	61-70	3.1
11-20	18.6	71-80	4.9
21-30	17.1	81-90	2.1
31-40	10.0	91-100	1.2
41-50	10.4		

Suburban Riding

The average amount of riding done in a suburban location was 40.29 percent; the median was 40 percent. Only 2.2 percent of the respondents ride in a suburban setting more than 90 percent of the time. These data are summarized below:

Percentage of Suburban Riding	Respondents	Percentage of Suburban Riding	Respondents
0	3.6	51-60	8.2
1-10	13.2	61-70	6.6
11-20	13.0	71-80	8.1
21-30	15.7	81-90	3.8
31-40	12.4	91-100	2.2
41-50	13.2		

Expressway Riding

The average amount of expressway riding was 27.4

Table 1. Annual riding patterns by state.

State	Avg No. of Miles	No. of Months	State	Avg No. of Miles	No. of Months
Alabama	7260	9.89	Nebraska	6480	8.03
Arizona	9200	10.88	Nevada	8390	10.47
Alaska	5130	7.23	New Hampshire	6240	7.33
Arkansas	7070	9.30	New Jersey	6550	8.89
California	9050	10.54	New Mexico	6890	9.91
Colorado	7030	9.22	New York	6250	7.99
Connecticut	6210	8.39	North Carolina	7960	10.27
Delaware	7060	10.59	North Dakota	5090	6.61
District of Columbia	4210	10.29	Ohio	6160	8.02
Florida	8310	10.66	Oklahoma	7740	9.75
Georgia	8200	10.31	Oregon	7290	9.45
Hawaii	7140	11.08	Pennsylvania	6080	8.26
Idaho	7220	8.48	Puerto Rico	5500	11.50
Illinois	6060	7.80	Rhode Island	5600	8.28
Indiana	5810	7.88	South Carolina	7040	10.28
Iowa	6730	8.07	South Dakota	6240	7.36
Kansas	7300	9.35	Tennessee	6980	9.47
Kentucky	8130	8.77	Texas	8250	10.41
Louisiana	8880	10.58	Utah	6530	8.48
Maine	6840	6.85	Vermont	7000	7.10
Maryland	7260	9.56	Virginia	7960	9.84
Massachusetts	6270	7.96	Virgin Islands	6000	12.00
Michigan	6190	7.14	Washington	7540	9.42
Minnesota	6490	6.83	West Virginia	6430	8.21
Mississippi	6190	11.02	Wisconsin	6360	7.44
Missouri	7100	8.68	Wyoming	4750	7.55
Montana	6240	7.19	No answer	5670	7.97

percent and the median was 20 percent. More than one-fourth of the respondents, however, indicated that they only ride expressways 10 percent or less of the time and more than three-fourths of the respondents indicated that they ride expressways less than 40 percent of the time.

The Hurt data (1) show that expressway accidents account for only 10 percent of all accidents. Compared with our average exposure percentage of 27, expressways are underrepresented in accidents. These data are summarized as follows:

Percentage of Expressway Riding	Respondents	Percentage of Expressway Riding	Respondents
0	9.2	51-60	5.0
1-10	26.0	61-70	3.5
11-20	15.8	71-80	3.5
21-30	15.1	81-90	1.1
31-40	10.0	91-100	0.3
41-50	10.4		

Average Round Trips per Week

Almost one-third of the respondents indicated that they do not take any round trips. The average was 5.13 round trips per week, and the median was 4. Only 2 percent indicated that they take more than 20 round trips a week.

There was a problem with this question on our form, and the responses are suspect. A percent sign appeared next to the blank, which gave the impression that the question was asking what percentage of trips were round trips. Many of the returned forms had this question crossed off; other respondents wrote in such responses as "Every trip is a round trip if I'm still around to be filling out forms."

Miles per Round Trip

The average number of miles per round trip was 44.8; the median was 25 miles. An average round trip of more than 200 miles was claimed by 381 cyclists. The most common response was 20 miles per trip, which was given by 11 percent of the respondents.

Primary Trip Purpose

Commuting was the most frequent response; 40.8 percent gave this answer. Recreation was the only other sizable response (18 percent). Shopping, visiting, and other purposes totaled only about 5 percent. Multiple responses made up 34.6 percent of the responses, although the instructions requested the respondent to pick just one purpose. Apparently motorcycles are used for a variety of purposes and respondents wanted to show that. Trip purposes are summarized below:

Trip Purpose	Percent of Respondents
Commuting	40.8
Multiple response	34.6
Recreation	18.0
Visit friends	2.3
Shopping	1.0
Other	2.0
No answer	1.2

RIDER PROTECTION

Helmets

Ownership

Almost everyone (98.05 percent) indicated that they owned a helmet. Only 128 respondents out of 16 339 (0.78 percent) said that they did not own a helmet (1.17 did not respond properly). This figure matches that from a survey by the American Motorcycle Association, Applied Science Associates, and MSF (2, p. 1435), which indicated approximately the same high level of ownership--96.9 percent.

Excluding responses that were indecipherable or blank, 99.2 percent of the respondents indicated that they owned helmets and only 0.8 percent said that they did not. It is interesting to note that the percentage of those who missed this question or gave an illegible response was greater than the percentage of those who did not own helmets.

Relation to Brand of Motorcycle

In a comparison of motorcycle brand and helmet ownership, Harley-Davidson owners made up only 5.5 percent of the respondents but accounted for 27 percent of those without helmets. BMW owners, who made up almost 8 percent of the responses, accounted for only 3 percent of those who did not own helmets. This comparison is summarized below:

	Percentage by Manufacturer					
Item	Honda	Yamaha	Suzuki	Kawasaki	BMW	Harley-Davidson
Respondents	36.3	18.3	13.9	12.2	7.9	5.5
Those without helmets	20.3	17.2	8.6	10.2	3.1	27.3

Relation to Education

Helmet ownership is also related to respondent's education. Those with college degrees accounted for 30 percent of the responses but only 19 percent of the riders without helmets:

	Percentage by Education Level	
Item	College	High School and Technical School
Respondents	30.4	33.9
Those without helmets	18.8	39.9

Those who had graduated from high school and technical school, who accounted for close to 34 percent of the respondents, made up almost 40 percent of the riders without helmets. California accounted for one-fourth of the riders who do not own helmets but only about 14 percent of the respondents. Surprisingly, there were 24 states in which all respondents said that they owned helmets.

Color

White helmets are the most common (30 percent), followed by black (19.7 percent), red (11.4 percent), silver (10.7 percent), and blue (6.7 percent).

Reflectorized Material

About half the respondents indicated that their helmets did not have any reflective material. Slightly more than one-fourth indicated that they had reflectorized material on both the sides and the back.

According to the Hurt study (1), the most critical area for conspicuity is the front of the helmet. Unfortunately, our questionnaire did not have a space to show whether reflectorized material was used on the front. The maximum percentage of helmets that could have had such treatment on the front would have to be less than 30 percent (obtained by excluding those who had none or who had reflectorized material on the sides and back only).

Use

Only 1.5 percent indicated that they never wear a helmet when riding. A total of 78 percent of the respondents indicated that they wear a helmet all of the time. The average helmet use indicated was 91.2 percent of the time; the median was 100 percent.

These figures include those from states with mandatory helmet laws, where use approaches 100 percent, as well as from states where helmet use is observed to be 50 percent. Combining data from states in which helmets are mandatory with data from those not requiring helmets is relatively meaningless, except to report nationwide cyclists' claim to wear a helmet 91.2 percent of the time. Helmet use may be summarized as follows:

Percentage of Helmet Use	Respondents
0 (never)	1.5
25 (rarely)	3.2
50 (half the time)	2.5
75 (most of the time)	14.6
100 (always)	78.0
No answer	0.3

MSF records indicate that at the time of the survey there were nine states without helmet laws (whereas some states do not require helmets for cyclists older than 18). The respondents in these nine states (California, Colorado, Connecticut, Illinois, Indiana, Iowa, Maine, Rhode Island, and Washington) reported using a helmet 88.3 percent of the time. This self-reported use is much higher than direct observation has shown actual use to be.

In the observation of helmet use, figures of 47.8-68 percent have been obtained from states without helmet laws (Colorado and California) or states with laws that require helmets only for those younger than 18 (Maryland, South Dakota, and Kansas). It is possible that motorcycle magazine readers really do wear their helmets more often than other riders. A more probable explanation is that the respondents are overestimating their own use of helmets. They may mean to wear their helmets 80-90 percent of the time, but somehow the helmet is left behind. Observed helmet use for these five states is tabulated below:

State	Percent
Colorado	56.6
California	50
Maryland	68
South Dakota	57.3
Kansas	47.8

This difference between self-reported use of safety equipment and actual use shows up in seatbelt research also. Although observed seatbelt use is about 9-12 percent, it is typical that they are reported to be worn far more often.

Less than 5 percent of the respondents indicated that they rarely or never wear a helmet. Although only 4.7 percent of the respondents rarely wear helmets, 22 percent of the Harley-Davidson riders indicated this low use, whereas less than 2 percent of the BMW riders said that they rarely or never used helmets.

The table below gives the distribution by manufacturer of those who say they never use a helmet and those who say they always wear one:

		Use by Manufacturer (%)					
Level of Use	Overall Use (%)	Honda	Yamaha	Suzuki	Kawasaki	BMW	Harley-Davidson
Never	1.5	1.0	1.2	1.0	1.2	0.7	8.6
Always	78	78.8	80.3	81.3	75.2	86.1	54

Although more than three-quarters of the riders of foreign-made bikes indicated that they use their helmets all the time, only 54 percent of the Harley-Davidson riders claim to always wear a helmet. (Remember that more than half of these data is from states with helmet laws.)

Education level is also related to reported helmet use: the higher the education, the greater the helmet use.

Level of Education	Helmet Use (%) Never	Always
High school	2.2	72.5
Trade school	2.5	74.5
Less than two years of college	1.2	77.6
More than two years of college	1.2	79.8
College degree	1.3	84.3
Professional degree	0.6	85.8

Helmet use also increases with age. The lowest reported percentage of helmet use is that for the youngest group (16-20 years old)--only 50 percent report that they always use a helmet, despite the fact that more than three-fourths of the states mandate helmets for this age group.

It would seem reasonable to expect that respondents who do not own helmets also do not wear helmets. Yet more than half of those who do not own helmets indicated some helmet use and one-fifth of them indicate that they always use a helmet.

The states with the lowest reported use were North Dakota (only 48 percent always wear helmets), Nebraska (49 percent always), and Utah (54 percent always). States that have a mandatory helmet law report the greatest use of helmets. These data, however, are relatively meaningless since helmet use is probably more than 95 percent. California, which has never had a helmet law, has a surprisingly high reported use--77 percent indicated that they always wear helmets and only 1.8 percent stated that they never do.

Glove Use

Although 1.6 percent never wear gloves, only 37 percent indicated that they always wear gloves. The mean glove use was 69.1 percent; the median was 75 percent:

Percentage of Glove Use	Respondents
0	1.6
25	18.8
50	18.2
75	23.8
100	37.0
No answer	0.6

The use of gloves showed the same tendency as helmet use but was more moderate. Glove use increased with education and age and was highest for BMW riders. Respondents who had taken a rider-training course used gloves slightly more often than those who had not taken a course (average, 77.5 percent versus 67.3 percent).

The highest glove-use state was Alaska--an average of 89 percent. California again had a surprisingly high use, 83 percent, especially considering the amount of fair weather there. The lowest average glove use was in Puerto Rico--31 percent.

Boot Use

About half the respondents (48 percent) indicated that they always wear boots; this was the most common response. The average use was 75.83 percent; the median response was 75 percent. Boot use is summarized below:

Percentage of Boot Use	Respondents
0	4.1
25	10.7
50	11.1
75	25.4
100	48.3
No answer	0.3

Although Harley-Davidson riders indicated that they do not tend to use protective gear as frequently as others do, they make much greater use of boots than anyone else. More than 68.5 percent of the Harley riders indicated that they always wear boots compared with BMW riders, of which about 58.4 percent do. Boot use does not seem to be influenced by education: college graduates report about the same boot use as high school graduates. Boot use does seem to be associated with the size of the motorcycle. The use of boots climbs steadily from 62 percent for 100-cc bikes to 88 percent for 1200-cc bikes.

Boot use, like helmet and glove use, increases with increasing age, from 55 percent for teenagers to more than 80 percent for those more than 35 years old. Alaskan cyclists have the highest boot use (85 percent), whereas Puerto Rican cyclists have the lowest (62 percent).

Brightly Colored Clothing

Less than 10 percent of the respondents indicated that they always wear bright clothing. The average was only 44.7 percent of the time; the median was 50 percent. (These figures, however, are not even close to what would be obtained with a direct-observation study.) These data are shown below:

Percentage of Bright-Clothes Use	Respondents
0	10.0
25	37.4
50	24.5
75	17.9
100	9.2
No answer	0.9

The Hurt exposure data (which were collected by direct observation) indicated that only 5.1 percent of the motorcyclists wear high-visibility jackets. The Hurt report found that cyclists wearing high-visibility jackets were involved in significantly fewer accidents than those in average-visibility clothing. The use of bright clothing is a powerful countermeasure to avoid accidents, yet in the Hurt exposure data only about 5 percent of those observed were taking advantage of this benefit.

In the collection of data on use of brightly colored clothes (as well as on helmets, gloves, boots, and headlights), respondents were restricted to using the following responses: zero percent, never; 25 percent, rarely; 50 percent, half the time; 75 percent, most of the time; and 100 percent, always. Very few respondents indicated zero percent or never on any of the questions, including this one. The next choice, 25 percent or rarely, was used by about 40 percent of the respondents and possibly reflects a figure more like 5 percent than 25 percent.

Harley-Davidson riders report the lowest use of bright clothes (33.8 percent), although the use of bright clothes was low for riders of all kinds of bikes. BMW riders did not come out highest on use of bright clothes. They reported 44 percent, whereas Honda riders claimed 47 percent.

Comparing the rest of the questions to use of bright clothing does not really offer any revealing comparisons, probably because so few cyclists make use of highly visible clothes.

Headlight Use

More than three-fourths of the respondents indicated that they always ride with their headlight on. The average headlight use was 88.1 percent, but the median response was 100 percent.

This finding is not really noteworthy; since 1978, most headlights have been wired on. A number of the respondents, after checking 100 percent, also indicated that they do not have a choice. For example, one respondent wrote, "What else can I do? There's no switch!"

Because the newer bikes come with the headlight wired on and most of the bikes in the survey were models from the late 1970s or 1980s, it was expected that the majority of the responses would be "always." This is the case for most of the motorcycle manufacturers except for Harley-Davidson, whose riders indicated that they have the headlight on (in the daytime) only about 68.2 percent of the time. The data are summarized below:

Percentage of Time with Headlight on	Respondents
0	3.9
25	5.8
50	3.0
75	8.5
100	78.2
No answer	0.6

MOTORCYCLE CHARACTERISTICS

Number Owned

Surprisingly, just about everyone indicated that they own at least one motorcycle (97.5 percent) and 40 percent indicated that they own more than one. The average was 1.7 motorcycles per respondent although the median was one bike per person. In all, the respondents indicated that they own 27 324 motorcycles:

No. Owned	Respondents (%)
0	2.5
1	57.7
2	24.2
3	8.6
4	3.6
5	1.5
6	0.9
7	0.3
8	0.2
9+	0.5

Brand

Honda, as expected, accounted for the greatest share of the bikes--36.3 percent. Next were Yamaha (18.3 percent), Suzuki (13.9 percent), Kawasaki (12.1 percent), and, surprisingly, BMW (7.9 percent). Harley-Davidson accounted for 5.5 percent and other bikes made up 4.1 percent.

This is slightly out of line with new-registration data, which give Honda 38 percent of the market and BMW less than 1 percent. Possibly those who ride Hondas subscribe to fewer motorcycle magazines, whereas BMW riders tend to read more motorcycle magazines (or at least return more survey forms).

Engine Size

The largest motorcycle reported by more than one respondent had a 1600-cc engine. The average-size engine was 743 cc. The smallest was 50 cc.

The most common engine size was 750 cc, reported by 20.2 percent of the respondents. This matches the Hurt figure (1) of 21.2 percent for 750-cc engines almost exactly.

Color

The most common color for a motorcycle is black (31.6 percent), followed by red (24.2 percent), and blue (13.3 percent). No other color accounted for more than 10 percent.

Year

The oldest motorcycles reported by more than one person were made in 1905, followed by four 1907s; however, 98.7 percent of the bikes were made since 1960 and 97 percent were made since 1970. The most frequently reported year was 1980 (21.6 percent), followed by 1978 (19.3 percent), and then 1979 (18.5 percent). The average year (1976.5) is meaningless, but the median response of 1978 indicates that half the bikes were made in 1978 or more recently.

RIDER CHARACTERISTICS

Training

Only 15.1 percent of the respondents had taken a rider-training course, whereas 83.8 percent had not and 1.08 percent did not answer properly. This figure matches the Hurt-study figure of 15.7 percent who indicated that they had learned from a course or from professionals.

The percentage of respondents who had taken a rider-training course varied slightly by the bike they ride; 18 percent of the BMW riders indicated that they had taken a course, whereas only 12 percent of the Harley riders indicated that they had.

There were 2467 respondents who said they had taken a rider-training course. The average length of these courses was 18.9 h; 88.6 percent of the courses had a classroom portion and 72.2 percent had an on-cycle portion in an off-street setting. More than half the courses (53.2 percent) had an on-street, on-cycle phase.

The percentage of respondents who had taken a rider-training course increased slightly at higher levels of education, but this does not seem to be related to age (except for those less than 16, only 7.8 percent of whom have taken a course).

Surprisingly, 20 percent of the Alaskan cyclists indicated that they had taken a rider-training course, although MSF does not even list one course in Alaska.

The states that had the highest percentage of respondents who indicated that they had taken a rider-training course were Hawaii and Rhode Island (which have legislation pertaining to motorcycle rider-training courses). In Hawaii, 51.4 percent of the respondents had taken such a course.

Rhode Island has a law requiring all first-time motorcycle license applicants to take a minimum 10-h motorcycle rider-training course. Minnesota also had a high percentage of respondents who had taken such a course (24.4 percent). The state has a rider-course law that requires riders under 18 to take a minimum of 14 h of training.

The state with the lowest number of trained riders was Indiana; only 4.7 percent of the 297 respondents had taken a course. Next were Massachusetts (5 percent), West Virginia (5.7 percent), Idaho (6.2 percent), and Kentucky (6.5 percent).

Sex

Men accounted for 95.9 percent of the respondents; women, 3.7 percent; only 0.4 percent (68 respondents) did not answer. Leaving these out brings the division to 96.3 percent men and 3.7 percent women. This compares closely with the Hurt study exposure data, which reported 98.4 percent men and 1.4 percent women observed riding.

Age

The average age was 35; the median was 33. Half of the respondents were between 21 and 35. The oldest respondent was 83 years old and 101 respondents were 70 or older.

Less than 2 percent of the respondents were younger than 17 years old, which supports the quality of the data. The age question was left blank by 88 respondents.

Compared with the Hurt-study riders, our respondents are a little older; the median rider age in the Hurt exposure data was 26.7 compared with our median of 33.

Education

High school degree alone was the education level most frequently indicated, by 21.3 percent. Next came college degree (17.1 percent), two or more years of college (16.3 percent), professional degree (13.3 percent), less than two years of college (13 percent), and technical school (12.6 percent). Respondents who have attended at least some college made up 60 percent of the survey.

Residence

The most responses (13.8 percent) were from California, as might be expected. New York (6.2 percent) and Illinois (5.7 percent) were the only other states with more than 5 percent response. Texas, Pennsylvania, and Ohio were next with 4.7 percent each.

CONCLUSION

Perhaps the most interesting finding is that motorcyclists are so willing to participate in a study of this nature. More than 16 000 cyclists took the time to complete the form, address an envelope, and use their own stamp. This study showed that valuable information can be collected from a national (and even international) sample of motorcyclists with a minimal cost to the surveyor.

A number of our findings duplicate or approximate the findings in the Hurt study. Although the Hurt study was only done in a portion of one state, our national figures help to show that the findings apply to the rest of the country.

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Moped and Bicycle Use by University of Hawaii Students

C. S. PAPACOSTAS

The findings of two user surveys that attempted to determine the characteristics of moped and bicycle users and their school trips are discussed. Among the items covered are the degree of use of these devices, modal shifts, impact on other modes, trip-length characteristics, and problem areas. Because school trips by college students represent a significant market share of bicycles and mopeds, the information derived can add to the accumulating knowledge regarding mopeds and bicycles and the competition between them.

Recent increases in bicycle and moped use for both utility and recreational travel have stimulated the allotment of considerable attention to these modes. In Hawaii as elsewhere in the nation, an accelerated rate of construction of special facilities has occurred. In addition, the 1978 State Legislature defined mopeds and bicycles as separate categories of devices distinguished from motor vehicles and revised the rules and regulations governing their use.

A paper by Papacostas and Yoshioka in this Record describes the legislative background of moped and bicycle use in Hawaii and presents the findings of a study that has analyzed the characteristics of mopeds renters in Honolulu, their trips, and their accident patterns.

This paper concentrates on another significant market segment, University of Hawaii students and their school trips. The scope of the study was initially envisioned to be confined to moped users. However, during the early stages of the study it became evident that a significant portion of current moped users had shifted from bicycles. Consequently, the scope of the study was expanded to include bicyclists in an attempt to also discern the reasons behind the decision not to shift from bicycles to mopeds.

STUDY APPROACH AND DATA SOURCES

The study consisted of conducting and analyzing two similar user surveys. Bicycle and moped users were interviewed at various locations on the university campus. The questionnaires employed were divided into three sections. The first section elicited information about the respondents such as age and sex. The second section concentrated on the attributes of school trips and included items relating to the respondent's previous mode of travel and the reasons for shifting to the current mode. The last section sought information about the highway system from the perspective of the respondents and asked for suggestions for improvement.

In addition to the interviews, a series of counts of parked devices were taken throughout the campus at various times of the day in order to ascertain the relative numbers of bicycles and mopeds in use by students for their school trips. To arrive at an estimate of the absolute numbers of these devices, approximately 450 students were approached and asked to indicate the mode by which they traveled to school. This information was used in conjunction with enrollment data to arrive at an estimate of the number of bicycle and moped commuters.

STUDY FINDINGS

Degree of Use

The counts of stationary devices made on different days and times, which reveals a constant ratio of about nine bicycles for every moped, are listed below:

Day and Time	No. of Mopeds	No. of Bicycles
Thursday a.m.	40	326
Thursday p.m.	20	274
Friday a.m.	48	410
Friday noon	47	441
Friday p.m.	31	260

In order to estimate the absolute numbers of bicyclists and moped users, 454 students were approached randomly and asked to indicate their mode of travel. The resulting frequencies are given below. Multiplication of the total enrollment at the university by the sample frequencies gave an estimate of the total market share of each of the modes; these values are also included:

Mode	Sample Frequency	Relative Frequency (%)	Estimated Total
Walking	100	22.0	4400
Bicycle	37	8.2	1630
Moped	5	1.1	220
City bus	83	18.3	3660
Car (driver)	159	35.0	7000
Car (passenger)	68	15.0	3000
Motorcycle	2	0.4	90

Considering the sample size, the ratio of bicyclists to moped users shown is consistent with the earlier counts. According to the table above, approximately 220 students travel to school by moped and 1630 by bicycle. The most common mode of travel is the automobile, which, including both drivers and passengers, accounts for 40 percent of the total. Walking is next with a 22 percent share, followed by the city bus system, which attracts approximately 18 percent of the students. Taken together, bicycles and mopeds account for a little more than 9 percent.

Age and Sex

The average ages of 23 for bicyclists and 22 for moped users were not found to be different at the 0.05 level of significance. The two groups also exhibited similar profiles with respect to sex, but these were found to be quite different from the characteristics of the overall enrollment. The table below indicates that men have a greater propensity than women to use either device; the computed confidence intervals at the 0.95 level revealed that the proportion of male bicyclists ranges from 62 to 88 percent and the proportion of male moped users from 60 to 84 percent in contrast to their 50.4 percent representation in the overall population of 20 051 students. Women make up 49.6 percent of the overall population.

Mode	Percentage of Use: Men	Percentage of Use: Women
Bicycle (N = 40)	75	25
Moped (N = 50)	72	28

Previous Mode

The responses to a question that elicited the mode used prior to shifting to the currently used device are given below. A considerable shift from bicycles to mopeds is evident; 28 percent of current moped users came from bicycles. As stated earlier, this finding raised the question of why other bicyclists were not shifting to mopeds, which led to the conduct of the second survey.

	Bicycle (N = 40)		Moped (N = 50)	
Previous Mode	No.	Percent	No.	Percent
Walking	26	65	13	26
Bicycle	1	3	14	28
City bus	8	20	7	14
Automobile	5	12	16	32

By using the proportions implicit above, the hypothesis that the proportions of the two groups that had shifted from buses were the same could not be rejected. On the other hand, a similar hypothesis regarding previous automobile users was rejected at the 0.05 level but could not be rejected at the 0.01 level of significance. Consequently, further investigation of this question is warranted. Because a much greater number of bicyclists have shifted from the automobile, the effect of this device on the reduction of car use is much greater in comparison with mopeds.

Of the 21 students who reported that they shifted to their respective devices from the automobile, 11 had been riders and 10 indicated that they used to drive to school. A comparison of these responses with the overall driver/passenger split tabulated earlier reveal that automobile passengers are more likely to be attracted by either bicycles or mopeds. This finding carries important implications regarding the ability of the two types of devices to affect a reduction in the use of automobiles.

Reasons for Current Modal Choice

Both bicyclists and moped users were asked to give the reasons for their choice of mode. The responses to this open-ended question are summarized below. The categories shown in the table were established during the analysis phase of the project, and this necessitated a certain amount of judgment. For example, responses relating to the cost of gasoline were placed under the economy category, whereas those that emphasized the need to conserve energy on grounds of principle or philosophy were considered to constitute environmental concerns. This classification also applies to the information contained in the next three tabulations.

Reason	Bicycle	Moped
Speed	23	17
Economy	20	25
Exercise	18	--
Comfort	17	19
Environmental concern	2	4
Total	80	65

With respect to the principal reasons that encouraged their current mode choices, both groups emphasized speed, economy, and comfort. Speed was cited more frequently by bicyclists and economy headed the moped users' list. Environmental concerns were found to be relatively unimportant as incentives for the choice of device. It is interesting to note that environmental concerns emerged as reasons given for the decision not to use a given mode (see below). The bicycle was frequently cited as a means for physical exercise.

As mentioned earlier, a significant number of moped users had shifted from bicycles. The reasons given by the 13 respondents as underlying this trend are listed below:

Reason	Frequency
Speed	7
Comfort	5
Economy	2
Other	2
Total	16

Again speed, comfort, and economy were the main reasons for this decision. In order to discover the factors that inhibited other bicyclists from shifting to mopeds, the bicycle survey inquired about the respondents' plans relating to the acquisition of a moped. Only two bicyclists indicated that they were contemplating this move. The vast majority of bicyclists said that they had no plans whatsoever to obtain a moped. When asked the reasons for this, 34 respondents specified cost as the most prevalent reason followed by the lack of opportunity to exercise and environmental considerations:

Reason	Frequency
Cost	16
Exercise	11
Environmental concern	10
Availability of other mode	7
Other	10
Total	54

Recall that economy was ranked second following speed as an incentive for obtaining a bicycle and that exercise was one of the major reasons favoring this mode. Environmental concerns, especially noise, which were not cited as major reasons supporting the use of bicycles, came to the respondents' minds quite often as a reason against the use of mopeds. This finding implies that students are more concerned with maximizing their mobility and level of service (speed, comfort) within their economic constraints and less concerned with indirect effects such as environmental pollution.

Those who did shift to mopeds were consistent with the entire moped group in identifying economy, comfort, and speed, although the order in which these factors were ranked was reversed. Finally, the availability of alternative modes for their total travel needs, including the bicycle, contributed to the decision not to invest in a moped.

Other Modal Shifts

The matrix of the table below presents the two most frequently cited reasons given for all modal shifts observed in the samples:

Mode Shifted From	Reason for Shift to: Bicycle	Moped
Walking	Speed, exercise	Speed, economy
Bicycle	Not applicable	Speed, comfort
City bus	Economy, speed	Economy, speed
Automobile	Economy, exercise	Economy, comfort

It is noteworthy that intermodal movements from walking to bicycle and moped as well as from bicycle to moped consistently give priority to service improvement (i.e., speed). In contrast with this phenomenon, shifts from buses and automobiles consistently rank economy first. Taken together, these two attributes imply that there exists a general trend toward the better level of service provided by modes of higher technology subject to cost constraints. Consequently, a campaign by public authorities to induce a reduction in automobile use, at least on the part of college students, would stand a better chance of succeeding by emphasizing cost savings rather than other considerations such as environmental impacts or congestion, even though the latter may be the motives for the campaign. In the case of the decision between bicycle and moped, a trade-off between exercise and comfort is also evident.

Impact on Other Modes

The table below represents a preliminary estimate (based on limited data) of the collective effect of bicycles and mopeds on the utilization of other modes in the case of school trips by college students.

Mode	Diversion (%)	Approximate Round Trips per Day
Walking	20	1200
City bus	9	370
Automobile (passenger)	4	150
Automobile (driver)	2	150

Walking was affected to the highest degree both in terms of the percentage of walkers diverted and the total amount of trip reduction. Bus ridership among students showed a 9 percent reduction due to bicycles and mopeds. The corresponding reductions among automobile passengers and drivers were found to be 4 and 2 percent, respectively, each corresponding to about 150 round trips between home and school per day.

Trip Length

The preceding discussion does not pinpoint other trip attributes that may be central to the modal preferences identified. For example, it is reasonable to expect that trip length is closely related to the need for improving speed, the highest-ranked incentive for shifting from bicycles to mopeds.

Figure 1 shows the cumulative trip length and frequency distributions corresponding to bicyclists and moped users derived from information regarding the residential location of interviewees. Also shown with dashed lines is the distribution corresponding to those who have shifted from bicycles to mopeds and are also included among all moped users.

Figure 1. Distributions of trip length and frequency.

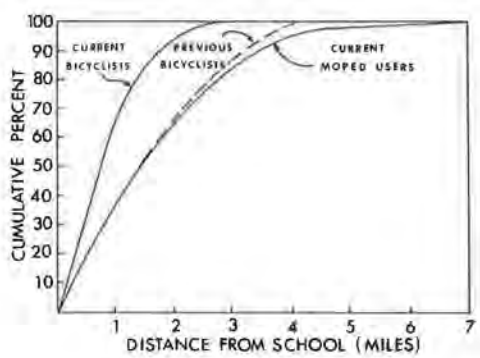

Figure 1 shows the size of the tributary areas from which bicyclists and moped users are drawn. This information may be of assistance to those in charge of providing the physical facilities for these devices. Bicyclists appear to be drawn from a maximum distance of approximately 3 miles from their school destination. On the other hand, moped use is seen to extend to a distance of 7 miles. The 85th percentiles corresponding to the two modes are found to be 1.5 miles for bicycles and 3.2 miles for mopeds. It is also of interest to note that the trip lengths of those who had shifted to mopeds exhibited a closer resemblance to the moped distribution than to the distribution corresponding to bicyclists. About 25 percent of those who shifted modes reside outside the 3-mile radius that defines the bicycle tributary area and about half reside at a distance farther than the 85th percentile. Thus trip length is an important determinant that should be used judiciously to interpret the more general responses discussed earlier. The above quantification of this attribute can offer guidance to those responsible for providing special facilities for bicycles and mopeds, at least in terms of project sequencing.

Problem Areas

The responses to an open-ended question that elicited suggestions for the improvement of the travel experience of the interviewees are summarized below:

	Percentage of Answers	
Problem	Bicyclists (N = 79)	Moped Users (M = 82)
Bikeways (more, wider, separate)	46	49
Road surface (bumps, drainage)	26	33
Inconsiderate motorists (car, bus, taxi)	14	6
None	3	1
Other	11	11

The two groups were found to be in general agreement with respect to the top-ranked problem areas, i.e., the need for additional and better-designed facilities, the improvement of roadway surfaces, and the need to make other motorists more sensitive to bicyclists and moped users. Only a small percentage of respondents found the transportation system adequate. These findings agree with those discovered by a study of moped renters reported by Papacostas and Yoshioka in this Record.

SUMMARY AND CONCLUSIONS

The analysis of responses to two user surveys augmented by normalizing data where available revealed the following about the use of bicycles and mopeds by college students in Honolulu for their school trips.

A little more than 9 percent of the student body (or about 1850 students) travel between home and school by either bicycle or moped; bicyclists outnumber moped users by a ratio of 9 to 1.

Preliminary estimates of the resultant reductions in the use of other modes show a 20 percent reduction in the case of walking to school, a 9 percent decrease in bus use by college students, a 4 percent reduction in automobile ridership, and a 2 percent decrease in automobile driving. These percentages represent about 1200, 370, 150, and 150 students, respectively, out of a total enrollment of 20 000.

A higher proportion of previous walkers was found among the current bicyclists as compared to moped users and a significant proportion of the latter had switched from bicycles. Both groups considered speed, economy, and comfort to be the major incentives for their choice of mode. The opportunity to exercise was also ranked high by bicyclists. These findings must be viewed in relation to the attributes of the mode used previously.

Speed, comfort, and economy (in that order) were the major reasons cited by those who shifted from bicycles to mopeds. On the other hand, cost, the opportunity to exercise, environmental concerns, and the availability of other modes of travel were given most frequently as the reasons inhibiting the purchase of a moped.

The maximum trip lengths for bicycles and mopeds were found to be 3 and 7 miles, respectively, and the corresponding 85th percentiles were 1.5 and 3.2 miles. Trip length appears to be an important criterion for mode choice in general and the choice between bicycles and mopeds in particular.

Level of service (i.e., speed) was the major factor favoring higher-technology modes, whereas cost was found to exert an opposing influence. In the case of the choice of bicycles vis-à-vis mopeds, a secondary trade-off between physical exercise on one hand and comfort on the other was detected. As stated earlier, trip length played a part in this phenomenon.

Finally, the two groups agreed that the lack of special facilities, the condition of roadway surfaces, and insensitivity on the part of motorists are major problems faced by bicyclists and moped users.

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