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FINAL DESIGN AND IMPLEMENTATION PLAN FOR EVALUATING THE EFFECTIVENESS OF FMSS 122: MOTORCYCLE BRAKE SYSTEMS

Kayla Costenoble
Stephen J. Thoren
Gaylord M. Northrop

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

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16. Abstract

This report covers the final design and implementation plan for evaluating the effectiveness of FMVSS 122: Motorcycle Brake Systems. The plan for the evaluation study considers measurability criteria, alternative statistical techniques, laboratory tests, data availability/collectability, resource requirements, work schedule, and other factors. The overall objective of the Standard is accident avoidance. This objective is to be achieved by specifying required equipment for motorcycle brakes and establishing performance test procedures for these systems. The goals of the Standard are to improve motorcycle braking performance by increasing stopping capabilities and decreasing stopping distances, and to avoid accidents by insuring safe motorcycle braking performance under both normal and emergency conditions. The extent to which the Standard achieves these goals is obscured by the fact that accident-avoidance braking performance requires rather precise hand and foot coordination, and is highly dependent upon the braking abilities of the rider. The plan described in this study contains five coordinated evaluation programs, plus one for determining additional costs due to the Standard. The first study analyzes mass accident data in relation to accident avoidance, injury reduction and effects of brake failure. The second study is a three-part data collection survey of motorcycle riders, tires, and modifications made to motorcycles. The third study, an analysis of NASS and California accident data, is very similar to the first task. Study number four is a dynamometer test of motorcycle brakes in a controlled laboratory setting. The fifth task uses volunteer and professional riders to test the performance capabilities of motorcycle brakes and to analyze the behavior of motorcycle riders. The last study is the cost data analysis. In summary, the entire program would require approximately five staff years of effort, would take three years to complete, at a total cost of $348,000.

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METRIC CONVERSION FACTORS

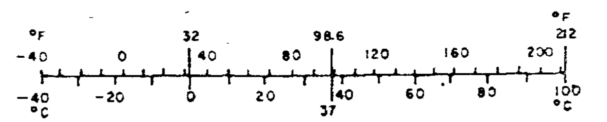
Approximate Conversions to Metric Measures

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

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

Approximate Conversions from Metric Measures

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



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CEM	Consultants
Mr. John Ball	Mr. Robert Cromwell
Mr. Diccon Bancroft	Mr. John Fitch
Dr. Hans Joksch	Dr. Alan Gelfand
Mr. Robert Lengel	Dr. Leonard Hafetz
Mr. Joseph Reidy	Dr. Uwe Koehn
Mr. Edward Sweeton	Dr. Michael Sutherland

ABBREVIATIONS USED

FMVSS	Federal Motor Vehicle Safety Standard
CEM	The Center for the Environment and Man, Inc.
NHTSA	National Highway Traffic Safety Administration
DOT	Department of Transportation
JAMA	Japan Automobile Manufacturers Association, Inc.
fpsps	Feet per Second per Second
HSRC	Highway Safety Research Center
SAE	Society of Automotive Engineers
CHP	California Highway Patrol
AMA	American Motorcycle Association
RSEP	Restraint Systems Evaluation Project
MDAI	Multidisciplinary Accident Investigation
HSRI	Highway Safety Research Institute
NCSS	National Crash Severity Study
NASS	National Accident Sampling System
VMT	Vehicle Miles of Travel
CDC	Collision Deformation Classification
AIS	Abbreviated Injury Scale
mph	Miles per Hour
CPIR	Collision Performance and Injury Report
FARS	Fatal Accident Reporting System
cc	Cubic Centimeters
ANOVA	Analysis of Variance

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1.0 INTRODUCTION

This report is the third in a series of three reports which contain the final design and implementation plan for evaluating the effectiveness of three selected Federal Motor Vehicle Safety Standards (FMVSS). The three selected FMVSSs are:

- FMVSS 105 - Hydraulic Brake Systems in Passenger Cars
- FMVSS 108 - Side Marker Lamps and High Intensity Headlamps (Only)*
- FMVSS 122 - Motorcycle Brake Systems

This report contains the final design and implementation plan for evaluating the effectiveness of FMVSS 122 - Motorcycle Brake Systems.

1.1 Background for FMVSS 122 - Motorcycle Brake Systems

FMVSS 122, effective January 1, 1974, specifies required equipment relating to motorcycle brake systems and establishes test procedures for these systems. FMVSS 122 basically codified existing SAE recommendations which were last revised on March 1, 1971, and were published by NHTSA in the *Federal Register* that same month. Most manufacturers had complied with the SAE recommendations relative to brake systems, and few design changes were directly attributable to FMVSS 122 [1]. This, and other issues, make difficult the evaluation of the effectiveness of FMVSS 122.

The original effective date for FMVSS 122 was September 1, 1973; it was extended to January 1, 1974, to give the Japanese--who account for 85 to 90 percent of motorcycle sales in the U.S.--and other manufacturers sufficient model change-over time [2]. This Standard has not been significantly changed or modified since it first became applicable. Minor changes involving dynamic testing of the motorcycle brake systems have been made and are stated below:

- Effective October 14, 1974: Service brake systems for motorcycles with attainable speed in one mile of 30 mph or less were exempted from three tests: fade and recovery, reburnish, and final effectiveness.
- Effective June 14, 1976: Change in tire type and test procedure skid number.

This Standard applies to both two-wheeled and three-wheeled motorcycles.

1.1.1 Purpose of FMVSS 122

The overall purpose of the Standard is to avoid accidents by insuring safe motorcycle braking performance under both normal and emergency conditions. Safe motorcycle braking performance is to be achieved by specifying required equipment for motorcycle brake systems and establishing performance test procedures for these systems.

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*The formal title of FMVSS 108 is *Lamps, Reflective Devices, and Associated Equipment*. The Standard covers 15 separate lighting elements, of which only two are considered.

1.1.2 General Requirements of FMVSS 122

All motorcycles manufactured after January 1, 1974, are required to have either a split hydraulic service brake system or two independently actuated service brake systems. However, split hydraulic brake systems for motorcycles are still in the developmental, experimental stage; they are not available on commercially-manufactured motorcycles. According to the SAE motorcycle brake subcommittee chairman, split hydraulic brakes are covered by FMVSS 122 for the following reasons:

- The motorcycle brake Standard followed the passenger car brake Standard.
- When and if such systems become available, they will be covered by an existing Standard.
- These systems do exist on some three-wheeled motorcycles, such as those used by the Post Office [3].

Actuation of a service brake system may be either mechanical or hydraulic. If a braking system is hydraulically actuated, each master cylinder must have a separate reservoir for each brake circuit. In addition, the filler opening for each reservoir must have a cover, seal, and cover retention device. The minimum reservoir capacity must be equivalent to one and one-half times the total fluid displacement resulting when all wheel cylinders or caliper pistons serviced by the reservoir move from a new-lining-fully-retracted position to a fully-worn-fully-applied position.

In addition to the split or independent braking requirement, the Standard requires that one or more electrically operated service brake system failure indicator lamps be mounted in front of and in clear view of the rider.* Each

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* The use of the term motorcycle "rider" rather than "driver" throughout this study is quite deliberate. Not only is it the term used by motorcyclists themselves, but it also serves as a reminder of the many differences between the two types of operators. A car is far more "forgiving" than a motorcycle. There are many things a car driver can do --light a cigarette, drink a cup of coffee, turn his head to talk to a passenger--which might be disastrous if done by a motorcyclist. In addition, a sense of closeness develops between a cyclist and his cycle, the more he rides it and becomes familiar with it. This characteristic has been expressed well by writer R.M. Pirsig [4]:

> "On a cycle the frame is gone. You're completely in contact with it all. You're *in* the scene, not just watching it anymore... that concrete whizzing by five inches below your foot is the real thing, the same stuff you walk on... the whole experience is never removed from immediate consciousness."

indicator must have a red lens with the legend "Brake Failure" on or adjacent to it. The failure indicator lamp will be activated under the following conditions:

- When not more than 20 pounds of pedal force is applied to the service brake in the event of pressure failure in any part of the service brake system.
- When level of brake fluid in a master cylinder reservoir drops to less than the manufacturer's specified safe level or to less than one-half the fluid reservoir capacity (without application of pedal force).
- When ignition switch is turned from "Off" to "On" or "Start" position.

FMVSS 122 also requires visual inspectability of the brake lining thickness for both drum and disc brakes. Visual inspection of the drum brake shoe lining either directly or with a mirror must be possible without removing the drums. The disc brake friction lining must also be visually inspectable without removing the pads.

Finally, a parking brake is required equipment on all three-wheeled motorcycles. This brake must be engaged by mechanical means and operated by friction principles.

1.1.3 Measures of Effectiveness

The overall effectiveness of this Standard is the degree to which it achieves its objective--accident avoidance. The primary conceptual measure of effectiveness would be the number of accidents that were avoided and did not happen as a result of compliance with the braking performance requirements of the Standard. However, since these occurrences are known only to the riders immediately involved and are almost never recorded, using the number of accidents that were avoided due to the Standard as a measure of effectiveness would be quite difficult. As an alternative, the corollary measurement of accidents that occurred but which could have been avoided had the brake systems complied with the Standard might be used. However, since data on motorcycle accidents are either non-existent or inadequate, using this alternative as a measure of effectiveness would also present problems. Any attempt to evaluate FMVSS 122 using motorcycle accident data would require detailed investigations of accidents. If enough data were available, it could be determined which make/model year motorcycles complied with the Standard and which did not. Then the relative frequency of accidents in which brake performance could be a causal factor could be compared for each group. Obtaining data for this type of analysis would necessitate sending a team of motorcycle accident investigation experts to the scene of an accident. From this it might be possible to determine whether or not the accident could have been avoided had the motorcycle brake system complied with the Standard.

A quantitative measure of effectiveness would be the reduction in the number of brake-related motorcycle accidents from Pre-Standard to Post-Standard vehicles. However, as mentioned before, motorcycle accident data are scarce and, therefore, this type of analysis would be very difficult. Also, there is no clear distinction between Pre- and Post-Standard motorcycles since most manufacturers complied with the requirements of the Standard before it became effective January 1, 1974. According to a NHTSA specialist on FMVSS 122, this Standard basically codified existing SAE recommendations with which the industry had already complied.*

Another measure of effectiveness should be the number of accidents that were caused as a result of compliance with the Standard. Brakes in compliance with the Standard will decrease the stopping distance of the motorcycle and could cause a greater number of front-rear collisions where the automobile, if following too closely, collides with the rear of the motorcycle.

On the other hand, if the Standard has led to an increase in braking effectiveness [i.e., decreased stopping distances, ability to stop in a straight line, smooth control of stop (front and rear wheels), reduction in fade, etc.], then another measure of effectiveness might be a decrease in the number of rear end collisions involving motorcycles colliding with the rear of automobiles.

Finally, as another quantitative measure of effectiveness, Pre-Standard and Post-Standard motorcycles could be tested on a specially designed motorcycle dynamometer. Measurements could be made of the degree to which Pre-Standard brake systems compare with Post-Standard brake systems.

*The latest and most recent revisions to SAE Motorcycle Road Test Code J108a and Service Brake System Performance Requirements J109a were March 1971.

1.1.4 Means of Complying with the Standard

As mentioned before, most manufacturers were following SAE recommended practices for the design of safe braking systems before FMVSS 122 became effective on January 1, 1974. The most recent SAE recommendations and the first published notice of FMVSS 122 both occurred early in 1971. This gave motorcycle manufacturers three years to "comply" before the performance specifications officially became a Federal Standard. The SAE recommendations for independent or split brake systems were, in general, sufficient to comply with the Standard.

Motorcycle manufacturers are providing independent front wheel and rear wheel braking circuits which are either mechanically operated drums or hydraulically operated discs. The choice of system configuration is dependent on the size and weight of the cycle, the purpose or use for which it is intended, and consideration of the general ability of motorcycle operators. Although there are no set rules, some generalities in the use of braking systems can be observed. Large tour cycles and medium and large sport cycles tend to use hydraulic disc brakes on the front wheel. Medium displacement cycles generally use a double leading shoe drum system on the front wheel, but there appears to be a trend toward discs here also. The light, small displacement commuter motorcycles are usually equipped with a single leading shoe drum system on the front wheel. The rear braking circuit on most motorcycles is usually a single leading shoe drum with only a very few employing rear disc systems [5].

1.1.5 Primary and Secondary Effects of Compliance

The primary effect of compliance with the Standard should be improved braking performance during both normal and emergency situations. In general, braking performance is a function of stopping distance, ability to maintain desired direction of control (usually in a straight line), and the force required to lock the brakes (brakes which lock easily are undesirable). With proper operation of the brakes, stopping distances for Post-Standard motorcycles will be less than for Pre-Standard cycles. Brake failure rates should also be less frequent for motorcycles that are in compliance with the Standard. However, because the performance of motorcycle brake systems is so highly dependent upon the proper operation of the brakes by the rider, the primary effect of compliance (improved braking performance) will be obscured. Proper operation of the brakes involves correct coordination of the front and rear brakes. Many motorcycle riders rely primarily on the rear brakes either because of inexperience or the fear of locking the front wheel [6]. This severely reduces the effectiveness of the brake system.

In summary, the degree to which compliance with the Standard will result in improved braking performance depends not only on the capability and condition of the brakes, but also on at least the following: the rider's ability to correctly modulate front and rear brakes separately to avoid wheel lock-up and subsequent loss of stability; the tire tread characteristics; the road surface; the wetness or dryness of the road; the lighting conditions; and, as much as anything else, the braking skill of the operator.

The 1971 SAE specifications for motorcycle braking systems were based, at that time, on what brakes should do, not on what they could do, according to R. A. Little, who was Chairman of the SAE Motorcycle Brake Subcommittee [7]. At that point, the requirements of the Standard went beyond the state-of-the-art. Compliance with the Standard has resulted in motorcycle brakes providing greatly reduced stopping distances and has had a substantial effect on performance [7].* Potential secondary effects of the Standard include the following:

- Loss of motorcycle control while braking. The newer motorcycle brake systems may be too effective, especially on wet or slippery road surfaces. Brakes respond and perform as well when road surfaces are wet or dry, but since there is less friction between the tires and road because of the wet or slippery road surface, the possibilities for brake lock-up and subsequent skidding are increased [8]. This, of course, may cause the operator to lose control and prevent him from otherwise being able to avoid a collision.**
- Rear End Collisions. Should newer motorcycles that comply with the Standard stop suddenly in traffic and the vehicle directly behind is unable to stop in time, this situation could very well contribute to an increase in the frequency of rear end collisions between cars (striking) and motorcycles (struck). This situation may be very difficult to define since there might be a tendency for car drivers to follow motorcycles more closely than other vehicles.

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*For example, California highway patrolmen, on motorcycles with Pre-Standard braking systems, would shout, as they stopped speeders, "Wait, I'm coming back!" as they braked past. They would then turn around and ride back to the stopped vehicle. This no longer occurs with Post-Standard brakes [7].

**Anti-lock braking systems for motorcycles are now being developed, which could improve this situation.

1.1.6 Real World Performance of the Standard

Data on motorcycle accidents involving brake performance are either non-existent or inadequate. Therefore, estimating the real world performance of FMVSS 122 is presently a very difficult task. In order to gather the necessary amount of detailed data to evaluate the effectiveness of the Standard, teams of motorcycle accident investigation experts would have to be sent to the scene of motorcycle-involved accidents. Since this type of investigation is relatively expensive, little has been done on a widespread scale. In the existing data, it is difficult to find any significant causal link between motorcycle accidents and defective brakes. Section 2.0 discusses additional problems in the evaluation of the Standard.

1.2 Summary of Evaluation, Cost Sampling and Work Plan

The plan to evaluate the effectiveness and cost of FMVSS 122 comprises six analyses. They are:

- Analysis of Mass Accident Data
- Motorcycle Surveys (Riders/Tires/Structural Modifications)
- Analysis of NASS and California Accident Data
- Motorcycle Dynamometer Brake Tests
- Field Test of Braking Performance and Rider Behavior
- Cost Data Analysis.

1.2.1 Analysis of Mass Accident Data

This analysis is concerned with (1) determining whether accidents are avoided or severity of injury reduced due to motorcycle brake specifications in the Standard; and (2) investigating the effects of motorcycle brake failure. The mass accident data that will be considered in the analysis include FARS, New York State, North Carolina, Texas and Washington State. The first part of the study will be undertaken by tabulating car-motorcycle front-rear collisions and analyzing driver and environment characteristics in relation to Pre- and Post-Standard braking systems. The second part of the study investigates the extent of motorcycle brake failure in Pre-Standard and Post-Standard motorcycle together with the effects on the number and severity of motorcycle accidents. Because of the expected great variability and lack of level of detail in the available data files, the above analyses cannot be expected to establish the efficacy of the Standards if improvements are small.

1.2.2 Motorcycle Surveys

This analysis is concerned with conducting a three-part data collection survey designed to obtain additional data on motorcycle rider experience, tire usage, and motorcycle modification. Each of the three surveys will be conducted by mail. Selected sets of potential recipients who could participate in the survey include motorcycle owners, dealers and repair and maintenance shops. The first survey is designed to estimate the important characteristics of the general population of motorcycle riders. These characteristics include age, sex, weight, height, marital status, education, occupation, motorcycle experience, accident experience, etc. The second survey has the objective of determining the types of tires which various classes of motorcycles are using. Data to be collected include motorcycle size, type of tires originally on motorcycle, type of tires presently on motorcycle, primary motorcycle use, etc. The third survey is designed to gather data on the frequency and degree of motorcycle modification, with the emphasis on brake modification. Both motorcycle owners and motorcycle dealers/repairers will be questioned.

1.2.3 Analysis of NASS and California Accident Data

The analysis is very similar to that accomplished with mass accident data. The effects of accident avoidance, injury severity and motorcycle brake failure are analyzed using NASS and California accident data. The analyses are first undertaken during the first year and repeated during the second and third year, as more data become available.

1.2.4 Motorcycle Dynamometer Brake Tests

This part of the evaluation study is directed toward conducting laboratory dynamometer tests of motorcycle brakes to test compliance with FMVSS 122 performance characteristics that are independent of the effect of operator skill. The controlled dynamometer brake tests are designed to consider such factors as brake system type, motorcycle weight and structure, road surface conditions, weather conditions, weight loading, vehicle pitch (roll), weight shifting, lever or pedal force of brake application, sensitivity of front wheel brake, condition of hydraulic brake system, deceleration capability, fade resistance, effects of water or contamination and system life. The results of previous brake system tests that used methods other than those specified in the Standard would first be reviewed. Tests will be performed on a wide range of available current motorcycles. Brake performance tests for front and rear brakes will be conducted separately, under various simulated conditions.

1.2.5 Braking Performance Experiments

This portion of the evaluation study is designed to conduct laboratory-type experiments with both professional and non-professional riders to (1) test the performance capabilities of Pre- and Post-Standard motorcycle brakes; and (2) analyze the behavior of motorcycle riders. Both portions of the study will be carried out at special test facilities. In the first part of the study, under varying conditions (wet surface, curves, etc.) the performance of Pre-Standard and Post-Standard braking systems will be compared. Riders and motorcycles will be selected for the experiments by means of a Latin square design. A second set of experiments will be conducted with Post-Standard braking systems only. It will be concerned with evaluating the effects of rider characteristics, habits, and experience in relation to control of the motorcycle, stopping distances, etc. This experiment is concerned with determining the ability of typical motorcycle operators to exploit the capabilities of motorcycles with different methods of braking, including slip ratio control, wheel deceleration control and angular jerk control.

1.2.6 Cost Sampling Plan

This analysis is concerned with the determination of direct costs to implement FMVSS 122. Cost categories are confined to direct manufacturing, indirect manufacturing, capital investment (including testing), manufacturer's markup, dealer's markup and taxes. A frequency sampling plan has been developed which assumes that the manufacturer's cost of compliance varies according to the manufacturer and engine displacement.

1.2.7 Work Plan

The work plan for the evaluation study of FMVSS 122 is divided into a total of six Tasks. Assuming that all Tasks are carried out, the estimated resources required for evaluating the effectiveness of FMVSS 122 are $348,000. This figure includes estimated requirements of five staff-years. The entire study would require three years to complete.

Task 1 is concerned with the analysis of mass accident data to evaluate the effects of motorcycle brake specifications on injury reduction. It is estimated that six months will be required for the completion of the Task 1 study. The total resources required for Task 1 are estimated to be $30,000. This total includes accomplishing the Task effort with 0.5 staff-years and $5,000 for data processing. The probability of satisfactorily evaluating the effectiveness based on only Task 1 is estimated to be about 0.05.

Task 2 involves a three-part data collection mail survey to obtain additional data on motorcycle rider experience, tire usage, and motorcycle modification. It is estimated that six months will be required for the completion of the Task 2 study. The total resources required for Task 2 are estimated to be $50,000. This total includes accomplishing the Task effort with 1.2 staff years, $9,000 for equipment costs and $2,000 for data processing.

Task 3 is concerned with the analysis of NASS and California accident data. It is estimated that the initial analyses will be completed in six months, with subsequent 2-month periods for additional analysis scheduled toward the end of the second and third year. The total resources required for Task 3 are estimated to be $30,000. This total includes accomplishing the Task effort with 0.5 staff-years and $5,000 for data processing.

Task 4 involves conducting laboratory dynamometer tests of motorcycle brakes. It is estimated that six months will be required for the completion of the Task 4 study. The total resources required for Task 4 are estimated to be $100,000. This total includes accomplishing the Task effort with 1.0 staff-years, $25,000 for equipment costs, and $2,000 for data processing.

Task 5 is designed to conduct field tests with professional and non-professional motorcycle riders to both test brake performance and evaluate rider behavior. It is estimated that nine months will be required for the completion of the Task 5 study. The time period includes a 4-month preparation phase that provides for obtaining motorcycles, selecting riders for tests and preparing the test facilities. The total resources required for Task 5 are estimated to be $97,000. This total includes accomplishing the Task effort with 1.2 staff-years, $25,000 for laboratory costs, $7,000 for equipment and $5,000 for data processing.

Task 6 encompasses the cost sampling plan which is directed toward determining the direct costs of implementing FMVSS 122. Task 6 will be completed in six months during the first year of the overall study. It is estimated that the total resources required are $41,000; this includes 0.8 staff-years of effort and $1,000 for computer processing.

In summary, the study to determine the effectiveness and costs of FMVSS 122 requires resources of $348,000 and three years to complete. It is judged unlikely that the Standard will be successfully evaluated without undertaking all of the Tasks described above.

1.3 References for Section 1

1. Telephone conversation with S. Shadle, Standard Specialist, NHTSA, November 2, 1977.

2. U.S. Department of Transportation. "Preamble to amendment to motor vehicle safety standard no. 122," *Federal Register*, June 16, 1972. (Docket no. 1-3; notice no. 4)

3. Telephone conversation with R. A. Little, SAE Motorcycle Brake Subcommittee Chairman and member, California Highway Patrol, California, January 17, 1978.

4. Pirsig, R.M. *Zen and the Art of Motorcycle Maintenance*. New York, Bantam Books, 1975.

5. Dean, P. "Braking the works," *Cycle Guide*, v. 8, no. 7, July 1974.

6. Hurt, H.J., Jr. and C.J. DuPont. "Human Factors in Motorcycle Accidents," *Proceedings: International Automotive Engineering Congress and Exposition*, Detroit, Michigan, February 28-March 4, 1977. (SAE 770103)

7. Telephone conversation with R.A. Little, Chairman, SAE Motorcycle Brake Subcommittee and member, California Highway Patrol, California, December 30, 1977.

8. Telephone conversation with P. Dean, Engineering Editor, *Cycle Guide*, Compton, California, November 2, 1977.

2.0 APPROACHES TO THE EVALUATION OF FMVSS 122 - MOTORCYCLE BRAKE SYSTEMS

The overall purpose of FMVSS 122 is accident avoidance. This purpose is to be accomplished by specifying required equipment for motorcycle brake systems and establishing performance test procedures for these systems. The objective of this Standard is to insure safe motorcycle braking performance under both normal and emergency conditions.

2.1 Problems in Evaluating the Standard

In evaluating the effectiveness of FMVSS 122, several problems will be encountered which will make the evaluation of this Standard difficult.

The major problems with evaluating the Standard are:

- It is very difficult to find any significant causal link between motorcycle accidents and defective brakes. There are several other more significant causal factors involved in motorcycle accidents. These are discussed in Section 3.1.4.
- There is a lack of detailed data in both the mass accident and, especially, existing detailed accident data bases. Also, existing accident files which include variables on mechanical defects lack specificity (i.e., was brake failure due to wet brakes or to hose or cable failures, etc.).
- Since most manufacturers were following SAE recommended practices for the design of safe braking systems (which were sufficient to comply with the Standard) before FMVSS 122 became effective on January 1, 1974, there is no clear-cut distinction between Pre-Standard and Post-Standard motorcycles.
- Increased capabilities (relative to the car) of motorcycles to maneuver out of an accident situation by steering rather than braking will influence the effectiveness measures for this Standard.
- Rider characteristics play an important role in evaluating the effectiveness of this Standard. The most important characteristic is the rider's degree of experience. Other important characteristics to consider include age, sex, fatigue, vision, alcohol consumption, etc.

Other problems in evaluating the Standard are:

- Many motorcycle accidents occur which are never reported; this affects and biases the total accident numbers in data bases, and adds to the difficulties already encountered with utilization of existing or future motorcycle accident data files. Reasons for the under-reporting include lack of insurance (to cover damage to the motorcycle), cost of repairs below the minimum necessary for reporting, membership in cycle clubs, and unwillingness to become involved with enforcement figures.

- The influence of other Standards relating to motorcycles or the performance of motorcycle brake systems will confound the evaluation of FMVSS 122. These Standards include FMVSS 106 (Brake Hoses), FMVSS 116 (Motor Vehicle Hydraulic Brake Fluids), and FMVSS 123 (Motorcycle Controls and Displays). FMVSS 123 is particularly important; it standardized location of motorcycle brakes in September 1974, nine months after FMVSS 122 became effective. This Standard will benefit inexperienced motorcyclists and borrowers of motorcycles.
- Registration figures usually include motor bicycles and motor scooters under the general motorcycle heading. If possible, these vehicles, which are not covered by the Standard, should be removed from the analysis. However, if this cannot be done, they are expected to have a relatively small confounding effect.
- Road conditions will have more influence on the effectiveness of motorcycle brake systems than on automotive brake systems.
- Improper coordination of the front and back brake is another real world factor that will influence the effectiveness of the Standard.
- In many car/motorcycle accidents, the car driver and not the motorcycle rider has been found legally at fault.
- The fact that most car/motorcycle accidents are affected by the car driver's actions will have to be considered, since any change in their attitudes and awareness of the dangers to motorcyclists will affect the number of car/motorcycle accidents which occur.

2.2 Proposed Evaluation Approaches

To obtain information to evaluate the effectiveness of FMVSSS 122, six approaches have been proposed:

- Analysis of Front-Rear and Left Turning Collisions
- Brake Failure Analysis
- Motorcycle Dynamometer Brake Test
- Analysis of Braking Performance
- Analysis of Rider Behavior
- Survey of Motorcycle Riders, Tires, Modifications.

Table 2-1 addresses the results of each of the evaluation approaches. It should be emphasized that the survey of motorcycle riders, tires, and modifications is an effort to gather data which will be useful in developing evaluation methodologies and in interpreting the results of other analyses.

TABLE 2-1

SIX APPROACHES FOR EVALUATING THE EFFECTIVENESS OF MOTORCYCLE BRAKE SYSTEMS

Approach	Description Section	Results
• Analysis of Front-Rear and Left Turning Collisions	3.1	Estimate of the reduction in motorcycle accidents and injury severity due to the motorcycle brake specifications of FMVSS 122.
• Brake Failure Analysis	3.2	Estimate of the effects and extent of motorcycle brake failure on the number and severity of motorcycle accidents.
• Motorcycle Dynamometer Brake Test	3.3	Performance characteristics of Post-Standard motorcycle brake systems *independent of the operator skill factor*.
• Analysis of Braking Performance	3.4	Performance capabilities of Pre- and Post-Standard motorcycle braking systems.
• Analysis of Rider Behavior	3.5	Information on the riding behavior of motorcycle riders.
• Survey of Motorcycle Riders, Tires, Modifications	3.6	Estimates on (1) the characteristics of the general motorcycle rider population, (2) frequency and degree of motorcycle modification, and (3) the number of motorcycles using the various types of available tires.

A summary of the particular problems which may be encountered in each of the suggested six approaches follows:

1. Analysis of Front-Rear and Left Turning Collisions. Lack of detailed data in both the mass accident and, especially, in detailed accident data bases. Greater detail is desired not only on which vehicle (automobile or motorcycle) was apparently at fault, but also on brake-related causes, if there were any (for example, did the motorcyclist misuse or not use his brakes).

2. Brake Failure Analysis. Although many accident files include a variable on mechanical defects, their lack of specificity (i.e., was brake failure due, for example, to the brake hose, or to wet brakes, etc.) makes a detailed, meaningful analysis very difficult.

3. Motorcycle Dynamometer Brake Test. This would measure braking system compliance with the requirements of the Standard, but since there is no rider involved, it would give no indication of how the vehicle would react in a real world normal or emergency traffic situation when the use of even the most responsive braking system depends on the skill, perception and reaction of the rider.

4. Analysis of Brake Performance. This test will indicate performance differences between Pre- and Post-Standard motorcycles with riders. Unfortunately, it cannot test the reaction of these riders, or of the brakes on the motorcycles they are test riding, in a real world emergency situation (that is, immediately before a crash), since one could hardly justify asking these riders to, essentially, risk their lives.

5. Analysis of Rider Behavior. This would go beyond measuring brake performance to give data on the characteristics of motorcycle riders in general. Its major problem, however, is identical to that presented in Approach #4--these riders would not be reacting to real world emergency traffic situations, which is when their skill is tested to the utmost.

6. Survey Data. This has been suggested as a means of obtaining demographic data on motorcycle riders, their experience, and their accidents. Presently available data are small in volume. Information gathered from this survey will be useful in interpreting the results of the other analyses suggested. However, we do not expect a very significant response to a survey of this nature.

2.3 Organization of the Effectiveness Evaluation Plan

The general approach to evaluating the effectiveness of any Standard is to undertake first those evaluation tasks which:

- Can be done early.
- Show significant promise of achieving success in evaluating the effectiveness of the Standard.
- Can be performed relatively inexpensively.

If appropriate data are available in the mass accident data files available from states, and detailed accident data bases such as RSEP, MDAI, NCSS and (in the future) NASS, then statistical analyses are usually the first recommended task(s). In some instances, clinical analyses of available data, surveys, and/or preliminary field or laboratory tests may be appropriate to augment and/or enhance the results expected from the frist round of statistical data analyses.

The initial statistical and supporting analyses and tests usually occupy approximately the first year of the evaluation program (time for preparation of Requests for Proposals, proposal review, and contracting is included). The first major decision point is then reached. For some Standards, the initial analyses may be adequate to evaluate the Standard with satisfactory statistical confidence levels. In the case of other Standards, the initial analyses will only provide the basis for conducting surveys, field and laboratory tests, and additional detailed data collection and analysis efforts. As much as two, three or more years of work may be required, and there may be several additional decision points, where NHTSA can decide whether the evaluation process is adequate or should be continued.

CEM has outlined evaluation programs lasting from three to six years. In each case, it is CEM's judgment that there is a reasonably high probability that, by the end of the program, the effectiveness of the Standard will have been satisfactorily evaluated. However, in the event the issue remains in doubt, a number of "Next Possible Steps" are outlined.

Figure 2-1 indicates a flow diagram/decision tree for evaluating the effectiveness of FMVSS 122. A time-phased Gantt chart is found in Section 5, which describes the Work Plan in detail. A brief description of the Tasks and Decision Points is given below.

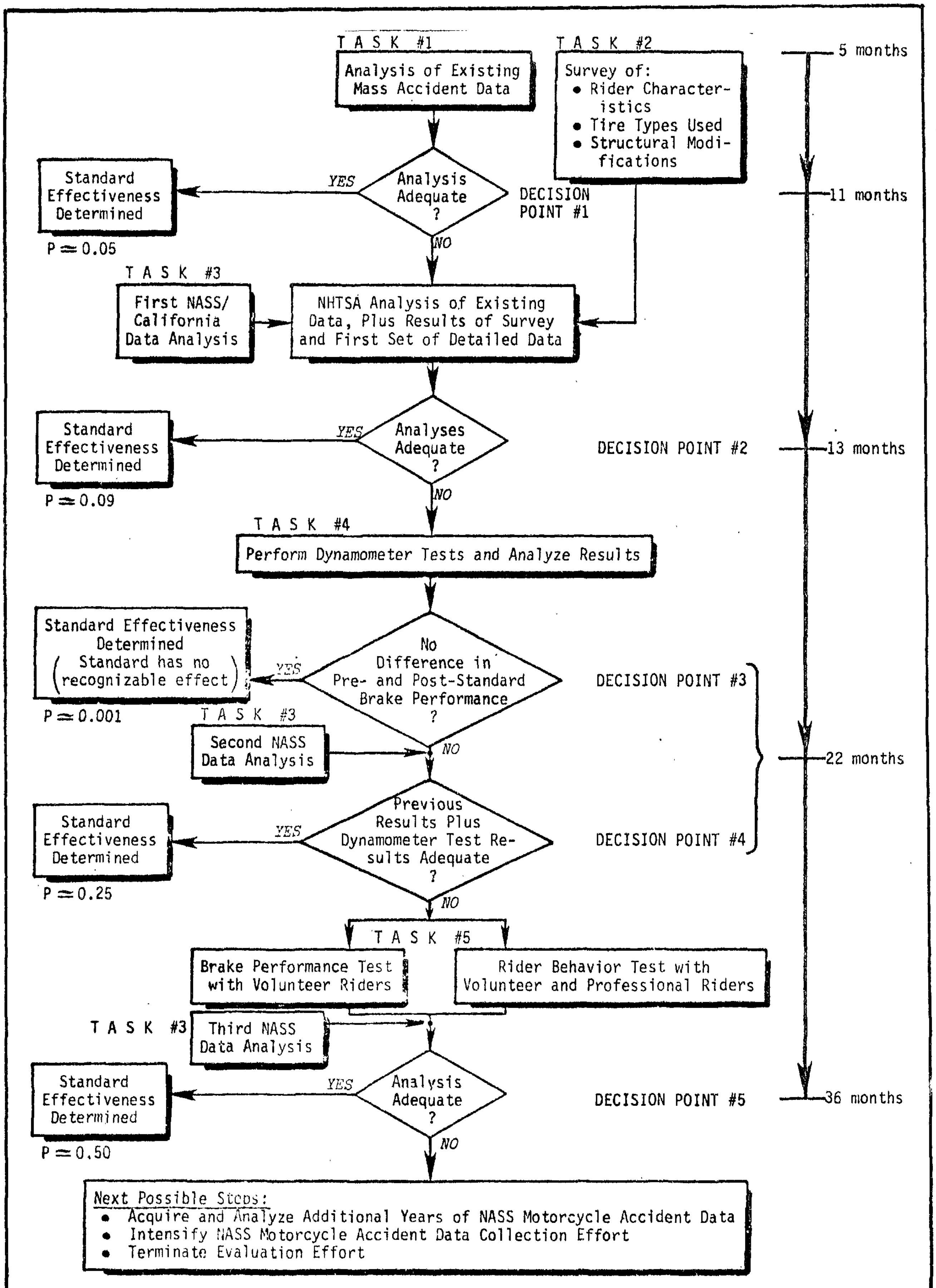

Figure 2-1. Flow chart for proposed evaluation of FMVSS 122: Motorcycle Brake Systems.

Task #1: Analysis of Existing Mass Accident Data

Existing mass accident data from states will be analyzed to determine if there is a reduction in motorcycle brake-related accidents/injuries as a function of introduction of the Standard. The study will also provide information relevant to conditions associated with brake-related accidents. This information will be useful in subsequent analysis.

Decision Point #1

The mass accident data analysis will be reviewed to see if it is adequate to evaluate the Standard. It is not expected that it will be.

Task #2: Survey of Rider Characteristics/Tires/Structural Modifications

This Task will be initiated at the same time as Task #1. It is a mail survey which will provide background information on potentially confounding effects that may influence the mass accident data analysis, and/or subsequent analyses.

Task #3: Analysis of NASS and California Accident Data

In this Task, detailed motorcycle accident data from NASS and a California study (now in progress) will be analyzed to determine the effectiveness of Pre- and Post-Standard motorcycle brakes. In the event the evaluation requires performance of later Tasks, subsequent addition to the NASS data base will be evaluated at appropriate points.

Decision Point #2

The combination of Task #1, #2, and #3 results will be reviewed by NHTSA and a decision made concerning the adequacy of the analyses. It is not anticipated they will be adequate. If this is the case, laboratory dynamometer tests of motorcycle brakes will be undertaken.

Task #4: Motorcycle Dynamometer Test

Pre- and Post-Standard motorcycles with essentially common tire types will be tested on dynamometers to determine braking differences.

Decision Point #3

If the dynamometer tests show no difference between Pre- and Post-Standard brake performance, it may be deduced that the Standard has produced no recognizable effect, and the evaluation may be terminated. (Revision of the Standard might be considered.) However, this outcome is considered highly unlikely.

Task #3 (Continued): Analysis of New NASS Data

Because an additional year of NASS data will be available, the previously-developed analysis programs will be re-run, and the NASS analysis updated.

Decision Point #4

If, as may be expected, the dynamometer tests clearly establish Pre- and Post-Standard brake characteristics, then this new information will be used to reinterpret the results from the previous tasks, including the updated NASS analysis. It is possible--though not highly likely--that this evaluation will be adequate. In the more probable event that the evaluation cannot yet be concluded, field tests will be made.

Task #5: Field Tests of Brake Performance and Rider Behavior

Professional and volunteer riders will be obtained to determine characteristics of Pre- and Post-Standard motorcycles, and the variations in rider performance. This additional information is expected to enhance the ability to interpret previously derived results.

Decision Point #5

After updating the NASS data analysis all results will be reviewed. At this point, the probability of having adequate results is estimated to be about 50 percent. If it is concluded the results are inadequate, there are at least three possible next steps.

Next Possible Steps

Several additional years of NASS data might be acquired and analyzed. As the data base grows, the analysis may become more adequate, although the inclusion of new Pre-Standard motorcycle accidents will diminish. It may be appropriate to fund an intense NASS motorcycle accident data collection and analysis effort, or it may be appropriate to terminate the evaluation.

3.0 EVALUATION PLAN

3.1 Analysis of Front-Rear and Left Turning Collisions

3.1.1 Introduction

The purpose of this analysis is to determine the number of accidents avoided or the decrease in injury severity because of the motorcycle brake specifications of FMVSS 122.

If the requirements of FMVSS 122 have led to an increase in brake effectiveness, it might be possible to show this effect by using mass accident data to investigate front-rear and left turning collisions between motorcycles and automobiles (or other motor vehicles). That is, motorcycle brake systems complying with the Standard ought to have increased stopping capabilities and decreased stopping distances. This might mean (and we must emphasize the speculative nature of such an investigation; there are many other factors involved) that in comparing Pre- and Post-Standard motorcycles, we would find:

- A decrease in collisions involving motorcycles colliding with the rear of automobiles.
- A decrease in collisions involving motorcycles colliding with oncoming automobiles turning left.

These accidents involve the conspicuity, maneuverability and braking ability of the motorcycle-rider combination. At least two types of accidents do not involve braking ability to any serious extent. These are collisions in which a motorcycle is hit by an automobile it is passing (side-swipe or the automobile turns left) and collisions in which a left-turning motorcycle is hit by an oncoming vehicle.

This analysis will require the use of mass and detailed accident data files.

3.1.2 Data Requirements

The following are the variables that should be included for this analysis. Some of these variables cannot be obtained from the available mass accident data bases, so that other means must be used.

- Vehicle Characteristics
  - Vehicle type (make, model, model year)
  - Vehicle size, weight
  - Vehicle modifications
  - Vehicle defects
  - Vehicle tires
  - Other measures of vehicle geometry
- Environmental Conditions
  - Highway type
  - Highway surface
  - Highway condition
  - Weather conditions
  - Light conditions

- Rider Characteristics
  - Experience on motorcycles
  - Age
  - Sex
  - Status of rider (owner/borrower)
- Types of Brakes on Motorcycle
  - Front
    - -- Drum (single or double leading shoe)
    - -- Disc (single or double actuated pucks)
    - -- Double disc (single or double actuated pucks)
  - Rear
    - -- Drum (single or double leading shoe)
    - -- Disc (single or double actuated puck)
- Manner of Collision
- Mechanical Defects Noted
- Other
  - Time of day
  - Use of helmet/shield
  - Protective clothing worn (pants, gloves, footwear)
  - Number of persons on motorcycle
  - Impact speed

Our search of the available mass accident data bases indicates that the variables not obtainable are:

- Vehicle modifications
- Vehicle tires
- Type of brakes (pre- or post-Standard and detailed characteristics)
- Rider experience on motorcycle
- Protective clothing worn
- Status of driver
- Number of persons on motorcycle.

3.1.3 Data Acquisition and Preparation

Accident data tapes will be acquired and processed in order to obtain the desired information. The sources of accident data include mass accident data from Texas, North Carolina, New York, Washington State and the Fatal Accident Reporting System (FARS). CEM's initial investigation of the mass accident data files is summarize below.

- Fatal Accident Reporting System (FARS). Motorcycle data are available. In the 1976 FARS file, 6.34 percent (2,823) of the 44,483 vehicles involved in 31,619 accidents were motorcycles [1]. There are multiple variables available in this file which would be useful in this type of analysis. They include:
  - Vehicle description: make, model, body type, model year.
  - Collision with other motor vehicles in transport, on other roadways, parked, etc.
  - Manner of collision (rear end, head on, etc.).
  - Relation to roadway (on roadway, shoulder, outside right-of-way, etc.).

- Speed limit.
- Time of day.
- Pavement surface type.
- Alignment and grade
- Adverse surface conditions.
- Light condition.
- Adverse weather/atmosphere.
- Character of roadway.

- New York, North Carolina, Texas and Washington State data files contain similar information on accidents in which motorcycles were involved. In 1973, there were 242,883 motor vehicle accidents recorded in the North Carolina data base. Of these, 2,905 (or, 1.2 percent) were motorcycle accidents. Texas variables include "other factor" columns which provide an opportunity to record information giving a more detailed picture of the accident, such as what caused the vehicle to swerve or veer from its intended course, or what caused it to slow or stop on the road. Washington State data include "miscellaneous actions" and "other action" codes which list skidding, sudden slowing maneuvers, special maneuvers such as "started to overtake--struck by overtaken vehicle," and foot slipping off brake.

Investigation of the detailed accident data files in relation to motorcycle accidents indicates that the three major sources presently available--RSEP, MDAI and NCSS-- are of no use; and the sample size in the one future source--NASS--will be inadequate. Both the Restraint Systems Evaluation Project (RSEP) and the Multidisciplinary Accident Investigation (MDAI) files exclude motorcycles as primary case vehicles, but include them as a type of vehicle struck. However, RSEP does not provide motorcycle make,model, or model year, which makes this file unusable; and the frequency of the motorcycle being the first object struck is so low (only 0.65 percent of a total of 8,795 in the MDAI file) that it renders this file also unusable. Again, motorcycles are not considered case vehicles in the National Crash Severity Study (NCSS), and no injury data is provided for accidents in which motorcycles are involved, which eliminates NCSS as a possible data source.

The National Accident Sampling System (NASS) has been designed to collect representative data on a large number of accidents. When completed, this system will be a probability sample of approximately 18,000 accidents annually (including motorcycle accidents), which have been investigated by accident investigation technicians. The system has been designed to provide accident research data to support evaluation of Federal Motor Vehicle Safety Standards and countermeasures [2].

In considering the mass accident data bases, one has to take into account other FMVSSs for motorcycles to see if the effects of these might be confounded with the brake Standard. FMVSS 106 (Brake Hoses) became effective in January

1968; FMVSS 116 (Motor Vehicle Hydraulic Brake Fluids) became effective in December 1968. Both of these certainly will affect brake performance and, for this reason, it is proposed that 1968 and earlier motorcycles be removed from the data analysis. Some other Standards will also have some effect, but in a more restricted or accountable way.

3.1.4 Preliminary Results

There has been a significant increase in the use of motorcycles in the U.S. over the past several years. Since 1969, 96 percent of the motorcycles sold in the U.S. were imports and, of this number, approximately 85 to 90 percent were Japanese. Table 3-1 compares motorcycle and automobile registrations; figures have been rounded to the nearest ten thousand. Table 3-2 shows the number of motorcycles manufactured, where they were manufactured, and comparative percentages.

TABLE 3-1

MOTORCYCLE AND PASSENGER CAR REGISTRATION, 1967-1976
(in millions)

Registrations	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Total Motorcycles	1.95	2.10	2.32	2.81	3.34	3.80	4.36	4.96	4.97	5.10
New Motorcycles					0.93	1.01	1.19	1.02	0.75	0.78
Passenger Cars	80.41	83.62	86.87	89.26	92.74	92.10	101.76	104.90	103.37	

Sources: Motorcycle Industry Council, Inc.[3]; Motor Vehicle Manufacturers Association [4].

Table 3-3 is presented to show that the death rate for motorcycles is approximately four times that for all vehicles. This crude comparison can, however, be misleading. Leaving aside questions about the accuracy with which vehicle miles of travel are estimated, these rates may reflect characteristics of the riders or occupants rather than differences between vehicles. In order to make accurate comparisons between other vehicles and motorcycles, the rates for all vehicles must be standardized to motorcycle rider characteristics (or calculated on a population matched on motorcycle rider characteristics). It might then be found that motorcycles are as safe or as lethal as any other means of transportation.

Between 1964 and 1975, the number of registered* motorcycles in the U.S. increased 404 percent, for an average increase of 16 percent a year [6]. Although the rate of increase has slowed since the early seventies, there has

*Many states do not require registration and licensing of off-road vehicles--motorcycles, minibikes, go-carts.

TABLE 3-2

MOTORCYCLES MANUFACTURED OR IMPORTED IN THE U.S.: NUMBER, COUNTRY, AND PERCENT
(Thousands)

Country and Number Produced (000's)	Year							
	1969	1970	1971	1972	1973	1974	1975	1976
Estimated U.S. Production	40	35	25	35	45	40	40	80
(% of Total)	*6%*	*3%*	*2%*	*2%*	*4%*	*3%*	*4%*	*11%*
U.S. Motorcycle Imports	640	1,090	1,540	1,690	1,210	1,540[1]	950[1]	660[1]
(% of Total)	*94%*	*97%*	*98%*	*98%*	*96%*	*97%*	*96%*	*89%*
TOTAL	680 *100%*	1,125 *100%*	1,565 *100%*	1,725 *100%*	1,255 *100%*	1,580 *100%*	990 *100%*	740 *100%*
Distribution of Imports								
Japan *(% of Total)*		928 *85%*	1,340 *87%*	1,470 *87%*	1,020 *84%*	1,353 *90%*	865 *88%*	598 *81%*
European Countries *(% of Total)*		126 *12%*	147 *10%*	161 *10%*	129 *11%*	113 *7%*	98 *10%*	131 *18%*
All Others *(% of Total)*		36 *3%*	52 *3%*	59 *3%*	57 *5%*	39 *3%*	18 *2%*	9 *1%*
TOTAL		1,090 *100%*	1,539[2] *100%*	1,690 *100%*	1,206[2] *100%*	1,505[3] *100%*	981[3] *100%*	738[3] *100%*

[1]Import totals for 1974, 1975, and 1976 exclude motorized bicycles (mopeds).

[2]Differences in totals between the two parts of the table are found in the original source figures.

[3]These figures for 1974, 1975, and 1976 include estimated imports of motorized bicycles (mopeds): 1974: 13,000; 1975: 32,000; 1976: 78,000.

Source: Motorcycle Industry Council, Inc. [3].

TABLE 3-3

ANNUAL DEATH RATES: MOTORCYCLES AND ALL VEHICLES
(per 100 million VMT)

	1971	1972	1973	1974	1975
All Vehicles*	4.57	4.43	4.24	3.61	3.47
Motorcycles**	17.6	17.0	16.8	15.3	14.6

*National Safety Council [5].

**Calculated from DOT/NHTSA [6] and Motor Vehicle Manufacturers Association figures [4,7].

been no other type of registered motor vehicle whose growth approaches that of motorcycles. This rapid growth has two main consequences. First, drivers of other vehicles are becoming more aware of motorcycles; second, the rider population is changing, so that patterns of use may also be changing. Both of these factors may well produce trends in accident rates, obscuring any effects due to the Standard. Table 3-4 presents the increase in motorcycles compared to population and to other motor vehicles.

TABLE 3-4

GROWTH IN MOTOR VEHICLE REGISTRATION AND POPULATION

	1964	1975	Ave. Annual Percent Increase 1964-1975	Percent Increase 1964-1975	1976 (Preliminary)	Percent Increase 1975-1976
Total Registered Motor Vehicles	87,294,543	137,917,200	4.25	57.99	142,397,000	3.25
Automobiles	71,984,540	106,712,600	3.64	48.24	109,675,000	2.78
Trucks	14,019,143	25,775,700	5.69	83.86	27,125,700	5.24
School Buses	222,098	368,300	4.71	65.83	387,600	5.24
Commercial Buses	83,317	93,800	1.08	12.58	98,700	5.22
Motorcycles, etc.	985,445	4,966,800	15.84	404.02	5,110,000	2.88
U.S. Resident Population, July 1	191,141,000	213,124,000	0.99	11.50	214,649,000	0.72
Registered Motor Vehicles Per Capita	0.46	0.65	3.19	41.30	0.66	1.54

Source: DOT/NHTSA [6].

One of the problems that will be encountered in the analysis of automobile-motorcycle collisions is the overall lack of detailed data in both the mass accident and, particularly, the detailed data bases. Both the RSEP and MDAI files exclude motorcycles as primary case vehicles. Although they do list them as a type of vehicle struck, motorcycles account for only a very small percentage of struck vehicles. The April 1977 MDAI Codebook listed 8,795 objects under "first object contacted in collision accidents [8]. Of these, *motorcycles accounted for only 0.65 percent*. Also, the RSEP file does not give make, model, or model year of the struck vehicle. These problems effectively eliminate these data files in any analysis of rear end collisions involving cars striking motorcycles.

In motorcycle accident data that do exist, it is difficult to identify the role of brakes in causing or avoiding an accident. There are several other more significant causal factors involved in motorcycle accidents. A major cause of motorcycle accidents appears to be the failure of car drivers to perceive and react appropriately to motorcycles on the road. In a Highway Safety Research Center study of 935 reported motorcycles accidents in 1968, automobile drivers were at fault 62 percent of the time in car/motorcycle accidents [9].

Another major cause of motorcycle accidents is improper operation of the motorcycle by the rider. In regard to braking performance, inexperience and/or the fear of locking the front wheel may result in the improper application of the brakes (front and rear brakes are separately applied on most motorcycles). However, when operated by an experienced motorcycle rider, these brakes are probably the most effective of any vehicle on our roads. A skilled operator, independently controlling brakes on each wheel, can stop in a remarkably short time. Braking reaction time for a motorcycle rider is less than the average 0.75 seconds for car drivers because the motorcyclist's foot does not have to be removed from the gas pedal to apply the brake; the rider's foot peg is in a convenient position to apply the brake by merely rocking the left foot forward. Also, the front wheel hand brake may be applied without removing the right hand from the handgrip and throttle control.

However, because it <u>does</u> take a high level of skill to properly operate the two sets of brakes on a motorcycle, improper operation of motorcycles is common. A high degree of coordination between the front and rear brake is required to attain levels of deceleration necessary to avoid collisions. Typically, the front brake accounts for approximately two-thirds of the total retarding force during maximum braking on a motorcycle [10]. If the rider applies too much front brake torque, the front wheel will lock-up and skid. Since the side force capability of the tire vanishes as the wheel lock-up occurs, the skidding front wheel will quickly slide out to one side or the other, and a fall will occur. Therefore, there is a reluctance to use any great amount of front brake. Even though modern motorcycle disc brakes have stable force feedback which allows accurate modulation of the front brake, there is a general lack of use of the front brake [10]. The Highway Safety Research

Institute of the University of Michigan utilized riders with different degrees of experience in their development of a new method for motorcycle brake testing [11,12]. They found that the professional rider made greatest use of the front brake, while the skilled and novice riders, apparently for lack of confidence in controlling front wheel braking, made greater use of the rear brake.

Road and weather conditions are also factors involved in motorcycle accidents. However, these factors may be as insignificant and as difficult to measure as is the role of defective brakes in causing motorcycle accidents.

It is difficult to find any significant causal link between motorcycle accidents and defective brakes in studies that have been conducted on motorcycle accidents. Several studies of motorcycle accidents have been conducted by the University of North Carolina's Highway Safety Research Center (HSRC). In the HSRC study mentioned earlier [9], only five accidents (0.5 percent) were attributed to mechanical failures, none of which may have involved brake failure (no further breakdown was given). In HSRC's 1974 analysis of 2,410 motorcycles involved in reported accidents, only one percent of all single motorcycle accidents and 0.6 percent of all car/motorcycle accidents occurred because of defective brakes [13].

The California Highway Patrol made a special survey of motorcycle accidents between October 16 and November 30, 1967, and compared results to 1966 data. During 1966, motorcycles accounted for approximately 5 percent of all fatal accidents and 5 percent of all injury accidents[14]. Of the 970 motorcycle accidents investigated, 413 were found to be in some type of violation: licenses, rules of the road, vehicle equipment, etc. Brake failure violations accounted for 0.2 percent of the equipment violations; equipment violations were 4.1 percent of total violations.

It is evident that the role of brakes in causing or avoiding motorcycle accidents is small. This will make evaluating the effectiveness of FMVSS 122 difficult.

3.1.5 Analysis

The analysis of the mass and detailed accident data will aim at answering the following questions:

- Has the Standard allowed more motorcycles to avoid accidents?
- Is the degree of injury severity in accidents reduced?

To determine any increase in accident avoidance, the ratio technique discussed in relation to FMVSS 105 (Hydraulic Brake Systems in Passenger Cars)* accident avoidance is recommended. To apply the technique, two kinds of accidents need to be considered: one that is affected by the ability to brake and a second that is free of braking ability and also free of other Standards or changes coming into effect during the time period in question.

For the first kind of accident, any accident that involved (or should have involved) the motorcycle trying to brake should be considered. The second type of accident which is to be free of braking ability (to be used as an exposure measure) could be an automobile striking a motorcycle while the cycle is making a left turn. FMVSS 123 (Motorcycle Controls and Displays, effective September 1974) will clearly affect the ability to brake, as this Standard required braking controls to be standardized on all vehicles, so motorcycles with strange brake control arrangements should be removed, if possible. FMVSS 119 (New Pneumatic Tires for Vehicles Other than Passenger Cars, effective September 1974) is also a confounding effect, but one that probably cannot be removed. If this is the case, this Standard will confound the results.

A very speculative approach to determine if the Standard decreased the expected number of accidents is by regression. One could try to regress the number of accidents on factors such as the number of motorcycles on the road, miles driven, use of helmets, speed limit, etc., and finally on the percentage of motorcycles with brakes meeting the Standard. If the coefficient of this latter variable is significant in a negative direction, effectiveness would be indicated. However, the variability of the data is expected to be so great that not much hope is expected for this method. Regression requires the assumption that any decrease is due to the Standard.

In attempting to determine any injury reduction due to the Standard, one must realize that the data can only give the distribution of injury severity

*CEM Report 4228-588: *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 105: Hydraulic Brake Systems in Passenger Cars* [23].

conditional on an accident having occurred and been reported. More specifically, let I_i be the event "an injury of class i" where i might represent the AIS level of injury severity. Let A be the event "an accident occurred and was reported." Then, on the basis of accident data, one can only estimate the conditional probability $P(I_i|A)$ of an injury of level i, given a reported accident. If it is assumed that all accidents resulting in injuries of level i are reported (that is, $I_i = I_i \cap A$), then the unconditional probability $P(I_i)$ of an injury of level i is given by:

$$P(I_i) = P(I_i \cap A) = P(I_i|A) \cdot P(A).$$

So if one is interested only in the ratios of the probabilities of injuries, the conditional probabilities are enough. If the specific values of the probabilities are needed, then some estimate of the probability of an accident occurring and being reported must be obtained.

In this analysis, the dependent measure from an accident that involved braking is,e.g., the AIS value, while the important independent variable is whether or not the motorcycle had brakes meeting the Standard. Important concomitant variables include many of those listed earlier plus size and momentum of the object struck.

The possible modes of analysis are the analysis of covariance and the log-linear model; the latter, as usual, requires making discrete several continuous variables. Because of the large number of concomitant variables, some simplifying data reduction techniques would be in order.

The analysis of the mass accident and detailed accident data would follow these steps:

1. Obtain mass accident data and detailed accident data (if available) bases for the years 1969 and later.
2. Obtain exposure data on motorcycles which will probably have Pre-Standard braking systems (1969-1971) and on those which will probably have Post-Standard systems (1972 and later).
3. Process data to obtain overall tabulations on front-rear and left-turning collisions of car-motorcycle and motorcycle-car sets.
4. Analyze driver and environment characteristics (i.e., light and weather conditions) in relation to Pre- and Post-Standard braking systems.

Figure 3-1 outlines how the proposed evaluation study would be carried out.

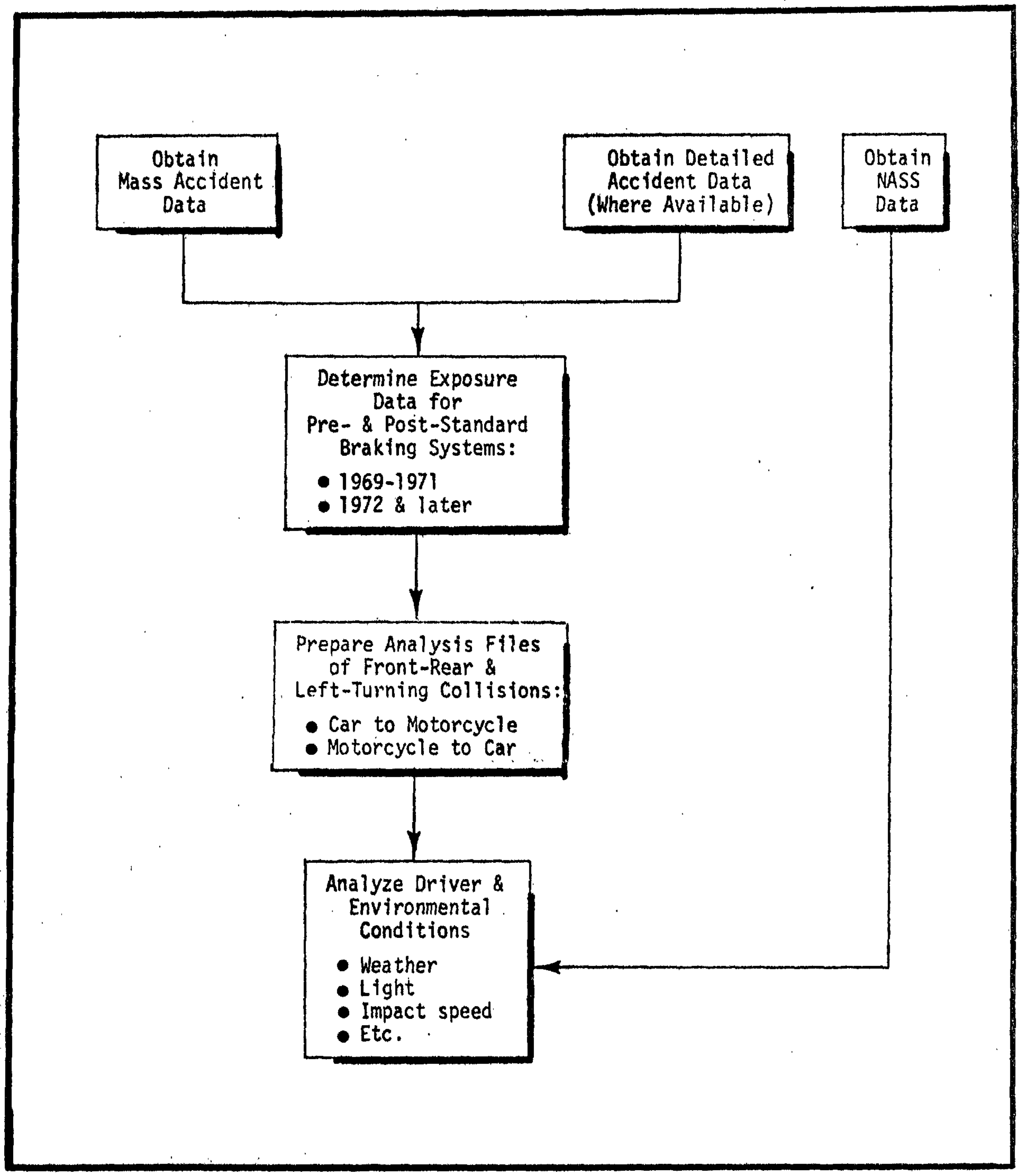

Figure 3-1. Front-rear and left-turning collisions approach.

3.2 Brake Failure Analysis

3.2.1 Introduction

The purpose of this analysis is to use existing data to determine the extent and effects of motorcycle brake failure on the number and severity of motorcycle accidents.

Accident investigations indicate that vehicle mechanical problems have far more serious consequences for motorcycles than for passenger cars and other motor vehicles. Paucity of data, however, is a major problem; there is very little information available on mechanical defects as a cause of motorcycle accidents. In addition, for any analysis, the type of mechanical failure must be carefully defined; was it a defect, a deterioration, a malfunction, or a complete breakdown? Such detail does not appear in the available accident data.

Braking errors by the motorcycle rider are a more common causal factor in car/motorcycle accidents than are motorcycle mechanical defects (especially brake failures). The most common braking error is the overreaction at the rear brake, causing a rear wheel skid; and underreaction at the front brake with little, if any, utilization of that brake. Motorcycle brakes are, therefore, difficult to use with maximum skill and accident avoidance effectiveness. They become even more of a hazard if they are defective in any way.

3.2.2 Data Requirements

For the brake failure analysis,the following variables are required:

- Brake Failure Types
  - Cable Failure
  - Hose Failure
  - Wet Brakes, etc.
- Motorcycle Make, Model, Model Year
- Weather Conditions
- Road Conditions (wet vs. dry)
- Vehicle Miles Traveled (VMT)
- Number of Registrations
  - Pre-Standard
  - Post-Standard

With brake failure, there are not many concomitant variables. The most important is the age of the motorcycle. Since the Standard addresses wet brakes and one might expect better results for the Post-Standard brakes in such a situation, whether or not it was raining or snowing is another important variable. Initial speed should also be considered, but surrogates will be necessary, since initial speed is not readily available. In order to see if this Standard reduced deaths due to brake failure, an exposure measure is needed. The number of motorcycles struck making left turns (a non-braking accident for the cycle) is such a measure. The number of Pre- and Post-Standard motorcycles is another measure. The most important concomitant variable to be considered, however, is the age of the motorcycle.

3.2.3 Data Acquisition

A detailed accident file, such as NASS or some other special study, might be able to provide the multiple variables desired. However, because of the increasingly small number of motorcycles on the road in the years desired (1969, 1970 and 1971 motorcycle model years), NASS (or other) sampling will have to include every one of the accidents involving motorcycles for these years.

Special research is being conducted at the University of Southern California under DOT/NHTSA sponsorship. This research consists of on-the-scene, in-depth multidisciplinary investigation in the Los Angeles area of at least 900 motorcycle accidents and the acquisition of at least 3600 police traffic reports for comparison [10]. It is expected that this data will become part of the NASS system. Initial data collected indicates that vehicle mechanical problems have far more serious consequences for the motorcycle than for the contemporary passenger automobile. The study is, however, focusing on "certain critical human elements... identified as common to a great part of the accidents investigated" [10]. These include motorcycle conspicuity, rider skill, training and licensing, and protective clothing and equipment.

There is a small but detailed accident data base which could provide limited data on accidents caused by motorcycle brake failures. The California Highway Patrol (CHP) has one of the largest motorcycle patrol fleets in the country, and has conducted various in-house studies of motorcycle accidents *involving CHP vehicles only* (which does, of course, limit the size of the data base).* CEM's contact with R. A. Little [15] a member of the CHP and chairman of the SAE Motorcycle Brake Subcommittee, indicated his organization's willingness to contribute to a brake system failure analysis but he suggested that very little, if any, data on motorcycle accidents related to mechanical defects is available. For this reason, a controlled laboratory or a test track experiment may be more appropriate to attempt to see if the Standard has indeed improved braking performance in everyday situations.

*Also, such a data base would be highly biased because only large motorcycles and skilled riders are involved; the motorcycle operators have frequent legally-acceptable reason to engage in high speed riding; and the great majority of the riding is on major highways with relatively little exposure in residential and commercial areas.

3.2.4 Preliminary Results

As discussed in Section 3.1.4, finding adequate existing data to analyze the effects of brake failure will be difficult. CEM's contact with motorcycle-related groups (NHTSA; Motorcycle Safety Foundation; Motorcycle Industry Council; American Motorcycle Association; SAE Motorcycle Brake Subcommittee) has led to the conclusion that accident data on brake defects are either not available, not usable, not useful, or not detailed.

The problems associated with the analysis of front-rear and left-turning collisions, discussed in Section 3.1.4, also apply to this approach.

3.2.5 Analysis

The analysis of the mass and detailed accident data will aim at answering the following question:

- Has the probability of brake failure been reduced?

The discussion in Section 3.1.3 concerning the effects of various Federal Standards relating to motorcycle regulation also applies to the analysis discussed in this section. For the analysis of brake failure, accidents in which brake failure occurred need to be compared with some exposure measure. These results will confound the various types of brake failure, e.g., hose failure, wet brakes, etc., since they are not separated in the data bases. This is not the usual success/failure situation, since most of the "successes" are not recorded. Frequently, no accident would have occurred had the brakes not failed, but the information is collected only for accidents. However, if the rates are on a per vehicle basis, they can be found directly, once the number of motorcycles in each class (Pre-Standard and Post-Standard)* is known. If the rates are based on some other measure of exposure, such as vehicle miles of travel, then under assumptions of proportional exposure, certain other accidents can be used to find the rates for Pre- and Post-Standard motorcycles to within a constant of proportionality. Such accidents could be, for example, motorcycles turning left and being hit by oncoming passenger cars. This type of accident is affected mainly by the conspicuity of the rider/motorcycle combination, which is likely to change only gradually from year to year. If the ratio of the rates is of interest, no more than this is necessary.

*Since many motorcycles had brakes that already met the Standard before its January 1, 1974, effective date, they would have to be included with Post-Standard motorcycles.

Using "control" accidents, the initial analysis proceeds as follows. The accident counts are defined in Table 3-5. The model is that these counts are Poisson, with means as defined in Table 3-6.

TABLE 3-5

DATA AND MODEL FOR BRAKE MALFUNCTION ANALYSIS

	Actually Observed Counts		Expected Counts* Under Model	
	Pre	Post	Pre	Post
Brake Malfunctions	n_{11}	n_{12}	$\lambda_1 e_1$	$\lambda_2 e_2$
Control Accidents	n_{12}	n_{22}	ηe_1	ηe_2

*Accidents involving brake malfunctions occur at rate λ_1 for Pre-, λ_2 for Post-Standard brakes. The control accidents occur at rate η. The exposure measures are e_1 for Pre, e_2 for Post-Standard brakes.

The null hypothesis is that $\lambda_1 = \lambda_2$, and assuming the Standard is beneficial, the alternative is that the rate of occurrence of accidents involving brake malfunctions has decreased; that is, λ_2 λ_1. It is possible to argue that the alternative is any change in the rate, i.e., $\lambda_2 \neq \lambda_1$, since the Standard might cause brake malfunctions to increase.* Conditioning on the number of accidents involving Pre-Standard brakes and the number of accidents involving Post-Standard brakes, one is led to a test for equality of two proportions P_1 *vs.* P_2, where

$$P_i = \lambda_i / (\lambda_i + \eta), \quad i = 1, 2.$$

Since for automobile/motorcycle accidents, about 0.6 percent involve motorcycle brake malfunction and 4.4 percent have the motorcycle turning left and the automobile going straight (the control accident), P_i is about 0.12, or λ_i is approximately $\eta/7$.

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*This might happen if the Standard led to an improvement in component reliability just enough for riders to get out of the habit of performing routine maintenance that was vital previously, but not enough for maintenance to be unnecessary.

Let ratio λ_2/λ_1 be r, where r is expected to be less than 1. Under the assumptions of the model, 1/r is the odds ratio of the table of expected counts in Table 3-5, and is estimated by the odds ratio of the corresponding table of actual counts.

Let
$$\hat{r} = \frac{n_{11}\ n_{22}}{n_{12}\ n_{21}}$$

and
$$s = \frac{1}{n_{11}} + \frac{1}{n_{12}} + \frac{1}{n_{21}} + \frac{1}{n_{22}} .$$

Then the expected value of ln $(\hat{r})$ is
$$E\ \{\ln \hat{r}\} = \ln r + \text{terms of order } (e_1\lambda_1)^{-1},\ (e_2\lambda_2)^{-1},\ (e_1\eta)^{-1},\ (e_2\eta)^{-1}$$

and further
$$E\ \{s\} = \text{var}\ (\ln \hat{r}) + \text{terms of order } (e_1\lambda_1)^{-2},\ (e_2\lambda_2)^{-2},\ (e_1\eta)^{-2},\ (e_2\eta)^{-2}$$

To a good approximation, ln $\hat{r}$ is normally distributed with mean ln r and variance s (the approximation is much improved if ½ is added to the observed counts $n_{11}, \ldots n_{22}$ and $\hat{r}$, s are calculated using these modified counts).Hence, confidence intervals can be constructed for r using the standard normal theory--the null hypothesis is that ln r is zero, the alternative is that ln r is less than zero. Thus the null hypothesis is rejected at level α if

$$\frac{\ln \hat{r}}{s} < Z_\alpha$$

and a $(1-\alpha)$ confidence level for r is:

$$0 \leq r \leq \hat{r}\ \exp\ (sZ_{1-\alpha})$$

where Z_α is the 100α'th percentile of the standard normal distribution. Sample sizes needed to achieve a level α test with power β lead to r, s combinations satisfying

$$\left|\ln(r)\right| \geq \left|Z_{1-\alpha} + Z_\beta\right|\ s.$$

Assuming that the two smallest counts (corresponding to $e_1\lambda_1$, $e_2\lambda_2$) are equal and that there are seven times more control accidents, Table 3-6 is produced. It shows the number of accidents related to brake malfunctions required (for each of Pre- and Post-Standard brakes) for a one-sided test with level 0.05 (five percent) and power at least 0.95 for the values of r smaller than or equal to the value of r shown under the given value of n. This table assumes that there are at least seven times as many control accidents, both Pre- and Post-Standard.

TABLE 3-6

TRUE VALUES OF **r** IN TEST OF LEVEL 0.05*

Smallest Number of Brake Malfunction Accidents**	10	20	40	100	200	400	1000
Underlying True r	0.21	0.33	0.46	0.61	0.70	0.78	0.85

*Needed to have power 0.95 against r=1.

**This count applies separately to Pre-Standard and Post-Standard brakes, and there are at least seven times this many control accidents for each of the Pre- and Post-Standard brakes.

In using mass accident and detailed accident data files to analyze accidents caused by brake defects, the following steps will take place:

1. Obtain mass accident and detailed accident data (where available) bases for the years 1969 and later.
2. Obtain exposure data for Pre-Standard motorcycle braking systems (1969-1971) and Post-Standard systems (1972 and later).
3. Prepare analysis tapes of accidents caused by brake failure.
4. Perform analysis.
5. Evaluate results.

3.3 Motorcycle Dynamometer Brake Test

3.3.1 Introduction

The purpose of the laboratory dynamometer testing of motorcycle brakes is to test compliance with FMVSS 122 performance characteristics independent of the operator skill factor.

At present, the Standard requires extensive testing of motorcycle brake systems involving multiple stops and starts at a wide range of speeds (30 MPH to 80+ MPH). These are field tests involving rider control. This method seems to be fundamentally inadequate for objective evaluation of motorcycle braking performance. Examples of field evaluation of motorcycle brakes--all of which comply with FMVSS 122--are given in Appendix D. These evaluations were performed by *cycle guide* magazine. A brief review of these evaluations reveals that motorcycle brakes may meet FMVSS 122 standards performance and still be considered unsuitable by professional riders for use by inexperienced riders, and/or dangerous when involved in wet weather driving and/or panic stops. A series of selected quotes illustrating these points is given in Table 3-7. It is to be noted that all of these comments apply to 1974 and 1975 production motorcycles which meet FMVSS 122.

TABLE 3-7

SOME COMMENTS ON BRAKE SYSTEMS BY MOTORCYCLE TEST RIDERS

- "Our best panic stops were 140 feet, 3 inches from 60 mph and 39 feet, 10 inches from 30 mph; we could have bettered these figures considerably if the bike hadn't been so squirrely."
- "The stop from 60 mph was worse...because the rear wheel had a tendency to step out to the left and get the bike sideways."
- "...quite a few times, the bike wobbled badly during a quick stop. We kept the machine under control, but it could have easily gotten away from a less experienced rider under similar circumstances."
- "Our best tire-smoking, adrenaline-pumping panic stops brought the Four to a halt in 136 feet 6 inches from an actual 60 mph and in 37 feet 6 inches from 30 mph."
- "In the rain both brakes lost much of their power and predictability. Initial pressure at the lever or pedal had little effect, but additional pressure caused abrupt braking, making it difficult to maintain control."
- "An over-zealous applicant will lock the wheel...the rear brake caused a few problems... All of our testers had difficulty slowing the bike down without locking the rear wheel, due to the on-off 'toggle-switch' behavior of the brake. And when this happened, it usually stalled the engine."
- "We liked it (front disc brakes), but some beginners may find it a little too powerful at first, especially considering the limited adhesion characteristics of the front tire."
- "When wet, the front brake lost a little of its initial power. And on wet pavement the rear brake became particularly touchy..."

Source: *cycle guide* magazines: volume 8 (1974) and volume 9 (1975).

A controlled motorcycle dynamometer brake test is proposed in order to estimate the effects of various factors on braking performance without the involvement of a rider. Tests will be made on three different classes of vehicles: used Post-Standard motorcycles, new Post-Standard motorcycles, and refurbished Pre-Standard motorcycles (these last two groups will have their brakes properly broken in prior to testing). The points of interest include what effect the Standard had, and how brake performance alters with use.

3.3.2 Data Requirements

Factors to consider include:

- Type of brake system
- Motorcycle weight, geometry, structural stiffness
- Road surface conditions
- Weather conditions (wet or dry)
- Weight loading
- Vehicle pitch (roll)
- Weight shifting
- Lever or pedal force of brake application
- Sensitivity of front wheel brake
- Condition of hydraulic brake system
- Deceleration capability, including:
  - Changes resulting from temperature variations
  - Coefficient of friction variations, especially those which result in a self-energizing or "grabbing" effect.
- Fade resistance
- Effects of water or other contamination
- System life, including pad and/or lining durability.

3.3.3 Data Acquisition and Preparation

Three classes of motorcycles will be tested (Section 3.3.1,above). Since the effect of brake use on brake performance is of interest, the used Post-Standard motorcycles will be divided into two groups, using mileage as a use indicator: between five and ten thousand miles for the first group, and between 15 and 20 thousand miles for the second. With the new Post-Standard motorcycles and the refurbished Pre-Standard motorcycles there are a total of four groups of vehicles to be tested.

Motorcycles are made by a variety of manufacturers and come in a variety of sizes. These factors will influence brake performance, so models to be tested will be classified by:

- Manufacturer
  - Honda
  - Yamaha
  - Kawasaki
  - Suzuki
  - Harley Davidson
  - Other
- Engine Displacement
  - 125-349 cc
  - 350-449 cc
  - 450-749 cc
  - 750 cc and over.

This cross classification gives at most 24 cells. Within each of these cells, there are four groups of motorcycles. The reliability of the results will be assessed by using three different motorcycles for each of the four groups in each of the cells of the cross classification, so that at most 288 vehicles will be tested.

Tire characteristics play a significant role in the accident avoidance capabilities of motorcycles [17]. Because the braking capability of a motorcycle is influenced by tire age, type, purpose, and whether it is used or new, etc., it is necessary that all motorcycles used in the dynamometer test have similar tires--that is, new, standard type tires appropriate for the size of the motorcycle to be tested.

The motorcycles to be tested will be mounted on a dynamometer test setup. No rider will be involved. Instrumentation will be used on the motorcycle brake system to measure line pressures, lining temperatures, brake pedal force, etc. The dynamometer will be capable of measuring rotational speed, energy expended in braking, simulated vehicle velocity, and other parameters associated with the vehicle output. Brake line pressure or force recorders may be used to establish the relative work done by front and rear brakes during the testing. Tests to be performed could include measuring and recording:

- Brake fade at various speeds and stopping distances, during fixed numbers of successive stops.
- Sensitivity (force vs. grab) under various speeds and stopping distances.
- Lining temperatures.

- Brake line pressures, forces, torques, or tensions to all wheels during testing.
- Variation in all wheels.
- Any failures or malfunctions of the system.

3.3.4 Preliminary Results

In the Department of Transportation's 1976 annual report [16], NHTSA suggested that its review of FMVSS 122 had led to the conclusion that its effectiveness is limited because it depends on riding skills to properly proportion front/rear braking. In a NHTSA-sponsored study, the University of Michigan's Highway Safety Research Institute (HSRI) developed a method of measuring brake performance independent of rider influence on front/rear proportioning [11,12]. This method may be used to formulate an amendment to the present Standard. In its study, HSRI outlined what it considered the shortcomings of FMVSS 122's present testing requirements, and then developed their tow-test method. The shortcomings addressed were:

- Hazards of high speed stops. During its initial work, HSRI used professional, skilled, and novice riders to go through the full complement of effectiveness, burnish, fade, and water recovery procedures as specified in FMVSS 122. In testing one vehicle, the professional rider, starting from an initial speed of 105 MPH, caused a front wheel lock-up with his first brake application. His skill enabled him to recover control; riders with less skill probably would have fallen.
- General insensitivity of brake torque effectiveness to the work history provided by the burnish procedure and to the thermal loading incurred during the fade and recovery tests.
- Reduced torque effectiveness of drum-type brakes during immersion type wetting procedures.
- Margin of superiority of skilled over unskilled riders.

HSRI's test methodology for motorcycle brake testing had two basic features:

1. The test motorcycle is towed by a support vehicle at constant velocity for all of its dynamic performance measurements.
2. All tests are conducted with braking control effort being applied to only one actuator at a time. That is, the rider is instructed to apply the front <u>or</u> the rear brake input actuator up to the braking limit.

Another NHTSA-sponsored study relates to the development of motorcycle accident avoidance test procedures to quantify the handling characteristics of motorcycles. This work was performed by Calspan Corporation [17]. Although motorcycle braking performance was not addressed in this effort (it focused on steady-state cornering, lane changing and tire performance), the method developed is applicable to evaluate other performance characteristics.* The Calspan study involves applying a computer simulation program of motorcycle dynamics to determine performance characteristics. Calspan's vehicle-rider model is a system of three rigid masses with eight degrees of freedom of motion: six rigid-body degrees of freedom of the rear frame, a steer degree of freedom of the front wheel, and a rider lean degree of freedom. Although the Calspan team feels that certain improvements in the model are "essential" for broad application to studies of motorcycle accident avoidance capability, "the simulation has been shown to yield reasonable representations of motorcycle-rider behavior in selected applications" [17].

3.3.5 Analysis

In conducting a laboratory dynamometer test of motorcycle braking systems, the following steps would take place:

1. Review results of previous braking system tests which have used testing methods other than those specified in the Standard (i.e., HSRI, Calspan).
2. Prepare test facility and obtain selected number of motorcycles in various size and weight ranges.
3. Establish test procedures.
4. Instrument test motorcycles and mount of dynamometer.
5. Conduct braking performance tests for front and rear brakes separately, under various simulated conditions (weather, road surface, force of application, etc.)
6. Analyze and evaluate results of tests.

These steps are outlined in Figure 3-2.

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*The Calspan report indicated that the simulation studies could have been extended to include braking characteristics, but this was deliberately not done because "detailed investigation of this aspect of performance would have compromised the degree to which the directional control characteristics could be studied" [17].

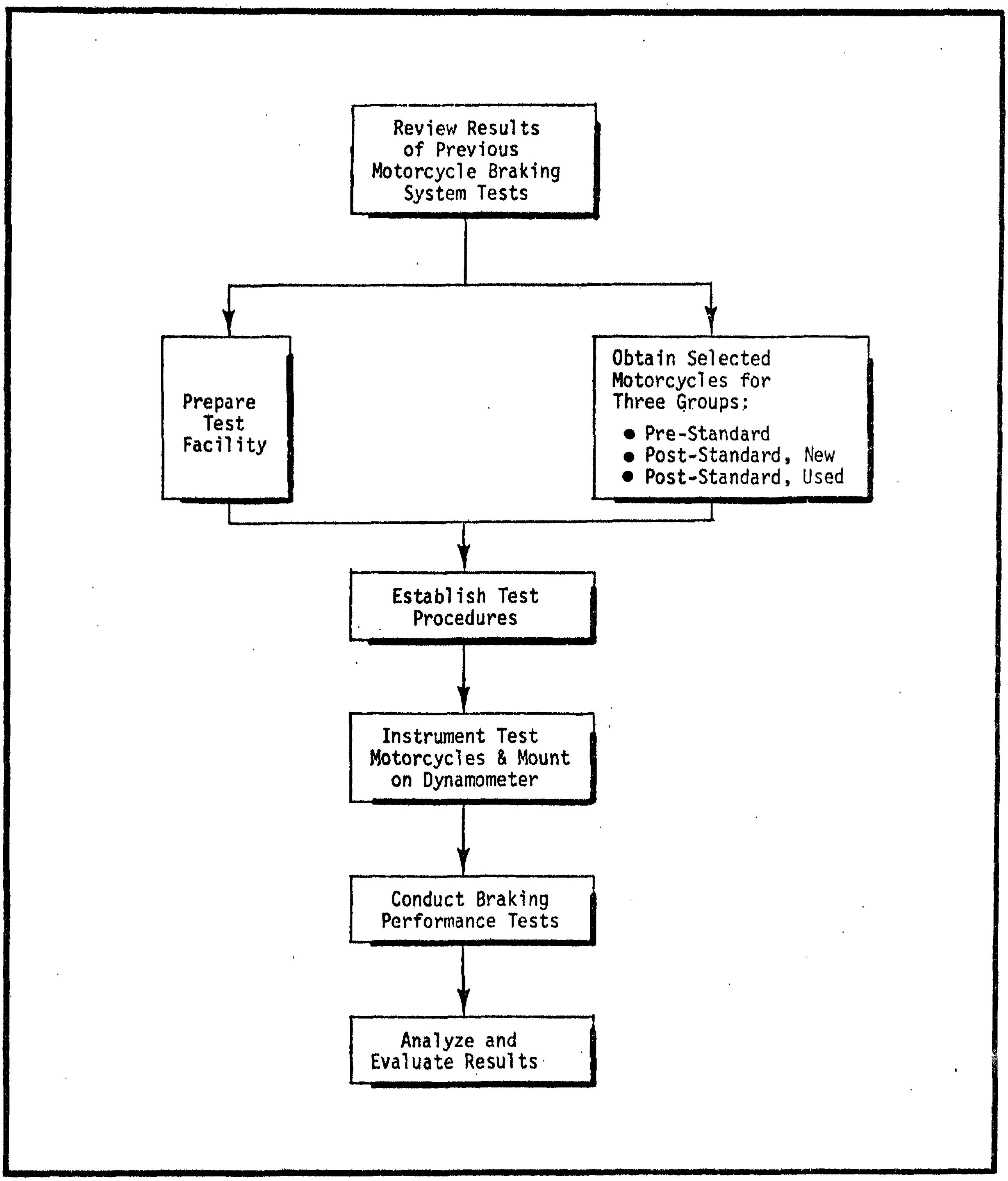

Figure 3-2. Motorcycle dynamometer brake tests.

3.4 Analysis of Braking Performance

3.4.1 Introduction

The purpose of this task is to design an experiment to test the performance capabilities of Pre- and Post-Standard motorcycle braking systems. A "laboratory" type test is being suggested in which professional and volunteer non-professional riders test-ride motorcycles equipped with Pre-Standard brakes (also referred to as "old brakes" in this discussion) and Post-Standard brakes ("new brakes") so that differences in braking performance can be measured. The non-professional riders have been suggested so that the differences determined are those which occur among the typical riders in reacting to everyday motorcycle riding experiences. The professional riders will provide control group data.*

This experiment has been suggested because the available data indicates a decreasing population of Pre-Standard motorcycle brakes. Few motorcycles required any change in brake systems when the Standard became effective in January of 1974; they already complied with the 1971 SAE recommendations upon which the Standard is based [18]. Therefore, in order to use real world accident data, it would be necessary, in general, to look for pre-1972 models to find Pre-Standard braking systems.

Evaluating the performance of the Pre-Standard brakes and comparing them to the Post-Standard systems would only be possible if enough of each type had been involved in accidents and there were data available. Unfortunately, police-level accident investigation reports generally lack the level of detail required for Standard evaluation. In addition, what data are available indicate a very low percentage of accidents caused by brake defects (around 0.6 percent). Therefore, we are suggesting a "laboratory" type test.

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*CEM believes that motorcycle policemen with at least 10 years of experience may provide a pool from which "professional" riders can be obtained. Some areas of the country (such as Southern California) have skilled precision-riding organizations, composed largely of law officers, who may be quite willing to participate.

3.4.2 Data Requirements

The following variables are of interest for this experiment:

- Type of Brakes
  - Disc
  - Drum
- Motorcycle Make, Model, Model Year
- Motorcycle Size, Weight
- Rider Characteristics
  - Age
  - Sex
  - Experience (ability of rider)
- Age of Brakes
  - Pre-Standard
  - Post-Standard.

In conducting this experiment, the major treatment difference in which we are interested is the new and old brakes. However, such variables as the size of the motorcycle, the type of brakes (disc, drum), and the ability of the rider should also be considered. Further, the learning experience of the riders as they pass through the experiment also merits consideration.

3.4.3 Data Acquisition

To obtain the desired information required for the analysis of braking performance, an experiment utilizing "typical" (i.e., non-professional) motorcycle riders and professional riders will be conducted for both Pre- and Post-Standard braking systems.

Measurements will be taken on the length of time it takes to stop on receiving a signal after having passed through a water puddle. Other such measurements will also be taken. Some of these will include:

a) Minimum straight line stopping distances in narrow lanes defined by pavement markings or rubber cones.

b) Minimum stopping distances in curves of decreasing ratio, defined as above.*

c) Same as b) with reverse camber road surfaces.

d) a) through c) with different and intermittently uneven coefficients of friction road surfaces, and rough road surfaces (vertical curves).

Brake line pressure recorders are suggested to establish the relative work done by the front and rear brakes during the events outlined above.

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*The stopping distances are useful since they indicate how controllable the motorcycle is when performing a typical avoidance manuever.

3.4.4 Preliminary Results

Data from the State of Connecticut Motor Vehicle Department for 1974 through 1976 indicate that 95 percent of all motorcycle registrations during those years were model year 1964 or 1965 or later, as shown in the graphs in Figure 3-3. Of this 95 percent:

- In 1974: 48% were pre-1972; 52% were post-1972; total = 58,662.
- In 1975: 41% were pre-1972; 59% were post-1972; total = 60,645.
- In 1976: 34% were pre-1972; 66% were post-1972; total = 60,395.

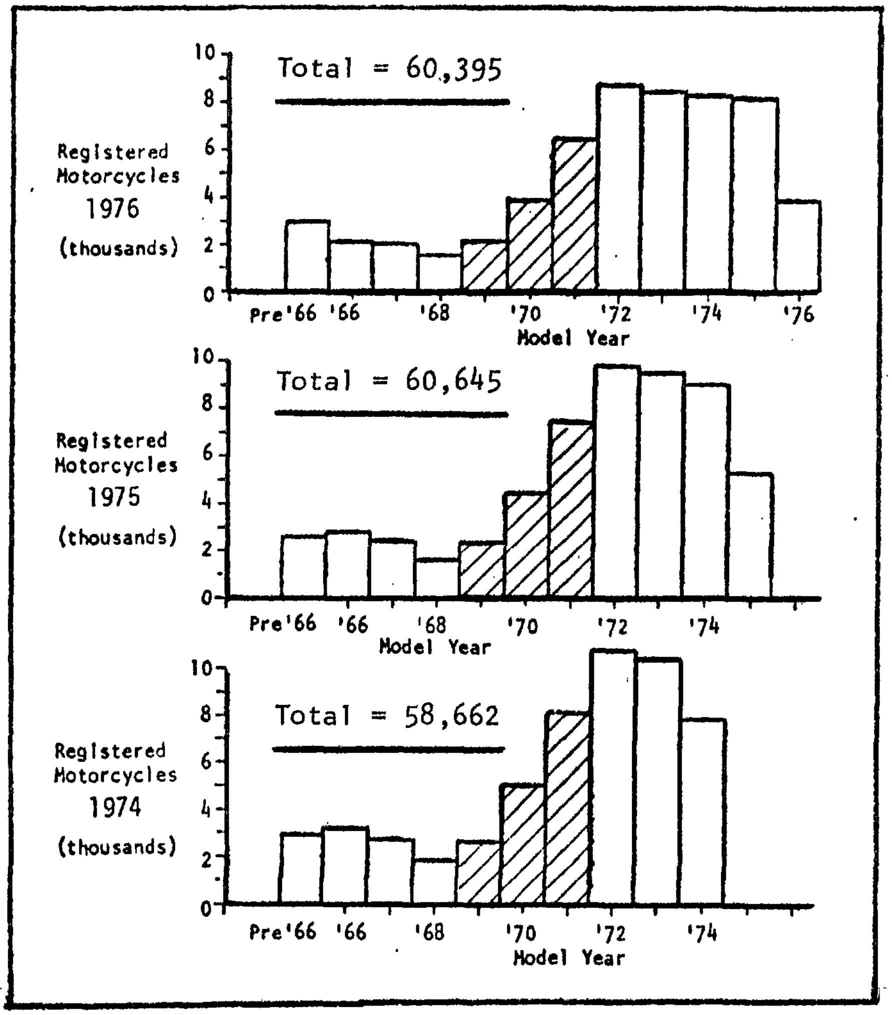
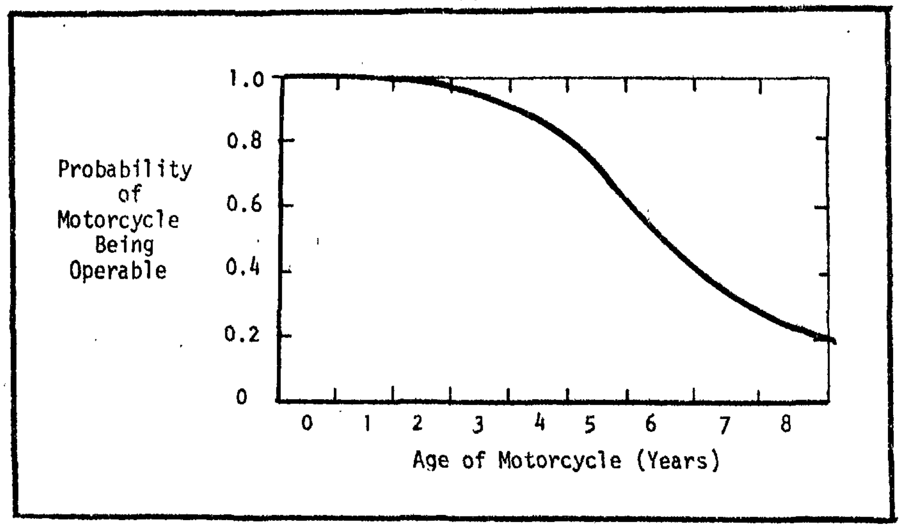


Figure 3-3. Age distribution of motorcycles registered in Connecticut, 1974-1976.

The shaded areas in Figure 3-3 indicate the number of registered Pre-Standard motorcycles in the three years of interest for analysis purposes: 1969, 1970, and 1971*. It is possible to derive the age mix of a motorcycle population for a given model year if the probability that a cycle of a given age will still be operable is known. This probability has been developed by the Yamaha Motor

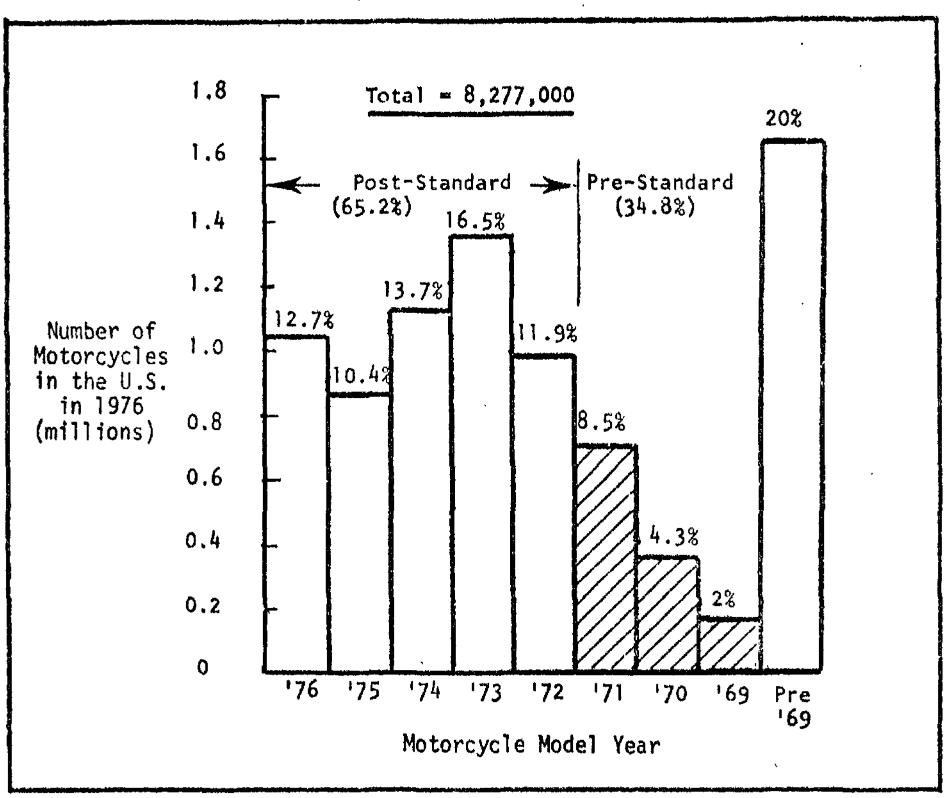
*Pre-1968 cycles have been excluded to try to eliminate the confounding effects of other Standards introduced in 1968 which affect motorcycles.

Co., Ltd., and is pictured in Figure 3-4 [3]. Note that the operability rate of a motorcycle drops sharply when the vehicle age exceeds 3.5 years. It is estimated that three out of every four motorcycles are operable after 4.5 years and that the average (and median) operable life is about six years. An estimate of the age mix of the 1976 motorcycle population is shown in Figure 3-5. Again, shaded areas indicate the Pre-Standard years selected for analysis.



Source: *1977 Motorcycle Statistical Annual* [3].

Figure 3-4. Probability of motorcycle being operable.



Source: Derived from figures in [3].

Figure 3-5. Estimated 1976 U.S. motorcycle population.

3.4.5 Analysis

Suppose there are I different sizes of cycles; then the number of different cycles is 2I, one of each size with new brakes, one with old. It would seem to be most efficient to run a 2 x I factorial experiment with a 2I x 2I Latin square. In the Latin square, the 2I treatments are the 2I different cycles; the rows are 2I different drivers, while the columns are the 2I different time periods. Latin squares and factorial designs are discussed in various design of experiment books, such as Cochran and Cox's *Experimental Designs* [19].

The number of riders and motorcycles one can handle at about the same time would limit the size of the Latin square, but a number of such subexperiments could be run. Let us assume, again for preciseness, that three sizes of motorcycles are to be tested, giving us six cycles and six riders with each rider making six rides. Suppose the particular 6 x 6 Latin square chosen at random is the square pictured below [19, p.145]. If I, II and III denote the three sizes of motorcycles; O and N old and new brakes, then using Cochran and Cox's notation, let A=I O; B=I N; C=II O; D=II N; E-III O; and F=III N. The square is:

Driver Time Periods	Driver Number					
	1	2	3	4	5	6
1	I O	I N	II O	II N	III O	III N
2	I N	III N	II N	II O	I O	III O
3	II O	II N	III O	III N	I N	I O
4	II N	I O	III N	III O	II O	I N
5	III O	II O	I O	I N	III N	II N
6	III N	III O	I N	I O	II N	II O

The first time Driver #1 rides a motorcycle in the experiment, he will ride a Size I cycle with old brakes, the second time Driver #1 rides, he has a Size I motorcycle with new brakes,...the fourth time Driver #5 rides, he has a Size II motorcycle with old brakes.

The advantages of this design are that (1) each driver rides each motorcycle and (2) each motorcycle is ridden in each time period, i.e., each experience period. Therefore, the fact that a rider is more experienced on his sixth ride than on his first is taken into account. There is flexibility in how the experiment is run, because it is not required that, for example Driver #1 takes his third ride before Driver #5 takes his fourth, although that is possible. The experiment only requires that Driver #1 take his third ride before his fourth. However, in the interest of avoiding confusion, it may be advantageous to insist that all riders' first ride be completed before any rider may start his second ride.

One would expect that a number of such Latin squares would be run and then combined in the analysis. If K such squares are run, one would have the following partial analysis of variance (ANOVA) table.

Source	df
Brakes	1
Size	I-1
Size x Brakes	I-1
[Cycles]	[2I-1]
Time Periods	2I-1
Drivers	K(2I-1)
Squares	K-1
Remainder	2(KI-1) (2I-1)
Total	$K \times 4I^2-1$

As in all experimental designs, if data are incomplete and balance is lost, the analysis becomes more complicated. This should be avoided to the extent possible, by making sure riders complete the test, which should be possible if the experiment is kept reasonably small.

The question of the physical safety of the motorcycle riders must, of course, be considered. In fact, a major criticism of the present Standard centers around the hazards of the high speed stops (up to and over 100 mph) required to test the brakes. Although the safety aspect must be taken into consideration here, the number and type of tests required will hopefully be at a low level of danger.

It has been suggested that a similar "laboratory" type test might be performed by having the professional and volunteer riders use their own motorcycles, which would be instrumented and which would then be measured for the deceleration levels the riders achieve in everyday riding. Since the design of this test is different from the design proposed above, the analysis will need to be modified. It will, however, remain straightforward. Since each rider only uses one motorcycle, larger numbers of riders will be needed to determine the effect of the brakes than in the more efficient Latin Square experiment.

To conduct the proposed analysis of braking performance, the following steps will be necessary:

1. Obtain motorcycles with Pre- and Post-Standard braking systems. It may be necessary to modify current motorcycles in order to have brakes similar to those considered Pre-Standard.
2. Obtain enough professional and "typical" (non-professional) motorcycle riders to perform the tests (volunteer, or perhaps there will be a small reward, in addition to the opportunity to ride motorcycles under test conditions).
3. Prepare test facility for various measures being tested (wet surface, curves, etc.).
4. Have a sufficient number of riders complete prescribed braking tests.
5. Compare performance of Pre- and Post-Standard braking systems.

Figure 3-6 shows the suggested analysis approach.

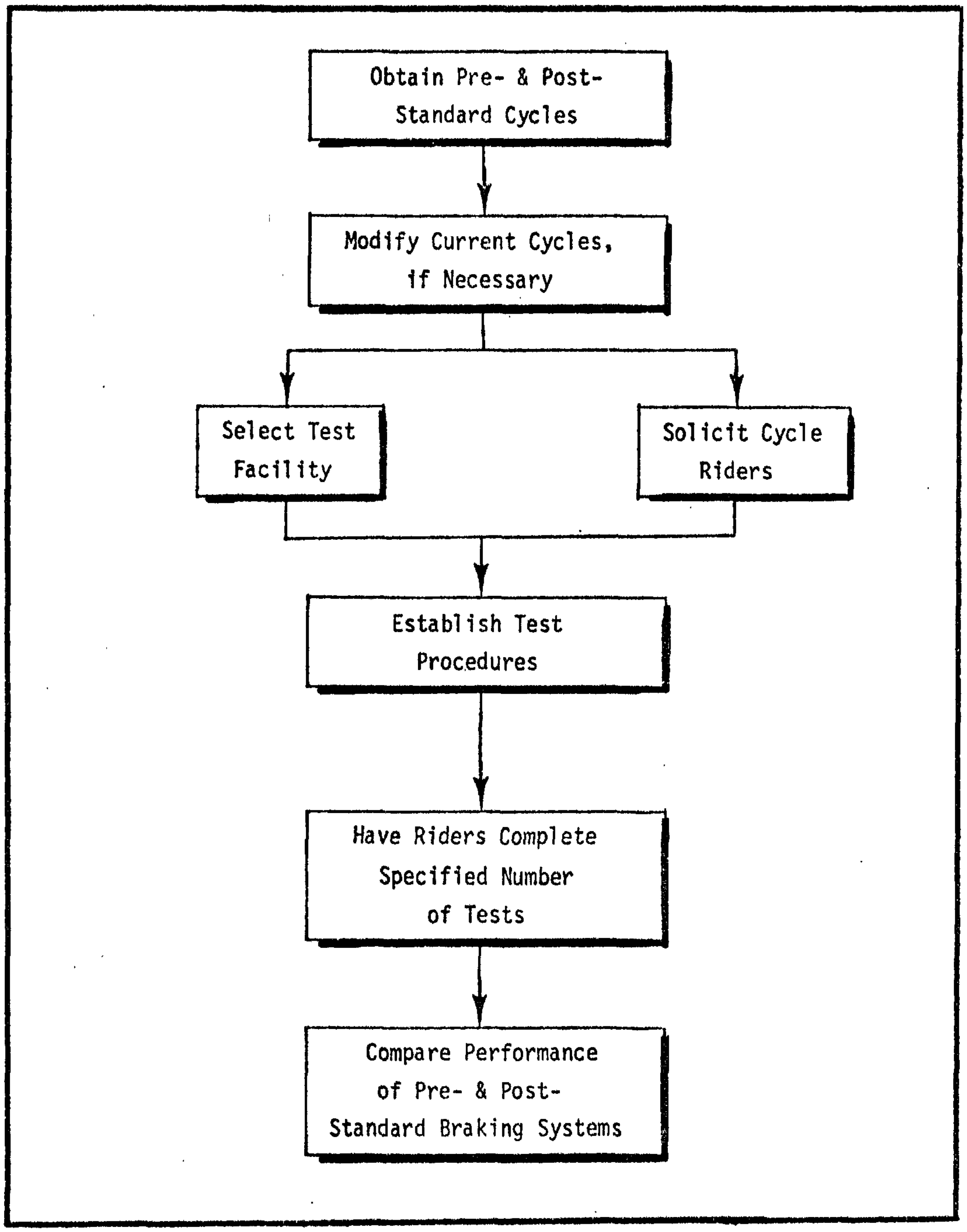


Figure 3-6. Analysis of braking performance.

3.5 Analysis of Rider Behavior

3.5.1 Introduction

The purpose of this laboratory-type experiment is to obtain data on the riding behavior of motorcycle riders. This would include, but would not be limited to the rider's braking performance.

The inherent instability of motorcycles is closely linked to braking performance. Stressing motorcycle brakes without inducing wheel lock-up requires a high level of skill. Antilock braking devices are now being developed which will allow the motorcycle operator to apply both front and rear brakes fully in emergency situations without skid-controlling modulation, resulting in maximum stress on the braking system. Until these antilock braking devices are fully developed, motorcycle braking systems are likely to be under-utilized except by operators of professional levels of proficiency.

The rider behavior experiment is proposed to determine the ability of typical motorcycle operators to exploit the capabilities of the machine (and, specifically, the braking system). The experiment would use a test track, instrumentation of motorcycles of various types and sizes, and have "typical" riders use the test track. Then, experienced professional motorcycle riders will ride the same machines over the same track, to determine differences in use of motorcycle brake capabilities.

3.5.2 Data Requirements

The rider behavior experiment will be looking for the effects of:

- Rider characteristics (age, sex, experience, etc.)
- Road conditions
- Acceleration
- Weather conditions (wet *vs.* dry)
- Braking habits of riders
- Rider experience related to:
  - Stopping distances
  - Motorcycle control
- How need for stability affects braking performance.

3.5.3 Data Acquisition

The data will be acquired from the results of the rider behavior experiment. The riders in this experiment will use their own motorcycles, and allow a professional rider to use their motorcycles, also.* The "typical" riders needed could be solicited through newspaper advertisements and other means. The professional rider, used here as a contol, might be a motorcycle patrol policeman or a professional racer. The professional rider will be familiar with tracks, since he rides a great deal, but he will need to familiarize himself with each motorcycle used in the test before his performance is recorded. The "typical" rider will be much more familiar with his machine, but he will need some practice runs on the track before recordings of his rides are made. Thus, this experiment will measure the extent to which the capabilities of the motorcycle (including braking) as shown by the professional rider are not used by the typical rider.

The experiment might be conducted as follows. Volunteer riders arrive at the test track. They have previously authorized instrumentation of motorcycles, signed any appropriate waivers, and filled out a questionnaire detailing age, sex, length of time with current motorcycle, prior on and off road riding experience, past accidents, and other personal information as deemed relevant. Information about the motorcycle has been recorded also: make, model, repairs, modifications, tires, brake type, etc. The motorcycle is instrumented; the condition of the test track and the weather noted; and the volunteer rider and the professional rider ride around the track. Each will need several runs to familiarize himself with what will be unfamiliar to him (the professional with the motorcycle, the non-professional with the track) before the test recordings are made. The instrumentation of the motorcycle is designed to measure acceleration and deceleration levels and brake pressures.

3.5.4 Preliminary Results

Riding behavior of motorcyclists is a significant factor in the performance of motorcycles and, especially, in the performance of motorcycle braking systems. A discussion of the role of the motorcycle rider in causing or avoiding an accident can be referred to in Section 3.1.4.

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*Questions of liability for motorcycle use, while important, are beyond the scope of this study. The "typical" riders could receive some financial compensation for participating in the study.

3.5.5 Analysis

In conducting the rider behavior analysis, the following steps will take place:

1. Obtain "typical" (non-professional) riders through advertising media (volunteer or otherwise is to be determined). These riders must own motorcycles with Post-Standard braking systems (1972 and later) and must be willing to use their motorcycles on a test track.
2. Hire professional motorcycle riders.
3. Prepare test track for various conditions.
4. Instrument motorcycles.
5. Send "typical" and professional riders through the test track, with the professional rider riding each volunteer rider's machine (after a familiarization period).
6. Analyze the effect of rider characteristics/habits/experience in relation to control of the motorcycle, stopping distances, etc. demonstrated by the volunteer rider controlled for by the same variables for the professional rider.

Figure 3-7 is an outline of the suggested approach.

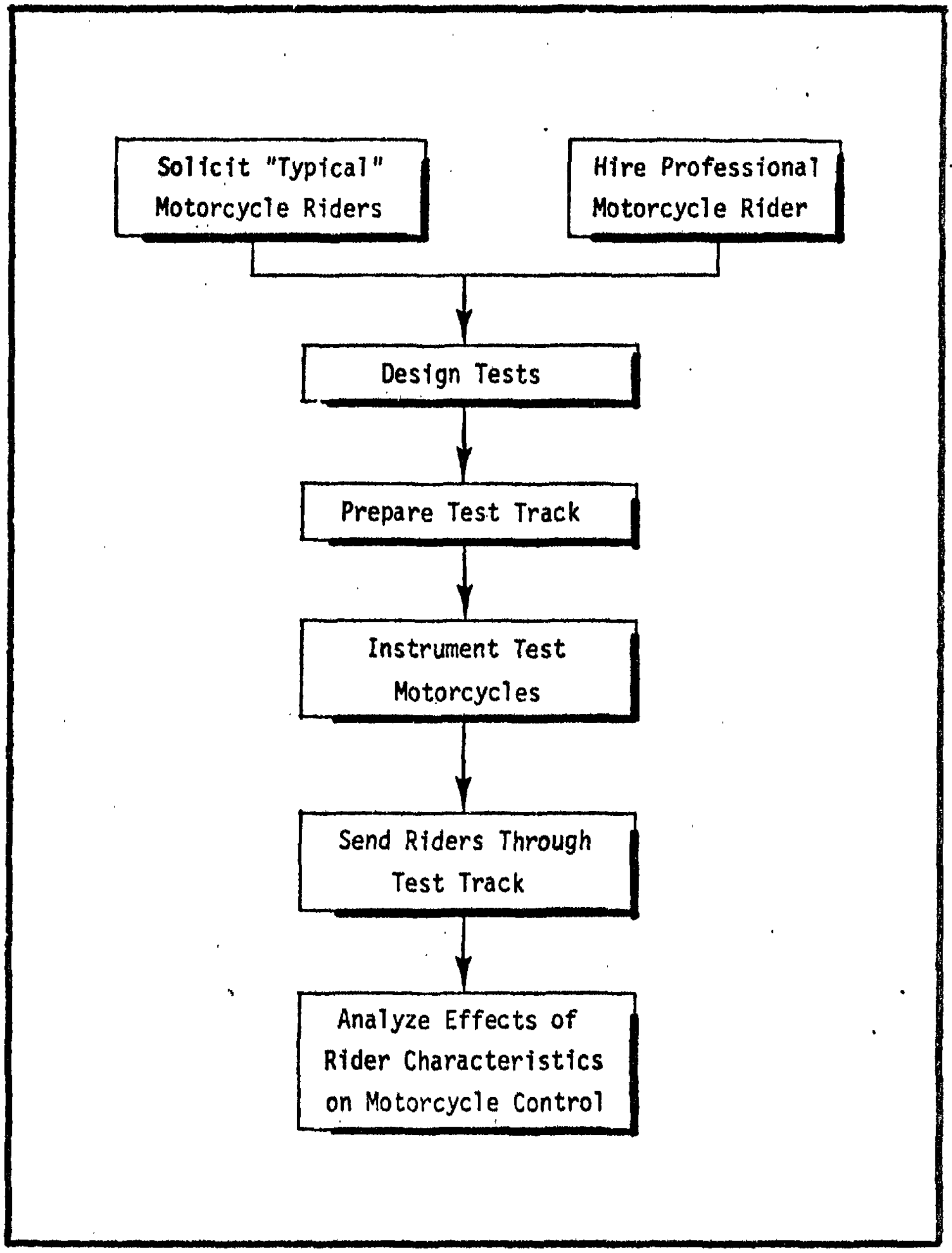

Figure 3- 7 . Rider behavior analysis.

3.6 Survey of Motorcycle Riders, Tires, Modifications

3.6.1 Introduction

The purpose of this survey is to gather presently scarce data which will be useful in developing evaluation methodologies, and in interpreting the results of other analyses. This three-part survey is meant to provide information that will aid in evaluating FMVSS 122. The information it will develop is needed to understand the potential effect of the Standard for the typical rider.

The survey is divided into three parts:

1. Motorcycle Riders. The purpose of this section of the survey is to estimate the characteristics of the general population of motorcycle riders. As mentioned before (Section 3.1.4), motorcycle brakes are probably the most effective of any vehicle on the highways when operated by an experienced rider. However, because a high level of skill is required to properly operate the braking system, improper operation is common. Unfortunately, many aspects of motorcycle riding can only be mastered through experience. Therefore, this section of the survey, which is devoted to motorcycle riders, seeks answers to both demographic data and the experience of motorcycle riders.

2. Motorcycle Tire Use. The purpose of this section of the survey is to determine which and how many motorcycles are using the various types of tires available. One of the conclusions of a Calspan study of motorcycle accident avoidance capabilities was their identification of the significant rôle of tire characteristics in motorcycle response[17]. Findings of particular significance were the:
   - Sensitivity of the response parameters to camber thrust coefficient with respect to absolute value and to any differences between front and rear tires.
   - Importance of pneumatic steering torque requirements.
   - Initial categorization of steer requirements at trim.

   Because tire characteristics play a role in accident avoidance, it is of interest to know which and how many motorcycles are using the various types of available tires. Tire usage will obviously have an effect on the evaluation of the effectiveness of FMVSS 122.

3. Modified Motorcycle Survey. The purpose of this section of the survey is to gather data on the frequency and degree of motorcycle modification, with the emphasis on brake modifications. In this section, motorcycle dealers and repair shops will be included, in addition to motorcycle owners.

   Questions which this section would attempt to obtain answers to include:
   - How important is brake adjustment?
   - How frequently are brakes modified?
   - Is FMVSS 122 of any value once motorcycle owners or shops have adjusted the brakes so they are no longer in their original condition?

It may be most effective to send an overall survey--containing questions for demographic purposes--to the entire motorcycle population chosen, but send the tire and modification sections to selected subsets of the whole population.

3.6.2 Data Requirements

The following are the questions that will be asked by each of the proposed sections of the survey:

- Motorcycle Rider Survey
  - Age
  - Sex
  - Weight
  - Height
  - Marital Status
  - Education
  - Occupation
  - Number of years spent riding motorcycles
  - Type (if any) of motorcycle driver education
  - Number of motorcycles owned
  - Make, model, size of present motorcycle
  - Primary type of riding done
  - Accident experience with motorcycles.

- Motorcycle Tire Use Survey
  - Motorcycle size
  - Type of tires originally on motorcycle (front and rear)
  - Type of tires presently on motorcycle (front and rear)
  - Primary use of motorcycle
  - Type of motorcycle (street, trail)
  - Age of motorcycle
  - How often tires have been changed
  - Information on tire blowouts and/or other problems encountered.

- Modified Motorcycle Survey
  - Make, model, year, displacement of motorcycle
  - Bought new or used
  - Any accidents on this motorcycle
  - Any modifications made on the motorcycle and description of changes. Areas to consider include:
    - -- Seats
    - -- Brakes
    - -- Foot rests
    - -- Handlebars
    - -- Front forks.

3.6.3 Data Acquisition

Data will be acquired by means of surveys mailed to motorcycle owners and motorcycle sales and repair shops, with telephone follow up of non-respondents.

3.6.4 Preliminary Results

According to a survey conducted by the Gallup Organization, there were approximately seven million motorcycles owned in the U.S. in 1974 [20]. Data from that survey are discussed below and are summarized in Table 3-8.

Sixty-six percent of all motorcycle owners were under 30 years old, and nine out of ten were male. The type of brake system chosen by a manufacturer for a particular model is a function of cycle size or engine displacement, intended use, and rider experience. The Gallup data breaks down ownership into eight displacement classifications, ranging from 50 cc and under to 600 cc and over. Approximately one-half of the seven million motorcycles in 1974 were smaller than the 191-250 cc class. Each displacement class is further divided into use categories of street, off-road and dual purpose. In general, street motorcycles are of larger displacement and off-road cycles tend to be smaller. Of all the motorcycles owned in 1974, 45 percent were considered street cycles, 14 percent were off-road, and 41 percent were dual purpose. It does not necessarily follow that a cycle designed for a particular purpose will be used for that purpose. The Gallup survey shows that 37 percent of all motorcycles surveyed were used only on the street, and 22 percent were used only off-road. The remainder were used both on and off the road.

Rider experience is, at best, an abstract design criteria. A big displacement, super-cycle may be designed for an experienced rider, but it will not necessarily follow that the purchaser of such a machine will be experienced. The American Motorcycle Association (AMA) conducted a survey in 1976 which, in part, attempted to determine the experience level of motorcycle owners [21]. The data are presented in Table 3-9. Eighty-five percent of all motorcycle operators responding to the survey had four years or more experience. It should be noted that the AMA survey was conducted two years later than the Gallup study and represented a much smaller sample size. A specific breakdown of experience level versus type of motorcycle owned was not developed in either study.

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*Tables 3-1, 3-2, 3-3, and 3-4 give additional information on the growth of the motorcycle population in the U.S.

TABLE 3-8

SUMMARY OF 1974 GALLUP MOTORCYCLE SURVEY

Type of Cycle	(%)
Street	45
Dual Purpose	41
Off-Road or Other	14
	100

Use of Cycle	(%)
Street	37
Dual Purpose	41
Off-Road or Other	22
	100

Engine Size	All Cycles (%)	Street Cycles (%)	Dual Purpose (%)	Off-Road (%)
50 cc & under	3	3	2	4
51 -100 cc	23	11	31	36
101-125 cc	8	2	12	18
126-190 cc	9	6	14	6
191-250 cc	10	7	10	17
251-400 cc	18	22	16	9
401-600 cc	8	15	3	3
Over 600 cc	13	26	3	1
Unknown	8	8	9	6
	100	100	100	100

Motorcycle Owners

Age Range	(%)
Under 21	36
21-29	30
30-49	29
50 & Over	5
	100

Sex	(%)
Male	91
Female	9
	100

Source: Gallup Organization Survey [20].

TABLE 3-9

MOTORCYCLE OPERATING EXPERIENCE - 1976 AMA SURVEY

Motorcycle Operating Experience	Percent
1 Year or Less	3
2 to 3 Years	12
4 to 5 Years	17
6 to 10 years	36
11 Years or More	32
Total	100

Source: *AMA News* Reader Profile [21]

Because they felt that some modifications to motorcycles would increase their accident probability, the California Highway Patrol (CHP) organized a special study during November 1969 on motorcycle equipment modification. A survey was made of 542 motorcycles involved in fatal and injury traffic accidents for five equipment modifications suspected to affect driver control: extended front forks, lowered seat, raised foot rests, irregular handlebars, and no front wheel brakes. Approximately eight percent of the 542 motorcycles in accidents had equipment modification. Of this eight percent, about 1.3 percent of the modifications were considered to be the cause of the accident [22]. An analysis of the accidents indicated the following rank ordering of modifications in decreasing importance to accident contribution.

- *No front wheel brakes.* ← Most contributory
- Extended front forks.
- Lowered seat.
- Raised foot rests.
- Irregular handlebars. ← Least contributory

The importance of tire characteristics in the overall performance of motorcycles has been verified by the Calspan study of motorcycle accident avoidance capabilities discussed in Section 3.6.1 [17]. There are four basic functions of a motorcycle tire which are also common to most pneumatic tires. Their function are to:

- Support and cushion a load.
- Transmit driving and braking torque.
- Develop cornering and directional stability forces.
- Envelop obstacles.

The functional requirements of motorcycle and automobile tires are quite similar. The exception is that a motorcycle tire must operate at higher camber angles and generate more of its cornering power through camber thrust. Motorcycle tread designs can be broken down into three basic categories: street, off-the-road, and combinations of the two that are intended for both on and off the road use. Selection of the proper size and type of tire is an important factor in vehicle performance. On new motorcycles, where the tires are fitted as original equipment, few problems are expected. However, individual owners sometimes replace the original tire with another which may not be the proper tire size or type. Misapplication of tire type can be a problem. Therefore, it is the purpose of the section of the survey dealing with tires to determine what motorcycles are using what tires.

3.6.5 Analysis

The following steps will take place in conducting the survey:

1. Design the three-part survey.
2. Develop data collection methodology.
3. Select sets of recipients for each part of the survey:
   - Motorcycle owners.
   - Motorcycle dealers.
   - Motorcycle repair and maintenance shops.
4. Mail out surveys.
5. Process and analyze data.

This approach is outlined in Figure 3-8.

3.6.6 Sample Sizes

The 1974 Gallup survey had 4,187 respondents. Since the proposed survey will be analyzed in greater detail, a total of 7,500 respondents is suggested. A pilot survey of, say, 500 individuals will show how many individuals should receive the mailed questionnaire, given the response rate to both the mailing and telephone followup. As for motorcycle sales and repair shops, a sample of between 500 and 1,000 should be adequate.

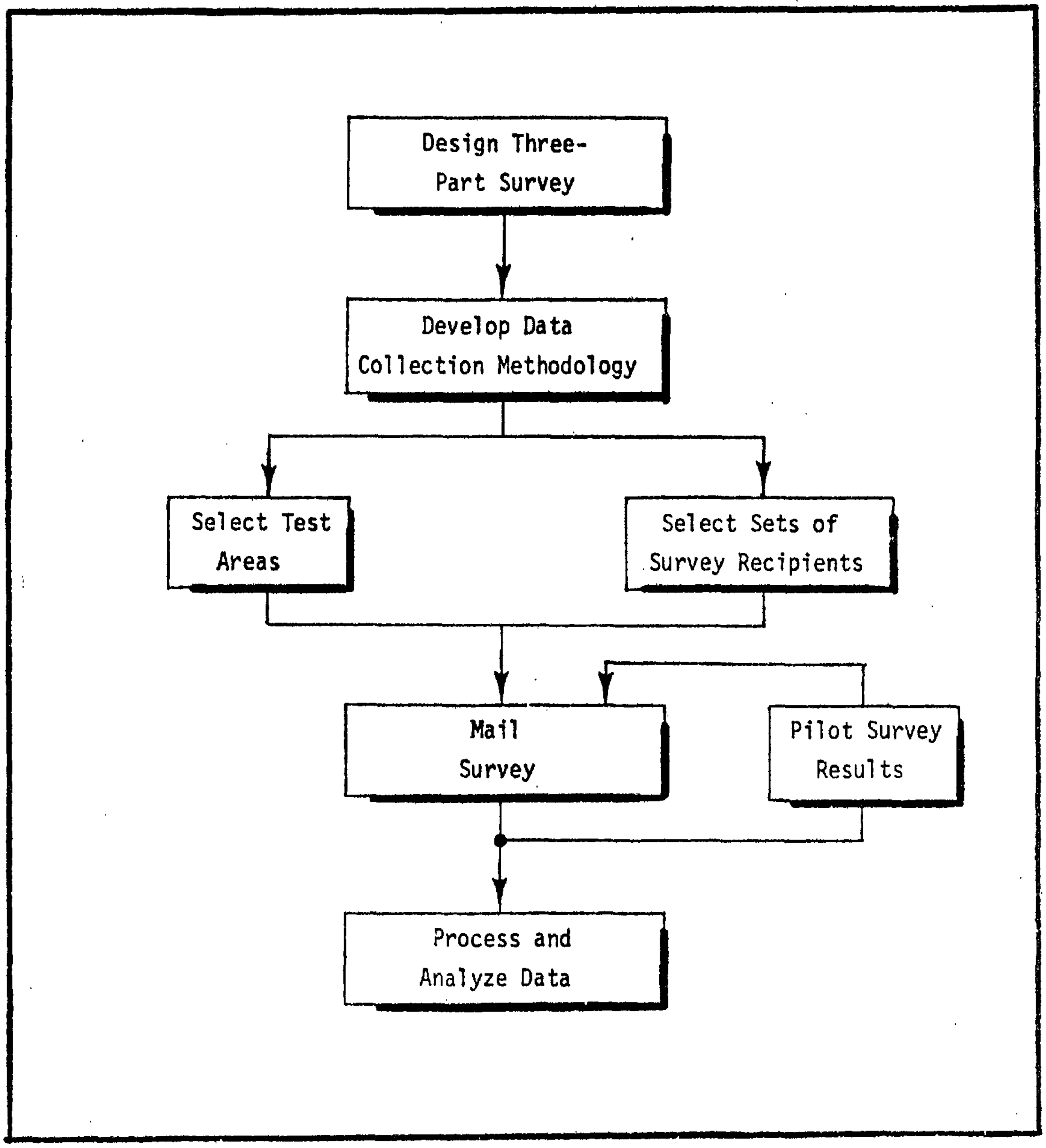

Figure 3-8. Survey of motorcycle riders, tires, and modifications.

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4.0 COST DATA AND SAMPLING PLAN

4.1 Background

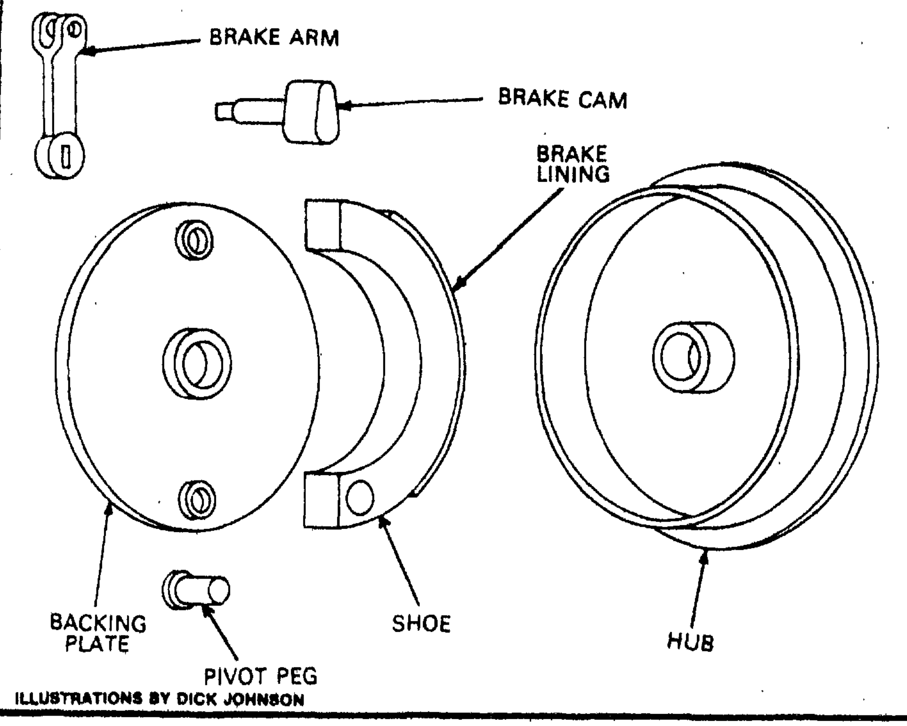
FMVSS 122 basically codified existing SAE recommendations last revised on March 1, 1971 [1]. The Standard is designed to insure safe motorcycle braking performance under normal and emergency conditions. It specifies required equipment relating to motorcycle brake systems and establishes test procedures for these systems for all vehicles manufactured after January 1, 1974.

Most manufacturers had complied with the SAE recommendations relative to brake systems and few, if any, design changes were directly attributable to FMVSS 122 [1]. Compliance with the Standard requires each motorcycle to have either a split service brake system or two independently actuated service brake systems. Split systems consist of two or more sub-systems actuated by a single control designed so that a leakage, linkage,or cable failure of a component in a single subsystem will not impair the operation of the other subsystem.

Actuation of a service brake system may be either mechanical or hydraulic. If a braking system is hydraulically actuated, each master cylinder must have a separate reservoir for each brake circuit. In addition, the filler opening for each reservoir must have a cover, seal, and cover retention device. The minimum reservoir capacity must be equivalent to one and one-half times the total fluid displacement resulting when all wheel cylinders or caliper pistons serviced by the reservoir move from a new lining fully retracted position to a fully worn, fully applied position.

Motorcycle manufacturers, in general, are providing braking circuits which are either mechanically operated drums or hydraulically operated discs. Drum brakes may be either "single-leading-shoe" or "double-leading-shoe." Disc brakes are classified as either "single-action-caliper" or "double-action-caliper" [2].

The basic components of a drum-type brake are shown in Figure 4-1. To actuate this system the motorcycle operator squeezes the brake lever which pulls on a brake cable or rod. This causes the brake arm to rotate, which in turn rotates the cam lobe. The cam forces the brake shoe against the hub and the friction between the lining on the shoe and the hub slow the motorcycle. This principal is illustrated in Figure 4-2. If the shoe is mounted

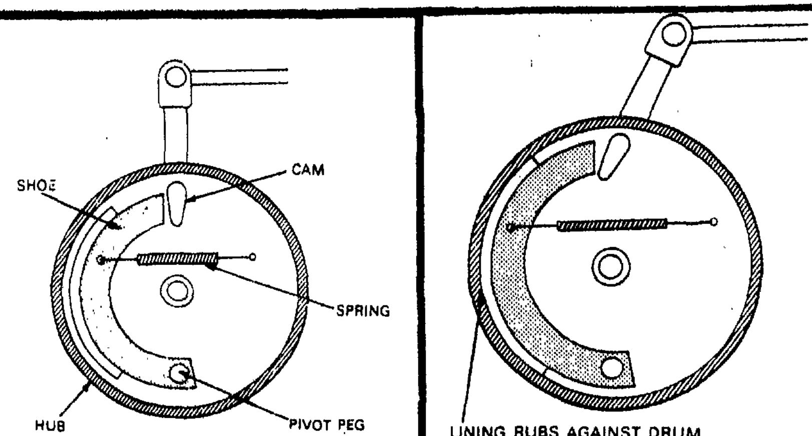


THE BASIC BRAKE PARTS

A basic brake consists of: the wheel hub, whose inside circumference serves as a brake drum; the brake shoe, a curved piece of metal with a special lining on the outside; the backing plate, a large, flat disc on which the shoe mounts; the brake cam, which makes the shoe move; the brake arm, that connects to the brake cable or rod and mounts on the end of the brake cam; and the pivot peg, which bolts onto the backing plate and fits through the hole at the bottom end of the shoe.

Source: *cycle guide* [2].

Figure 4-1. Basic drum brake components.



DRUM BRAKE NOT IN USE

When the brake is not in use, a spring holds the shoe against the low part of the cam lobe, and there is a small space between the outside of the shoe and the inside circumference of the drum.

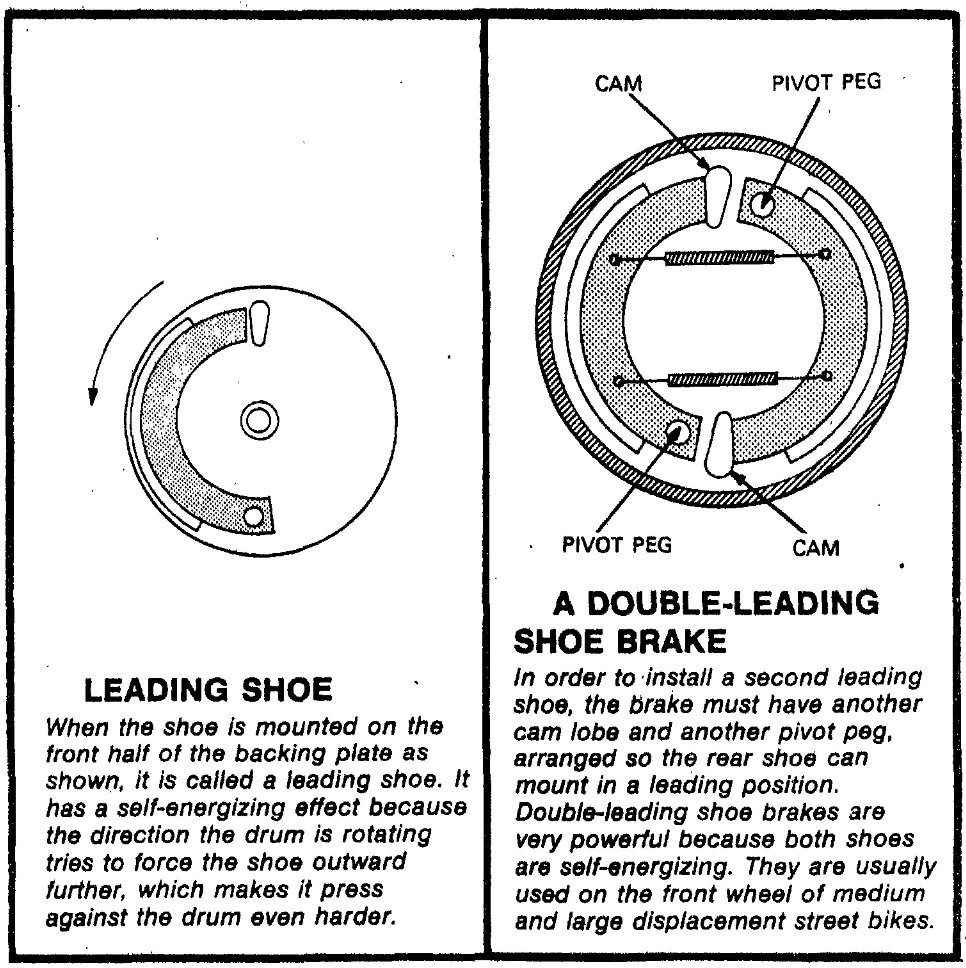
DRUM BRAKE IN USE

When the rider squeezes the brake lever, the cable (or rod) pulls the brake arm, causing the cam lobe to turn. The lobe forces the shoe outward until it rubs against the inside of the drum. If the shoe rubs hard enough, it will create enough drag to stop the wheel.

Source: *cycle guide* [2]

Figure 4-2. Operation of the drum brake.

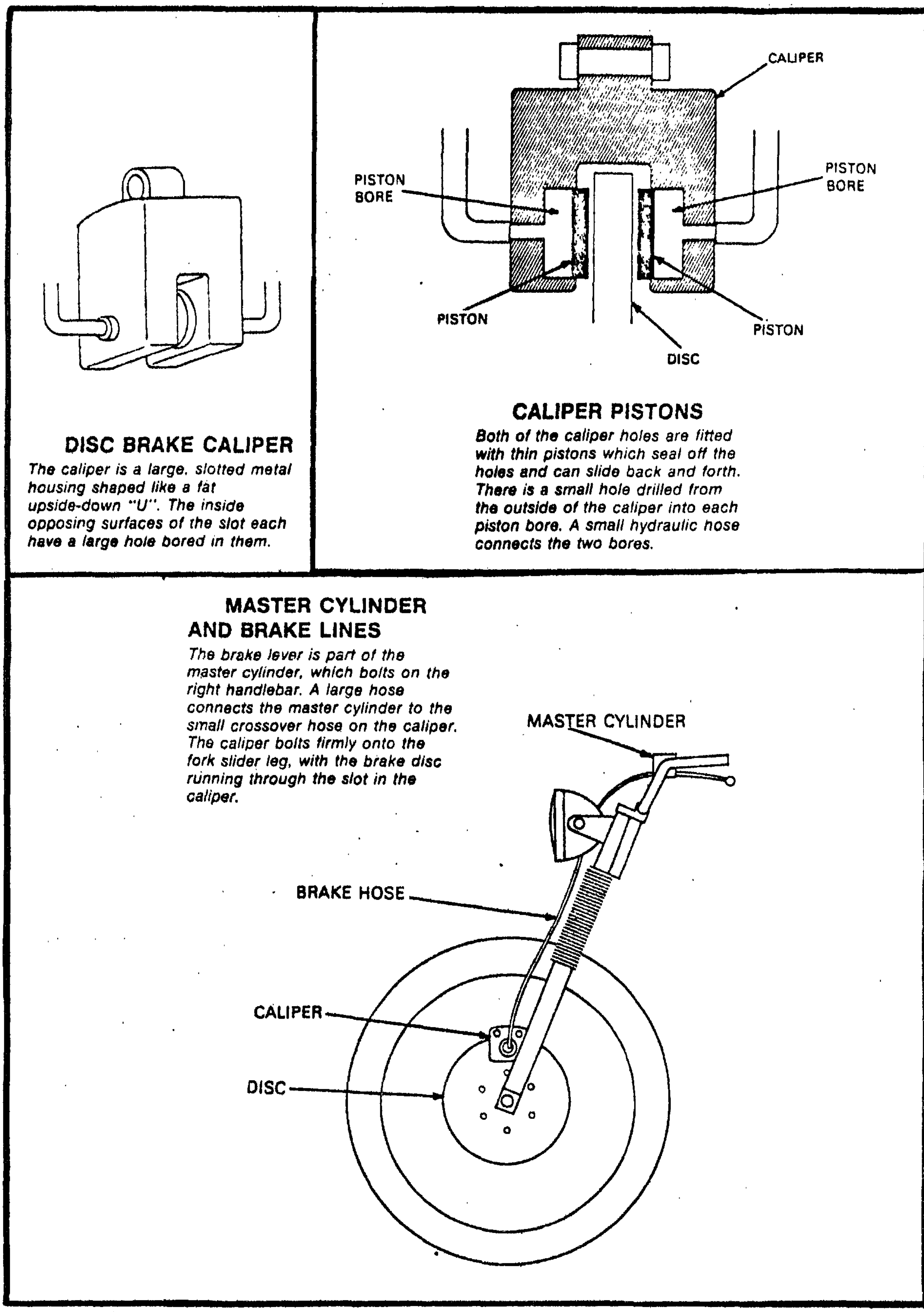
on the front half of the backing plate, the brake is a "single-leading-shoe" drum brake. The double-leading shoe design incorporates two brake shoes. Both single and double-leading shoe brakes are shown in Figure 4-3.



Source: *cycle guide* [2].

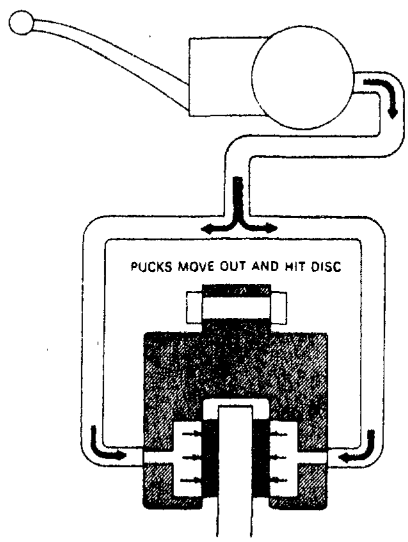
Figure 4-3. Single and double-leading shoe drum brakes.

The disc brake operates in a different manner than the drum system. Braking friction is applied by pinching a spinning disc firmly attached to the wheel hub. The major components of disc brake circuit are illustrated in Figure 4-4. Actuation is hydraulic. If the pinching forces are applied from both sides of the disc the brake is called "fixed caliper, double action." The "floating caliper, single action" is designed to apply an active force on one side of the disc against a passive force on the other side. These differences are illustrated in Figure 4-5.



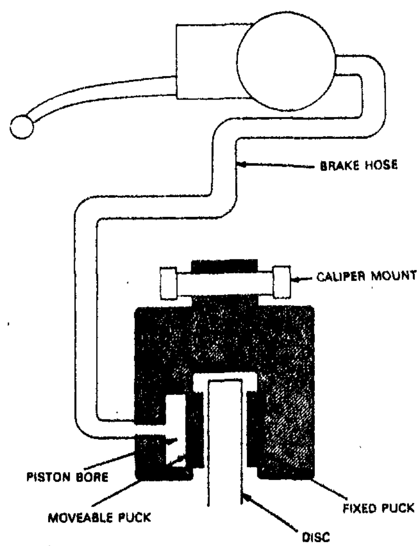
Source: *cycle guide* [2].

Figure 4-4. Disc brake circuit components.



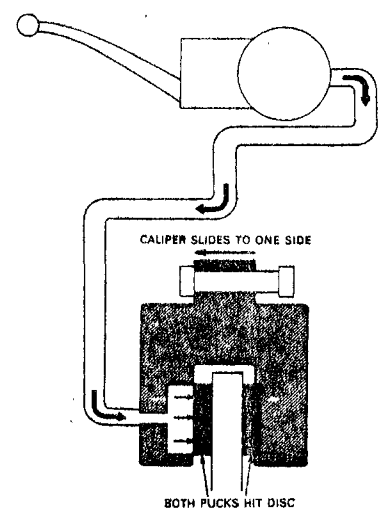
14. DOUBLE-ACTION FIXED CALIPER DISC BRAKE AT WORK

The inside of the master cylinder, brake lines, and caliper piston bores is filled with brake fluid. When the rider applies the brake, the brake lever puts pressure on the fluid in the master cylinder. This pressure forces the caliper pistons outward until they hit the sides of the spinning disc. The pistons pinch the disc tightly, causing a drag on the disc and making the wheel stop. The sides of the piston nearest the disc are covered with small discs of brake lining material. These discs are called "pucks."



15. A SINGLE-ACTION FLOATING CALIPER DISC BRAKE

Some calipers have only one piston bore and one moveable puck. The other puck bolts to the opposite side of the caliper slot. The caliper does not bolt firmly to the fork slider leg; it can slide back and forth slightly on its mounting bolt.



16. SINGLE-ACTION FLOATING CALIPER DISC BRAKE AT WORK

When the brake is applied, the lever puts pressure on the brake fluid in the master cylinder. This forces the caliper piston outward until it touches the spinning disc. Then, the pressure forces the entire caliper to shift so the fixed puck moves toward the disc. The caliper shifts until the pucks are pinching the disc tightly. The pucks then pinch the disc in the same way as the double-action caliper, stopping the wheel.

Source: *cycle guide* [2].

Figure 4-5. Single-action floating caliper and double-action fixed caliper disc brake circuits.

Manufacturers employ these various brake systems to provide independent front wheel and rear wheel braking. Their choice of systems is dependent on the size and weight of the motorcycle, the purpose or use for which the motorcycle is intended, and consideration of the general ability of motorcycle operators. Although there are no set rules, some generalities in the use of braking systems can be observed [2]. Large tour motorcycles and medium and large sport motorcycles tend to use hydraulic disc brakes on the front wheel. The disc brakes exhibit better fade characteristics and dissipate heat more effectively under heavier loads. Medium displacement motorcycles generally use a double leading shoe-drum system on the front wheel, but there is a trend toward disc systems. The light, small displacement, commuter bikes are usually equipped with a single-leading-shoe drum system on the front wheel. The rear braking circuit on most motorcycles is a single shoe drum, with only a very few employing rear disc systems.

In addition to the split braking requirement, the Standard requires that an electrically operated brake system failure indicator lamp be mounted in front of and in clear view of the driver. Each indicator must have a red lens with the legend "Brake Failure" on or adjacent to it.

Three-wheeled motorcycles must be equipped with a parking brake. This brake must be engaged by mechanical means and operated by friction principles.

Since most manufacturers followed SAE recommended practices before the Standard became effective and these practices were sufficient to comply with the Standard, there are essentially no direct manufacturing costs linked to compliance. There are some maintenance and labelling costs incurred through compliance, but these costs are generally under one dollar per motorcycle [1].

4.2 Relevant Cost Items

The major components and elements of a motorcycle brake system that must be considered in evaluating the costs of compliance with FMVSS 122 are shown in Table 4-1. Costs relating to changes in these items which were made in response to the Standard should be included.

TABLE 4-1

MAJOR COMPONENTS AND ELEMENTS OF MOTORCYCLE BRAKE SYSTEMS

- Drum Brake Circuit
  - Mechanical Actuation Device
  - Linkage and Brake Arm
  - Hub
  - Brake Shoe
  - Brake Lining
  - Backing Plate
  - Brake Cam
- Disc Brake Circuit
  - Actuation Device
  - Master Cylinder
  - Brake Hose
  - Caliper
  - Disc
- Brake System Failure Indicator Lamp
  - Bulb
  - Sensor
  - Connectors and Associated Wiring
  - Red Lamp Shield

To establish total costs, other items must be considered in addition to the costs of components or hardware involved in modifications to a braking system. At the very least, direct and indirect manufacturing costs and capital investment must be considered. Consumers certainly pay for the marginal effect of manufacturers' markup, dealers' markup, and taxes when they purchase a motorcycle. The NHTSA methodology also includes lifetime operating and maintenance costs as part of the total cost of a system. We will not include these life time costs.

The manufacturing costs are a function of:

- Material amount
- Material cost
- Labor required for component assembly

- Wage rate
- Overhead rate (indirect labor and materials)
- Labor required for component installation.

Capital investments should be amortized over the useful life of the equipment and estimated level of production. Manufacturers' markup, dealers' markup, and taxes are percentage amounts applied to the base costs.

4.3 Frequency Sampling Plan

The purpose of this activity is to acquire reliable estimates of the increased costs incurred by manufacturers in complying with FMVSS 122. The manufacturers must be the source of information on cost figures, but accounting practices and design philosophies may well vary from manufacturer to manufacturer, and this must be controlled for. We recommend that estimates be obtained from the various manufacturers of the costs incurred in complying with FMVSS 122.

For a given manufacturer, we expect that costs of compliance for brake system components will vary according to the power of the motorcycle's engine. This power is conveniently summarized by engine displacement. For labels and indicator lamps, the size of the motorcycle may influence the cost, but this is not very likely. Since size is also related to engine displacement, the sampling plan must stratify on at least two variables:

- Manufacturer: Honda, Yamaha, Kawasaki, Suzuki, Harley-Davidson.
- Engine displacement: Under 125 cc, 125-349cc, 350-499 cc, 450-749 cc, 750 cc and over.

The five manufacturers listed above are the major ones in the American market. In the period from 1971 to 1976 they accounted for between 90 and 94 percent of all new motorcycle registrations each year [3]. The engine displacement categories are standard within the industry; for street motorcycles, the estimated population breakdown in 1976 was:

- Under 125 cc: 7 %
- 125-349 cc: 12 %
- 350-449 cc: 31 %
- 450-749 cc: 24 %
- 750 cc and over: 26 %

When information on the costs of components and labels affected by the Standard is collected for models both before and after the Standard became effective, the incremental cost of compliance can be found by extrapolation. It must be ascertained, however, what portion of this incremental cost is due to changes in the braking system and its components that the manufacturer would have made even without the Standard, for many of these changes would have been introduced anyway. Since the question of intent is an extraordinarily hard one to determine, at best one can say that incremental costs mentioned above, when ascribed entirely to the Standard, will overestimate the cost of compliance. Acquiring the necessary information for all models produced, in all relevant variations, is costly and unnecessary. If we assume some structure for the cost in relation to manufacturer and motorcycle characteristics, it is then possible to design a sampling scheme whereby only some motorcycle models are examined. The particular structure assumed for the cost will lead to the sampling plan, and the stronger the assumptions, the smaller the sample size needed. If it is assumed that costs are the same for all models and manufacturer, only one observation need be made.

However, costs are assumed to differ according to manufacturer and to engine displacement. At the most, 25 models need to be sampled, if cost is assumed to be the same for all models of fixed engine displacement and manufacturer. Within each cell of the cross classification manufacturer by engine displacement, a model should be picked at random, possibly weighting the models by their share of the market. The naive approach of sampling only those models with the greatest share of the market is likely to grossly underestimate the true cost of compliance, since it is precisely for these models that more cost effective techniques of manufacture may have been developed.

If more models can be sampled, then estimates of the variability of the overall average cost can be made. Also, various mathematical models for the cost of compliance can be examined. If an additive model is assumed, then some of the degrees of freedom can be assigned to the error term in the model, trading off increased precision against the possible introduction of bias.

4.4 References for Section 4

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3. Motorcycle Industry Council, Inc. *1977 Motorcycle Statistical Annual*. Newport Beach, Calif., 1977.

5.0 WORK PLAN

The Work Plan for the evaluation of FMVSS 122 is divided into five Tasks. They are:

- Task 1: Analysis of Mass Accident Data
- Task 2: Motorcycle Surveys (Riders/Tires/Structural Modifications)
- Task 3: Analysis of NASS and California Accident Data
- Task 4: Motorcycle Dynamometer Brake Tests
- Task 5: Field Test of Braking Performance and Rider Behavior
- Task 6: Cost Data Analysis.

The logical sequence of subtasks within each Task is given in Figure 5-1. The time sequencing within each Task and the estimated resources required are given in Figure 5-2 and Figure 5-3. For the purpose of developing this Work Plan, the entire study is assumed to start on January 1, 1979.

The first two Tasks are scheduled to be completed during the first year of the evaluation study. The adequacy of the analysis of mass accident data and the motorcycle surveys to evaluate the Standard will be assessed at the first Decision Point at Month 11. The initial analysis of NASS and California accident data under Task 3 will be completed two months later, permitting a reevaluation at the second Decision Point at Month 13. It is considered unlikely that the evaluation of the Standard will have been completed at this time.

The fourth Task, conducted during the second year, is the laboratory dynamometer tests of motorcycle brakes. Upon completion of this Task at Month 22, two Decision Points are scheduled. NHTSA could evaluate (1) whether any difference exists between the performance of Pre- and Post-Standard brakes (Decision Point #4) and (2) whether the dynamometer test results, the additional analysis of NASS and California accident data and earlier results of the first three Tasks are sufficient to evaluate the Standard.

The third year of the evaluation study will focus on field tests of both braking performance and riders. Both professional and non-professional riders will participate. At the end of the third year, the final Decision Point to evaluate the Standard is reached.

Assuming that all Tasks are carried out, the estimated resources required for evaluating the effectiveness of FMVSS 122 are $348,000. This figure includes estimated requirements of five staff years. The entire study would require three years to complete.

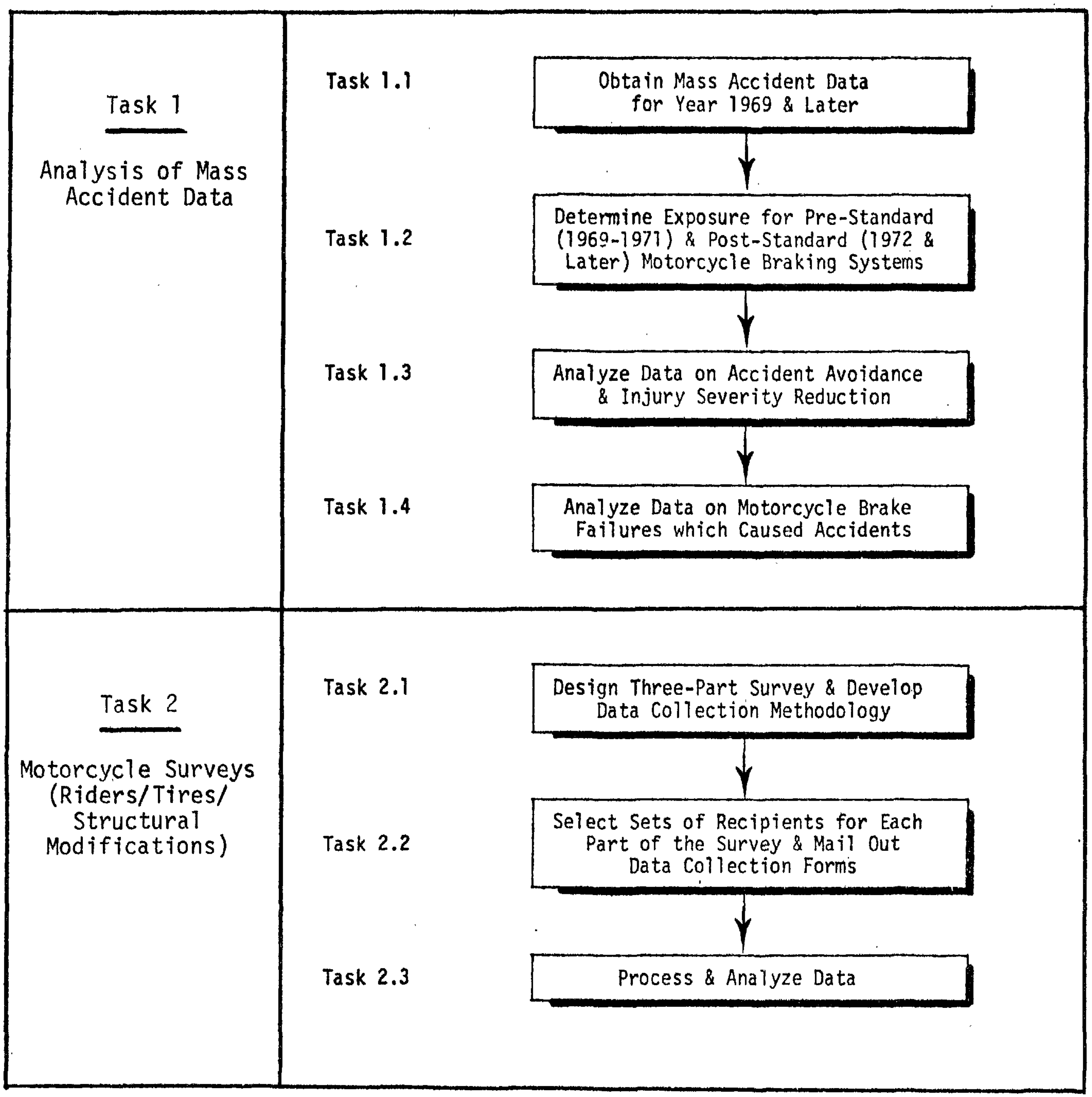

Figure 5-1. Flow chart for proposed study to evaluate FMVSS 122: Motorcycle Brake Systems.

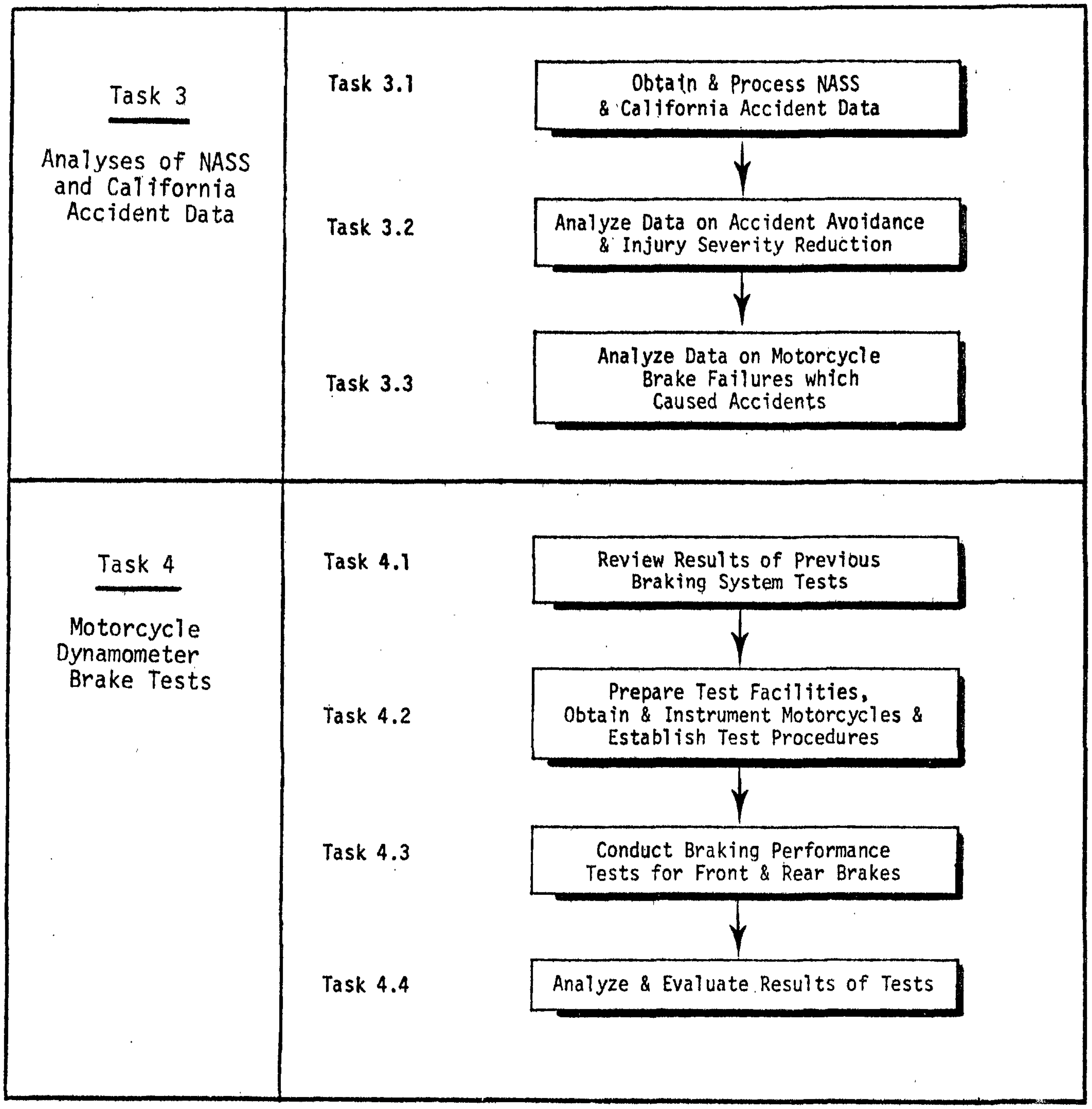

Figure 5-1 (Continued).

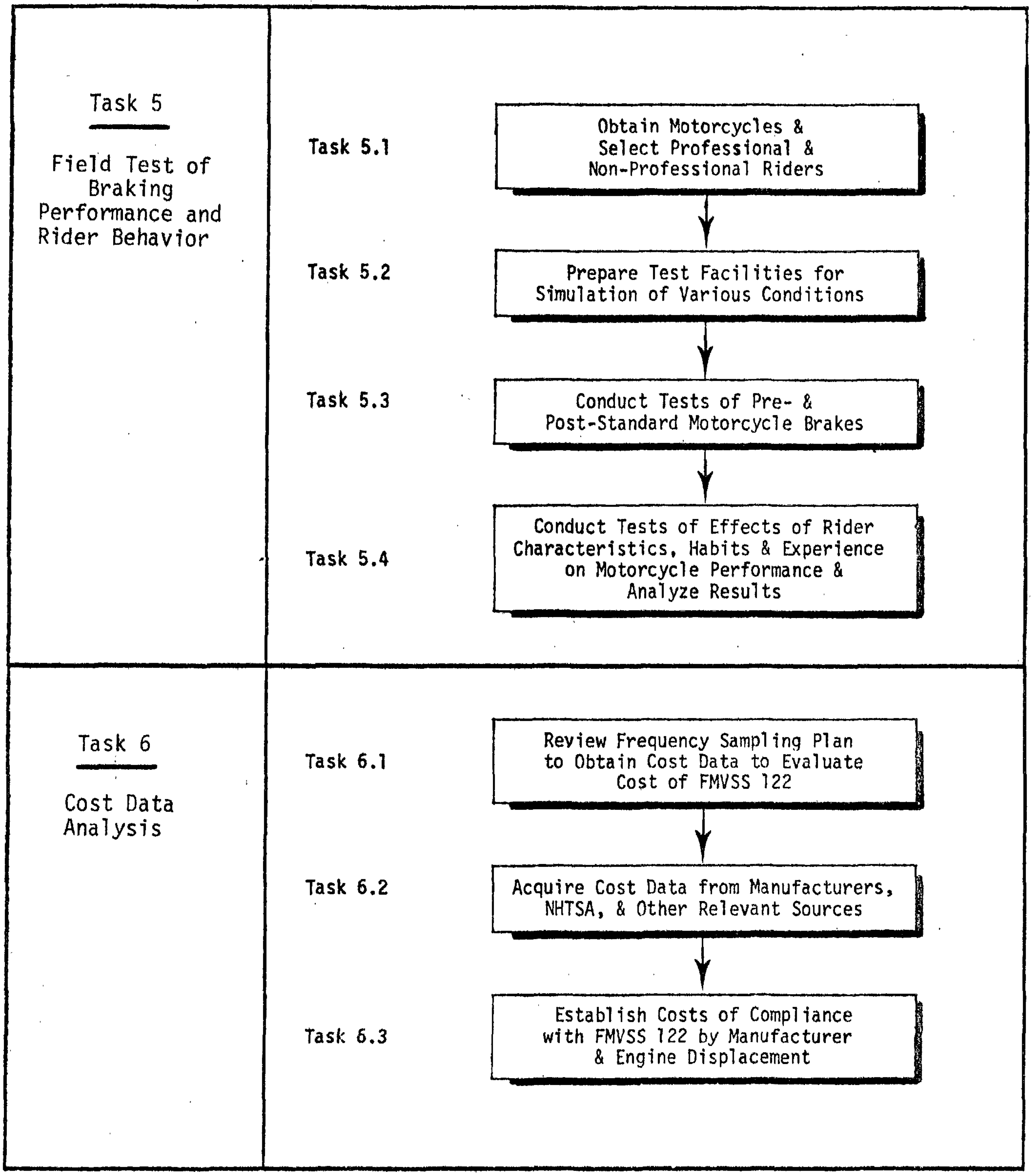

Figure 5-1 (Concluded).

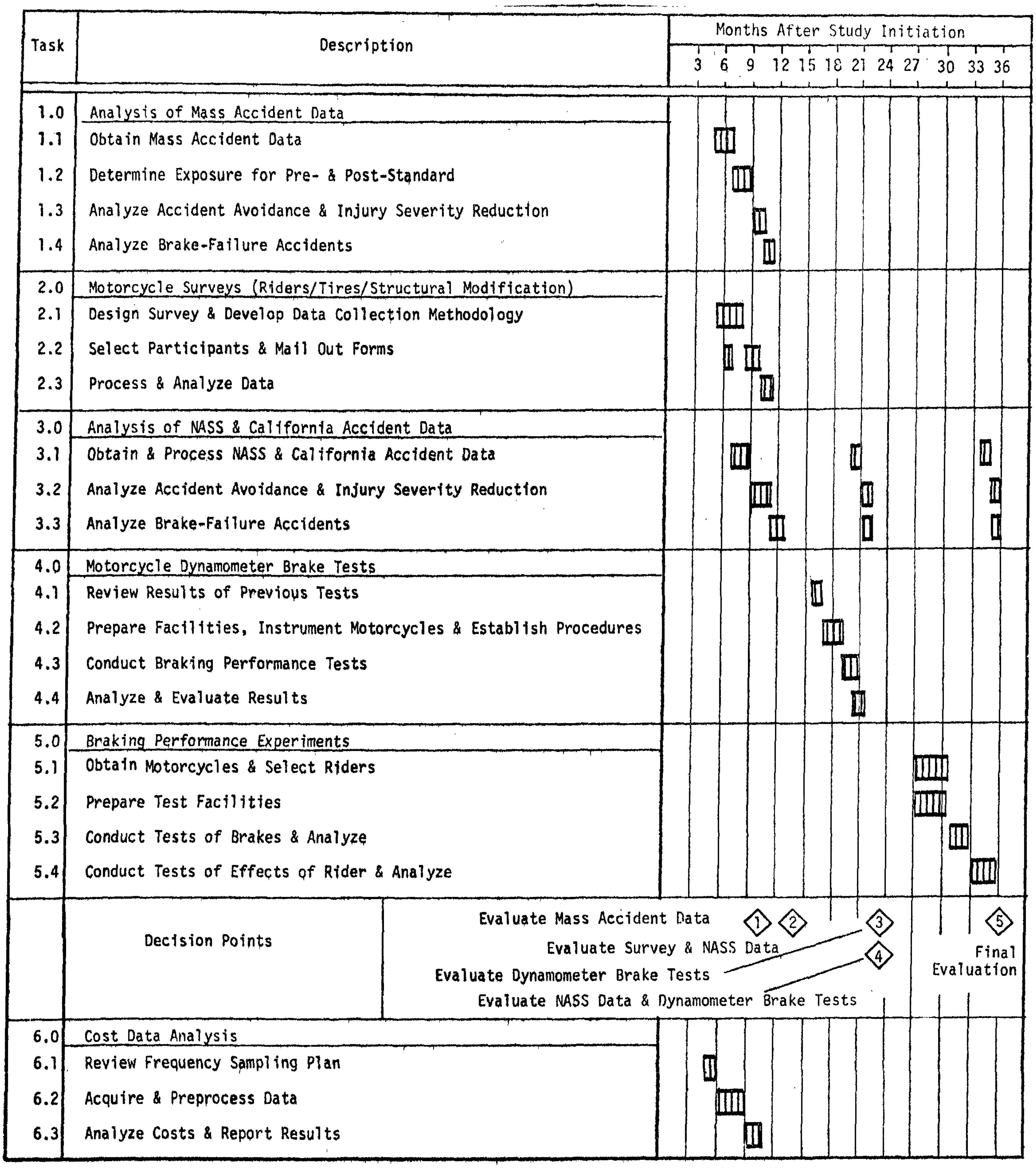

Figure 5-2. Schedule of tasks for evaluation of FMVSS 122: Motorcycle Brake Systems.

Task	Description	Staff Years	Staff Cost ($)	Data Processing Cost ($)	Lab Cost ($)	Equipment Cost ($)	Field Data Cost ($)	Total Cost ($)
1.0	Analysis of Mass Accident Data							
1.1	Obtain Mass Accident Data	0.1	5K	-	-	-	-	5K
1.2	Determine Exposure for Pre- & Post-Standard	0.1	5K	1K	-	-	-	6K
1.3	Analyze Accident Avoidance & Injury Severity Reduction	0.2	10K	3K	-	-	-	13K
1.4	Analyze Brake-Failure Accidents	0.1	5K	1K	-	-	-	6K
	Total	0.5	25K	5K	-	-	-	30K
2.0	Motorcycle Surveys (Riders/Tires/Structural Modification)							
2.1	Design Survey & Develop Data Collection Methodology	0.2	10K	-	-	-	-	10K
2.2	Select Participants & Mail Out Forms	0.5	10K	-	-	9K	-	19K
2.3	Process & Analyze Data	0.5	19K	2K	-	-	-	21K
	Total	1.2	39K	2K	-	9K	-	50K
3.0	Analysis of NASS & California Accident Data							
3.1	Obtain & Process NASS & California Accident Data	0.2	10K	2K	-	-	-	12K
3.2	Analyze Accident Avoidance & Injury Severity Reduction	0.2	10K	2K	-	-	-	12K
3.3	Analyze Brake-Failure Accidents	0.1	5K	1K	-	-	-	6K
	Total	0.5	25K	5K	-	-	-	30K
4.0	Motorcycle Dynamometer Brake Tests							
4.1	Review Results of Previous Tests	0.1	5K	-	-	-	-	5K
4.2	Prepare Facilities, Instrument Motorcycles & Establish Procedures	0.3	15K	-	5K	25K	-	45K
4.3	Conduct Braking Performance Tests	0.3	13K	-	20K	-	-	33K
4.4	Analyze & Evaluate Results	0.3	15K	2K	-	-	-	17K
	Total	1.0	48K	2K	25K	25K	-	100K
5.0	Braking Performance Experiments							
5.1	Obtain Motorcycles & Select Riders	0.2	10K	-	-	7K	-	17K
5.2	Prepare Test Facilities	0.2	10K	-	5K	-	-	15K
5.3	Conduct Tests of Brakes & Analyze	0.4	20K	3K	10K	-	-	33K
5.4	Conduct Tests of Effects of Rider & Analyze	0.4	20K	2K	10K	-	-	32K
	Total	1.2	60K	5K	25K	7K	-	97K
6.0	Cost Data Analysis							
6.1	Review Frequency Sampling Plan	0.1	5K	-	-	-	-	5K
6.2	Acquire & Preprocess Data	0.3	15K	0.5K	-	-	-	15.5K
6.3	Analyze Costs & Report Results	0.4	20K	0.5K	-	-	-	20.5K
	Total	0.8	40K	1K	-	-	-	41K
	Grand Total	5.2	237K	20K	50K	41K	-	348K

Figure 5-3. Schedule of required resources for evaluation of FMVSS 122.

5.1 Task 1 - Analysis of Mass Accident Data

Task 1 is concerned with (1) determining whether accidents are avoided or severity of injury reduced due to motorcycle brake specifications in the Standard; and (2) investigating the effects of motorcycle brake failure. The mass accident data that will be considered in the analysis include FARS, New York State, North Carolina, Texas and Washington State. The first part of the study will be undertaken by tabulating car-motorcycle front-rear collisions and analyzing driver and environment characteristics in relation to Pre- and Post-Standard braking systems. The second part of the study investigates the extent of motorcycle brake failure in Pre-Standard and Post-Standard motorcycles, together with the effects on the number and severity of motorcycle accidents. Because of the expected great variability and lack of level of detail in the available data files, the above analyses cannot be expected to establish the efficacy of the Standards if improvements are small.

It is estimated that six months will be required for the completion of the Task 1 study. The total resources required for Task 1 are estimated to be $30,000. This total includes accomplishing the Task effort with 0.5 staff-years and $5,000 for data processing.* The probability of satisfactorily evaluating the effectiveness based on only Task 1 is estimated to be about 0.05.

5.2 Task 2 - Motorcycle Surveys

Task 2 is concerned with conducting a three-part data collection survey designed to obtain additional data on motorcycle rider experience, tire usage, and motorcycle modification. Each of the three surveys will be conducted by mail. Selected sets of potential recipients who could participate in the survey include motorcycle owners, dealers and repair and maintenance shops. The first survey is designed to estimate the important characteristics of the general population of motorcycle riders. These characteristics include age, sex, weight, height, marital status, education, occupation, motorcycle experience, accident experience, etc. The second survey has the objective of determining the types of tires which various classes of motorcycles are using. Data to be collected include motorcycle size, type of tires originally on motorcycle, type of tires presently on motorcycle, primary motorcycle use, etc. The third survey is designed to gather

*CEM's estimates are based on the assumption that this work will be conducted by a contractor who already has most of the data tapes. We recognize that there is a certain likelihood that this work will be done in-house by NHTSA, with appropriate cost savings.

data on the frequency and degree of motorcycle modification, with the emphasis on brake modification. Both motorcycle owners and motorcycle dealers/repairers will be questioned.

It is estimated that six months will be required for the completion of the Task 2 study. The total resources required for Task 2 are estimated to be $50,000. This total includes accomplishing the Task effort with 1.2 staff-years, $9,000 for equipment costs and $2,000 for data processing. The probability of satisfactorily evaluating the effectiveness of the Standard, based on information from Tasks 1 and 2 and the initial analysis in Task 3 is estimated to be about 0.09.

5.3 Task 3 - Analysis of NASS and California Accident Data

The analysis in Task 3 is very similar to the first Task. The effects of accident avoidance, injury severity and motorcycle brake failure are analyzed using NASS and California accident data. The analyses are first undertaken during the first year and repeated during the second and third year, as more data become available.

It is estimated that the initial analyses will be completed in six months, with subsequent 2-month periods for additional analysis scheduled toward the end of the second and third years. The total resources required for Task 3 are estimated to be $30,000. This total includes accomplishing the Task effort with 0.5 staff-years and $5,000 for data processing.

5.3 Task 4 - Motorcycle Dynamometer Brake Tests

Task 4 is directed toward conducting laboratory dynamometer tests of motorcycle brakes to test compliance with FMVSS 122 performance characteristics that are independent of the effect of operator skill. The controlled dynamometer brake tests are designed to consider such factors as brake system type, motorcycle weight and structure, road surface conditions, weather conditions, weight loading, vehicle pitch (roll), weight shifting, lever or pedal force of brake application, sensitivity of front wheel brake, condition of hydraulic brake system, deceleration capability, fade resistance, effects of water or contamination and system life. The results of previous brake system tests that used methods other than those specified in the Standard would first be reviewed. Tests will be performed on a wide range of available current motorcycles. Brake performance tests for front and rear brakes will be conducted separately, under various simulated conditions.

It is estimated that six months will be required for the completion of the Task 4 study. The total resources required for Task 4 are estimated to be $100,000. This total includes accomplishing the Task effort with 1.0 staff-years, $25,000 for laboratory costs, $25,000 for equipment costs, and $2,000 for data processing. The probability of satisfactorily evaluating the effectiveness of the Standard at the end of the second year, using results of the first four Tasks, is estimated to be about 0.25.

5.5 Task 5 - Braking Performance Experiments

Task 5 is designed to conduct laboratory-type experiments with both professional and non-professional riders to (1) test the performance capabilities of Pre- and Post-Standard motorcycle brakes; and (2) analyze the behavior of motorcycle riders. Both portions of the study will be carried out at special test facilities. In the first part of the study, under varying conditions (wet surface, curves, etc.) the performance of Pre-Standard and Post-Standard braking systems will be compared. Riders and motorcycles will be selected for the experiments by means of a Latin square design. A second set of experiments will be conducted with Post-Standard braking systems only. It will be concerned with evaluating the effects of rider characteristics, habits, and experience in relation to control of the motorcycle, stopping distances, etc. This experiment is concerned with determining the ability of typical motorcycle operators to exploit the capabilities of motorcycles with different methods of braking, including slip ratio control, wheel deceleration control and angular jerk control.

It is estimated that nine months will be required for the completion of the Task 5 study. The time period includes a 4-month preparation phase that provides for obtaining motorcycles, selecting riders for tests and preparing the test facilities. The total resources required for Task 5 are estimated to be $97,000. This total includes accomplishing the Task effort with 1.2 staff-years, $25,000 for laboratory costs, $7,000 for equipment and $5,000 for data processing. The probability of satisfactorily evaluating the effectiveness of the Standard, using information from all five effectiveness evaluation Tasks, is estimated to be about 0.5.

5.6 Task 6 - Cost Data Analysis

Task 6 is concerned with the determination of direct costs to implement FMVSS 122. Cost categories are confined to direct manufacturing, indirect manufacturing, capital investment (including testing), manufacturer's markup, dealer's markup and taxes.* A frequency sampling plan has been developed which assumes that the manufacturer's cost of compliance varies according to the manufacturer and engine displacement. The two levels of interest for the Standard are:

1. Manufacturer: Honda, Yamaha, Kawasaki, Suzuki, Harley-Davidson.
2. Engine displacement: Under 125 cc, 125-349 cc, 350-449 cc, 450-749 cc, 750 cc and over.

The cost of compliance is of interest in two aspects: total cost and cost/vehicle. For total cost, models should be assigned on the basis of their dollar share of the market, and for per vehicle costs, models should be chosen on the basis of vehicle share of the market. In this way, the standard error of the overall cost estimates is minimized.

Task 6 will be completed in six months during the first year of the overall study. It is estimated that the total resources required are $41,000; this includes 0.8 staff-years of effort and $1,000 for computer processing.

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*These are the cost categories specified by NHTSA. One should realize that manufacturers' and dealers' markups are not easily obtainable for specific models (if at all). The overall "markup" is the difference between the actual price set at the time of sale,largely according to market conditions, and the total manufacturing costs, which are to some extent determined years in advance,when the motorcycle is designed,and to some extent by the volume actually produced,which results from the market conditions.

Taxes play a different role; some are a factor which can enter the cost calculation (e.g., property taxes). Income taxes,however, are levied on profit,which is a residual and not predictable (if a manufacturer operates at a loss,no income taxes are due).

APPENDIX A

FEDERAL MOTOR VEHICLE SAFETY STANDARD 122:

MOTORCYCLE BRAKE SYSTEMS

MOTOR VEHICLE SAFETY STANDARD NO. 122

Motorcycle Brake Systems

S1. Scope. This standard specifies performance requirements for motorcycle brake systems.

S2. Purpose. The purpose of the standard is to insure safe motorcycle braking performance under normal and emergency conditions.

S3. Application. This standard applies to motorcycles.

S4. Definitions.

"Braking interval" means the distance measured from the start of one brake application to the start of the next brake application.

"Initial brake temperature" means the temperature of the hottest service brake of the vehicle 0.2 mile before any brake application.

"Skid number" [means the frictional resistance of a pavement measured in accordance with American Society for Testing and Materials (ASTM) Method E-274-70 (as revised July, 1974) at 40 mph, omitting water delivery as specified in paragraphs 7.1 and 7.2 of that method. (41 F.R. 24592—June 17, 1976. Effective: 6/14/76)]

"Speed attainable in 1 mile" means the speed attainable by accelerating at maximum rate from a standing start for 1 mile, on a level surface.

"Stopping distance" means the distance traveled by a vehicle from the start of the brake application to the point where the vehicle stops.

"Split service brake system" means a brake system consisting of two or more subsystems actuated by a single control designed so that a leakage-type failure of a pressure component in a single subsystem (except structural failure of a housing that is common to all subsystems) shall not impair the operation of the other subsystem(s).

S.5 Requirements. Each motorcycle shall meet the following requirements under the conditions specified in S6, when tested according to the procedures and in the sequence specified in S7. Corresponding test procedures of S7 are indicated in parentheses. If a motorcycle is in-

TABLE I

STOPPING DISTANCES FOR EFFECTIVENESS, FADE AND PARTIAL SYSTEM TESTS

	Stopping distance, feet			
	Effectiveness tests			
Vehicle test speed m.p.h.	Preburnish effectiveness total system (S5.2.1)	Preburnish effectiveness partial mechanical systems (S5.2.2)	Effectiveness total system (S5.4) (S5.7.1)	Effectiveness partial hydraulic systems (S5.7.2)
	I	II	III	IV
15	13	30	11	25
20	24	54	19	44
25	37	84	30	68
30	54	121	43	97
35	74	165	58	132
40	96	216	75	173
45	121	273	95	218
50	150	337	128	264
55	181	407	155	326
60	216	484	185	388
65			217	415
70			264	527
75			303	606
80			345	689
85			389	788
90			484	872
95			540	971
100			598	1076
105			650	1188
110			723	1302
115			791	1423
120			861	1549

[(39 F.R. 32914—September 12, 1974. Effective: 10/14/74)]

TABLE II

BRAKE TEST SEQUENCE AND REQUIREMENTS

SEQUENCE L.C.	Test procedure	Requirements
1. Instrumentation check	S7.2	
2. First (Preburnish) effectivess test:		
(a) Service brake system	S7.3.1	S5.2.1
(b) Partial service brake system	S7.3.2	S5.2.2
3. Burnish procedure	S7.4	
4. Second effectiveness test	S7.5	S5.3
5. First fade and recovery test	S7.6	S5.4
6. Reburnish	S7.7	
7. Final effectiveness test:		
(a) Service brake system	S7.8.1	S5.5.1
(b) Partial service brake system	S7.8.2	S5.5.2
8. Parking brake test (three-wheeled motorcycles only)	S7.9	S5.6
9. Water recovery test	S7.10	S5.8
10. Design durability	S7.11	S5.8

capable of attaining a specified speed, its service brakes shall be capable of stopping the vehicle from the multiple of 5 mph that is 4 mph to 8 mph less than the speed attainable in 1 mile, within stoppping distances that do not exceed the stopping distances specified in Table 1.

S5.1 Required equipment—split service brake system. Each motorcycle shall have either a split service brake system or two independently actuated service brake systems.

S5.1.1 Mechanical service brake system. Failure of any component in a mechanical service brake system shall not result in a loss of braking ability in the other service brake system on the vehicle.

S5.1.2 Hydraulic service brake system. A leakage failure in a hydraulic service brake system shall not result in a loss of braking ability in the other service brake system on the vehicle. Each motorcycle equipped with a hydraulic brake system shall have the equipment specified in S5.1.2.1 and S5.1.2.2.

S5.1.2.1 Master cylinder reservoirs. Each master cylinder shall have a separate reservoir for each brake circuit, with each reservoir filler opening having its own cover, seal, and cover retention device. Each reservoir shall have a minimum capacity equivalent to one and one-half times the total fluid displacement resulting when all the wheel cylinders or caliper pistons serviced by the reservoir move from a new lining, fully retracted position to a fully worn, fully applied position. Where adjustment is a factor, the worst condition of adjustment shall be used for this measurement.

S5.1.2.2 [Reservoir labeling. Each motorcycle shall have a brake fluid warning statement that reads as follows, in letters at least 3/32 of an inch high:

"**WARNING:** Clean filler cap before removing. Use only _______ fluid from a sealed container." (Inserting the recommended type of brake fluid as specified in 49 CFR § 571.116, e.g. DOT 3)

The lettering shall be—

(a) Permanently affixed, engraved or embossed;

(b) Located so as to be visible by direct view, either on or within 4 inches of the brake fluid reservoir filler plug or cap; and

(c) Of a color that contrasts with its background, if it is not engraved or embossed. (38 F.R. 14753—June 5, 1973. Effective: 1/1/74)]

S5.1.3 Split service brake system. In addition to the equipment required by S5.1.2 each motorcycle equipped with a split service brake system shall have a failure indicator lamp as specified in S5.1.3.1.

S5.1.3.1. Failure indicator lamp.

(a) One or more electrically operated service brake system failure indicator lamps that is mounted in front of and in clear view of the driver, and that is activated—

(1) In the event of pressure failure in any part of the service brake system, other than a structural failure of either a brake master cylinder body in a split integral body type master cylinder system or a service brake system failure indicator body, before or upon application of not more than 20 pounds of pedal force upon the service brake.

(2) Without the application of pedal force, when the level of brake fluid in a master cylinder reservoir drops to less than the recommended safe level specified by the manufacturer or to less than one-half the fluid reservoir capacity, whichever is the greater.

(b) All failure indicator lamps shall be activated when the ignition switch is turned from the "off" to the "on" or to the "start" position.

(c) Except for the momentary activation required by S5.1.3.1(b), each indicator lamp, once activated, shall remain activated as long as the condition exists, whenever the ignition switch is in the "on" position. An indicator lamp activated when the ignition is turned to the "start" position shall be deactivated upon return of the switch to the "on" position unless a failure exists in the service brake system.

(d) Each indicator lamp shall have a red lens with the legend "Brake Failure" on or adjacent to it in letters not less than 3/32 of an inch high that shall be legible to the driver in daylight when lighted.

S5.1.4 Parking Brake. Each three-wheeled motorcycle shall be equipped with a parking brake of a friction type with a solely mechanical means to retain engagement.

APPENDIX B

DISCUSSION OF STATISTICAL TECHNIQUES

DISCUSSION OF STATISTICAL TECHNIQUES

INTRODUCTION

The field of statistics has grown out of a variety of disciplines such as political science, economics, biology, geology and agricultural genetics. Statistical techniques address a variety of problems faced by each of these disciplines. During this century, various mathematical foundations have been constructed for the field of statistics and many of the seemingly disparate techniques have been shown to be closely related in terms of their mathematical content. This similarity between techniques developed in different fields is due to the underlying similarity of the problems addressed in these fields: namely, successfully making inferences about a larger parent population, given the tremendous variation in the sampled data.

Statistics involves reducing the complexity of large amounts of data, so hypothesized relationships can be tested, while controlling for possible sources of error and extraneous variation. Some researchers emphasize statistical use of sample characteristics to make inferences about population characteristics. Some emphasize statistical use of hypothesized models and the concomitant techniques of parameter estimation, parameter testing and assessment of "goodness of fit."

Irrespective of particular emphasis, statistics is useful for the simple reason that many of the facts we wish to know are only knowable at great cost in time and effort and so we are *forced* to use a "sample" of manageable size to provide us with an approximate understanding of the situation. Economically, statistics allows us to arrive at highly probable answers by analyzing only a small subset of information on the total population considered.

In a field such as statistics where techniques have been developed from many different perspectives,it is not surprising to find that supposedly different techniques overlap in applicability and indeed sometimes may be shown to be equivalent. With the advent of readily available computers and statistical software, numerous investigators in the life sciences and natural sciences are discovering for themselves the usefulness of using a multiplicity of techniques to explore their data. For, while it is the rare data set that can satisfy all the technical assumptions of any given statistical technique, it is *also* the rare statistical technique that is so "unstable" as to demand that all of its technical assumptions be met exactly. This property of being "robust," i.e., continuing to produce reasonable answers under a variety of unreasonable conditions, is enjoyed by many of the statistical techniques that are applicable to the data bases available for the evaluation of the effectiveness of Federal Motor Vehicle Safety Standards (FMVSS). Indeed, today many of the classical statistical techniques are being rebuilt in more robust form and there are available a variety of robust modifications to the processes of estimation that are amenable to any linear model situation, e.g., regression, analysis of variance, and loglinear analysis [1].

Besides both the creation of software packages supplying a variety of high quality statistical procedures and the development of robust techniques of inference, the last decade has also seen the development of new techniques, new software and, indeed, a new way of thinking about data analysis. John Tukey was one of the first to call attention to the split in statistical analysis between those textbook techniques that are perfect for well controled experiments and the less formal techniques and procedures that are useful for undesigned experiments or when simply "exploring" new data. Tukey christened the former "confirmatory data analysis" and the latter "exploratory data analysis." The original analogy used to contrast the two sets of attitudes was to point to the differences between formal court proceedings used to arrive at "the truth" *versus* the more intuitive and less formal inferential behavior that a good detective, such as Sherlock Holmes, would allow himself in the process of collecting evidence that might or might not be used in a formal court proceeding at some later data. While exploratory data analysis is never an answer in itself, experience with its techniques has shown that it has unique value to the researcher when faced with large, complex and perhaps faulty data bases. An introduction to the wealth of techniques in exploratory data analysis is available from Tukey's text and computer software for many of these techniques exists at a number of the larger university computer centers [2].

Recently the field of data analysis (as differentiated from formal mathematical statistics) has also been influenced by the development of useable "Bayesian" and pseudo-Bayesian techniques of inference. While these techniques are firmly rooted in a purely mathematical foundation of inference, their acceptance has been limited, due to the continuing controversy among statisticians as to their appropriateness in various situations. The nub of the problem is that Bayesian techniques make a point of allowing prior information (sometimes subjectively arrived at) to influence the results of estimation, model building and, indeed, the complete process of inference from data. Such honesty about the use of subjective information obviously is disturbing to those who feel that data analysis both can and should be a totally objective process. However, the benefits of Bayesian and pseudo-Bayesian techniques are quite attractive and their use by a researcher in dealing with a real analysis problem should not be seen as an endorsement of the full Bayesian philosophy of inference. Bayesian-like techniques of data smoothing and of simultaneously estimating many parameters are of real value when trying to reduce the complexity and dimensionality of multidimensional data sets. Similarly, such techniques allow a researcher to incorporate previous data bases into the analysis of his present data base in a logical, mathematically tractable and theoretically desirable way. Most classical statistical procedures are hard put to find a way to use such prior information when exploring a new data base.

When addressing the particular problems of measuring the effectiveness of various FMVSSs using the existing data bases, it would be unwise to become too attached to any one approach to the analysis. Given the variety of data bases and the variety of problems each data base presents, only a healthy electicism towards statistical method and philosophy will provide the "robustness" of inference and thoroughness of analysis necessary for adequate assessment of effectiveness. The following discussion of different statistical techniques is provided in the spirit of fostering such healthy electicism. Each technique is applicable to some of the existing data sets and, in fact, it would often be valuable to explore a particular data base using many such techniques jointly or sequentially. For example, many data bases provide the researcher with multidimensional tables of frequency counts in a number of categories. Such data are amenable to many of the exploratory data analytic techniques to look for potential structure; they are also amenable to a number of data reduction techniques such as principal component analysis and factor analysis in an effort to reduce its complexity and dimensionality; more formally, the data or some transformation of the data may be modeled, explored and smoothed using loglinear analysis. Similar analyses may be tried using classical linear models methods and "trusting" in the robustness of such methods [3]; finally, Bayesian-like techniques are applicable when such tables of counts are updated periodically and one wishes to use the structure of past tables to influence the analysis of the most recent table.

The point is that a thorough assessment of effectiveness demands a willingness to apply many techniques to each collection of data and to assess findings of each technique in light of the quirks of the data and in light of the findings of other techniques.

This appendix is intended to provide an introduction to the concepts, vocabulary and logic of some of the many statistical and data analytic techniques that are applicable to the evaluation of the effectiveness of Federal Motor Vehicle Safety Standards.

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ANALYSIS OF COVARIANCE

The analysis of covariance (ANACOVA) is a statistical procedure which provides a model for the behavior of a continuous dependent variable as a linear function of a set of independent variables, some of which are continuous and some of which are discrete. In this sense it combines the features of both a regression analysis (continuous independent variables) and an analysis of variance (discrete independent variables). The entire problem is handled conditionally on the values of the independent variables so that the only variation assumed is in the dependent variables.

The most natural application of ANACOVA occurs when modeling observations (Y's) which have been taken in the format of one of the usual analysis of variance designs, but other observable variables (X's) are available to the researcher and they are suspected to be contributing significant effects to the magnitudes of the Y's apart from any effects in the analysis of variance portion. Then one ought to add to the model a regression of the Y's on these X's to better explain the variability of the former. The X's are called covariates or concomitant variables. The approach is to adjust the Y's according to the associated X's and only then use the adjusted Y's for analysis and interpretation of the data according to the original analysis of variance design.

An example will clarify the discussion of the previous paragraphs. Suppose we wish to study the braking distance to full stop for different vehicles. We take a set to such observation (Y's). Among the explanatory variables we might consider are:

(a) Brake type - disc, drum, disc/drum (categorical/discrete).
(b) Vehicle speed at time brakes are applied (continuous).
(c) Road surface condition - wet, dry, etc. (categorical/discrete).
(d) Vehicle weight (continuous).
etc.

If, for example, we wish to compare brake types, it is clear that any effects on stopping distance due to differences in brake types will be totally masked by the effect of vehicle speed at the time the brakes are applied. Hence, to run a meaningful test of differences in performance of brake types requires removing the effects of differing vehicle speeds at the time the brakes are applied. In this setting a test of differences among brake types would be handled by an analysis of variance while the differing vehicle speeds would be viewed as values of an independent regression variable. The addition of further discrete variables to this discussion elaborates the analysis of variance portion of the model while the addition of further continuous variables results in additional independent regression variables. However, the basic idea is unaffected. Ultimately, hypothesis tests will be developed for the presence of effects for either type of variable.

The important assumption usually demanded for a valid analysis of covariance is that the concomitant variables are unaffected by (i.e., independent of) the analysis of variance variables. In the above example, for instance, it is reasonable to assume that the vehicle speed at the time the brakes are applied is independent of the type of brake system on the vehicle. Even when such independence may not quite hold, one can still apply an analysis of covariance. However, the interpretation of the results of such an analysis must be carefully considered due to the confounding of variable effects.

We now formally develop the analysis of covariance (ANACOVA). For convenience we assume one categorical (or discrete) variable and one continuous varable and then the model:

$$(1) \quad Y_{ij} = \mu + \alpha_i + \beta(X_{ij} - \bar{X}..) + \varepsilon_{ij}$$

$$j = 1, \ldots, n_i, \; i = 1, \ldots, k$$

with

$$\bar{X}.. = \sum_{i=1}^{k} \sum_{j=1}^{n_i} X_{ij}/n \quad \text{and} \quad n = \sum_{i=1}^{k} n_i$$

In this model we would interpret Y_{ij} as the observed stopping distance of the j^{th} vehicle (or j^{th} stop of one vehicle) having brake type i. X_{ij} is the associated vehicle speed at the time the brakes were applied and is centered about $\bar{X}..$; the overall mean of the X_{ij}'s and ε_{ij} is the model error for the observations. These errors are assumed normally distributed and independent (the latter being quite reasonable in our example). The parameter μ is the overall mean braking effect; α_i is the effect due to brake type i; and β is the regression coefficient for the independent variable, vehicle speed.

Two hypotheses are of interest to test

H_1: $\alpha_1 = \alpha_2 = \ldots\alpha_k = 0$, and

H_2: $\beta = 0$

H_1 tests for the brake effects, i.e., no differences in performance of the different brake types. H_2 tests whether the inclusion of the covariate actually explained a significant amount of the variation in the Y's. Presumably H_2 will be rejected or else we would not be considering the X's in the first place. In our example, certainly vehicle speed at the time the brakes are applied affects the vehicle's stopping distance.

From (1)

$$Y_{ij} - \beta\,(X_{ij} - \bar{X}..)$$

would be exactly the adjusted observation we would want for testing H_1. Unfortunately, since β is unknown, these adjusted Y_{ij} are not "observable." However, if b is an estimate of β we will define

$$Y_{ij} - b\,(X_{ij} - \bar{X}..)$$

as the adjusted value of Y_{ij} (usually said to be adjusted to $\bar{X}..$). This adjustment of the Y observations will change the entire picture of the experiment.

Let us introduce convenient and somewhat "standard" notation for the various sums of squares to be considered.

$$S_{yy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_{..})^2$$

$$T_{yy} = \sum_{i=1}^{k} n_i (\bar{Y}_{i.} - \bar{Y}_{..})^2$$

$$E_{yy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_{i.})^2$$

$$S_{xx} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2$$

$$T_{xx} = \sum_{i=1}^{k} n_i (\bar{X}_{i.} - \bar{X}_{..})^2$$

$$E_{xx} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2$$

$$S_{xy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})(Y_{ij} - \bar{Y}_{..})$$

$$T_{xy} = \sum_{i=1}^{k} n_i (X_{i.} - \bar{X}_{..})(\bar{Y}_{i.} - \bar{Y}_{..})$$

$$E_{xy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})$$

where

$$\bar{X}_{i.} = \sum_{j=1}^{n_i} X_{ij}/n_i \text{ and } \bar{X}_{..} \text{ as before}$$

$$\bar{Y}_{i.} = \sum_{j=1}^{n_i} Y_{ij}/n_i \text{ and } \bar{Y}_{..} = \frac{\sum_{i=1}^{k} n_i \bar{Y}_{i.}}{n} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} Y_{ij}}{n}$$

It is easy to verify that $S_{yy} = T_{yy} + E_{yy}$, $S_{xx} = T_{xx} + E_{xx}$ and $S_{xy} = T_{xy} + E_{xy}$. Computational formulas for these quantities may be easily developed by expansion.

First consider the hypothesis H_2. From (1) we may fit a regression line for each of the n_i observations at a fixed i. The resultant estimators would be

$$b_i = \frac{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})}{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i}\ )^2} \qquad i = 1, \ldots. k$$

Pooling these estimations we obtain:

$$\bar{b} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2} = \frac{E_{xy}}{E_{xx}}$$

$\bar{b}^2 E_{xx}$ is the sum of squares associated with $\bar{b}$ while $E_{yy} - \bar{b}^2 E_{xx}$ is the appropriate error sum of squares. The former has one degree of freedom associated with it while the latter has n - (k+1) = n-k-1. Thus, we can test H_2 using:

$$(2) \qquad \frac{\bar{b}^2 E_{xx}}{(E_{yy} - \bar{b}^2 E_{xx}) / (n-k-1)}$$

The statistic (2) is distributed as F with 1 and n-k-1 degrees of freedom and we reject H_2 for large values.

While $\bar{b}$ seems to have arisen in a rather arbitrary manner,one can show that it is, in fact, the least squares estimator of β.

Returning to H_1, under this hypotheses (1) becomes

$$(3) \qquad Y_{ij} = \mu + \beta (X_{ij} - \bar{X}_{..}) + \varepsilon_{ij}$$

The model in (3) is just a simple linear regression for the entire set of n observations. The least squares estimate of β for such a model is

$$\hat{b} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})(Y_{ij} - \bar{Y}_{..})}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2} = \frac{S_{xy}}{S_{xx}}$$

$\hat{b}^2 S_{xx}$ is the sum of squares associated with $\hat{b}$ while $S_{yy} - \hat{b}^2 S_{xx}$ is the error sum of squares for fitting (3). The difference between the error sum of squares of the reduced model (3) and the error sum of squares of the full model (1) is the sum of squares associated with the α_i, i.e., with H_2 and equals

$$(S_{yy} - \hat{b}^2 S_{xx}) - E_{yy} - \bar{b}^2 \; E_{xx})$$

This sum of squares may be shown to have k-1 degrees of freedom associated with it while as before the error sum of squares for the full model has n-k-1. Thus, we can test H_1 using

(4) $$\frac{[(S_{yy} - \hat{b}^2 S_{xx}) - (E_{yy} - \bar{b}^2 E_{xx})]/(k-1)}{(E_{xx} - \bar{b}^2 E_{xx})/(n-k-1)}$$

The statistic (4) is distributed as F with k-1 and n-k-1 degrees of freedom and we reject H_1 for large values of F.

In addition to performing the F tests in (2) and (4) it is customary to present a table of adjusted $\bar{Y}_i$'s as an aid in interpretation. The adjusted $\bar{Y}_i$'s are defined as

$$\bar{Y}_i - \bar{b}\ (\bar{X}_{i.} - \bar{X}_{..})$$

In our example the adjusted $\bar{Y}_i$ would be the average stopping distance for vehicle(s) with brake type i adjusted for speed when brakes were applied. These adjusted average stopping distances can be compared directly to assess differences in average performance of the various brake systems.

The reader seeking further detail on the analysis of covariance may consult Bancroft or Snedecor and Cochran for elementary discussions [1,2].

To illustrate the Analysis of Covariance, consider the following fictitious data set.

Vehicle Number	Brake Configuration		Speed at Time Brakes Applied	Stopping Distance*
1	Drum	Type 1	30	80 (4.38)
2	Drum	Type 1	40	105 (4.65)
3	Drum	Type 1	50	170 (5.13)
4	Drum	Type 1	60	240 (5.48)
5	Disc/Drum	Type 2	30	64 (4.16)
6	Disc/Drum	Type 2	40	92 (4.52)
7	Disc/Drum	Type 2	60	226 (5.42)
8	Disc	Type 3	30	60 (4.09)
9	Disc	Type 3	50	140 (4.90)
10	Disc	Type 3	60	210 (5.35)

*Values in parentheses are logarithms of stopping distances, which will be used in the alternative analysis. These values are plotted in Figure B-1.

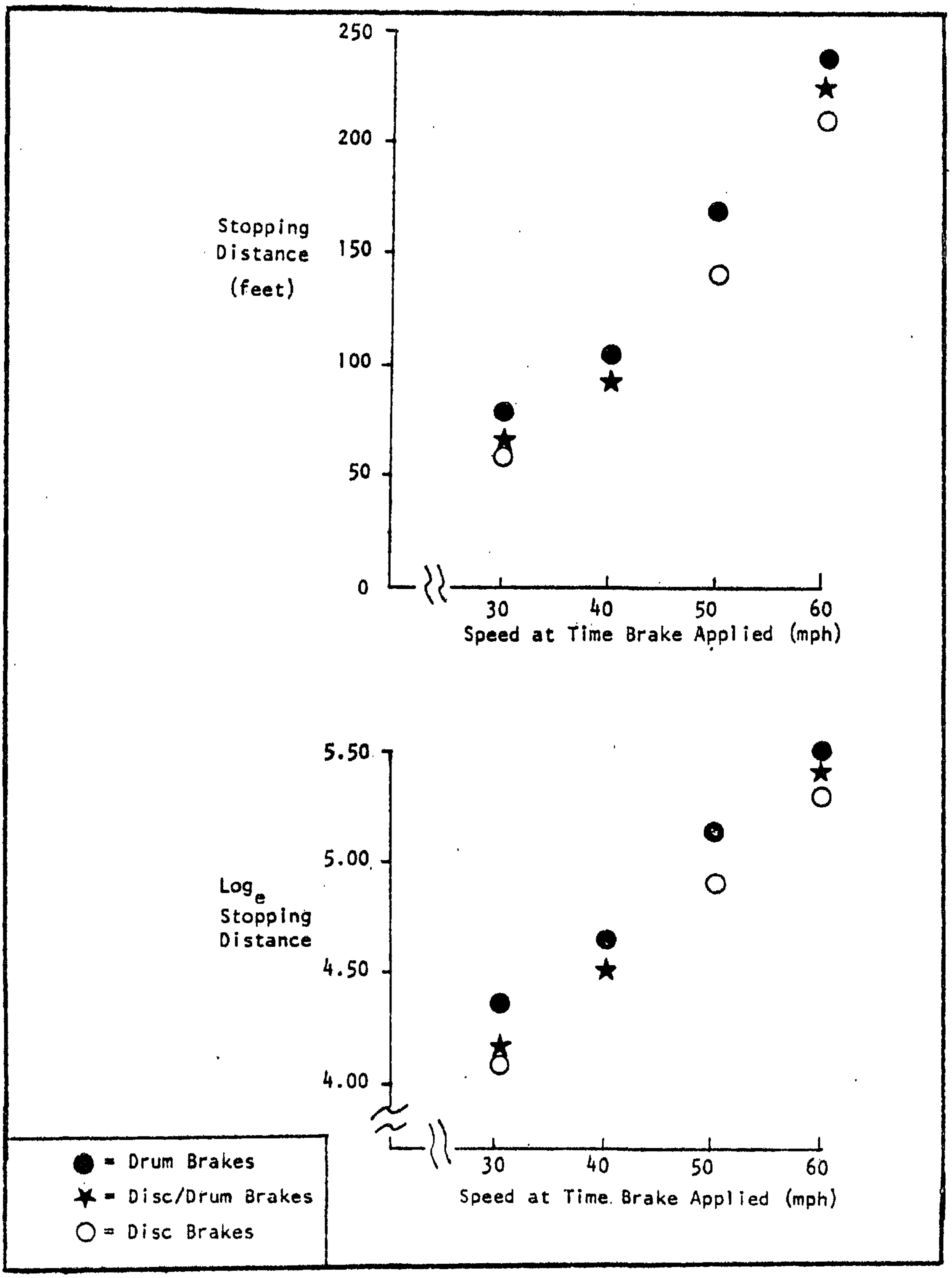

Figure B-1. Plots of fictitious stopping distances.

For this set of data we compute:

$$S_{yy} = 49{,}372.1 \ , \ S_{xx} = 1450 \ , \ S_{xy} = 8095$$

$$E_{yy} = 47{,}830.1 \ , \ E_{xx} = 1433.31 \ , \ E_{xy} = 8048.3$$

$$T_{yy} = 1542.0 \ , \ T_{xx} = 16.7 \ , \ T_{xy} = 46.7$$

Our pooled estimate of β is

$$\hat{\beta} = \frac{E_{yy}}{E_{xx}} = 5.6$$

The associated F statistic for H_o: $\beta = 0$

is $$\frac{(E_{xy}^2/E_{xx})/1}{(E_{yy}-E_{xy}^2/E_{xx})/7} = \frac{45{,}192.4}{376.8} = 119.9$$

which is extremely significant,as would be expected.

To test H_o: $\alpha_1 = \alpha_2 = \alpha_3 = 0$, we compute the associated F statistic

$$\frac{[(S_{yy}-S_{xy}^2/S_{xx}) - (E_{yy}-E_{xy}^2/E_{xx})]/2}{(E_{yy}-E_{xy}^2/E_{xx})/7} = \frac{771.01}{376.80} = 2.05$$

which yields a description level of significance of approximately 0.2 under an F distribution with 2 and 7 d.f. respectively. While this is not terribly significant, it suggests that with more observations the hypothesis may be more decisively rejected.

The adjusted $\bar{Y}_{i.}$'s are

$$\text{adj } \bar{Y}_{1.} = \bar{Y}_{1.} - \hat{\beta}\ (\bar{X}_{1.} - \bar{X}_{..}) = 141.25 - 5.6\ (45-45) = 141.25$$

$$\text{adj } \bar{Y}_{2.} = \bar{Y}_{2.} - \hat{\beta}\ (\bar{X}_{2.} - \bar{X}_{..}) = 127.33 - 5.6\ (43.33-45) = 136.67$$

$$\text{adj } \bar{Y}_{3.} = \bar{Y}_{3.}\ \ \hat{\beta}\ (\bar{X}_{3.} - \bar{X}_{..}) = 136.67 - 5.6\ (46.67-45) = 127.33$$

Our variance estimate is $\hat{\sigma}^2 = 276.8$ with $\hat{\sigma} = 19.4$. Thus $\hat{\sigma}_{\text{adj } \bar{Y}_{1.} - \text{adj } \bar{Y}_{2.}}$ $= \hat{\sigma}_{\text{adj } \bar{Y}_{1.} - \text{adj } Y_{3.}} = 14.7$ and $\hat{\sigma}_{\text{adj } \bar{Y}_{2.} - \text{adj } \bar{Y}_{3.}} = 15.8$ and we see that the difference in adjusted $\bar{Y}_{i.}$ is within the standard deviation, an insignificant finding.

However, a bit of study of the data indicates that speed at time brakes are applied (X) and stopping distance (Y) are not linearly related but are related approximately exponentially; (this is in fact suggested by numerous studies), i.e.,

$$Y = ae^{bx}$$

Hence, log Y and X would be approximately linearly related. Suppose we redo the analysis of covariance with log stopping distance as the dependent variable. The log stopping distances are given in parenthesis in the last column of the data table.

For this new ANACOVA we have

$S_{yy} = 2.47$	$S_{xx} = 1450$	$S_{xy} = 58.8$
$E_{yy} = 2.39$	$E_{xx} = 143.3$	$E_{xy} = 58.33$
$T_{yy} = 0.08$	$T_{xx} = 16.7$	$T_{xy} = 0.47$

This time $\hat{\beta} = 0.041$ and the associated F statistic for $H_o: \beta = 0$ is 1013.2. Again to test $H_o: \alpha_1 = \alpha_3 = 0$, we obtain

$$F = \frac{0.0666/2}{0.0164/7} = 14.2$$

That is, now F is significant at level 0.005. The transformation of the data has drastically improved the fit of the model and dramatically revealed the differences between the brake systems. The differences are also shown by the adjusted log $\bar{Y}_{i.}$ which are:

$$\text{adj log } \bar{Y}_{1.} = 4.91$$

$$\text{adj log } \bar{Y}_{2.} = 4.77$$

$$\text{adj log } \bar{Y}_{3.} = 4.74$$

Again, if we look at $\hat{\sigma}^2 = 0.0023$, we have $\hat{\sigma} = 0.048$. Thus, we have $\hat{\sigma}_{\text{adj log } \bar{Y}_{1.} - \text{adj log } \bar{Y}_{2.}} = \hat{\sigma}_{\text{adj log } \bar{Y}_{1.} - \text{adj log } \bar{Y}_{3.}} = 0.036$ and $\hat{\sigma}_{\text{adj log } \bar{Y}_{2.} - \text{adj log } \bar{Y}_{3.}} = 0.039$. Now the difference in adjusted log $\bar{Y}_{i.}$ can exceed (between 1 and 3) 4 times the standard deviation, a highly significant finding.

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LOGLINEAR MODELS

Most of the classical statistical techniques such as regression analysis, correlation analysis, analysis of variance and their multivariate extensions concern themselves with the problems of finding, describing and assessing the significance of relationships between continuous variables. Analysis of variance (and related techniques) provide methods to assess the variability of a continuous variable on the basis of the presence or absence of discrete variables and so it provides a possible beginning point for the analysis of a discrete dependent variable behavior as a function of discrete independent design variables.

For many years the standard practice when faced with truly categorical or frequency count data was to use analysis of variance even though its use could not be generally supported by theory. However, through the tricks of transforming the original dependent variable, theoretical justification for analysis of variance of discrete data could be argued.

Recently the problem of correctly analyzing discrete data has been put on a solid theoretical footing with the development of loglinear models, which are described by Haberman, and Bishop, Fienberg and Holland [4,1]. Rather than continue to belabor the mathematics of the normal probability distribution that forms the backbone of the linear models involved in regression analysis and analysis of variance, a number of researchers have applied themselves to the development of a body of theory that is specifically designed for the analysis of frequency count data, especially frequency count data that take the form of cross-classified tables of counts.

The essential idea that allows development of such models is replacing most of the normal distribution by the Poisson distribution as a starting point for any theoretical discussion. The Poisson and the related multinomial distribution are the basic sampling distributions used in frequency count data. Just as the normal distribution enjoys the properties of being mathematically tractable, broadly applicable, and theoretically justifiable for continuous data,so too does the Poisson enjoy the same properties for discrete data. By modeling frequency counts as random variables generated by Poisson processes, the problem of analyzing such sets of counts can be couched in terms of the well developed theory of estimation for exponential families of frequency distribution [4,6].

In matrix notation the classical models can be expressed as follows: let $\underset{\sim}{Y}$ be a vector of observed values, let $\underset{\sim}{X}$ be a design matrix, let $\underset{\sim}{\beta}$ be a vector of model parameters, then any of the standard regression and analysis of variance models may be expressed as

$$E(\underset{\sim}{Y}) = \underset{\sim}{X}\underset{\sim}{\beta} \qquad (1)$$

where $E(\cdot)$ is the usual expectation operator. Loglinear models may be expressed similarly by letting $\underset{\sim}{f}$ be a vector of frequencies, $\underset{\sim}{T}$ a design matrix and $\underset{\sim}{c}$ a vector of model parameters, then the loglinear model is given as

$$\ell n\ E(\underset{\sim}{f}) = \underset{\sim}{T}\ \underset{\sim}{c} \qquad (2)$$

where ℓn is the logarithm function.

Once the model, (2), is set up, the problem of estimating the vector of parameters $\underset{\sim}{c}$ must be considered. Concomitantly the problem of estimating the actual predicted values, $E(\underset{\sim}{f})$, must be faced. Fortunately, if one solves either problem, the other is automatically solved.

Various researchers have suggested various techniques to solve the estimation problem. The major schools of thought can be categorized as the maximum likelihood approach [1,4], the minimum discrimination information approach [5] and the weighted least squares approach [3]. All of these approaches are identical asymptotically and, more realistically, they all seem to agree on reasonable size data bases. However, there is no proof that for finite samples they would always "agree." The choice of technique is really a matter of specific application, complexity of analysis desired, and ease of computation. For most loglinear models as applied to cross-classified data, the maximum likelihood approach offers the user an easy algorithm to be employed to compute E(f) under the model and to, therefore, estimate the vector of parameters c. The algorithm is called iterative proportional fitting and dates back to 1940 when it was used to adjust tabled data so that the table's marginal distributions would "agree" with some desired standard distribution [2]. (See the Adjusting Rates section of this appendix for more discussion of the use of the iterative proportional fitting algorithm.) For situations in which more than just "model fitting" is desired, then a generalized Newton-Raphson technique must be used to solve the maximum likelihood equations or one must forego maximum likelihood and turn to one of the other techniques. Newton-Raphson maximum likelihood, weighted least squares and minimum discrimination information techniques all demand the ability to invert large matrices, but they all provide the user with the necessary parameter variance-covariance matrix needed for testing and setting confidence limits. Simply put, the detail of analysis desired is directly related to the computational power to which one must have access.

Regardless of the particular estimation techniques used to fit and test models for categorical data, it is now possible to explore such data from a sound theoretical footing with the use of loglinear analysis.

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CLUSTERING

A cluster is a group of similar objects. As such, clusters are very familiar; indeed, almost all words are cluster labels; car, house, physician, milkshake, green--all conjure in the mind generic objects or qualities. Clusters serve many purposes, of which three major ones are *summarizing, prediction,* and *theory development.*

Clusters summarize because objects are described by properties of the clusters to which they belong. All the details particular to the object and irrelevant to the present purpose are ignored. For example, in response to "What bit the mailman?" the reply, "a dog," or, "an Irish Setter," is better than "Sir Oliver Flaherty,..." where the pedigree has been omitted, even though all those responses describe the same animal.

Clusters predict because we expect objects in the same cluster to be similar, or to share similar properties. When the clusters being examined are sufficiently distinct (and particularly when this is unexpected), there is great incentive to uncover the reasons underlying the clustering. This may lead to new theory, and thus, the third major use of clustering.

The recent formal development of clustering techniques began in the 1950's spurred on by biologists interested in numerical taxonomy. Many of the techniques in use are eminently reasonable, but have as yet no sound statistical basis.* In the introduction to his book, *Exploratory Data Analysis,* Tukey says that it is well to know what you can do before you measure how well you have done it [6].

To the extent that methods of measuring "how well one has done" are still unavailable, clustering remains an art to be practiced with care. The ready availability of computer programs that cluster has probably led to an many unsound and incorrect analyses as the blind use of multiple regression.

Methods of Clustering

Clusters can be grouped as follows:

- Partitions
- Hierarchical clusters
- Clumps

In a partition, an object cannot belong to two clusters simultaneously, and every object is in a cluster. In hierarchical clusters there are different levels of clusters. At each level the objects are partitioned. At the highest level, all the objects are in a single cluster. Lower level clusters are either wholly within or wholly without higher level clusters--the classic example being the classification of animals: a lower cluster being "primates," which is part of "mammals," a subgroup of "vertebrates," etc. The hierarchy is often described by a tree or dendrogram,

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*However, it is reassuring to note that many sturdy babies have parents totally ignorant of genetics and physiology.

with high level clusters as big branches, lower level ones as twigs. The objects clustered would be leaves. Clumps are clusters that can overlap. In later sections, unique assignment of objects to clusters is the main interest and clumping is not considered.

So far, the objects to be clustered have not been clearly defined. In most applications the data are arranged as an array, with cases as rows and variables as columns. Usually the objects to be clustered are cases and the variables are used to determine cluster assignment. After clustering, the average or modal value of a variable in a cluster is the typical value for a case in the cluster. The cases have been reduced to a lesser number of clusters. The variables can be reduced in a similar manner. If linear combinations of variables are considered, the first few principal components or some small number of factors from a factor analysis might be kept. The clusters then correspond to the principal components or factors. There are also techniques that simultaneously cluster both cases and variables.

Some Specific Clustering Techniques

For each method described, the kind of data for which it is appropriate, the nature of the clusters produced and an illustrative example are given. The description of the technique is pared to the motivating rationale; greater detail and complete algorithms can be found elsewhere in the references.

K-means

This technique uses Euclidean distances. The variables used in the distance calculation should be continuous and properly scaled. Given a specific number K of clusters, it allocates objects to clusters so as to minimize the within-cluster sum of squares. The allocation is achieved by iterative swapping of points between clusters, and a version of the algorithm is soon to be available in the BMDP set of statistical computer programs.

The clusters produced by the K-means technique tend to be convex--if the clusters are expected to be snakelike, then K-means is inappropriate, as the "snake" generally will be broken into more than one cluster. See Figure B-2.

When the number of clusters, K, is changed, the new clusters need have no nice relationship to the old ones. Indeed, the question of how many clusters to use is still open, despite recent theoretical developments.

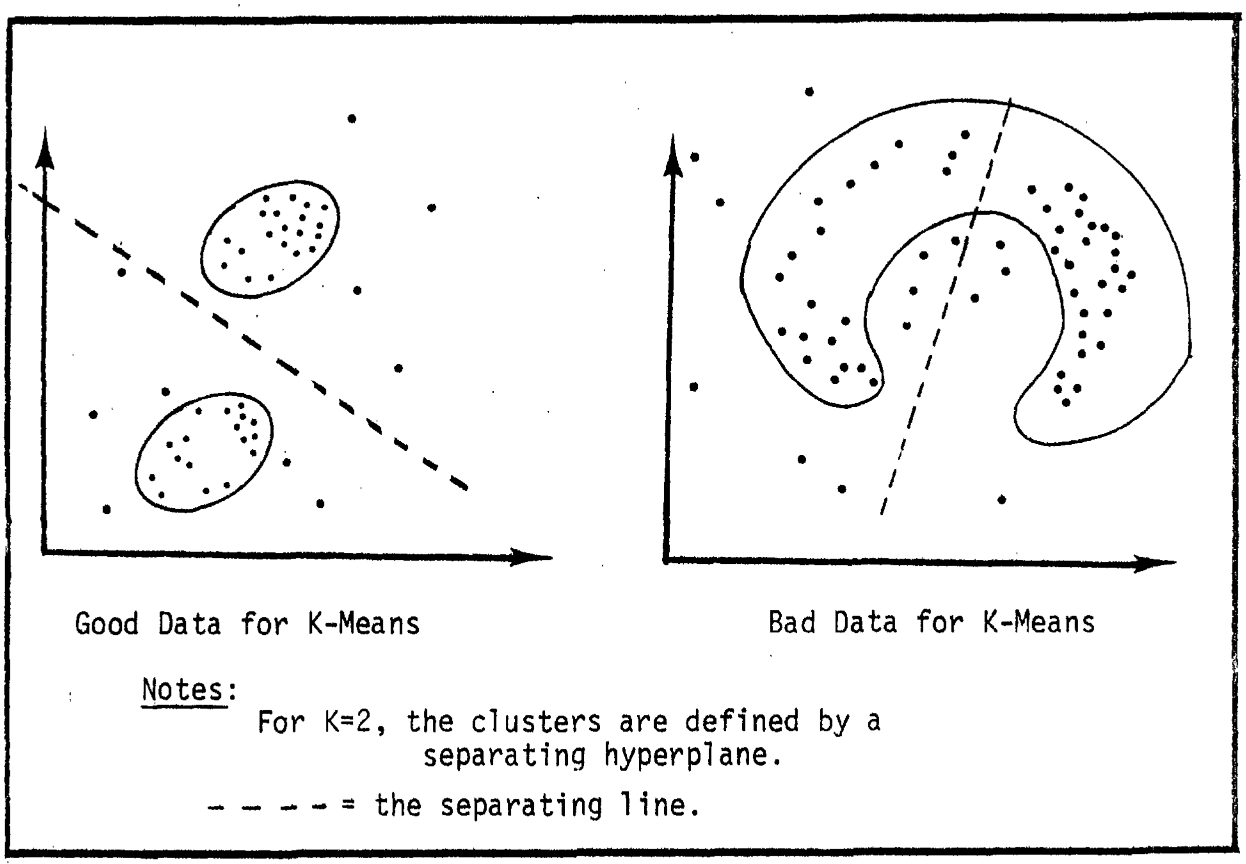

Figure B-2. K-means clustering.

Single Linkage

This method uses Euclidean distances, and it produces hierarchical clusters. Typical objects for which single linkage is a good technique are stars in the sky, and the corresponding clusters are constellations. With this example in mind (see Figure B-3) a clustering is determined by a threshold distance. If, by moving from star to star with jumps less than this threshold, it is possible to move from one star to some other star, then these stars are in the same cluster or constellation. When the threshold distance is increased, early clusters join to form larger ones. Single Linkage clusters are usually long and straggly, and are most unlikely to be convex. As such, they do not correspond to one's intuitive idea of a cluster being a distinct ball in multidimensional space. The fault, if any, lies with intuition, which is but the unusual and incomprehensible tamed by familiarity.

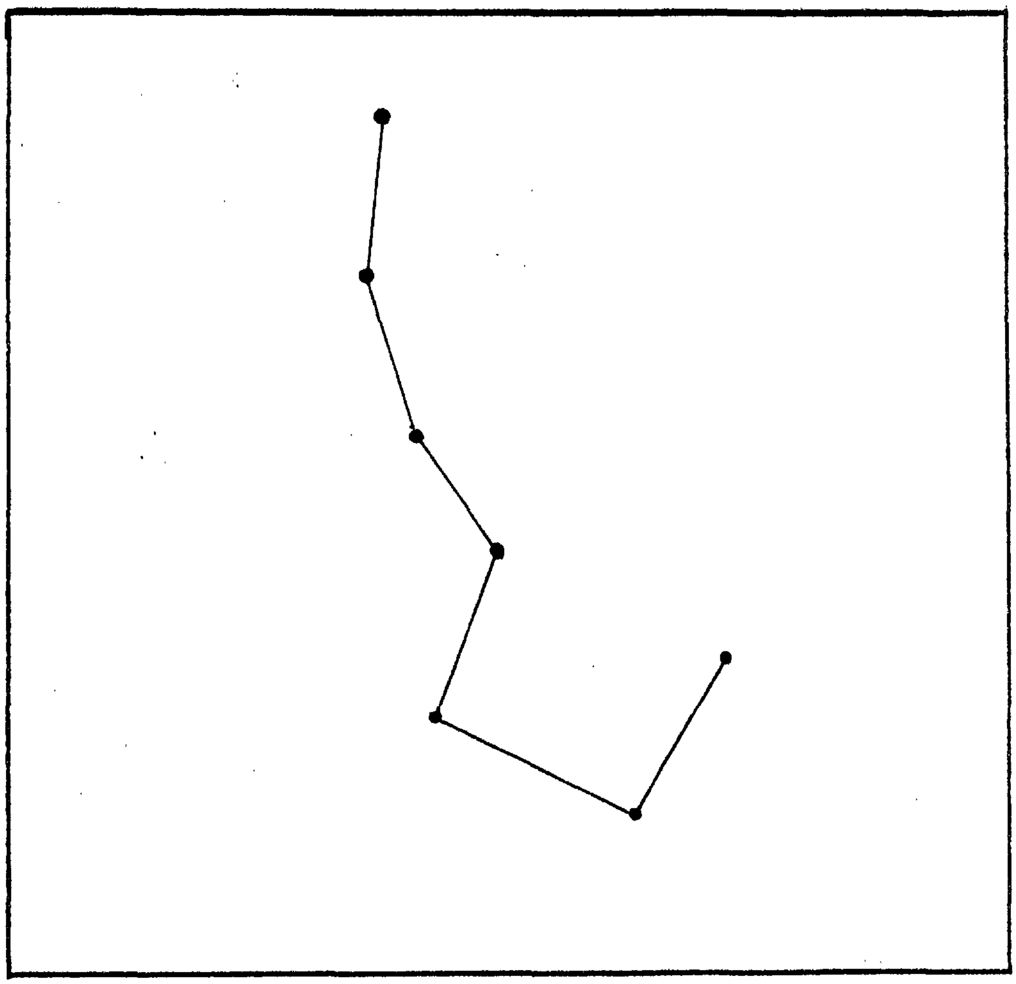

Figure B-3. The constellation Ursa Minor, with its single linkage cluster indicated.

Some Difficulties with Clustering

Almost all clustering algorithms work with distances. Once the clusters have been found, and compelling reasons for their existence unearthed, then good variables that separate the clusters can be defined. However, it is exactly these variables that we need to produce the clusters. This is not the "chicken or the egg" problem exactly, but it does show that the activity of clustering should be iterative: one clusters, then scrutinizes the results, and clusters again.

If variables are measured in different units--say speed in kilometers per hour, lengths in millimeters and distances in meters--they are not immediately comparable. They should be scaled before being used in calculating distances. The usual scaling standardizes using an inverse covariance matrix, to produce Mahalahobis-like distances. When doing this, it is most important to use the within cluster covariance matrices; even if the clusters are real, their positioning may lead to an overall covariance matrix that cannot show the individual clusters distinctly, as shown in Figure B-4.

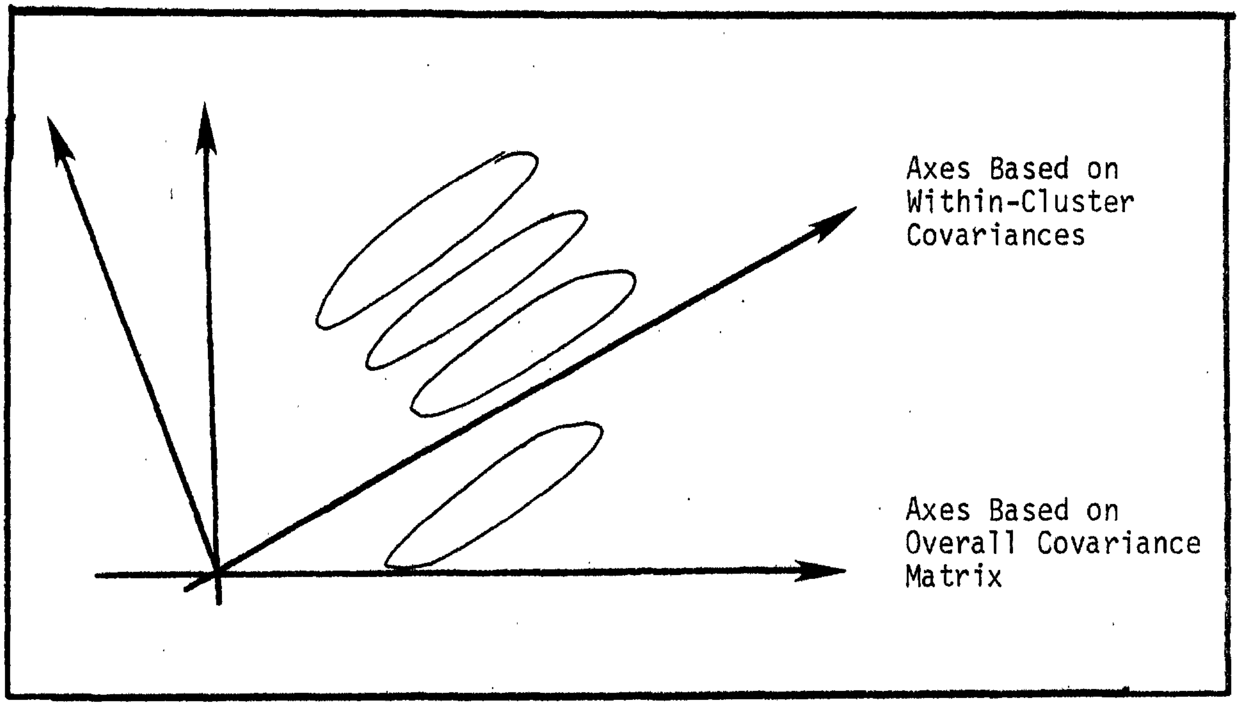

Figure B-4. Scaling with different covariance matrices.

Another question that has to be decided by the practitioner stems from the following: when many highly correlated measurements have been made on each object, the particular attribute measured is given importance corresponding to the number of measurements taken. Taken to extremes, only that attribute will be used in producing clusters. If Euclidean distance is used, this effect can be satisfactorily dealt with by using the principal components, each standardized to have unit variance, since the many essentially repeated measurements will tend to produce one principal component. However, by standardizing to unit variance, those principal components associated with the smallest latent roots, and which therefore correspond to random error in the data matrix, are given the same weight as the components with most of the information. Knowledge of both the clustering technique and the field in which it is applied is important if one is to guard against such possibilities.

The focus of much current research in clustering is how can the reality of clusters be assessed. For most clustering algorithms there is at best very limited theory leading to testable hypotheses. Most cluster validation is performed by running the algorithm on the data several times, omitting cases and/or variables at random. Those clusters that survive best are judged more likely to be actually present in the data. While the statistical theory can be circumvented by such devices, precise understanding of the relative merits of different clustering algorithms will develop only in conjunction with the theory.

References

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A thorough review of the literature to 1971.

[2] Hartigan, J.A. "Direct Clustering of a Data Matrix." *Journal of the American Statistical Association.* v. 67, no 337, March 1972 pp 123-129.

Methods of producing and displaying clusters directly on the data matrix are described. A very interesting paper, which rewards careful study.

[3] Hartigan, J.A. *Clustering Algorithms.* 1975 Wiley, New York.

Describes most of the common methods of clustering, and gives the then-known statistical theory,much of it for the first time.

[4] Van Ryzin, J. editor. *Classification and Clustering.* 1977 Academic Press, New York.

The proceedings of an advanced seminar, with many interesting papers. Particularly noteworthy are J. Kruskal on the relationship between multidimensional scaling and clustering, and I. J. Good on the purposes of clustering.

[5] Sokal, R.R. and P.H.A. Sneath. *Principles of Numerical Taxonomy.* 1963 W.H. Freeman and Company.

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MATCHING

Matching elements from two (or more) populations prior to making inferences about the differences between the populations has a long history in statistical studies. This is primarily due to the fact that matching is such an intuitively reasonable procedure.

Comparing similar elements to assess "treatment effects" rather than comparing, say, the two sampled population means seems like a reasonable procedure to use to reduce extraneous sources of variation that could possibly "mask" the treatment effect itself. Historically, it is this intuitively appealing notion that matching is, in effect, a "self blocking" technique useful for variance reduction that has made matching such a popular technique. Recently, matching has received added status as a straightforward method to reduce sampling costs in expensive experimental situations, e.g., experimental medical trials, surgical techniques or cancer treatment programs. Another recent application has been to apply matching in a *post hoc* fashion so as to "increase one's powers of inference" in non-experimental situations such as survey data.

It is especially the latter application of matching that is germane to the evaluation of FMVSSs using existing data bases, because we are often attempting to compare Pre- *versus* Post-Standard vehicles "free" of extraneous sources of variation. Matching is then very appealing as an easily understood method of variance reduction in observational evaluation studies such as the evaluation of Standards. However, there are definite methodological and even purely practical problems associated with matching. Over the last few years a number of researchers have strongly argued that matching is:

(1) Over-rated as a variance reduction technique.

(2) Expensive to implement, because even reasonably large data bases lose both in creating a large enough potential matching pool and then in searching for matches.

(3) Capable of producing extremely non-representative samples of "matched-pairs" neither member of which adequately reflects its parent population.

(4) Capable of actually masking certain effects related to the matching variables.

(5) Easily replaced by well-understood techniques of analysis of covariance and straightforward blocking, which is the most damaging observation.

Entry to this literature is afforded by the review articles of Cochran and Rubin, and McKinlay [1,2]. A less technical overview that sounds a cautionary note is the more recent article by McKinlay [3].

In conclusion, we do not recommend matching as one of the essential approaches to the analysis of the existing or proposed accident data bases. Our recommendation is based on the simple fact that for such large data bases it is methodologically sounder and more cost effective to use analysis of covariance and/or blocking as the basic approach to "controlled" comparisons of different groups. This is not to say that matching should not be used in the exploratory stages or even when asking specific questions--it should. Like aspirin, matching is not dangerous when used for specific small scale problems and when used in moderation. But is foolhardy when used to the exclusion of other more robust techniques or when used in situations, such as comparisons of large data bases, where it is expensive to implement, wasteful of potential data (the "unmatchables"), and potentially faulty in its implications.

References and Further Reading

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2. McKinlay, S. M. "The Observational Study--a review," *Journal of the American Statistical Association*, vol. 70, no. 351, 1975: 503-523.

3. McKinlay, S.M. "Pair-Matching--A Reappraisal of a Popular Technique," *Biometrics*, vol. 33, no. 4, 1977: 725-735.

ADJUSTING TABLES OF COUNTS OR RATES

There are many reasons why a data analyst must sometimes analyze and summarize "adjusted" data rather than original data. Most of the reasons are directly related to the fact that the raw data have certain undesirable properties due to difficulties that have occurred in the data generation and data collection processes.

Some frequently encountered situations and their related reasons for adjustment are:

The Direct and Indirect Methods of Adjusting Rates

These methods address the fact that rates of occurrence in various strata of different populations are not directly comparable if the populations have differing strata structures. This is true since the rates would reflect both differing strata structure and (possibly) population differences of interest to the analyst. It is necessary, therefore, to "hold" structure constant in some sense and only then proceed to make inferences about possible differences between populations. The direct adjustment method approaches the problem by creating a standard population structure and then applying each particular population's rates to this standard population. The result of such a process is a set of expected rates for each population that are comparable in the sense that they are all computed from an agreed-upon standard population structure but reflect individual population rates. The indirect adjustment method approaches the problem by creating a standard set of rates and then applying these standard rates to the number of exposed cases in each cell of the individual population's strata structure. The result is again a set of comparable expected rates for each of the populations. The classic technique used for creating a standard population structure is simply to use the sum of the individual populations; similarly, the classic technique to derive a standard set of rates is simply to sum the occurrences and exposures across population for each strata group. When the standard population or rates are chosen from some outside source, the decision is, of course, highly dependent on the analyst's understanding of the implications that various choices have for his adjustment procedure; in other words, the choice is a matter of subjectively choosing a standard that is appropriate to the particular analytic purpose at hand. A wealth of literature exists which discusses the usefulness and the dangers of such techniques. Entry to it would be provided by the following references: Fleiss (1973), Yerushalmy (1951), Kitagawa (1964), Kalton (1968), Goldman (1971) and Bishop, Fienberg and Holland (1975).

The Adjustment of a Table's Margins to Show "Structure" in the Table and the Adjustment of Different Tables' Margins to Allow Comparisons between Tables.

Often tables of counts are collected so as to allow assessment of association between the variables that define the table structure, e.g., a table of counts of accidents by age and sex of driver would be useful to explore the age-sex association. Of course, we must first define a meaningful and manageable measure of association. A useful reference to the rich field of measures of association is Chapter 11 of Bishop, Fienberg and Holland (1975); however, for our purposes we will focus on the cross-product ratio (for a 2 x 2 table) and on sets of such ratios for multidimensional tables. The essential characteristic of the cross-product ratio that makes it an ideal index of association is that it remains invariant under row and column multiplications by positive constants. Translated into real tables, this means that tables such as below exhibit identical association between factor A and factor B.

$$\left(\frac{2.4}{3.1} = \frac{4.40}{2.30} = \frac{12.20}{90.10} = \text{cross-product ratio}\right).$$

	B	
A	4	3
	1	4

	B	
A	4	30
	2	40

	B	
A	12	90
	1	20

They are simply row and/or column multiples of one another (double the first column and multiply the second by 10 to go from the first to the second table; halve the second row and multiply the first row by 3 to go from the second to the third table). In fact, any table of the form

	B	
A	$2\ r_1c_1$	$3\ r_1c_2$
	$1\ r_2c_1$	$4\ r_2c_2$

exhibits equivalent association between factor A and factor B. With the equivalence of tables under row and column multiplications in hand, we may now approach the problem of displaying association in a table "free of marginal disturbance." A useful approach to the problem of presenting the association in a table to an audience would be to find an equivalent table that has simple margins, such as all marginal totals being 100 or 1, and then use this table to discuss the association structure exhibited by the data. The same idea of "standardizing" the margins is extremely helpful when attempting to look for differences between the structures of two or more tables. By standardizing, the individual cells are directly comparable and similarities and differences stand out free of "masking" caused by marginal differences between the tables. References for the cross-product ratio that are recommended would include Bishop, Fienberg and Holland (1975), especially Chapter 2; Goodman (1964); Mosteller (1968); and Plackett (1973).

The Smoothing of Data to Provide More Precise Estimates of Cell Probabilities

Another problem facing the data analyst interested in the analysis of multidimensional tables is that he often has very small cell counts in a large proportion of his full table. Only by collapsing across variables do reasonable cell counts become available. In these situations (since the faith one can put in any particular estimated cell probability is essentially a direct function of the observed cell count), there are many cell estimates that the analyst feels unsure of. A solution to this problem is to use the lower dimensional "faces" of the multidimensional table to model the full table and thereby provide smoothed estimated cell probabilities with characteristically smaller variances than the raw cell proportions. This technique is the heart of the approach to loglinear model building that Bishop, Fienberg and Holland (1975) present. Their whole approach to loglinear models and, therefore, to adjustment by providing smoothed cell estimates, depends upon the process of marginal standardization just presented in the last section. Namely, lower dimensional observed marginal tables are used as the "standards" while the initial cell entries in the full table are all set to one so that no association (i.e., interaction term) will be preserved other than what exists in the "standard" marginal faces. Of course, other techniques of loglinear model building also provide smoothed estimates with smaller variances too, but they are not so intimately related to the process of marginal standardization. For example, for the mathematically inclined, Haberman (1974), especially pages 376-385, is recommended.

Thus, the reasons for adjustment are: (1) to allow for meaningful interpretation of data and meaningful comparison of separate sets of data; and/or (2) to provide cell estimates in contingency tables that enjoy greater precision than the original data's cell proportions.

Other than the techniques of rate adjustment already mentioned, there is but one underlying technique that must be mastered to accomplish the various "standardization" adjustments and most of the loglinear model building forms of adjustment: namely, iterative proportional fitting (IPF). This iterative technique was suggested by Deming and Stephan (1940) for the adjustment of tables to make margins fit properly; they orginally had no thought of "preserving association under marginal multiplications" but rather suggested IPF as an approximation to a least squares procedure they were proposing.

IPF is easy to remember if one can just focus beyond the acronym to the process of "iteratively proportioning the desired margins among the table's cells until all margins converge on the desired margins." In three dimensions we would begin with some margin, arbitrarily that of variable 1, and adjust every cell in a given layer of the margin by the same multiplicative factor, so that the adjusted layer adds up to the desired marginal total. Next, add up the adjusted marginal totals for variable 2 and adjust each level by multiplying by a factor that makes them add up to the desired variable 2 margin. This, of course, messes up the margin for variable 1, but proceed on to variable 3. Having completed the adjustment so that margin 3 adds up correctly, both margin 1 and margin 2 will be out of kilter. Now simply start the cycle over again with variable 1. The process of iteratively proportioning the margins converges rapidly to a table of all counts with the property that they add to the desired margins.

A simple example using a 2 x 2 table might be valuable:

	2	3	5	1
	1	4	5	1
Actual margin	3	7		
Desired margins	1	1		

→

.4	.6	1.	1
.2	.8	1.	1
.6	1.4		
1	1		

↙

.667	.429	1.096	1
.333	.471	.904	1
1	1		
1	1		

→

.609	.391	1	1
.368	.632	1	1
.977	1.023		
1	1		

→

.623	.382	1.005	1
.377	.618	.995	1
1	1		
1	1		

→

.620	.380	1.	1
.379	.621	1.	1
.999	1.001		
1	1		

STOP

Notice that the process of IPF has in fact left the cross-product ratio unchanged

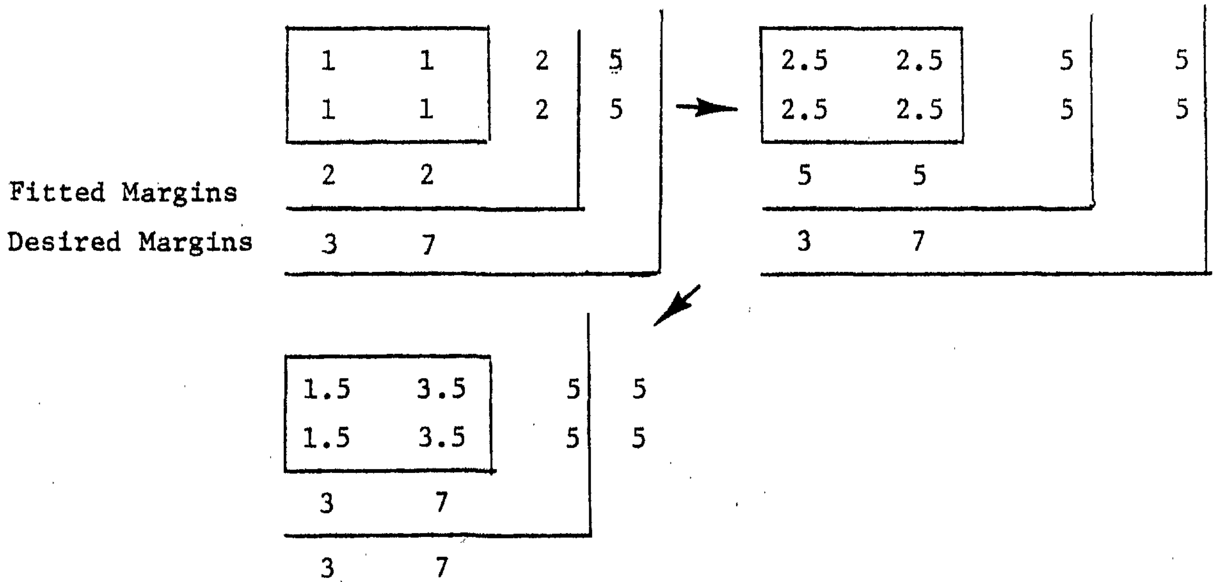
$$\left(\frac{.620 \times .621}{.379 \times .380} \approx \frac{8}{3}\right) .$$

IPF is the algorithm that one would use:

(i) To adjust table entries to fit more up-to-date margins such as when margins reflect recent low dimensional data but the table entries are drawn from an older detailed sample. In modeling terms, this situation is using the detailed sample for higher order terms and the low dimensional data for lower order terms.

(ii) To adjust table entries to fit hypothetical margins or some selected set of marginal totals such as all ones (1) or all 100's. This standardization of margins makes it easy to discuss table structure without being bothered by different sample sizes and marginal totals in various layers of the table and, of course, it provides a neat way to allow for immediate comparison of structure between similar tables unencumbered by marginal variation between tables.

Besides these classical uses of IPF to adjust tables, the algorithm can be used to create most loglinear models of interest in the analysis of multidimensional contingency tables. The only new trick involved is to pretend that all one has are the margins and then iteratively proportion them throughout the full table that is initially filled with a constant value in each cell. [It is convenient to pick one (1) as the constant for each cell.] This process yields cell estimates that are identical with those of the loglinear model which has terms corresponding to each of the marginal faces used in the IPF. Actually, there is a technical quibble here in that the use of, say, a two-dimensional margin in IPF is equivalent to having both the corresponding two-factor interaction and both single factor terms in the loglinear model. For detailed information, the reader is urged to refer to Bishop, Fienberg and Holland (1975), and Fienberg (1977) but a simple example would show the basics.



Note that the cross-product ratio is one (1) indicating complete independence or lack of association between factor A and factor B which corresponds to the loglinear model with no two factor interaction term.

The IPF algorithm is also valuable because (a) it provides non-zero cell estimates for cells with sampling zeros (providing that the whole layer is not empty) and (b) it is easily amended to fit very complicated models where certain cells have to have some particular value. The ability to provide non-zero cell estimates is a simple function of the fact that the initial table of ones (1) is used to spread the observed marginal totals through the table. Therefore, empty cells are "proportioned" a share of the marginal information for their row, column, layer, etc. Similarly, the characteristic of being able to fit tables (equivalently, models) with fixed zeroes, fixed diagonals, etc. is accomplished by simply leaving a zero in the initial table for those cells and adjusting the initial margins to "leave room" for whatever fixed value one wishes to have.

In summary, IPF is an easy-to-program algorithm with broad applicability to the various types of adjustment problems we have discussed. It is also the basis for computing the expected cell counts under a wide class of loglinear models and so it ties together the problems of adjustment and the related problems of data smoothing by model building and prediction for multidimensional contingency tables. One should not, however, believe IPF is necessarily the only or even the best answer to loglinear model building and the concomitant process of data smoothing. As an adjustment technique, IPF is a marvelous tool but as a model building and testing device it lacks certain traits. It can not, for example, provide the user with a parameter covariance matrix, so certain hypothesis tests and confidence level statements are precluded. The only solution to this problem is to turn to other techniques for model building and testing. Good references for such techniques would be: Bishop, Fienberg and Holland (1975) - Chapter 10 provides an overview of such techniques; Haberman (1974) - difficult but elegant presentation of the maximum likelihood approach; Grizzle, Starmer and Koch (1969) - the linear models (GENCAT) approach; and Kullback (1971) - the information theoretic approach to loglinear model building.

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APPENDIX C

DISCUSSION OF PROPOSED STANDARD IMPLEMENTATION COST CATEGORIES

NHTSA has stated that to measure the consumer's out-of-pocket expenses, the cost categories should be:

- Direct manufacturing
- Indirect manufacturing
- Capital investment (including testing)
- Manufacturers' markup
- Dealers' markup
- Taxes*

However, we feel that the consumer's initial costs are determined by a complex process, with different types of bargaining at the retail, wholesale, and manufacturing levels. It is well recognized, and also acknowledged by the auto manufacturers, that wholesale prices are set in response to market conditions, and that their relationship to manufacturing cost is loose. In a recent CEM study** this question was examined and no relation was found between annual increases in manufacturers' cost of satisfying FMVSSs as estimated by GAO, and the retail price increases.

Certain cost categories can be well estimated: direct and indirect manufacturing, and capital investment, including testing. These costs represent real resources used. The question of markups is conceptually very difficult, considering the manufacturers' pricing strategies (trying to cover a market spectrum) and the oligopolistic nature of the market. Using average gross profits for the manufacturing markup would be incorrect and misleading. To find the true markup would require a major study examining manufacturers' detailed cost data and pricing practices (internal and external).

The question of dealer markup is somewhat easier to consider conceptually; however, to determine it in practice is complicated by the trade-in of used cars. It appears highly likely that there is no fixed percentage markup on the dealer level, but a more complicated relationship which depends on the value of the new vehicle, the trade-in and other market conditions. Using an average gross profit, or the difference between wholesale and retail prices, would also be inaccurate and misleading.

With regard to the issue of taxes, this cost is not only borne in the form of a sales tax as the fraction of the components cost of the total car, but it is also accumulated at every stage of manufacturing in the form of property, payroll, sales (intermediate) and excise taxes. Income taxes are another cost; however, they are not directly related to the resources used but to the profitability of the manufacturers.

Therefore, based on the above discussion, we consider it beyond the state-of-the-art to estimate the true out-of-pocket cost of new car buyers due to satisfying the FMVSS. Good estimates of the costs of real resources consumed can be made, but these costs apparently are not passed on immediately or directly to the consumer of that model. Other costs (markups and taxes) are conceptually and practically difficult to establish. The most reliable estimate of consumer cost would have to be aggregated over the entire market and a several year period in order to account for changes in market strategy and conditions.

Another point of concern with regard to the collection of data on cost items is the periods of comparison--one model year before the effective date *versus* the model year that the Standard became effective or the next model year. The first point is that manufacturers have made changes to vehicles prior to the effective date of compliance, especially in the case of totally new models. Secondly, there is the learning curve effect in most manufacturing processes which will reduce the effective cost of manufacturing over time. With regard to this second effect, savings would be difficult to estimate, especially as these new components become more integrated into the basic structure of the vehicle. Therefore, using these time periods for comparison may tend to overestimate the cost of the Standard.

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*Personal communication from Warren G. LaHeist, January 1977.

**CEM Report 4194-574, *Program Priority and Limitation Analysis,* December 1976, Contract DOT-HS-5-01225.

APPENDIX D

ANALYSIS OF *CYCLE GUIDE* ROAD TESTS: 1974 AND 1975 MOTORCYCLES

D.1 INTRODUCTION

FMVSS 122 - Motorcycle Brake Systems - went into effect January 1, 1974. It specifies required equipment relating to motorcycle brake systems and establishes test procedures for these systems. The overall purpose of this Standard is to avoid accidents by insuring safe motorcycle braking performance under both normal and emergency conditions.

An authoritative publication in the motorcycle field is *cycle guide*, a monthly magazine which reports on competitive events, offers technical "how-to" articles, suggests travel and touring tips, and conducts regular road tests of new model motorcycles.

D.2 *CYCLE GUIDE* MOTORCYCLE ROAD TESTS

Reports on road tests of approximately three or four motorcycles are found in each issue of the monthly magazine. For the purpose of this report, magazines for 1974 and 1975 were investigated. Road tests of motorcycles used for trials/trail riding or for motocross racing were excluded, since off-street motorcycles do not have to meet the regulations of the Standard.

D.2.1 Description of the Road Test

Each motorcycle road test follows the same pattern. Each motorcycle is subjected to rigorous riding and testing. It is ridden under a variety of conditions (for example: average riding conditions; in downtown traffic; on hills, highways, and freeways; on smooth and rough roads; on windy and rainy days, etc.) and for long periods of time (many hundreds of miles). The published reviews include many pictures of the motorcycle in action and many pithy comments on the cycle's performance. The standard format is:

- General discussion of the motorcycle, including comparisons with past models.
- Engine and gearbox
- Handling
- Comfort and ride
- Braking
- Reliability during test
- Summary and conclusion.

In addition, a chart of specifications for each motorcycle is given (see Figure D-1 for an example) and each review concludes with three graphs showing the:

SPECIFICATIONS

	Engine type	two-stroke
	Cylinder arrangement	transverse, parallel twin
	Port arrangement	one intake, two transfers, one exhaust, piston-controlled
	Bore and stroke	70mm x 64mm
	Displacement	492.6cc
	Compression ratio	6.6:1
	Ignition	battery/dual coil/dual point
	Charging system	12-volt AC generator, silicon rectifier, solid-state voltage regulator
	Carburetion	two 32mm Mikuni slide/needle
	Air filter	washable oiled foam element
	Lubrication	oil injection, 1.9 qt. oil tank capacity
	Primary drive	helical-cut gears
	Clutch	wet, seven drive plates, seven driven plates
	Starting system	kick, in neutral only
	Transmission	5-speed, left foot shift
	Overall drive ratios	(1) 13.75; (2) 8.58; (3) 6.38; (4) 5.23; (5) 4.79
	Transmission sprocket	15-tooth
	Rear wheel sprocket	33-tooth
	Drive chain	⅝ in. pitch, ⅜ in. wide (#530)
	Front forks	2.6 in. travel
	Rear shocks	5-way adjustable, 1.8 in. travel
Brakes:	Front brake	drum, double-leading shoe
	Rear brake	drum, single-leading shoe, cable operated
	Front tire	3.25 x 19 Bridgestone ribbed
	Rear tire	4.00 x 18 Bridgestone universal
	Frame	tubular steel, double downtube
	Steering head angle	29 degrees from vertical
	Front wheel trail	5.1 in.
	Wheelbase	57 to 58.75 in.
	Length	87.5 in.
	Weight	412 lbs.
	Weight distribution	49% front, 51% rear
	Ground clearance	6.3 in. at sidestand bracket
	Seat height	31.5 in.
	Handlebar width	31.8 in.
	Handlebar grip height	42.5 in.
	Footpeg height	11.7 in.
	Instruments	tachometer, speedometer, trip meter resettable in tenths
	Gas tank	3.7 gal. steel
	Gas mileage	36.0 mpg average
	Best ¼-mile acceleration	14.66 sec., 89.9 mph
Stopping Distance:	Stopping distance from 30 mph	34 ft. 11 in.
	Stopping distance from 60 mph	123 ft.
	Suggested retail price	$1045 East and West Coast

Source: *cycle guide*, May 1974.

Figure D-1. Specifications for Suzuki T500L Titan.

- Amount of rear wheel torque available at any speed, at any rpm and in any gear.
- Amount of horsepower delivered to the ground as measured by a rear wheel dynamomoter.
- Minimum and maximum speed in miles per hour in each gear.

D.2.2 Data on Road Tests Analyzed

CEM analyzed 35 street motorcycles road tested by *cycle guide*; this included 18 1974 models and 17 1975 models. We considered manufacturer, size, types of front and rear brakes, stopping distances, separate comments on front and rear brakes, and *cycle guide*'s overall evaluation of the motorcycle's brake system.

Manufacturer

Japanese-manufactured motorcycles accounted for 80 percent of the 35 motorcycles tested by *cycle guide*. A detailed listing is in Table D-1.

TABLE D-1

NUMBER AND PERCENT OF MOTORCYCLES TESTED, BY MANUFACTURER

Manufacturer	Number and Percent
Japanese	28 - 80 %
Honda 10 (36%)	
Kawasaki 8 (29%)	
Suzuki 6 (21%)	
Yamaha 4 (14%)	
British (Triumph)	2 - 6 %
Bavarian (BMW)	2 - 6 %
American (Harley-Davidson)	1 - 3 %
Canadian (Can Am)	1 - 3 %
Italian (Laverda)	1 - 3 %
Total	35 101 % (due to rounding)

Size

The 35 motorcycles road tested were broken down into the same size categories CEM suggested using for the motorcycle dynamometer brake test to evaluate motorcycle performance. The weight among the tested cycles was distributed as follows:

- 125-349 cc: 8 cycles (22%)
- 350-449 cc: 6 cycles (17%)
- 450-749 cc: 7 cycles (20%)
- 750cc and over: 14 cycles (41%)

35 cycles (100%)

Types of Brakes

The type of front and rear brake was listed for all except one of the tested motorcycles. There is a great variety indicated among these cycles, both among the type of brakes on the cycle and the combination of front and rear types. However:

- Single action hydraulic disc brakes comprised 53 percent of the front brakes, and
- Single leading shoe rod-operated drum brakes comprised 65 percent of the rear brakes.

Table D-2 outlines the types of brakes *cycle guide* listed for the 34 motorcycles, on how many cycles they were found and the percent, for each, of the total.

TABLE D-2

TYPES OF FRONT AND REAR MOTORCYCLE BRAKES

Front Brakes	No.	%	Rear Brakes	No.	%
Single action hydraulic disc	18	53 %	Single leading shoe, drum, rod-operated	22	65 %
Single leading shoe, drum	5	15	Single leading shoe, drum, cable-operated	6	18
Double action hydraulic disc	3	9	Double action hydraulic caliper, disc	3	9
Double leading shoe, drum	2	6	Single leading shoe, internal expansion	2	6
Single action floating calipers, dual disc	2	6	Double leading shoe, drum, cable-operated	1	3
Single action hydraulic calipers, dual disc	2	6		34	101 %
Double action hydraulic calipers, dual disc	1	3			
Single action mechanical caliper, cable-operated	1	3			
	34	101 %			

*Due to rounding.

Stopping Distances

The riders of the *cycle guide*-tested motorcycles are experts; it would be difficult to impossible for average or novice riders to equal some of their best stopping distances. A few comments from the braking sections of the road tests indicate how the stops were achieved.

- "From 30 mph, we got...to a screeching halt in 37 feet 1 inch, and from 60 mph, it took 137 feet. The testers never felt apprehensive about using the full stopping power of the brakes because they worked so predictably."
- "Our best panic stops were 140 feet, 3 inches from 60 mph and 39 feet, 10 inches from 30 mph; we could have bettered these figures considerably if the bike hadn't been so squirrely."
- "The stop from 60 mph was worse..because the rear wheel had a tendency to step out to the left and get the bike sideways."
- "...quite a few times, the bike wobbled badly during a quick stop. We kept the machine under control, but it could have easily gotten away from a less experienced rider under similar circumstances."
- "Our best tire-smoking, adrenaline-pumping panic stops brought the Four to a halt in 136 feet 6 inches from an actual 60 mph and in 37 feet 6 inches from 30 mph."

Stopping distances were given for 20 out of the 35 motorcycles road tested. These distances represent the best real-world stops the riders could achieve from 30 and 60 mph. Table D-3 summarizes the best stopping distances achieved by the testers. Motorcycles are divided into size ranges, and distances are given for both the 30 and the 60 mph stops (occasionally, some figures are not available). The largest number of motorcycles for which stopping distances were published were those in the 750cc and above class. Thirteen of the 20 bikes for which stopping distance is available were in this large-size category. Among this group:

Stopping from 30 mph:

- The shortest stop was 33 ft, 4 in.
- The longest stop was 39 ft, 10 in.
- The average stop was 35 ft, 8 in.

Stopping from 60 mph:

- The shortest stop was 117 ft, 9 in.
- The longest stop was 153 ft, 4 in.
- The average stop was 138 ft, 6 in.

TABLE D-3

STOPPING DISTANCES FROM 30 AND 60 MPH
BY SIZE OF MOTORCYCLE

350-449 cc		450-749 cc		750 cc and Above	
Stops from 30 mph	Stops from 60 mph	Stops from 30 mph	Stops from 60 mph	Stops from 30 mph	Stops from 60 mph
33 ft	128 ft	34 ft, 7 in	123 ft	33 ft, 4 in	117 ft, 9 in
33 ft, 5 in	131 ft,10 in	37 ft, 1 in	136 ft, 6 in	34 ft	128 ft, 4 in
34 ft, 9 in	128 ft	37 ft, 6 in	137 ft	34 ft, 5 in	132 ft
			153 ft, 6 in	34 ft,10 in	133 ft, 4 in
				35 ft	137 ft, 3 in
				35 ft, 9 in	137 ft, 6 in
				35 ft, 9 in	139 ft, 5 in
				35 ft,10 in	140 ft, 3 in
				36 ft, 7 in	141 ft, 8 in
				38 ft, 4 in	147 ft,10 in
				39 ft,10 in	148 ft, 8 in
					153 ft
					153 ft, 4 in

D.2.3 CEM Rating Scheme

On the basis of separate comments on the front and rear brakes, and on the general comments in *cycle guide*'s summary and conclusion sections, we worked out a simple rating scheme for the 35 motorcycles road tested. An "A" rating indicates *cycle guide* comments that both brakes were good; "B" that one brake was good and one was criticized; and "C" indicates some critical comments on both front and rear brakes. The 35 motorcycles were rated as follows:

- A - 19 (54 percent)
- B - 9 (26 percent)
- C - 7 (20 percent)

35 (100 percent)

Table D-4, on the following pages, summarizes the information presented by *cycle guide* for the braking systems on the 35 motorcycles discussed in this report. It includes manufacturer, size, type of front and rear brake, and salient points from *cycle guide*'s comments on each motorcycle braking system.

TABLE D-4

CYCLE GUIDE EVALUATION OF MOTORCYCLE BRAKE SYSTEMS

Model Year	Name	Size	Type of Brake		Front Brake Evaluation
			Front	Rear	
'74	Can Am Explorer	175	n/a	n/a	Required considerable adjustment.
'74	Honda XL	175	Drum, single leading shoe.	Drum, single leading shoe,rod-operated.	Not strong enough for street.
'74	Yamaha RD	200	Drum, double leading shoe.	Drum, single leading shoe,rod-operated.	Too sensitive, too easy to lock up wheel accidentally.
'74	Honda CB	200	Single action, mechan. caliper,cable-operated.	Drum, single leading shoe,rod-operated.	Very clever, powerful, can stop in hurry, no noticeable fade.
'74	Kawasaki S3	400	Single action hydraulic.	Internal expanding, single leading shoe.	Powerful, fade-free. Can't skid accidentally.
'74	Kawasaki K2	400	Single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Have to squeeze too hard from high speed and squeeze causes front wheel lock up.
'74	Yamaha TX	500	Double action hydraulic disc.	Drum, single leading shoe.	Consistent, no fade or noise. Requires much handlebar pressure.
'74	Suzuki Titan	500	Drum, double leading shoe.	Drum, single leading shoe, cable-operated.	Predictable, progressive.
'74	Triumph TRST	500	Drum, single leading shoe.	Drum, single leading shoe,rod-operated.	No separate comment.
'74	Honda CB	550	Single hydraulic.	7" internal expanding.	Has enough level travel and feel so can use it hard, with confidence, but has high-pitched scream. "Superb."
'74	Yamaha TX	650	Double action hydraulic caliper disc.	Drum, single leading shoe,rod-operated.	Worked perfectly, consistently. Never wanted to lock up front wheel.
'74	Kawasaki H2B	750	Disc, single leading hydraulic caliper.	Drum, single leading shoe,rod-operated.	Nearly impossible to lock. Fades slightly.
'74	Laverda SF2	750	Dual disc, double action hydraulic calipers.	Drum, double leading shoe, cable-operated.	Feel is poor, action not very progressive, wheel locks.
'74	Suzuki GT Lemans	750	Single action floating calipers, dual discs.	Drum, single leading shoe, cable-operated.	Twin disc "fantastic," never faded, never pulled to side, never locked.
'74	Honda CB	750	Disc, single action hydraulic caliper.	Drum, single leading shoe, cable-operated.	Feel at lever "just very slightly mushy," so slows maximum stopping time.

TABLE D-4 (Continued)

Rear Brake Evaluation	Overall Brake Evaluation	Stopping Distances		CEM Rating
		From 30 mph	From 60 mph	
Susceptible to water.	Adequate, not overly sensitive, no danger of locking the wheels.			A
More powerful, can easily lock tires.	Reliable short distance transportation.			B
"Works perfectly," little fade.	Controllability during hard braking shaky at best, doesn't usually stop in straight line. Very predictable (both brakes) under normal braking ("Each panic stop was a white-knuckle, heart-stopping affair.").			B
Smooth, predictable, very little fade.	Can lock wheels only when you want to, easy to control during panic stop, good for novice rider.			A
Nice, progressive action. Fades only after repeated high speed stops.	Highly tuned, responsive, high performance.			A
Nice progressive feel, wheel never locks by accident.	Adequate, not oversensitive, doesn't fade very much. Reluctant to stop in straight line, causes longer stopping distances.			B
Easily locked up to 800 miles; after that, more progressive.	Always stops in straight line, even at 60 mph.			A
Never locks rear wheel accidentally, works progressively.	Both fade after 3-4 panic stops. Handlebars flex with hard braking, slow response, causes spills.		123 ft	C
Hard to locate	Do super job of stopping, predictable, progressive, don't fade, squeak when wet.			A
Mediocre; not much feel; lock up quickly, causing rear end to break loose and shake.	Difficult to coordinate superb front brake and mediocre rear brake during panic stops.			B
Not very powerful but adequate.	Work nicely during panic stops, progressive, quick, predictable, don't fade, easy to use.	37 ft, 1 in	137 ft,	A
Exceptionally controllable and progressive.	Stops quite well. Stayed straight and controllable during real panic stops. High degree of control.	34 ft,10 in	128 ft, 4 in	A
Too powerful; unprogressive; slight pressure gives lot of stopping distance,bit more pressure locks wheel.	Too much power. Okay in leisurely stop when applied slowly and carefully. Tend to skid in panic stops.	36 ft, 7 in	132 ft	C
Faded somewhat during brake testing.	"Outstanding--best of any big street bike we have tested." Neither pulls, fades. Predictable.		117 ft, 9 in ("new record for bikes")	A
Very sensitive and progressive. Braking and control limited by hopping and chattering of rear wheel during hard braking.	Quite powerful, but takes considerable effort to get that power.			A

TABLE D-4 (Continued)

Model Year	Name	Size	Type of Brake		Front Brake Evaluation
			Front	Rear	
'74	BMW R90/6	900	Single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Feedback and feel excellent. No noticeable pull to either side.
'74	Dunstall-Honda	900	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Will lock front wheel at any speed if exert a lot or pressure.
'74	Harley-Davidson	1000	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	
'75	Kawasaki F7D	175	Drum, single leading shoe.	Drum, single leading shoe,rod-operated.	One of finest on dual purpose machine. Powerful but predictable, easy to use, progressive, doesn't lock up unexpectedly.
'75	Yamaha DT Enduro	175	Drum, single leading shoe.	Drum, single leading shoe,rod-operated.	Will lock while riding.
'75	Suzuki Adventurer	185	Single action hydraulic caliper disc.	Drum, single leading shoe,rod-operated.	Powerful yet progressive, easy to use, good feel, no fade.
'75	Suzuki Sierra	185	Drum, single leading shoe.	Drum, single leading shoe, cable-operated.	
'75	Honda CB	360	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Progressive yet forceful; too powerful at first.
'75	Suzuki GT Sebring	380	Disc, single action hydraulic caliper.	Drum, single leading shoe, cable-operated.	
'75	Honda SuperSport	400	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Progressive, hard to lock, sure stopping, controllable.
'75	Kawasaki KH	400	Disc, single action hydraulic caliper.	Drum, single leading shoe, cable-operated.	Powerful, progressive enough to allow substantial amount of control, no fade.
'75	Kawasaki H1F	500	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	
'75	Honda SuperSport	550	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Powerful, quick stopping, bit over-sensitive, good control during panic stop.
'75	Honda SuperSport	750	Disc, single action hydraulic caliper.	Disc, double action hydraulic caliper.	Requires a lot of pressure, only moderately progressive.
'75	Suzuki Lemans	750	Dual disc, single action hydraulic calipers.	Drum, single leading shoe, cable-operated.	
'75	Triumph Trident	750	Disc, double action hydraulic caliper.	Disc, double action hydraulic caliper.	
'75	BMW R75/76	750	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	
'75	Kawasaki Z-1B	903	Disc, single action hydraulic caliper.	Drum, single leading shoe,rod-operated.	Requires powerful pull.
'75	Honda Gold Wing	1000	Dual disc, single action hydraulic calipers.	Disc, double action hydraulic caliper.	
'75	Dunstall-Kawasaki	1100	Dual disc, single action hydraulic calipers.	Drum, single leading shoe,rod-operated.	Tremendous power, good feel.

TABLE D-4 (Concluded)

Rear Brake Evaluation	Overall Brake Evaluation	Stopping Distances From 30 mph	Stopping Distances From 60 mph	CEM Rating
Too powerful and insensitive, can be locked easily.	Squeak whey they get hot.		137 ft, 6 in	B
"Terrible." Leverage and sensitivity lost, fades under hard use		35 ft	153 ft, 4 in	B
Both: Unpredictable during hard braking, doesn't want to stay in straight line. "Squirrely." Powerful, sensitive and give good feedback during sedate conditions.		39 ft,10 in	140 ft, 3 in	C
Much too sensitive at first (Needed few hundred miles of breaking in)	Both powerful, progressive, easy to use. Water did not affect.			A
Can be locked during pavement riding.				C
Can easily lock wheel with "overzealous mash" on pedal.	Not good in panic stops (front end takes nose-dive unless brakes applied smoothly, gradually.)			B
Both: Work progressively, give good feel, stay consistent and predictable during normal conditions. Both powerful and predictable for street and trail riding, for beginners and experts.				A
Too powerful and sudden; easy to lock rear wheel. Adversely affected by tires, front suspen.				C
Both: Sensitive, progressive, can use full without worrying about lock-up and stops quickly. Controllable, consistent quick stops.		33 ft, 5 in	136 ft, 4 in	A
Equally progressive, controllable.		33 ft	131 ft,10 in	A
Requires bit of pressure but did not lock or skid wheel; no fade.		34 ft, 9 in	128 ft	A
	Brakes fade, bike hard to control during panic stops.	34 ft, 7 in	153 ft, 6 in	C
No fade, noisy.	Very good.	37 ft, 6 in	136 ft, 6 in	A
Very good, progressive braking, sensitive. Noisy on bumpy surface.		34 ft	141 ft, 8 in	B
Both: No fade. Unusually easy to control during hard stops. Exceptional control.		34 ft, 5 in	137 ft, 3 in	A
Both: Hydraulic disc brakes powerful yet progressive. Sensitive to touch, not prone to lock easily. Generally excellent. Always stops in straight line. No fade.		35 ft,10 in	148 ft, 8 in	A
Both: Progressive, predictable. No controllable squeak or fade. Crisp.		35 ft, 9 in	153 ft	A
Easily brakes wheel.	Stops adequately for size, stops from any speed with avg. amount controllability.	33 ft, 4 in	139 ft, 5 in	A
Both: Both lost much power and predictability in rain. Difficult to maintain control. Powerful, progressive, except when wet, "and do a nice job of stopping the behemoth."		38 ft, 4 in	147 ft,10 in	C
Weak link, have to stand on pedal to lock up rear wheel. Meager stopping ability, bad pedal pos.		35 ft, 9 in	122 ft, 4 in	B