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DEVELOPMENT OF TECHNIQUES AND DATA FOR EVALUATING RIDE QUALITY
Volume III: Guidelines for Development of Ride-Quality Models and Their Applications

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16. Abstract

Ride-quality models for city buses and intercity trains are presented and discussed in terms of their ability to predict passenger comfort and ride acceptability.

This, the last of three volumes, contains procedural guidelines to be employed by transportation specialists in developing ride-quality models and in using them to evaluate passenger comfort in existing or future systems. Specific guidelines are provided for: 1) collecting vehicle-motion and passenger-comfort data in the field; 2) generating ride-quality models based on these data; 3) validating models against data from passengers on scheduled services; 4) using models to evaluate or predict vehicle ride quality; and 5) specifying ride characteristics for new vehicles.

Volume I is a summary, and Volume II contains a technical discussion of the ride-quality models developed during the research effort using the da ta gathered on city buses and intercity trains.

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PREFACE

This study of ride quality, which developed predictive models of passenger comfort and ride acceptability, was conducted by Dunlap and Associates, Inc., under Contract No. DOT-TSC-1090 in close cooperation with the University of Virginia as subcontractor. The project was under the direction of Dr. Richard Pepler, Vice President of Dunlap and Associates, Inc. The design and conduct of the field data collection was the prime responsibility of Mr. Leroy Vallerie, Principal Associate of Dunlap and Associates, Inc., and the data analysis and model development was the responsibility of Dr. Ira Jacobson, Associate Professor, Department of Engineering Science and Systems, University of Virginia. Mr. Vallerie was supported by Ms. Joan Edwards, and Messrs. Charles Goransson and John Henschel of Dunlap's professional staff. Dr. Jacobson was assisted by Drs. Richard Barber and Larry Richards and by Messrs. Steven Troester, Steven Schaedel and George Cushnie of the University of Virginia.

The success of the project depended on help of many kinds from many people. In particular, we would like to acknowledge the cooperation and assistance received from Mr. Charles Abell, Mr. Raymond Binheimer and the bus drivers of Connecticut Transit in arranging for and collecting data on city buses during the experimental trials and on regular scheduled services. Similarly, we thank Mr. Joseph Schmidt, Mr. Ross Higginbotham and Mr. Robert Breese in Washington and Mr. Thomas Fortier and Mr. Tim Salveson in the Hartford office of the National Railroad Passenger Corporation (AMTRAK) for their assistance in arranging our use of selected passenger rail cars and in contacting AMTRAK passengers. We are especially grateful to those men and women who volunteered to participate in our experiments and to those groups of passengers on scheduled services who had agreed in advance to provide additional ride quality data.

Finally, we would like to express appreciation for the support, guidance and encouragement that we received from Dr. E. Donald Sussman, Technical Monitor and Ride Quality Project Manager, and Mr. Edward A. Sands, Contracting Officer, Transportation Systems Center, U.S. Department of Transportation; and from Dr. Robert J. Ravera, Transportation Advanced Research Program (TARP) Manager, Office of Systems Engineering, Office of Secretary, U.S. Department of Transportation, Washington, D.C.

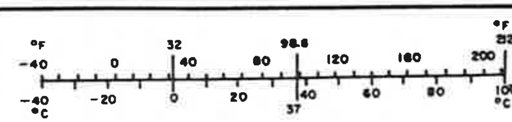
METRIC CONVERSION FACTORS

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

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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SYMBOLS AND ABBREVIATIONS

a_T = RMS transverse acceleration of vehicle

a_V = RMS vertical acceleration of vehicle

a_L = RMS longitudinal acceleration of vehicle

ω_R = RMS roll rate (rotation around longitudinal axis)

ω_P = RMS pitch rate (rotation around transverse axis)

ω_Y = RMS yaw rate (rotation around vertical axis)

m_T = mean transverse acceleration (sustained component)

m_Y = mean yaw rate (sustained component)

g = gravities, or 9.8 meters per second squared

^oC = degrees Celsius

^oF = degress Fahrenheit

R^2 = the proportion of variance in comfort judgments "explained" by regression equation; the square of the multiple correlation coefficient

dB(A) = decibels measured using the A-weighting system

deg/sec = degrees per second, a measure of angular velocity

RMS = root mean square; the data are processed to remove the long time constant (the mean)

$\bar{C}$ = mean comfort rating (empirically derived)

C' = mean comfort response predicted by a model

CPR = predicted comfort responses

α = the level of significance for a hypothesis test

σ = standard error of the coefficient

E_β = that value of a variable (say roll, ω_R) such at some percent in the sample lies within the range $\bar{\omega}_R \pm E_\beta$, that is within E_β units from $\bar{\omega}_R$.

GLOSSARY

ACCEPTABILITY: Degree to which a vehicle or system will be used by passengers.

BANDWIDTH: Range of frequencies contained in a given motion.

COMFORT: A subjective state of the passenger, assessed in the present research with a seven-point rating scale.

DECIBEL: A unit of measurement of sound intensity or power level.

EXCEDANCE COUNTS: Number of times a variable exceeds some chosen level in some unit of time.

FACTOR ANALYSIS: A set of techniques for determining the dimensionality of a set of variables, usually by finding the rank of the matrix of inter-correlations among the variables.

g-LEVEL: Amount of acceleration referred to the acceleration of gravity.

JERK: Rate of change of acceleration, usually pertains to the longitudinal direction.

LATERAL DIRECTION: In an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, the y axis represents the laterial direction.

LONGITUDINAL DIRECTION: In an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, the x axis represents the longitudinal direction.

MODEL: A mathematical (abstract) representation of some object, event or process.

PEAK VALUE: The maximum value of a variable.

PITCH: Rotation about the lateral axis (see lateral direction).

POINT OF PERCUSSION: Point about which vehicle can be considered to be in pure rotation giving rise to equivalent motion.

ROLL: Angular motion about an axis in the direction of travel, i. e., the x axis in the coordinate system adopted in this report (see longitudinal direction).

RMS: Root mean square of a variable.

SPECTRUM: The distribution of the values of any quantity.

TRANSVERSE DIRECTION: In an x, y, z coordinate system, with x oriented in the direction of travel of the vehicle, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, a transverse direction would be somewhere in the yz plane.

VERTICAL DIRECTION: In an x, y, z coordinate system, with x oriented in the direction of travel of the vehical, and z oriented perpendicular to the plane of the vehicle and directed into the supporting surface, the z axis represents the vertical direction.

YAW: Rotation about the vertical axis (see vertical direction).

I. INTRODUCTION AND GENERAL APPROACH

At the present time, ride quality models are mode specific and cannot be employed to evaluate all transportation systems. Attempts have been made to develop a composite model that can be applied more broadly. However, more work is needed on combining data for many modes before such a model can be fully realized. The transportation specialist, therefore, may find it necessary to develop a specific model for the particular system of interest. Only in this way can he accurately predict and evaluate those levels of vehicle motion considered comfortable and acceptable to the users of that system. To develop such a model, data are needed on passenger comfort and vehicle motion, gathered in the field under realistic conditions. Additional data are also needed on the passengers' acceptance of the ride, regardless of how comfortable they may be, and on other attributes of the vehicle's environment, e.g., noise and temperature. To collect such data, a program of research must be carefully planned and conducted using vehicles and riders representative of those in the system of interest. Such a program of research is best carried out in two phases as shown in Figure III-1; the first phase devoted to model development and the second to validation of the model using comfort data gathered from regular passengers.

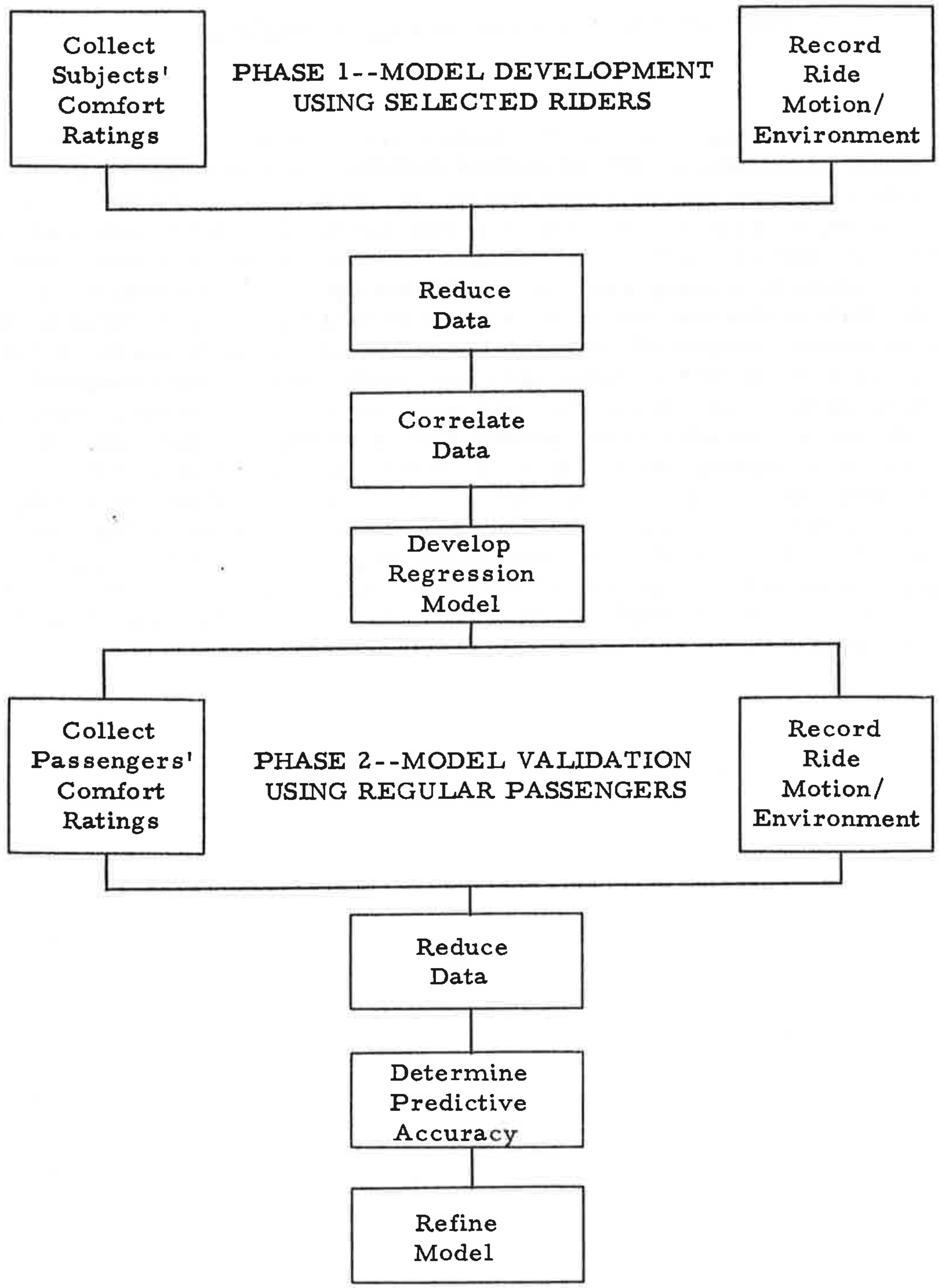

FIGURE III-1. GENERAL APPROACH.

II. DATA COLLECTION

The development and validation of ride quality models requires two types of data--passenger judgments of ride comfort and acceptability, and recordings of vehicle motion in all six degrees of freedom. The accuracy of the models depends, not only on the procedures employed in model development, but also on the quality of the data used as a basis for the models. Good data can only be gathered through the use of reliable instruments and valid measurement procedures. Data must also be collected in accordance with a plan designed to identify and/or control all human and environmental variables that might bias passenger judgments.

In Phase 1 of the program, data should be gathered under carefully planned conditions from selected groups of riders composed of individuals with those attributes of the riding public most likely to influence their perceptions of comfort. These attributes include age, sex and riding experience. The conditions of the ride should also be planned to include those attributes of the vehicle and its environment most likely to affect vehicle motion and passenger comfort.

In Phase 2, data should be collected from a sample of actual passengers and vehicles in regular service during trips that are representative of those for which the model is being developed. In this phase, control of the ride environment and passenger characteristics is difficult. However, they can and should be identified, measured and recorded for use in model validation and refinement.

In both phases, passenger ratings of ride comfort and acceptability must be collected using standardized scales of sensation and opinion so they can be analyzed statistically and correlated with selected measures of the vehicle's ride environment. Multiple regression analyses should then be performed between the passenger ratings and ride measures to determine the most efficient regression model for predicting comfort and acceptability from ride environment data.

A. Research Design

The passenger's perception of ride comfort and acceptability depends on the specific nature of the ride environment as well as his own physical and psychological make-up. The ride environment consists of a large number of variables as illustrated in Figure III-2. These variables fall into three major categories: the external inputs to the vehicle, the characteristics of the vehicle itself and the internal environmental conditions to which the passenger is exposed. The variables of interest to the researcher are those known or suspected to influence the ride quality of the vehicle under

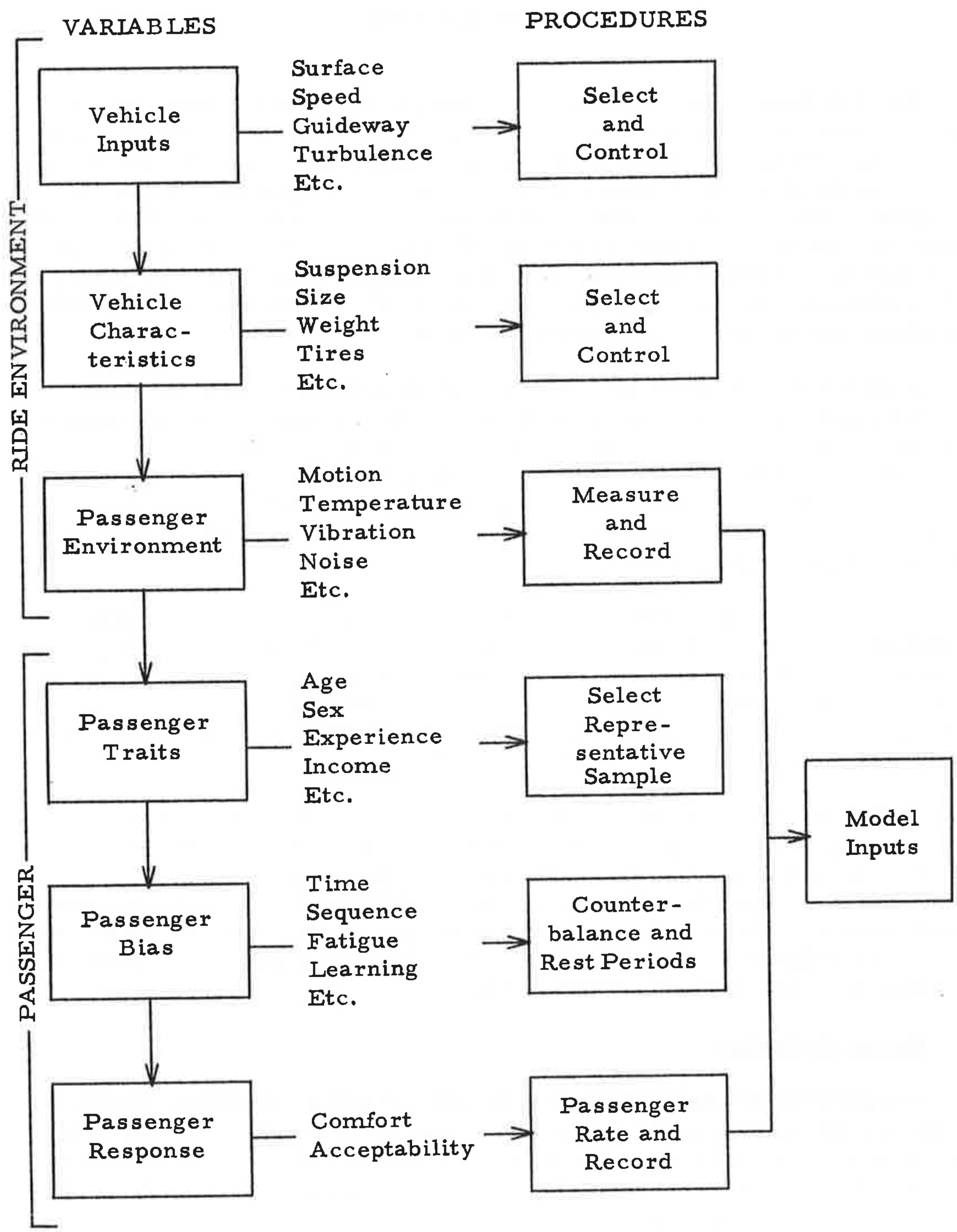

FIGURE III-2. GENERAL RESEARCH DESIGN.

study. In Phase 1, a wide range of these external variables and vehicle characteristics must be included in the research design; otherwise, models will be developed using too limited a sample of the ride environment for the particular transportation mode. Also, selected variables, known to influence the ride environment and passenger comfort, should be systematically controlled and/or varied in accordance with good experimental design practices. In this way, any possible effects of the order in which ride motions change that might bias passenger judgment of ride comfort can be attenuated, and the major external and vehicular variable(s) responsible for the differences in vehicle motion identified.

Both the physical and psychological traits of passengers are known to influence their perceptions of comfort and ride acceptability. Passenger traits per se and their influence on ride comfort are normally not of primary interest to the ride quality researcher. Nevertheless, traits such as age, sex and experience of riding related transportation models, known to influence passenger judgment of ride quality, should be accounted for in the research design. For this reason, riders selected to participate in Phase 1 of the research program should be representative of the traveling public at least in terms of these important traits, and stratified across the various experimental conditions in a systematic manner.

Other variables in the passengers' environment which are known to influence passenger perception of comfort should also not go unaccounted for in the research design. Among these variables, two of the most important ones are noise and temperature. At least these two variables should be periodically measured and recorded during the data collection. Other variables in the environment that may affect passenger judgments should also be noted by the experimenter. These include unusual odors, excessive smoking, violent maneuvers and other unusual conditions. These notes will aid the experimenter in interpreting anomalous data during analysis. The passenger environment, therefore, should be described as fully as possible and the critical variables measured as accurately as possible using calibrated instruments.

The specific research design employed to collect data will depend quite heavily on the mode of transportation being investigated,[1] the number of variables of interest in the ride environment, and, as always, the funds and time available to carry out the research effort. Replications of the data collection design should also be used if possible to enhance the reliability of the data. Subject groups should be representative of the traveling public and matched in terms of the age, sex, ride experience and other traits, e.g., language, socio-economic background, considered important by the experimenter.

[1]See Sections 2.3 and 2.4 of: Havron, M.D. and Westin, R.A. Experimental designs and psychometric techniques for the study of ride quality. Report No. DOT-TSC-OST-76-54. ENSCO, Inc., December 1976.

Unfortunately, it is usually not possible to replicate vehicle motions in the real world by arranging the various experimental conditions and subject groups in a classical orthogonal design, in which all permutations of each condition can be given to each group of subjects. Such variables as traffic conditions, speeds, turbulence, operators and weather conditions differ from one trial to the next even though the surface, suspension system and vehicle may be identical and careful controls are employed. It is difficult, therefore, to replicate exactly the same conditions in field research of this sort. The experimenter must select and include in his research design those variables (e.g., surface conditions, suspension systems and speeds) which will produce a range of motions similar to those experienced or likely to be experienced by passengers on vehicles in regular service.

An example of a design successfully employed to gather field data for the development of a bus model is shown in Table III-1. In this design, a route was carefully selected so that it contained road surfaces that were good, intermediate and bad in terms of smoothness and condition of repair. A total of nine road segments, three of each surface condition, were presented to two matched groups of subjects using two different buses, one with good suspension and the other with poor suspension. To attenuate order effects, the sequence of segments was different for each bus. Each segment lasted approximately one minute during which vehicle motion, noise and temperature were recorded, and the subjects rated ride comfort on a seven-point scale. Average time between segments was approximately five minutes. Subjects were given a 20-minute rest period after completion of the first nine segments on one bus (about one hour) and before starting the next nine segments on the next bus. A design such as this is uncomplicated, relatively simple to carry out in the field, and can yield large amounts of data for model development, the exact amount depending on the size of the subject groups.

B. Instrumentation

Instrumentation is needed to measure and record ride environment data on board vehicles in the field. Such instrumentation must be highly portable and require no external power. Instrumentation for measuring and recording vehicle motion parameters must be packaged small enough to fit under a passenger's seat where it will not obstruct the aisle. Special fixtures or vehicle modifications should not be required under any circumstances.

Vehicle motion instrumentation should consist of three linear accelerometers capable of measuring at least 0.1 to 20 Hz and three rate gyros with similar frequency characteristics. Alternatively, a network of accelerometers may be used at different locations and angular data computed by means of analysis. Motion data may be stored in either analog or digital form using a tape recorder. If the analog form is employed, the data can be multiplexed and stored on a single channel of the recorder.

TABLE III-1. PHASE 1 DESIGN OF A BUS STUDY

Route Segment*	Group A (24 Subjects)		Group B (24 Subjects)	
	Bus P	Bus G	Bus G	Bus P
1	a	b	a	b
2	b	a	b	a
3	c	c	c	c
4	b	a	b	a
5	c	c	c	c
6	a	b	a	b
7	c	c	c	c
8	a	b	a	b
9	b	a	b	a
Total:	9	9	9	9 = 36

36 Segments x 24 Subjects = 864 Comfort Ratings

* Each road segment is approximately 1 minute in duration.

a Good (smooth, new) surface condition

b Intermediate (some cracks, holes) surface condition

c Bad (pot holes, bumps, needs repair) surface condition

P Poor Suspension ($>$ 10 years old and in poor repair)

G Good Suspension ($<$ 2 years old and in good repair)

Environmental parameters such as temperature and noise level vary at a relatively slow rate and, therefore, can be measured and recorded manually. Small portable instruments are commercially available for measuring these parameters quickly and reliably. Care must be taken, however, to ensure that they are properly calibrated before use in the field. One channel of the recorder may be used to record these measurements by voice, together with any other measurements or comments deemed appropriate.

An example of instrumentation successfully used to measure and record motion in six degrees of freedom on board a variety of vehicles is shown in Figure III-3 below.

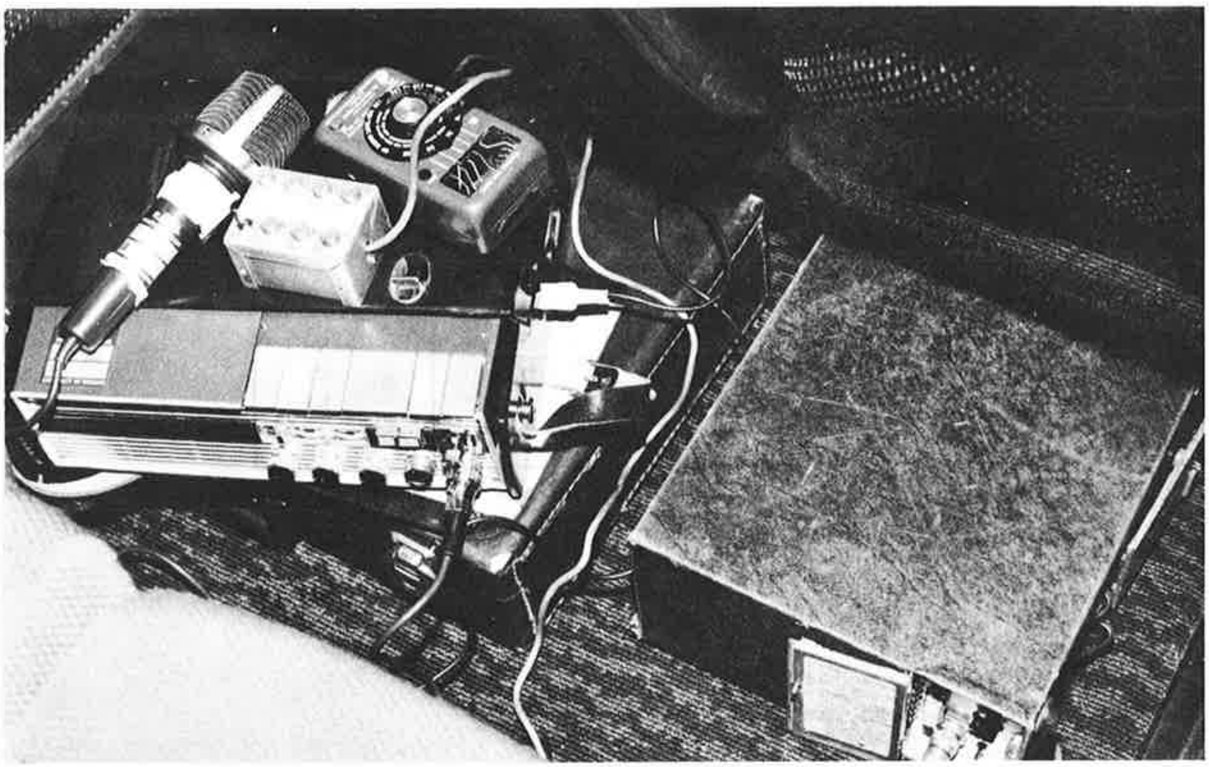

FIGURE III-3. PORTABLE ENVIRONMENTAL MEASURING SYSTEM (PEMS).

This instrumentation was developed by the University of Virginia and is known as the Portable Environmental Measuring System (PEMS). The PEMS is battery operated and contains three linear accelerometers, three rate gyros, a temperature transducer, Uher Tape Recorder (two channel) and a seven interval pulse generator. All of the data are FM multiplexed and stored on a single channel of the recorder. The second channel is used for voice recording during data collection. The battery is capable of providing power for a period of 12 hours without recharging. A handheld sound pressure meter is normally used with this package to measure noise level and a small thermometer to measure temperature. Both measurements are usually recorded by means of voice on the second channel of the recorder. Vehicle speed and other environmental conditions are also recorded by this means.

C. Data Forms

Passengers' ratings of comfort are the primary measures of ride quality used in model development and refinement. Ratings must be collected using standardized interval scales of sensation and opinion so they can be analyzed statistically and correlated with measures of the vehicle's motion and other physical measures of the ride environment.

Based on past experience, comfort is best rated using a seven-point scale with the characteristics as shown below. During both phases of the program, passengers should be requested to rate the comfort of ride during each segment of their trip using this scale. Passengers should not be coached regarding the motion levels which define these comfort levels but allowed to judge what is comfortable or uncomfortable for themselves. Once all segments of the trip are completed, the passengers should be asked to give a single comfort rating for the overall trip using the same seven-point scale.

Comfort Level	Comfort Scale
Very Comfortable	1
Comfortable	2
Somewhat Comfortable	3
Neutral	4
Somewhat Uncomfortable	5
Uncomfortable	6
Very Uncomfortable	7

The following five-point scale has been found satisfactory for obtaining data on the acceptability of ride. Such data are needed to define what level of ride quality is acceptable to the majority of passengers. A somewhat uncomfortable ride, for example, may be quite acceptable to passengers in some modes of transportation and not in others. Questions dealing with acceptability may be posed in many different ways; one successfully used in bus and train studies follows:

Considering the ride you have just rated, if you had a choice, would you:

_______ Be eager to take other rides?

_______ Take other rides without hesitation?

_______ Take another ride, but with some hesitation?

_______ Prefer not to take another ride?

_______ Not take another ride?

Since other variables in the ride environment are known to influence passenger perception of comfort and acceptability, data on seating, leg room and temperature should also be gathered from the passengers during both phases of the program. A five-point scale has proved to be satisfactory for this purpose. The scale is used in conjunction with a definitive statement about some aspects of the ride environment such as the following:

Your seat is comfortable:

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
_______	_______	_______	_______	_______

The passenger indicates how strongly he agrees or disagrees with the statement by checking one answer for each statement. Again, the passenger's responses are scaled 1 through 5, as above, for analysis.

The above described rating scales should be arranged and organized in the form of a booklet and given to each passenger at the beginning of the data collection run. Each segment and its associated comfort scale should be identified by a simple letter or number code. The comfort scales for individual segments should appear at the beginning of the booklet. Questions and scales dealing with overall comfort, acceptability of ride, and other features of the environment should appear on the last few pages of the booklet.

During Phase 2 of the program, when actual revenue vehicles are used, information must also be collected on the characteristics of the passengers who volunteer to participate in the study. Such information includes sex, household income, frequency of travel and purpose of trip. These data are required to ensure the sample is representative of the population.

An example of a passenger response booklet, successfully employed during the validation phase of an inter-city train study, appears in the Appendix to this volume. This booklet also contains two questions dealing with passenger value structure which were of interest during this particular study. The passengers experienced no difficulty in completing the scales or providing the information requested in this sample booklet.

D. Subject/Passenger Selection

A number of riders will be needed to participate as subjects during the Phase 1 data collection effort. Subjects must be representative of the traveling public at least in terms of important attributes such as age, sex and usage of the transportation mode under study. The researcher may also desire to stratify subjects in terms of other population variables. These variables include socio-economic group, occupation and level of education.

Subjects should be solicited from a number of different sources such as local businesses, civic organizations, universities and other groups. Leaders of such groups should be contacted, the purpose of the study explained and their cooperation sought well in advance of the date set for data collection. In an effort to select a representative sample of the public, a large number of subjects should not be drawn from any one group even though it may contain many individuals possessing a wide range of the passenger characteristics of interest, i.e., select only a few subjects from as many different groups as possible. Advertising in local newspapers may also be employed, if deemed necessary.

The actual number of subjects selected will depend on the research design. The design will dictate how many riders of each age, sex, etc., should be assigned to each subject group. Subject groups should not, in any event, number less than 24 in order to obtain sufficient estimates of comfort for each segment of the route.

To ensure that an adequate number of subjects actually participate in the study, approximately 10 percent more riders should be solicited than are actually needed. Some people will almost certainly not show on the day of the study for one reason or another. In an effort to hold "no shows" to a minimum, all subjects should be recontacted and their participation confirmed a few days in advance of the first data collection runs. At this time, subjects should be given information on times and meeting places as well as on the method of remuneration (if appropriate).

Remuneration of subjects should be fixed at a rate commensurate with the time and effort spent on the study as well as the inconvenience and cost involved in traveling to and from the departure site. Twenty dollars is not too much to pay subjects for giving up a Saturday morning to participate in a study of this sort.

During Phase 2, actual passengers on regular scheduled vehicles must be used to provide data for model validation and refinement. Solicitation of passengers on board the vehicle or immediately prior to departure is not practical, since, for example, it is inconvenient and cumbersome to set up and re-calibrate the motion measuring instrument in different cars of a train, or to move the instrument from one bus to another. The instrument must be located near the vehicle's center of percussion which means fare-paying passengers must be asked to relocate if they happen to occupy seats in this area. Based on past experience, it has been found more practical to reserve a vehicle such as a railcar or bus for the Phase 2 effort and, well in advance of data collection, solicit volunteer passengers who normally use this service. In this way, the researcher will know how many passengers he must plan to accommodate in the reserved vehicle and thereby be able to carry out the study without disturbing other passengers who do not wish to be involved.

Prior solicitation of actual passengers may be accomplished by means of advertising in local newspapers or by contacting travel agents who handle arrangements for passenger groups. Care must be taken in selecting passengers from such groups since they may be extremely homogeneous in terms of such population variables as age, sex and income. Even if newspaper advertising is used, the same care must be taken to ensure that a representative sample of the traveling public is selected for the Phase 2 effort.

Experience has shown that some incentive must be given to passengers for volunteering to participate in the study; otherwise, sufficient riders will not be obtained to validate the model. Paying the passengers' fare has been found to be an adequate incentive in both bus and train studies. In fact, the public's response to "free fare" advertised in newspapers has been nothing short of overwhelming. The researcher, therefore, should prepare to budget for this cost as well.

As in Phase 1, the researcher should recontact the passengers immediately prior to the actual conduct of the study to ensure their participation, to reconfirm departure times and places, and to inform passengers how the reserved vehicle will be identified and where it will be located, e.g., next to the last car in the train or behind the regular bus. It is imperative that the passenger not be confused or delayed in his normal travel. At departure sites and terminals, announcements over public address systems should also be given to help the passenger find the correct vehicle.

E. Route Selection

Ride comfort and acceptability are significantly influenced by the external inputs to the vehicle. Among these inputs are variables associated with surface conditions, guideway type, turbulance and vehicle speed. The exact nature of such variables and their importance in model development depend quite heavily on the particular mode of transportation under study. To ensure that the model is based on a representative sample of the vehicle's ride environment, every effort should be made to employ a wide range of these variables in the research design. To this end, routes employed in the Phase 1 effort should be carefully selected and pre-tested in advance of actual data collection. Roads with different types of surfaces and conditions of repair, for example, should be found and vehicle motion measured while traveling over them at typical vehicle speeds. Final selection of road segments for use in the study should be based on an examination of the recorded vehicle motion.

With some modes of transportation, e.g., aircraft and ships, it is not possible to achieve a high degree of control over external vehicle inputs. Nevertheless, every effort should be made to select routes that have a high probability of providing a typical range of vehicle motions. In the event such motions are not realized during data collection, additional runs must be made until a full range of typical vehicle motions is attained.

During the Phase 2 validation effort, a high degree of control over external vehicle inputs is also not possible since the researcher must use scheduled services over existing routes. These routes may or may not contain a wide range of vehicle input variables. However, it is possible to choose routes that, based on prior knowledge or inspection, are anticipated to provide a typical range of vehicle motions. In the case of land vehicles, routes can and should be pre-tested to ensure they provide a full range of typical vehicle motions. Comfort data gathered while traveling only over smooth intercity highways, for example, would not provide a ride environment that is typical of city buses. Subjective response data gathered under these conditions, therefore, should not be employed to validate models for city buses.

On trains, aircraft and other vehicles where it is difficult to preselect specific route segments for data collection, the ride environment variables should be sampled for approximately one minute at periodic intervals, at which times the passengers are asked to rate ride comfort. Past experience has shown that a one-minute interval every four minutes is satisfactory for this purpose. With this technique, many samples of the ride environment over the route are taken rather than a limited number of carefully chosen ones. Assuming the route segments selected provide a typical range of vehicle motions, under no circumstances should the number of segments used for data collection be less than eight. Again, more segments should be employed if a suitable range is not attained because of special conditions, weather, speeds, etc. It is important that the researcher plan for such contingencies.

F. Data Collection Procedures

The first task during the data collection effort of both phases should be to set up the motion recorder near the vehicle's point of percussion. At the same time, in Phase 1 data collection, the operator and crew members should be briefed on the route to be followed, speeds to be maintained, temperature regulation and other items necessary to ensure that the ride environment is controlled in accordance with the plan. It should be emphasized that under no circumstances should the operator jeopardize the safety of the riders or vehicle to accommodate the plan. Vehicle safety should remain the operator's responsibility entirely and the vehicle controlled accordingly.

Once subjects arrive at the departure site, response booklets should be handed out and seats assigned in accordance with a preestablished scheme. A seating plan is needed to determine the locations and distances of individual subjects from the vehicle's point of percussion. Subjects seated in the rear of the vehicle, for example, may experience more motion and rate the ride less comfortable than those seated elsewhere.

Booklets should be marked with the subject's identification and seat number. If the vehicle's seats are not numbered, index cards may be used for this purpose and temporarily taped to the seat.

Once the subjects are seated, they should be briefed on the procedures to be followed during data collection. This briefing should contain simple instructions on how the subjects should complete the rating scales and when they will be asked to do so. Following the briefing, questions should be solicited from the subjects and answered before the start of the first segment.

The researcher should alert the subjects when the vehicle is approaching, entering and leaving the test segment. At the end of the segment, the subjects should be instructed to rate the comfort of ride. The start and end of each segment and its identification code should also be marked on the motion recorder tape. Noise, temperature, vehicle speed and other selected environmental variables should also be measured and recorded during each segment. It is also important that the instrument operator record a verbal description of the ride environment during each segment. This record should contain a description of any unusual circumstances, e. g., traffic conditions, sudden steps, violent maneuvers and weather conditions, that may influence the subjects' responses and may assist in the analysis of anomalous data.

The route length and number of segments will dictate the length of the data collection run. A rest period of 15 to 20 minutes should be given after a maximum of one hour of running time. This period may also be used to accomplish other tasks, e.g., changing recorder tape, switching vehicles, assigning new seats and other procedures dictated by the research design.

When the last segment is completed, the subjects should be requested to indicate their comfort rating for the overall trip and the acceptability of ride. Response booklets should then be collected and the subjects paid for their participation in the study.

In Phase 2, essentially the same procedures, as described above, are used except for those that follow. Operators should not be requested to maintain control over their vehicle in accordance with a plan but allowed to operate as they normally would in regular service. Passengers are also not assigned seats but permitted to sit wherever they desire within the reserved vehicle. Rest periods are also not given since trips typically last less than one hour and none are given in real life. Finally, passengers are not paid but, if agreed in advance, are allowed to ride in a reserved vehicle and possibly without paying a fare.

III. DATA REDUCTION

The data gathered during both phases of the program should be reduced and analyzed in readiness for use in model development. The data reduction effort consists of two tasks. The first task involves the reduction of the subjective response data gathered by means of the rating scales. The second task is concerned with the reduction of the physical measures of the ride environment.

A. Subjective Response Data

Reduction of the subjective response data should be accomplished in a three-step process. The responses are first scaled utilizing the technique described above in Section II. C. The scaled responses are then tallied for each segment, experimental condition and subject variable using a matrix based on the original research design. For example, the matrix might contain columns or rows for segments, surface conditions, and suspension systems as well as for selected population variables such as age, sex and frequency of use. Once the cells in the matrix are filled and the tally completed, the frequency for rows and columns are calculated and cross-checked for accuracy. The final step in the process is to compute the mean and standard deviation for each segment and variable using a standard statistical technique such as the arbitrary origin method.

Histograms may also be prepared using the reduced data to evaluate trends, to identify anomolies and to evaluate the sensitivity of the data to the variables included in the research design. Other statistical techniques such as the analysis of variance, T tests and Chi-square may also be employed as appropriate, to analyze the data further if desired by the researcher. Such techniques, however, are not necessary for model development.

B. Environmental Data

The environmental data consist primarily of recordings of vehicle motion in six degrees of freedom--accelerations in the three linear directions and angular rates in the three rotational axes. The process used to reduce these data depends quite heavily on the form in which they are recorded. The description given here is for the reduction of analog data gathered by means of the PEMS. With this system, analog signals for the six degrees of freedom are FM multiplexed and recorded on a single channel of the tape recorder.

As illustrated in Figure III-4, the first step in the reduction process is to de-multiplex the recorded signal using discriminators to extract the individual signals for each degree of freedom. Each signal is then filtered

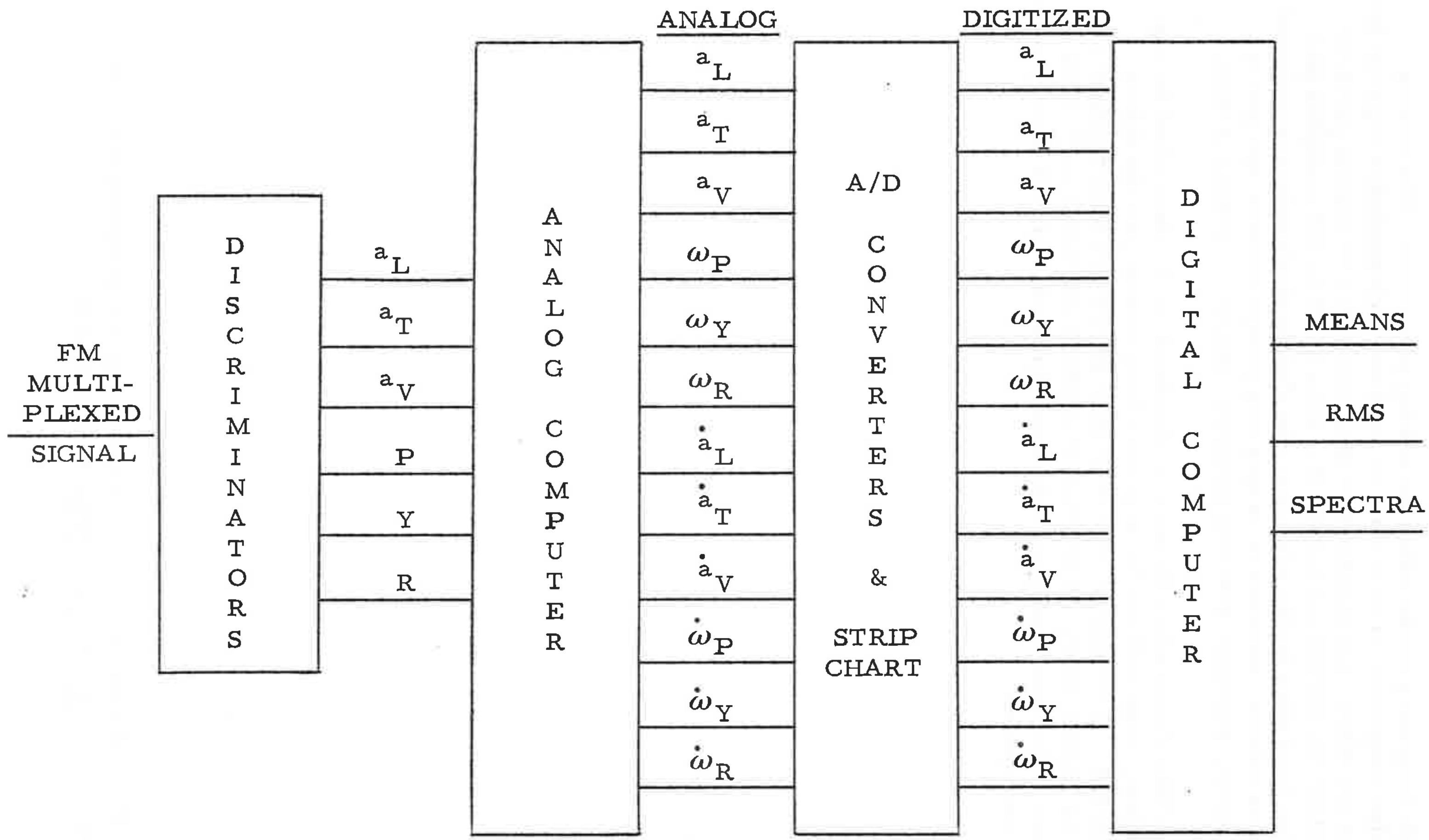

FIGURE III-4. SIGNAL PROCESSING SCHEMATIC.

to remove high frequency noise using an analog computer. The analog computer is also employed at this time to produce differentiated signals for each degree of freedom. All signals are then converted to digital form by means of an analog-to-digital converter at a rate of 50 to 100 samples per second. As the final step in the process, the digitized signals are reduced into means, rms values, excedance values and power spectra for use in model development, together with the reduced subjective response data.

Since all of the above procedures are standard ones, described in any text on the subject, they will not be repeated here except for the differentiation of signals. A simple circuit that may be used to differentiate signals is shown in Figure III-5, taken from Fairchild and Krovetz.[1] This circuit has been tested and found to introduce approximately 5% error, which is considered acceptable.

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[1] Fairchild, B. T. and Krovetz, L. J. Ten circuits for differentiation on analog computer, Control Engineering, February 1965.

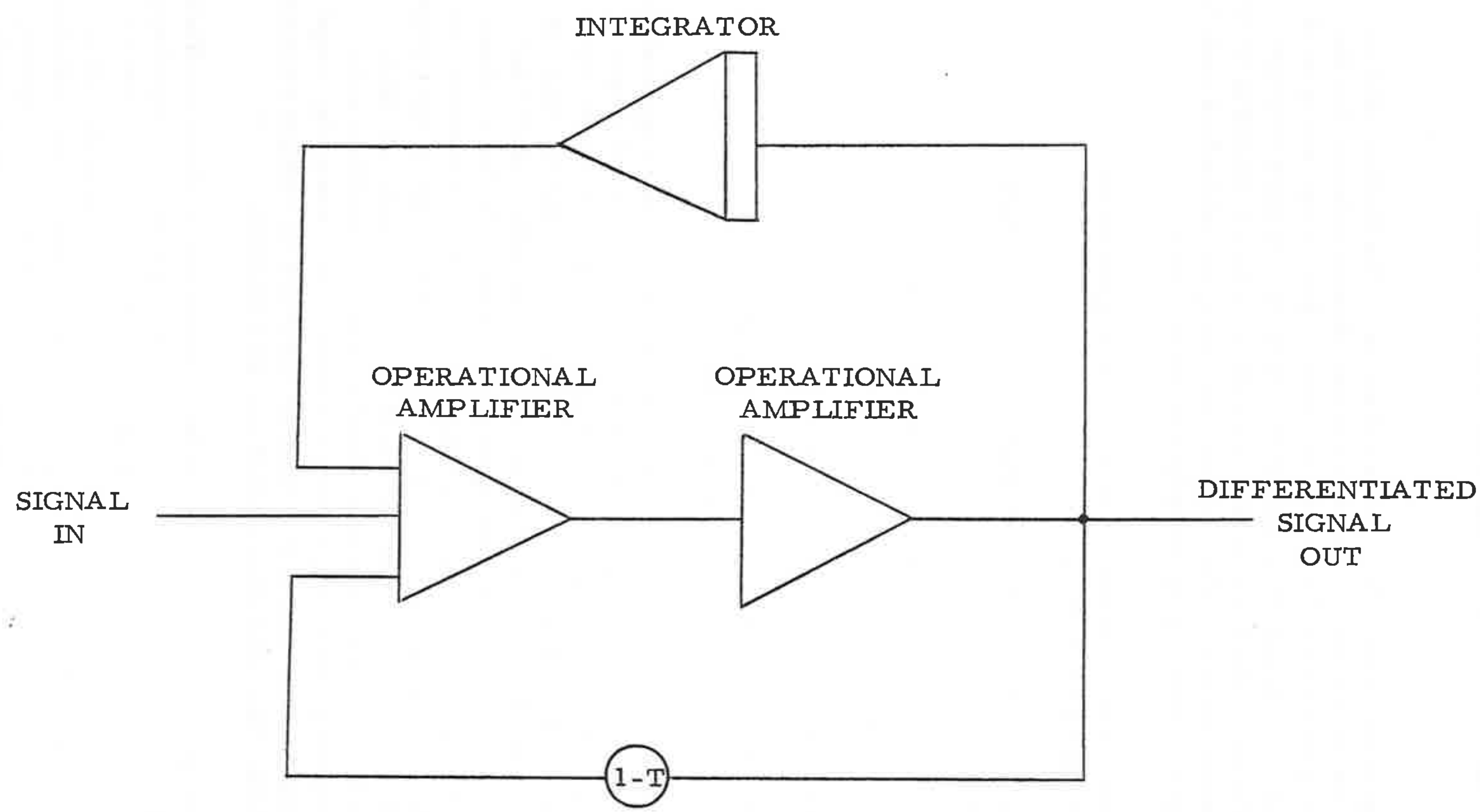

FIGURE III-5. DIFFERENTIATION CIRCUIT.

IV. RIDE QUALITY MODELING TECHNIQUES

The modeling process consists of several steps. The initial step is preparing the data for entry into a suitable computational scheme for determining the relationships which exist in the data. There are many techniques available; the one chosen is multiple regression analysis because of its relative simplicity. More elaborate techniques are not necessary for defining the relationship between the environment and the subjective reaction to it. The steps used in developing models are as follows:

1. Perform step-wise and concurrent linear regressions on all variables of interest.

2. Select those models which best describe the variation observed in the data.

3. Test these models on regular passenger data to ascertain goodness of fit.

4. Recommend the 'best' available model.

5. Compare the results of this model(s) with other known models or procedures for evaluating ride quality.

There are several points to note. First, in any step-wise regression of this type, there is no unique solution due to the high degree of intercorrelation among the ride environment variables. Judgment on the part of the analyst is required to determine which variables should be entered and in what order. Second, models must be used to evaluate conditions other than those for which the data were gathered. Although this is theoretically not allowed, in many cases, it is done in practice. However, in order to extrapolate to other situations, it is essential that the model represent a physical reality and not be just the 'best curve' through the data. Thus, any result that is counter intuitive should either be verified substantially or be removed from further consideration. For example, negative coefficients would lead to the conclusion that an increase in motion results in a more comfortable ride, and thus should not be retained.

There is a great deal of information in the simple correlation coefficients for the data. These coefficients can serve as a useful guide in determining which variables need be examined in future studies or which need further analysis. If, for example, the variable rms pitch rate has essentially a zero correlation with the subjective response but shows sufficient variability, then there is little need to evaluate this variable further. Similarly, if an independent variable has a correlation coefficient of nearly unity with another independent variable, then only one of these variables should appear in any regression equation. The analyst needs to be aware that this occurred and that it does not imply that the independent variable selected is the dominant one. In fact, the underlying cause-effect relationship may be due to the variable omitted.

Testing or, rather, validating the models which are finally chosen by the above method involves testing the goodness of fit of data obtained from regular passengers as compared with that generated by the models. One technique for doing this test is comparing the 'best' available model, previously generated, with one generated on the same variables for the validation data. Often, the ranges of the two sets of data will most likely differ. Hence, statistical comparison of the two sets of data should be performed to determine if the differences are significant or can be attributed to chance fluctuation of data.

Another simplier technique involves using the model, developed during Phase I, to predict comfort responses based on vehicle motion recorded during the Phase 2 validation effort. The predicted comfort responses are then correlated with those actually gathered from regular passengers. The size of the resulting correlation coefficient would indicate the "goodness of the model." The correlation coefficient, of course, should be tested to determine its statistical significance using standard techniques. This latter technique was employed to validate the models presented in the following section of this volume.

V. PRACTICAL APPLICATIONS OF MODELS

Ride quality models may be used to evaluate the ride quality of existing or proposed vehicles and to write specifications for new transportation systems.[1] Each of these applications involves selecting the appropriate model, restricting the analysis to those variables within the model and utilizing the quantitative relationships to derive equal comfort zones. It is important to note that none of these applications presupposes the level of ride quality that is acceptable to the general public. The user must select the level of comfort deemed appropriate for the vehicle in question. Some guidance for doing this is provided by previous work that has indicated a relationship between mean comfort level and perceived willingness to take another trip.[2] Although this is not necessarily accurate for all modes and subpopulations or for actual prediction of return trips, it does serve to indicate when passengers might become reluctant to "take another trip" on the mode in question. This relationship is shown in Figure III-6.

A. Specifications for New Vehicles

Models may be used to determine the ride quality specifications for new vehicles. Such specifications may be determined by following the steps described below:

- Select the desired mean comfort level.
- Restrict the non-inclusive variables.
- Apply appropriate comfort model.
- Generate equicomfort contours.
- Ensure new vehicle environment lies below generated equicomfort contours.

To illustrate this technique, it is applied to the specifications for a new light rail vehicle.

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[1] Models presented in the document should not be used where vehicle motion is characterized by uncommon or infrequent shocks (high crest factor motions).

[2] Jacobson, I. D. and Richards, L. G. Ride quality evaluation II: Modelling of airline passenger comfort. Ergonomics, 1976, 19(1), 1-10.

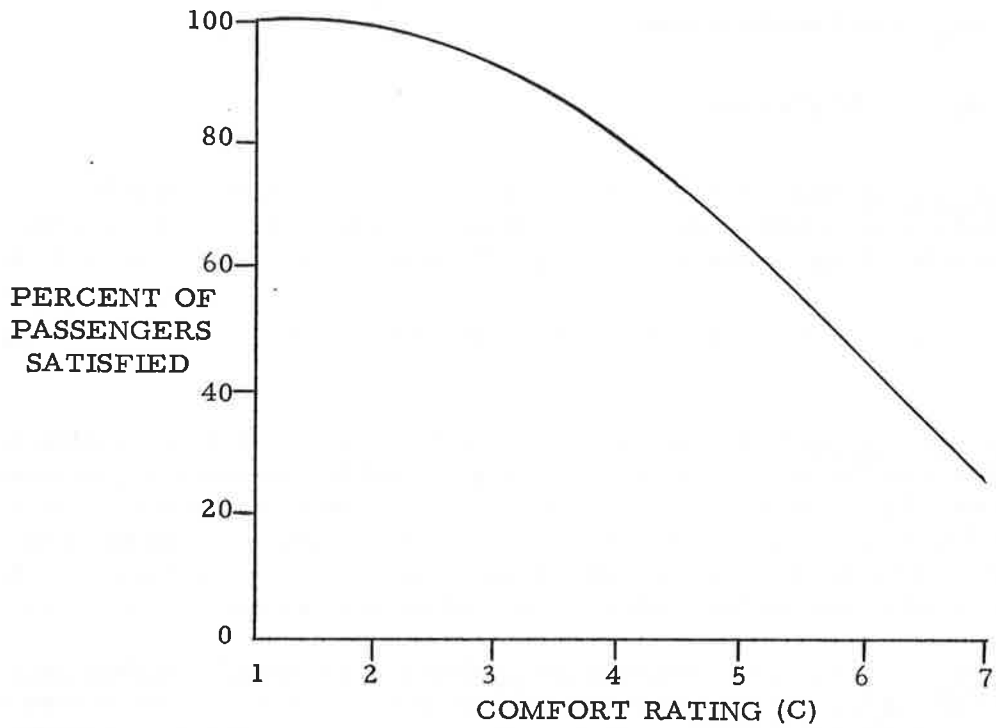

FIGURE III-6. PASSENGERS SATISFIED
AS A FUNCTION OF COMFORT.

Select the desired mean comfort level. Based on passenger acceptance as shown in Figure III-6, a mean comfort level of C = 3.0 (somewhat comfortable as per scale on Page 9) is chosen corresponding to approximately 90% of the population being satisfied with the ride. The user can choose any value desired.

Restrict non-inclusive variables. Since the model used contains only three of the motion variables and noise, all other variables which could cause comfort problems should be restricted to within the range for which the model holds. Thus:

$$\omega_P = 1.0 \text{ deg/sec rms}$$

$$\omega_Y = 2.5 \text{ deg/sec rms}$$

$$a_L = .02 \text{ g's rms}$$

Apply appropriate comfort model. Since the future light rail vehicle will exhibit characteristics which are similar to both trains and buses, the model considered appropriate is a composite model which gives comfort as:

$$C'' = 1.0 + .5\ \omega_R + 0.1\ [dB(A) - 65)] + 17a_T + 17a_V \qquad (1)$$

Generate equicomfort contours. Selecting a noise level representing the desired level on the vehicle in question, e.g., 80 dB(A), allows the generation of surfaces of equal comfort in the remaining three motion dimensions. This is shown in Figure III-7. Changing the noise level to 75 dB(A), as illustrated in Figure III-8, changes the contour substantially upward. That is, lowering the the noise level allows higher motion levels and maintains a given comfort rating.

Ensure new vehicle environment lies below generated equicomfort contours. Ensuring the design possesses vehicle motions, which do no exceed the values given for a prescribed railbed, will also ensure compliance with the chosen mean comfort rating. This requires the designer to meet a ride quality specification while still providing the freedom to trade one variable against another in achieving the desired level.

This, of course, does not assure adequate ride comfort for all possible combinations. However, it will give an adequate ride environment for all straight/level road and hill sections of the system. If there are a significant number of curves to be considered, the model for curves should be applied as above and be included as a second criterion to be met.

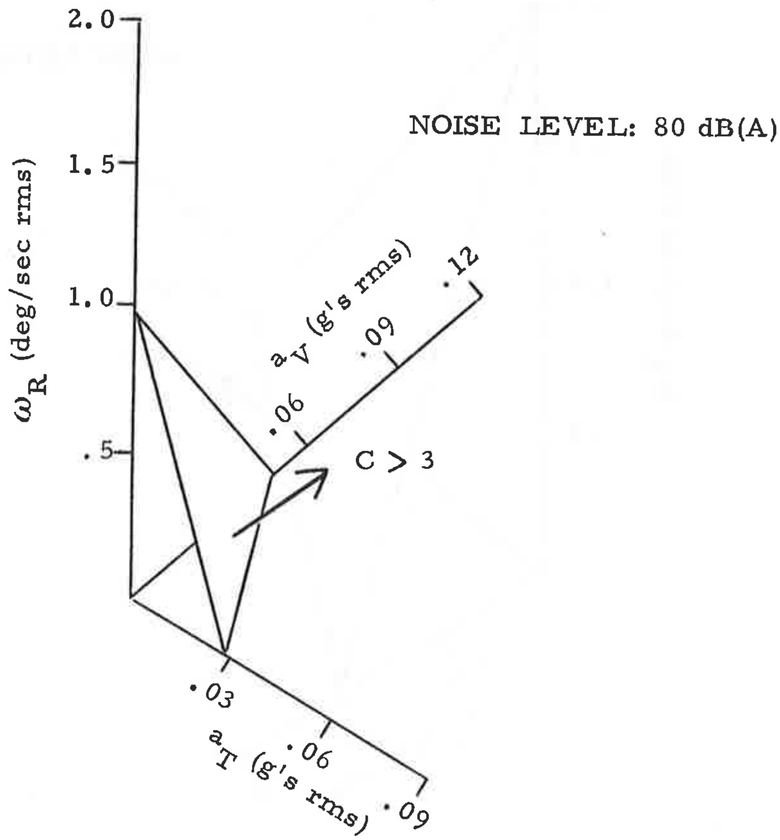

FIGURE III-7. EQUAL COMFORT SURFACE FOR 80 dB(A).

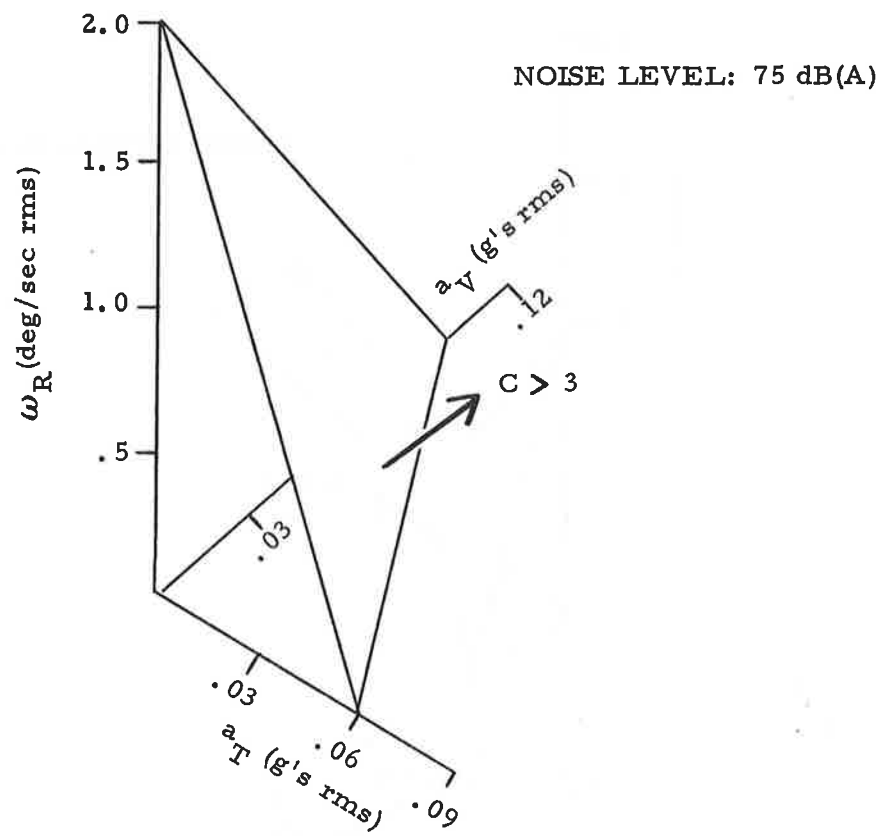

FIGURE III-8. EQUAL COMFORT SURFACE FOR 75 dB(A).

B. Evaluation of Existing Vehicles

To evaluate the ride quality of an existing vehicle, there are two alternative methods, depending on the data available. If sufficient data exist, taken aboard the vehicle of interest, to make a statistically meaningful prediction (no less than 25 separate measurements of at least 30-second duration over a variety of roadbeds), then the model(s) can be used directly. If not, an analytic process must be used to obtain motion data over the types of roadbeds likely to be encountered. The application described herein assumes the user has on hand the data needed to apply the appropriate model.

The steps to be taken are:

- Measure (or predict) existing ride environment.
- Select appropriate model.
- Check motion and noise variables to ensure model applicability.
- Apply selected model(s).
- Determine distribution about the mean.
- Determine satisfaction level.

To illustrate this technique, it is applied to the evaluation of the ride environment of a bus.

Measure existing ride environment. It is assumed, in this case, that an instrumentation package has been placed on the vehicle and that at least 25 segments of the route in question have been analyzed. For each of the 25 segments, the data should include rms values of three linear accelerations and three angular rates with the means biased out and noise in dB(A). Each sample should contain between 30 and 60 seconds of ride environment.

Select the appropriate model. If the vehicle to be evaluated is a bus over straight/level roads or hills, then the appropriate equation gives the mean comfort rating as:

$$C' = .87 + 1.05\,\omega_R \qquad (2)$$

If curves are to be evaluated as well, then the appropriate equation for curves must also be selected.

Check motion and noise variables. The next step in the process involves examining the ranges of the measured variables. This determines whether the equation is being used over the range for which it was derived or not. If not, the confidence in the results are seriously reduced. For the case of the bus, these ranges are (for straight/level roads or hills):

	ω_R (°/s)	ω_P (°/s)	ω_Y (°/s)	a_L (g's)	a_T (g's)	a_V (g's)	dB(A)
Min	1.1	1.2	1.1	.017	.031	.036	70
Max	4.6	3.6	3.5	.073	.134	.152	83

The user should assess the degree to which the variables, for the data being analyzed, meet these minimum and maximum ranges. Assuming that the data satisfy this requirement, continue with the next step.

Apply selected model. The selected model is applied for each segment. That is, the value of the rms roll rate (mean biased out) is used to determine a mean comfort rating for each segment. For example, if a segment has an rms roll rate of 2 deg/sec, the computed mean comfort rating would be C = 2.97.

Determine distribution about the mean. The distribution about the mean for each comfort rating can be found by using a distributive model such as:

$$P\ (\text{Comfort Rating} = c) = \binom{6}{c-1} \left[\frac{\bar{c}-1}{6}\right]^{c-1} \left[1 - \frac{\bar{c}-1}{6}\right]^{7-c} \qquad (3)$$

For the example segment of the previous step, this reduces to

$$P\ (\text{Comfort Rating} = c) = \frac{6\,!}{(7-c)\,!\,(c-1)\,!} \left[\frac{1.97}{6}\right]^{c-1} \left[1 - \frac{1.97}{6}\right]^{7-c} \qquad (4)$$

which gives the following distribution of responses for the seven comfort ratings as shown on the following page. This distribution indicates that although the mean comfort rating for the segment is 2.97, there are 31% of the respondees who can be expected to give a rating of 4 or worse.

Comfort Rating	% Responses
1	9
2	27
3	33
4	21
5	8
6	2
7	0

Determine satisfaction level. Another method of evaluation involves determining the percentage of passengers satisfied for the given mean rating. From Figure III-6, 92% of the passengers will be satisfied for a comfort rating of 2.97. The difference between this calculation and the one above for comfort is accounted for by recognizing that, although uncomfortable, a passenger may still be satisfied if the "other" benefits of the system outweigh comfort.

After each segment has been evaluated, the composite for the entire route can be determined.

C. Evaluation of Proposed New Travel Modes

In considering the ride quality of proposed new travel modes (e.g., magnetic levitated vehicle, air cushion vehicles and automated guideway vehicles), it is necessary to use caution in applying a mode specific model. These vehicles will not always have ride characteristics similar to a conventional mode, e.g., bus, train and aircraft. In many cases, they may have ride characteristics similar to portions of several conventional modes. If the ride environment differs significantly from any single existing mode, it is recommended that a composite model such as the following be used:

$$C' = 1.0 + .5\,\omega_R + 0.1\,[dB(A) - 65] + 17a_T + 17a_V \qquad (5)$$

The procedure to be followed for the actual evaluation parallels that given above:

- Analytically predict the expected ride environment.
- Select the appropriate model(s).

Determine the range of validity of the model.

Apply the selected model to determine mean comfort levels.

Determine distribution of responses about mean comfort levels.

Determine passenger satisfaction level.

The only differences between this application and the previous one for an existing mode are: in general, experimental ride environment data will not be available so that the motion and noise environment will have to be analytically determined, and the selection of the appropriate model will require a significant degree of judgment. In reference to the latter, some guidance is provided here.

There are three major areas to examine before determining the appropriateness of a mode-specific versus a composite model. These are: dominant motions, correlations between motion variables, and spectral content of motion variables.

First, regarding dominant motions, each mode is dominated by one or more motion/noise variables. For the bus mode, it is the roll rate; for the train, roll rate and noise level; and for the air mode, vertical acceleration, lateral acceleration and noise level. Should the new mode have ranges of the environmental variables exceeding those given in the table of minimums and maximums shown in Section V.B., it is possible for one or more of those variables to become the determinant of ride quality. In those cases where no model exists, the user is advised to apply a composite model for best results.

Next, an analysis of the correlation between motion variables should be carried out to determine the amount of interdependence. Finally, the spectra of the major degrees of freedom of the motion variables should be compared with the spectra for each of the existing modes. If the spectra are significantly different from those for existing modes, then a composite model should be used.

Once these comparisons have been made and the user determines that a composite model is the appropriate one, the steps given in Section V.B. should be followed, replacing the mode-specific model with a composite model.

APPENDIX

SAMPLE SUBJECTIVE RESPONSE BOOKLET

DUNLAP AND ASSOCIATES, INC.
and
UNIVERSITY OF VIRGINIA

IN AN EFFORT TO IMPROVE PUBLIC TRANSPORTATION, YOU ARE INVITED TO PARTICIPATE IN A RESEARCH STUDY. THE STUDY CONCERNS PASSENGER REACTIONS TO THE QUALITY OF RIDE AND OTHER FEATURES OF THE SERVICE. IF YOU ARE WILLING TO TAKE PART IN THIS STUDY, PLEASE COMPLETE THE QUESTIONNAIRE.

<u>You need not answer any question that offends you.</u>

1. Age: ___16-24 ___25-34 ___35-48 ___49 and up

2. Male_____ Female_____

3. Approximate household income (before taxes):

   ____under $10,000 ____$20,000 - $29,999

   ____$10,000 - $19,999 ____$30,000 or more

4. Are you a licensed automobile driver? ___Yes ___No

5. If you had wished, could you have used a car for this trip? _____Yes _____No

6. How often do you use this type of transportation?

   _____Daily _____Weekly _____Monthly _____Seldom

7. What is the purpose of your trip?

   _____Commuting _____Company Business

   _____Personal Business _____Pleasure

YOU ARE REQUESTED TO RATE THE QUALITY OF RIDE DURING THE PORTIONS OF YOUR TRIP INDICATED BELOW. USE A SINGLE CHECK MARK TO INDICATE YOUR RATING ON EACH COMFORT SCALE, AS APPROPRIATE.

Segment A

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment B

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment C

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment D

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment E

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment F

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment G

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment H

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment I

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment J

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment K

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment L

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment M

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

Segment N

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

NOW THAT YOU HAVE RATED THE QUALITY OF RIDE DURING SEPARATE PORTIONS OF YOUR TRIP, PLEASE GIVE A SINGLE RATING OF RIDE QUALITY FOR THE OVERALL TRIP.

8. The ride during this trip was:

____Very Comfortable

____Comfortable

____Somewhat Comfortable

____Neutral

____Somewhat Uncomfortable

____Uncomfortable

____Very Uncomfortable

YOU HAVE JUST RATED QUALITY OF RIDE. NEXT, PLEASE INDICATE HOW STRONGLY YOU AGREE OR DISAGREE WITH EACH STATEMENT ABOUT OTHER FEATURES OF THE TRIP. CHECK ONLY ONE ANSWER FOR EACH STATEMENT BELOW.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
9. Seat is comfortable:	____	____	____	____	____
10. Leg room is adequate:	____	____	____	____	____
11. Temperature is right:	____	____	____	____	____

12. Considering the ride you have just rated, if you had a choice, would you:

____ Be eager to take other rides?

____ Take other rides without hesitation?

____ Take another ride, but with some hesitation?

____ Prefer not to take another ride?

____ Not take another ride?

13. If we could significantly improve the service, how much more, if anything, would you be willing to pay per trip for each of the following, or any other improvement? (Please insert dollars, cents or zeros in the appropriate spaces.)

____ More frequent service

____ Improved cleanliness

____ Greater dependability (on timeness)

____ Faster service

____ Greater ride comfort

Other improvements (list)

____ ______________________________

____ ______________________________

____ ______________________________

14. If the fare were increased commensurate with the improvement(s) indicated above, how certain are you that you would continue to use this service?

0% 50% 100%

(Mark the scale, as appropriate)

THANK YOU FOR YOUR HELP

250 Copies

U. S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
KENDALL SQUARE, CAMBRIDGE, MA. 02142