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16. Abstract

This report describes Vehicle/Track Interaction Assessment Techniques (IAT) which are developed to provide standardized procedures and tools in order to:

Investigate the dynamic performance of railroad vehicles, and systematically identify and cure dynamic track interaction problems associated with a vehicle.

The IAT addresses ten performance issues: hunting, twist and roll, pitch and bounce, yaw and sway, steady-state curving, spiral negotiation, dynamic curving, steady buff and draft, longitudinal train action, and longitudinal impact. The report discusses the test and data analysis procedures required for each performance issue in terms of the control variables from track inputs that are required to create the test environment, the response variables to be measured, the extent of data analysis required, the data handling requirements, the performance indices to be used in interpreting the test results, and the potential test sites. This report is in two parts. Part I is contained in Volume I and covers the overall process of determining vehicle performance issues. Part II, comprised of Volumes II and III, discusses the detailed procedures to be used in the Vehicle/Track Interaction Assessment Techniques.

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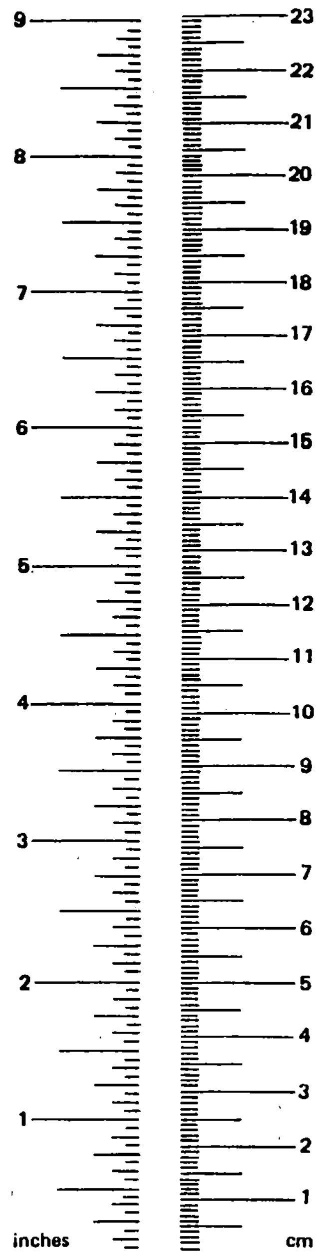
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

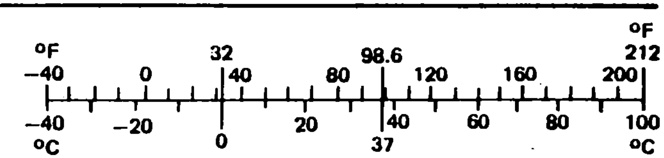
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight 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	36	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



PREFACE

This volume is the first of three volumes dealing with the Vehicle/Track Interaction Assessment Techniques (IAT) which were developed by the Transportation Systems Center (TSC) and its contractors: Arthur D. Little, Inc. (ADL), Battelle Columbus Laboratories (BCL), ENSCO, Inc., Kaman Sciences Corporation (KSC), Systems Control Technology, Inc.(SCT), and The Analytic Sciences Corporation (TASC).

This information was developed from the Stability Assessment Facility for Equipment (SAFE) Program. That program had direct input from the railroad affiliated personnel of the International Government-Industry Track Train Dynamics Research Program and the Federal Railroad Administration, Track Safety Research Division.

The Vehicle/Track Interaction problems addressed by the IAT, called "Performance Issues," are listed below:

- Hunting;
- Twist and Roll;
- Pitch and Bounce;
- Yaw and Sway;
- Steady State Curving;
- Spiral Negotiation;
- Dynamic Curving;
- Steady Buff and Draft;
- Longitudinal Train Action; and
- Longitudinal Impact.

These problems have been responsible for compromising rail vehicle stability in the past and are expected to be important issues for consideration in future designs.

The IAT has evolved over the past few years through experience gained in conducting a number of tests dealing with vehicle/track interaction. Essentially, the IAT is a systematic approach using a standardized set of procedures and tools (i.e., elements) for identifying, diagnosing and solving stability problems in a rail vehicle already in revenue service and for assessing the stability of a new or modified vehicle (freight car, passenger car, or locomotive) prior to its introduction into revenue service. The primary goal of the IAT is to provide a means of assessing the adequacy of rail vehicle stability at a minimum cost. This is accomplished by:

- Systematically developing an approach for identifying stability problems;
- Identifying the test procedures and tools necessary to assess the stability characteristics of the rail vehicles;

- Reducing, through the use of computer models, the amount of testing required;
- Summarizing the state-of-the-art in tools;
- Standardizing the nomenclature in stability assessment; and
- Providing the ability to compare data from different tests.

Although the IAT can determine the potential for derailment as a result of excessive motion between the wheel and rail or because of undesirable levels of wheel/rail interaction forces, it does not explicitly deal with derailments resulting from the failure of a vehicle or track component due to wear, fatigue, or excessive stress caused by these forces. Also, the IAT has been developed to assess the dynamic performance of most types of freight cars, locomotives, and passenger cars; however, a particular type of vehicle may not be sensitive to all Performance Issues. Therefore, the IAT incorporates a procedure for identifying the principal Performance Issues of concern for any vehicle design.

The IAT is organized in the form of Assessment Procedures. For each of three objectives of the IAT, a distinct procedure is identified and presented in the form of a flow chart. Thus, a procedure is defined for:

- The Modified Vehicle Assessment;
- The Vehicle Problem Diagnosis; and
- The Prototype Vehicle Assessment.

Each procedure requires a number of steps to be conducted in order to meet the specific Assessment Objective. Often, but not always, tests must be conducted to meet the Assessment Objective. These tests are distinctly different and complementary to the revenue service testing to which a new or modified vehicle is generally subjected. The IAT tests are designed to subject a vehicle or consist to a severe service environment which is simulated using test tracks or laboratory equipment. In this way, the range of dynamic characteristics of a vehicle could be brought out in a relatively short time. Achieving the same goal by means of a revenue service testing procedure may require extensive testing on many miles of track.

This document, which provides information on test and analysis procedures incorporated in the IAT, is divided into two parts. The first part introduces the IAT and provides the basic information on various Assessment Procedures and the steps to be taken in performing them. The second part consists of fifteen sections, each detailing one aspect of the Assessment Techniques. In this way, a potential user need only read Part 1 to understand the key aspects of the IAT; the details provided in the second part can be studied later while the user is gaining further knowledge of the IAT or before actually utilizing the IAT for Vehicle Performance Assessment.

This document was developed under the guidance of the TSC, with the following principal contributing individuals:

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The organizations involved in developing the document are shown on the next page.

This volume, the first of a three volume set, includes the following sections of Part I:

- 1 - Introduction to the Vehicle/Track Interaction Assessment Techniques
- 2 - The Structure of the Vehicle/Track Interaction Assessment Techniques
- 3 - Overview of Test and Data Analysis Procedures
- 4 - Typical Example for Performing an Assessment
- 5 - System Standard Nomenclature
- 6 - Summary of Part II Sections

SECTIONS	PRINCIPAL CONTRIBUTING ORGANIZATIONS*
PART I (ALL SECTIONS)	ADL
PART II	
A. Resources Available for Investigating Performance Issues	ADL
B. Accident History Investigation	ADL
C. Vehicle/Track Simulation Models	ADL/TSC
D. Rail Vehicle Model Validation	SCT
E. Test Plan Summaries	TSC
F. Test Facilities	ADL
G. Track Geometry Perturbations	TSC
H. Rail/Track Stiffness Measurements, Variations, and Simulations	TSC/BCL
I. Performance Indices	TASC
J. Analytical Techniques	ADL/ENSCO
K. Wayside and Onboard Instrumentation	TSC/ENSCO
L. Data Management	TSC
M. Field Test Planning	KSC
N. Vehicle Characterization	ADL/ENSCO
O. Reference Vehicle Usage	TASC

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ENSCO, Inc.
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SECTION 1

INTRODUCTION TO THE VEHICLE/TRACK INTERACTION ASSESSMENT TECHNIQUES

1.1 Background

The dynamic interaction between rail vehicle and track is of growing concern to the railroad industry. The ability to discover potential vehicle/track interaction problems before a vehicle is introduced into service would benefit the industry enormously, not only by improving rail safety through reductions in the number of derailments, but also by reducing the cost of modifications needed to solve such problems, since these modifications can be incorporated into the design before a large number of cars are manufactured.

There is a need for a more thorough investigation of the dynamic performance of a new or modified vehicle before it is introduced into revenue service. Only a limited dynamic evaluation is currently being done, partly because of the absence of clearly defined procedures to do such an evaluation. Existing procedures are not standardized, making it difficult to fully utilize the experience gained from the previous tests performed on similar vehicles. Also, the tests are generally not documented well enough for an outsider to thoroughly understand and interpret the test results. Therefore, each time a new or a modified vehicle is developed, a new set of test plans and procedures must be prepared and a comprehensive test must be performed to evaluate its dynamic performance. This is expensive and time consuming.

The absence of a thorough investigation of vehicle performance could permit a vehicle/track interaction problem to appear after a vehicle is introduced into revenue service. One example is the rock and roll problem with loaded 100 ton hopper cars, in which the crosslevel variations in the track, caused primarily by dipped staggered joints on 39 ft. bolted rail segments, created a roll resonance in the vehicles leading to many derailments [Ref. 1-1]. In such cases, even if a reasonable cure for a dynamic problem were to be found, its implementation may be difficult if a large number of cars were already in service.

Furthermore, in a situation where a problem is believed to exist and the vehicle is already in revenue service, investigations to identify and cure the problem were less cost-effective than they might have been. An example of such a situation is the investigation of the perceived derailment problem with the SDP-40F locomotive.

Amtrak SDP-40F powered trains, in service from mid-1973, were involved in 21 derailments by early 1978 [Ref. 1-2]. A number of tests were performed to determine if a problem really existed, and if so, to identify and correct the problem. These tests included those performed on the Chessie System during June 1977 [Ref. 1-2] on the Burlington Northern during Spring 1977 [Ref. 1-3], and finally, on a specially prepared "perturbed track" at the Transportation Test Center during

November and December 1978 [Ref. 1-4]. Although these tests provided significant information on the behavior of the locomotive, the same information could probably have been obtained sooner and at a lesser cost, had there been a set of well defined and standardized procedures for addressing this type of problem. The cost associated with "re-inventing" all the test planning for the subsequent Vehicle/Track Interaction Test, conducted at Starr, Ohio, on a Chessie track during May and June 1981, [Ref. 1-5] reinforced the need for this approach.

Thus, in addition to the need for assessment procedures for a new or a modified vehicle, there is a need for a method which would assist in systematically interpreting accident data, and in performing analytical studies and tests to identify and cure problems associated with a vehicle already in revenue service.

Finally, prompted by the needs to reduce fuel consumption and to improve dynamic performance, a number of new and innovative designs are being offered to the railroad industry. These include: radial trucks of various types, aluminum car, articulated intermodal car, and so on. A standardized set of test procedures are required to ensure that these innovations are properly evaluated before being generally accepted by the industry.

Recognizing these needs, the Transportation Systems Center, under the sponsorship of the Federal Railroad Administration, Office of Research and Development, has developed the "Vehicle/Track Interaction Assessment Techniques" (IAT) described in this document. The use of IAT by the railroads and equipment manufacturers for the dynamic performance assessment of vehicle or consist is expected to significantly reduce the overall cost of improving safety in rail transportation.

1.2 The Vehicle/Track Interaction Assessment Techniques

The IAT has evolved over the past few years through experience gained in conducting a number of tests dealing with vehicle/track interaction. Essentially, the IAT is a systematic approach using a standardized set of procedures and tools (i.e., elements) for identifying, diagnosing and solving stability problems in a car already in revenue service and for assessing the stability of a new or modified vehicle (freight car, passenger car, or locomotive) prior to its introduction into revenue service. The primary goal of the IAT is to enhance the safety of railroad operation by providing a means to assess the adequacy of rail vehicle stability at a minimum cost. This is accomplished by:

- Systematically developing an approach for identifying stability problems;
- Identifying the test procedures and tools necessary to assess the stability characteristics of the rail vehicles;

- Reducing, through the use of computer models, the amount of testing required;

- Summarizing the state-of-the-art in tools;

- Standardizing the nomenclature in stability assessment; and

- Providing the ability to compare data from different tests.

Because of these characteristics, the IAT offers certain distinct advantages over the current assessment procedures, as shown in Table 1-1.

The vehicle/track interaction problems addressed by the IAT, called "Performance Issues," are listed in Table 1-2. These problems have been responsible for compromising vehicle stability in the past and are expected to be important issues for consideration in future designs. A detailed discussion of Performance Issues appears in Subsection 2.4.

As discussed later, a variety of factors affect the dynamic performance of a rail vehicle. Some of these factors are: the track characteristics (geometry variations, compliance, rail surface condition, etc.), the vehicle properties and the consist make-up. The IAT attempts to integrate these factors in such a manner that an individual situation can be analyzed, and yet a systematic and standardized approach is maintained.

Although the Interaction Assessment Techniques can determine the potential for derailment as a result of a factor such as the excessive motion between wheel/rail or because of undesirable levels of wheel/rail interaction forces, it does not explicitly deal with derailments resulting from the failure of a vehicle or track component due to wear, fatigue, or excessive stress caused by these forces. Also, the IAT has been developed to assess the dynamic performance of most types of freight cars, locomotives, and passenger cars; however, a particular type of vehicle might not suffer from a deficiency in all Performance Issues. Therefore, the IAT incorporates a procedure for identifying the principal Performance Issues of concern for any vehicle design.

The IAT is organized in the form of Assessment Procedures. For each of the three objectives of the IAT, a distinct Procedure is identified and presented in the form of a flow chart. Thus, a procedure is defined for:

- The Modified Vehicle Assessment;

- The Vehicle Problem Diagnosis; and

- The Prototype Vehicle Assessment.

TABLE 1-1: THE BENEFITS OF IAT

PROBLEMS WITH CURRENT ASSESSMENT PROCEDURES	HOW DOES IAT HELP?
• Only limited dynamic testing is being done prior to the introduction of vehicles into revenue service because: - it is too time consuming and expensive; - the test procedures are not well defined.	• Reduces time and expenditure required through standardizing procedures and tools. • Identifies test procedures and helps develop a test plan.
• Diagnosis of a stability problem is difficult because: - it is difficult to formulate a hypothesis; - the results of other tests on the same equipment cannot be easily used; - the testing to confirm a hypothesis is expensive and time consuming.	• Assists in formulating a hypothesis based on the symptoms of the stability problem. • Standardizes the test procedures and resources, making it easier to use data from a previously run test for diagnosis by railroads, manufacturers and other organizations. • Helps in identifying the potential test sites and modifying them to perform the required tests.

TABLE 1-2: THE PERFORMANCE ISSUES ADDRESSED BY THE IAT

- Hunting
- Twist & Roll
- Pitch & Bounce
- Yaw & Sway
- Steady State Curving
- Spiral Negotiation
- Dynamic Curving
- Steady Buff & Draft
- Longitudinal Train Action
- Longitudinal Impact

As shown in Subsection 2.2, each procedure requires a number of steps to be conducted in order to meet the specific Assessment Objective. Often, but not always, tests must be conducted to meet the Assessment Objective. These tests are distinctly different and complementary to the revenue service testing that a new or modified vehicle generally goes through. The IAT tests are designed to subject a vehicle or consist to a severe environment which is simulated using test tracks or laboratory equipment. This way the range of dynamic characteristics of a vehicle could be brought out in a relatively short time. Achieving the same goal by means of a revenue service testing procedure may require extensive testing on many miles of track.

This document provides information on test and analysis procedures incorporated in the IAT. The structure of the document reflects its user oriented objectives, as described below.

1.3 The Structure of this Document

This document is divided into two parts. The first part complete in Volume I introduces the IAT and provides the basic information on various Assessment Procedures and the steps to be taken in performing them. The second part consists of fifteen sections in Volume II and Volume III, each detailing one aspect of the Assessment Techniques. This way, a potential user need only read Part I to understand the key aspects of the IAT; the details provided in the second part can be studied later while the user is gaining further knowledge of the IAT or before actually utilizing the IAT for Vehicle Performance Assessment.

In Part I, the Techniques are introduced in Section 1, and the structure of the IAT is described in Section 2. Some basic concepts associated with the IAT, such as Assessment Procedures, Test Categories, and Performance Issues, are also provided in the second section.

Section 3 deals with an overview of the Test and Analysis Procedures. This overview includes a Test and Analysis Procedure Matrix, which provides information necessary to prepare test/data analysis plans for each combination of Performance Issue and Test Category. The concept of Performance Indices is also proposed in this section. These indices provide a systematic and standardized way of assessing the dynamic performance of a vehicle on different track conditions. The benefits of using reference vehicles for test track calibration, test calibration, baseline usage, and service environment prediction are also discussed in Section 3.

Section 4 provides an example of how the interaction assessment can be performed for a typical stability problem. The scenario selected to illustrate the use of IAT deals with a 100-ton hopper car found to have above average rate of derailment.

Section 5 deals with the standardization of nomenclature used in vehicle/track interaction test program. In the past, the absence of such standardization has led to difficulties in interpreting and utilizing the data from previously run tests. Through use of standard nomenclature, the IAT will contribute to resolution of this problem and increase effectiveness in the common use of test data.

Finally, a summary of the contents of fifteen sections of Part II is provided in Section 6, along with the relevance of each to the overall structure of the IAT process. As mentioned earlier, these sections deal with the details of various aspects of the IAT which are summarized in Part I.

REFERENCES -- SECTION 1

1-1. Anon., "Track-Train Dynamics Harmonic Roll Series, Volume 1-4," Track/Train Dynamics Program.

1-2. Tong, P., Brantman, R., Greif, R., and Mirabella, J., "Tests of the AMTRAK SDP-40F Train Consist Conducted on Chessie System Track," FRA-OR&D-79/19, U.S. DOT, FRA, Washington, D.C., June, 1980.

1-3. Palmer, D.W. and Nayak, P. R., "SDP-40F Test on the Burlington Northern Railroad," prepared by Arthur D. Little, Inc., for Association of American Railroads, Chicago, Illinois, February, 1980.

1-4. Coltman, M., Brantman, R., and Tong, P., "A Description of the Tests Conducted and Data Obtained During the Perturbed Track Test," FRA/ORD-80/5, U.S. DOT, FRA, Washington, D.C., January, 1980.

1-5. Anon., "V/T Interaction Test: Test Documentation Report," Draft Report, Task 7, Contract DTRS-57-80-C-00132, prepared by Arthur D. Little, Inc., for Transportation Systems Center, Cambridge, MA, June, 1981.

SECTION 2

THE STRUCTURE OF THE VEHICLE/TRACK INTERACTION ASSESSMENT TECHNIQUES

The structure of the IAT is summarized in Subsection 2.1 in the form of a block diagram, which shows the tasks to be performed and the sequence of performance. Several important components of this summary block diagram are then explained in subsequent subsections.

2.1 The Summary of Structure Block Diagram

As shown in Figure 2-1, the IAT consists of a series of tasks, which, when performed in the prescribed sequence, lead to the ultimate objective of assessing the dynamic performance of a vehicle or a consist.

This process begins with the user developing the assessment objective and the vehicle/consist configurations for which the assessment has to be performed. As mentioned earlier, the IAT can address three objectives:

- To perform a stability assessment of a modified vehicle,
- To diagnose a vehicle stability problem, and
- To perform a stability assessment of a prototype vehicle.

Based on the assessment objective, an Assessment Procedure for fulfilling that objective is defined. An Assessment Procedure generally includes four major steps:

- Problem Identification,
- Analytical Study,
- Test Program, and
- Data Analysis.

However, not all these steps need to be performed every time an assessment is performed. Also, these steps should be performed in a definite sequence to achieve the objective, as explained by the Assessment Procedure flow charts in Subsection 2.2.

Depending on the assessment objective, and on the results of the first two of the four steps identified above, one or more Performance Tests may be found necessary. These tests fall under one of the following three categories:

- Proof Test;

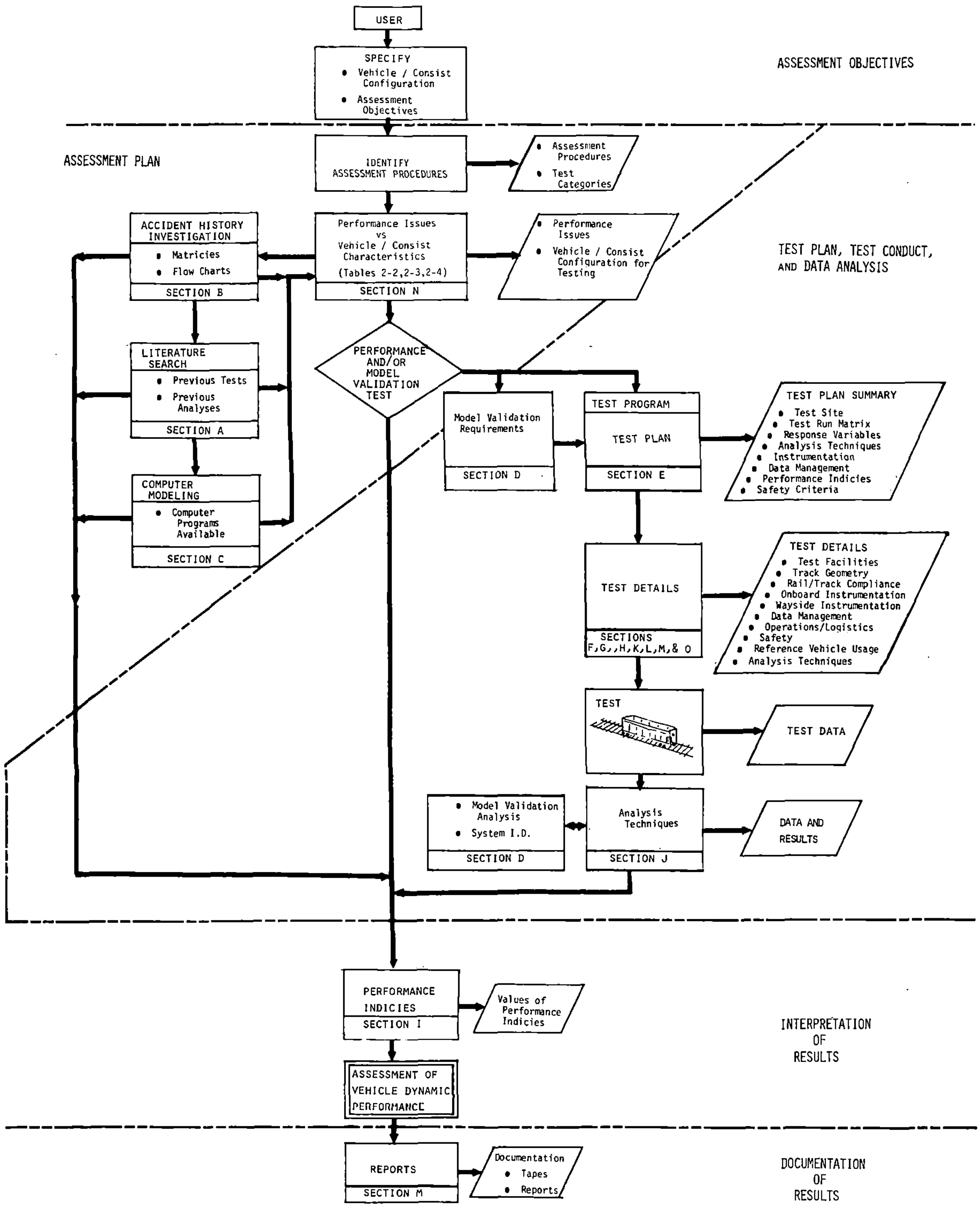


FIGURE 2–1 SUMMARY STRUCTURE BLOCK DIAGRAM

- Diagnostic Test; and

- Service Environment Test.

Once the Assessment Procedure is established and the appropriate Test Categories are identified, the next task is to identify the potential Performance Issues to be addressed. As mentioned in Table 1-2, IAT can address ten Performance Issues. Generally, for given vehicle/consist characteristics, only a few of these Performance Issues are of interest to the investigation. The tables provided in Subsection 2.4 identify vehicle/consist characteristics which can be used to establish the relevant Performance Issues. Also provided in that subsection is a table which shows how different vehicle modifications affect vehicle characteristics. This table can also be used to determine the Performance Issues to be studied for a given set of modifications. One key requirement in performing this task is to be able to obtain the vehicle/consist characteristics, which is described in detail in Section N (Vehicle Characterization).

As shown in Figure 2-1, the task of identifying the Performance Issues of interest gets assistance from the problem identification step which includes:

- Accident History Investigation,

- Literature Search, and

- Computer Modeling.

These "elements" interact among themselves and contribute to the task of determining the Performance Issues. The final result of this interaction is the identification of target Performance Issues for evaluation, with the side benefit of identifying vehicle/consist configurations for testing, as explained in Subsection 2.3.

As mentioned earlier, an Assessment Procedure may require that a test be conducted. As shown in the flow charts in Subsection 2.2, it is possible to conduct assessments without a test program. Often, however, a Model Validation test may also be needed to validate a computer model. Either type of test requires the same basic tasks to be performed, as shown in the Structure Diagram (Figure 2-1). Before conducting a test, a Test Plan is developed according to the instructions given in Section 3 and with the assistance of Section E (Test Plan Summaries). For a model validation test, the instructions given in Section D (Model Validation) are also required to develop the Test Plan. Once completed, the Test Plan serves as a guide for developing the details of the test. The Test Details document, developed with the assistance of the information provided in Sections F, G, H, J, K, L, M, and O, includes:

- Test Facilities (F);

- Track Geometry (G);
- Rail/Track Stiffness (H);
- Onboard Instrumentation (K);
- Wayside Instrumentation (K);
- Data Management (L);
- Field Test Planning (M);
- Safety (M);
- Reference Vehicle Usage (O); and
- Analysis Techniques (J).

Thus, all information required for conducting the test is identified at this stage.

The next task is performing the test. This generates raw test data which are processed using the analysis techniques described in Section J. In case the test is done for model validation, additional data processing described in Section D may also be required.

All the information obtained from the test and from the accident history investigation, literature search and computer modeling is used in the task of interpreting the results. The "Performance Indices" are valuable and powerful tools which can be used for the interpretation. As summarized in Subsection 3.2, and described further in Section I, the Performance Indices provide a simple and standardized way of assessing the performance of a vehicle. The determination and intrepretation of Performance Indices, coupled with additional analysis performed to give further understanding of the vehicle dynamic behavior, could constitute as assessment of vehicle dynamic performance.

The final task in the process is to prepare reports in predetermined formats as determined in the original assessment objectives. This last task, often neglected in the past, is emphasized in the IAT, because only through an adequate and standardized documentation can the assessment of a vehicle/consist benefit from those performed earlier on similar vehicle/consist configurations and thereby reduce the overall assessment costs. As shown in the Block Diagram, this documentation generally includes tapes of test data in a standardized format and reports on tests characteristics and test results.

The following three aspects of the IAT are highlighted in the next three subsections:

- Assessment Procedures,
- Assessment Objectives/Test Categories, and
- Performance Issues.

2.2 Flow Charts of Assessment Procedures

As mentioned earlier, the IAT consists of several Assessment Procedure steps to be performed in a definite sequence. These steps are selected based on the overall Assessment Objective and the results obtained from earlier steps. Table 2-1 shows suggested steps for each Assessment Objective. However, not each of these steps need be performed for a particular assessment, as explained below.

2.2.1 Assessment Procedure for Modified Vehicle Evaluation

Modifying a vehicle generally means adding or removing components or changing their designs (dimensions, material, or characteristics). As shown in Figure 2-2, the first task to be performed in evaluating the stability of a modified vehicle is to select the Performance Issues which may be affected by such modifications. This is accomplished through a Literature Search of problems in similar cars (see Section A), and use of the guideline tables provided in Subsection 2.3.

An analytical study, which generally includes mathematical analysis and computer simulation (see Sections A and C), is performed next. The results of this study may provide enough information to convince the user that the modifications would solve the problem. In this case the cars may be determined acceptable for service. However, if such information is not gathered, then a "Proof Test" may need to be performed. A Proof Test, as described in the next subsection, is a relatively simple vehicle test performed to address specific issues and meet precisely defined objectives.

The performance of the Proof Test results in the generation of raw data which are processed according to Levels 1 and 2 Data Analysis. As explained in Subsection 3.1, Level 1 Data Analysis typically includes simple statistical analysis and resonant frequency analysis, whereas Level 2 data analysis deals with more sophisticated techniques such as Threshold Exceedance Analysis and Frequency Spectral Analysis, in addition to the simpler techniques of Level 1 Analysis. In addition the appropriate Performance Indices are obtained from the processed data as well.

The results of the data analysis should provide enough information to compare the performance of the modified vehicle with that of the original vehicle and to determine that the original problem is solved without causing other problems. If, even at this stage, such determination is not possible, then there would be no choice except to examine alternate modifications. If such modifications are possible,

TABLE 2-1: SUGGESTED ASSESSMENT PROCEDURE STEPS FOR EACH ASSESSMENT OBJECTIVE

SUGGESTED ASSESSMENT PROCEDURE STEPS AND THEIR POSSIBLE ELEMENTS*	ASSESSMENT OBJECTIVE: MODIFIED VEHICLE ASSESSMENT (SEE FIGURE 2-2)	VEHICLE PROBLEM DIAGNOSIS (SEE FIGURE 2-3)	PROTOTYPE VEHICLE ASSESSMENT (SEE FIGURE 2-4)
1. PROBLEM IDENTIFICATION (PERFORMANCE ISSUE SELECTION)			
• Accident History Investigation	-	✓	-
• Literature Search	✓	✓	✓
• Analytical Model	-	-	✓
2. ANALYTICAL STUDY			
• Literature Search	✓	✓	✓
• Mathematical Analysis	✓	✓	✓
• Computer Simulation	✓	✓	✓
3. TEST PROGRAM CATEGORIES			
• Model Validation Test	✓	✓	✓
• Performance Test			
--Proof	✓	✓	✓
--Diagnostic	-	✓	✓
--Service Environment	-	-	✓
4. DATA ANALYSIS			
• Level 1	✓	✓	✓
• Level 2		✓	✓
• Level 3	-	-	✓

*Some or all of these elements may be chosen, depending on the path taken through the flow chart.

✓May be chosen.

-Would not be chosen.

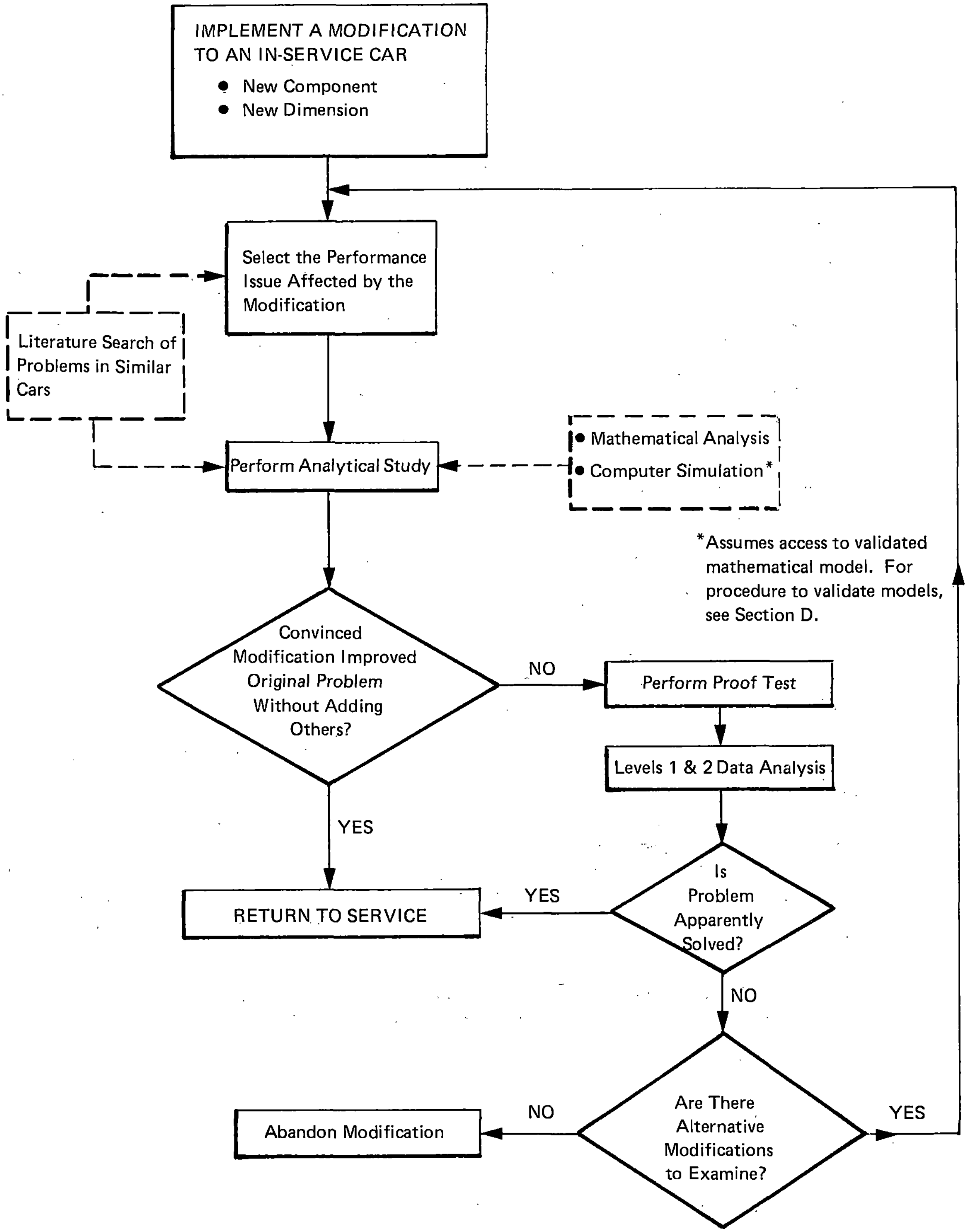


FIGURE 2–2 ASSESSMENT PROCEDURE FOR MODIFIED VEHICLE EVALUATION

then the complete process of determining the impact of the modification on stability is repeated. In absence of such alternate modifications, the whole idea of modifying the vehicle may be abandoned.

2.2.2 Assessment Procedure for Diagnostic Evaluation

As shown in Figure 2-3, this Assessment Procedure is more complex than that for a modified vehicle. The procedure starts when there is a suspicion that a stability problem exists in a vehicle (or a consist with specific characteristics). This suspicion can be based on an investigation of accidents in which no clear mechanical causes can be found, or it could also be based on non-accident problems, where the train operator observes unusual behavior of a consist, a set of similar cars or a locomotive. Comparing the performance of the vehicle under consideration with that of other similar vehicles may also lead to a suspicion of a possible stability problem.

Once a vehicle or consist configuration is suspected, a detailed service investigation is performed. This involves studying the statistics of overall accident pattern, the detailed characteristics of individual accidents, and service records. Section B shows how such an accident investigation can be performed. At the end of this investigation, one should be able to determine if there truly is a dynamic stability problem. If the problem does not exist, the cars under suspicion are returned to service. If the problem indeed exists, the detailed accident investigation may also reveal the cause of the problem. If the cause is not found in this manner, analytical studies are performed using literature search and computer models. The guideline tables presented in Subsection 2.4 are of use in identifying the potential Performance Issues before the analytical study is performed.

If even the analytical study fails to reveal the likely cause of the stability problems, a "Diagnostic Test" is performed. The next subsection shows what a Diagnostic Test involves and Subsection 3.1 identifies the characteristics of the Data Analysis that is performed on the raw data. This analysis would very likely reveal the nature of the problem.

At this stage, if the problem is not identified, then the following four options are available to the user:

- Live with the stability problem,
- Withdraw the vehicle,
- Operate on limited track, or
- Operate at limited speeds.

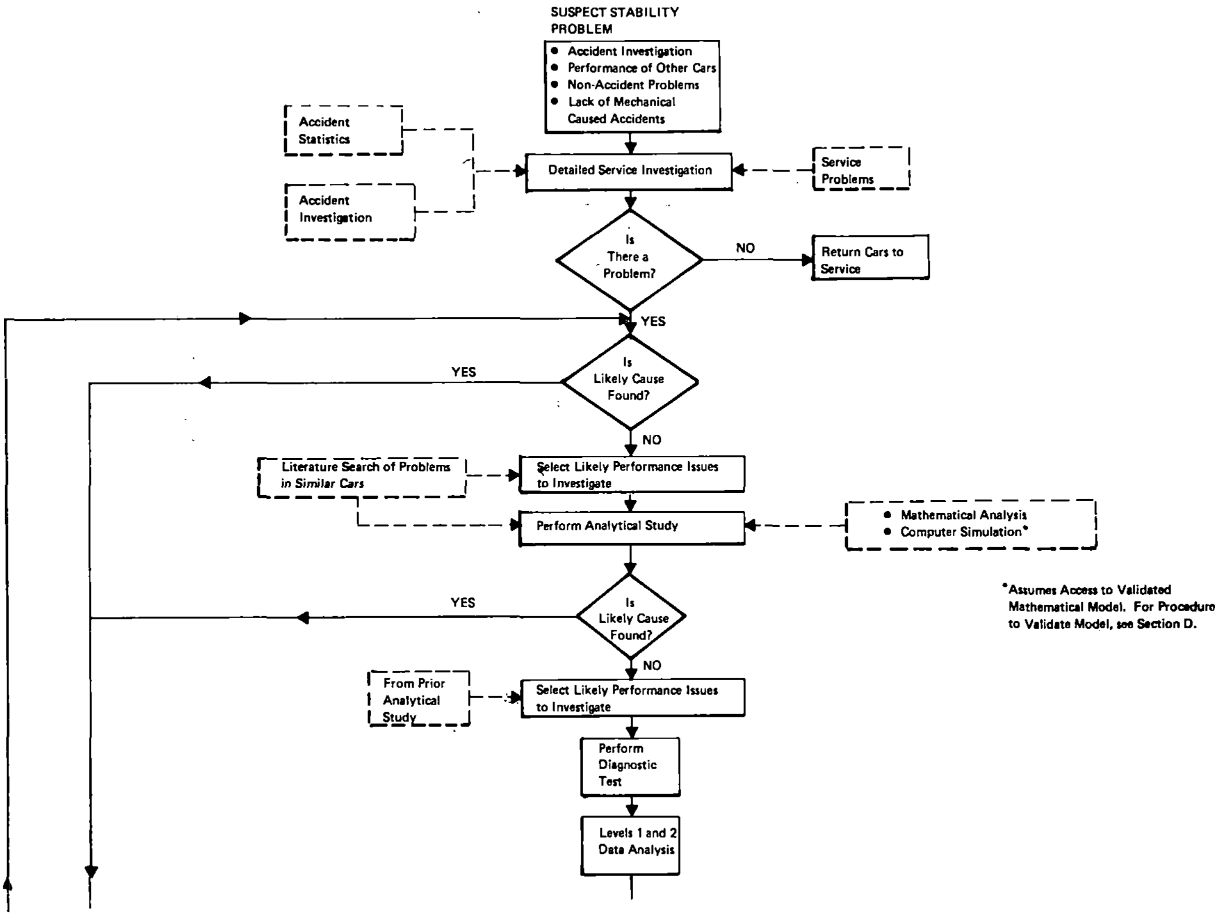


FIGURE 2–3 ASSESSMENT PROCEDURE FOR DIAGNOSTIC EVALUATION

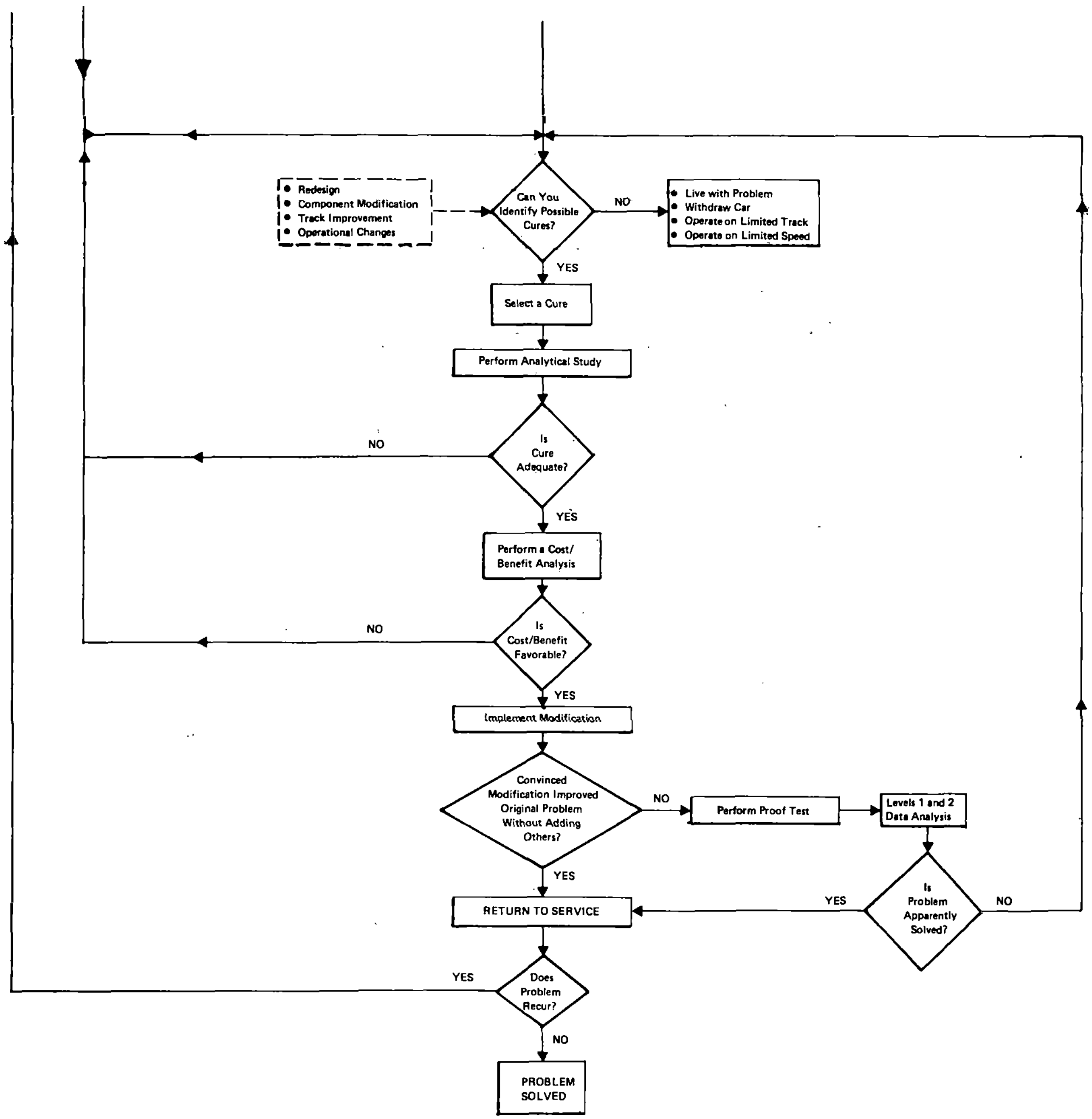


FIGURE 2–3 ASSESSMENT PROCEDURE FOR DIAGNOSTIC EVALUATION (CONT.)

If, however, the problem is identified, then different possible cures can be examined and one of them selected for implementation. The cure may involve:

- Redesign,
- Component Modification,
- Track Improvement, or
- Operational Changes.

The selected cure is first checked for adequacy using an analytical study. If it is not adequate, a new cure is selected. If, on the other hand, the cure is adequate, a cost/benefit analysis is performed to determine whether the cure is cost beneficial. If it is not cost beneficial, a new cure is found; if this cure is cost beneficial, then the modification is implemented and evaluated.

At this stage, the process becomes identical to that described earlier for a modified vehicle. That is, if the user is convinced that the modification solves the original problem without adding any further problems, the vehicles are returned to service. If the user is not convinced, then a "Proof Test" with the associated data analysis is performed. If the test shows that the modification is satisfactory, the cars are returned to service; if not, a new cure is identified and the process is repeated.

One final task to be performed before the problem is considered to be solved is to monitor the performance of the vehicles for a reasonable period to assure that the problem does not recur. If it does not recur, the objective of the Assessment Procedure is considered met.

2.2.3 Assessment Procedure for Prototype Vehicle Evaluation

This procedure should be used when a car is highly modified or new. As shown in Figure 2-4, the procedure begins with a limited test in which the vehicle is operated over a revenue service or a test track available to the user, with an objective of identifying obvious dynamic problems, such as the presence of large resonance motion in any particular mode (i.e., twist and roll, yaw and sway, and pitch and bounce), or difficulties in negotiating curves. The presence of a problem is obviously indicated if, during the course of the test, a derailment takes place, which can be attributed to vehicle/track interaction. At the end of this test, if the user is absolutely satisfied with the performance of the vehicle, the next few steps are skipped and the revenue service predictions are attempted. Otherwise, the Performance Issues to be investigated are selected based on the characteristics of the new or highly modified vehicle and its intended mode of operation. Once again, the guideline tables (See Subsection

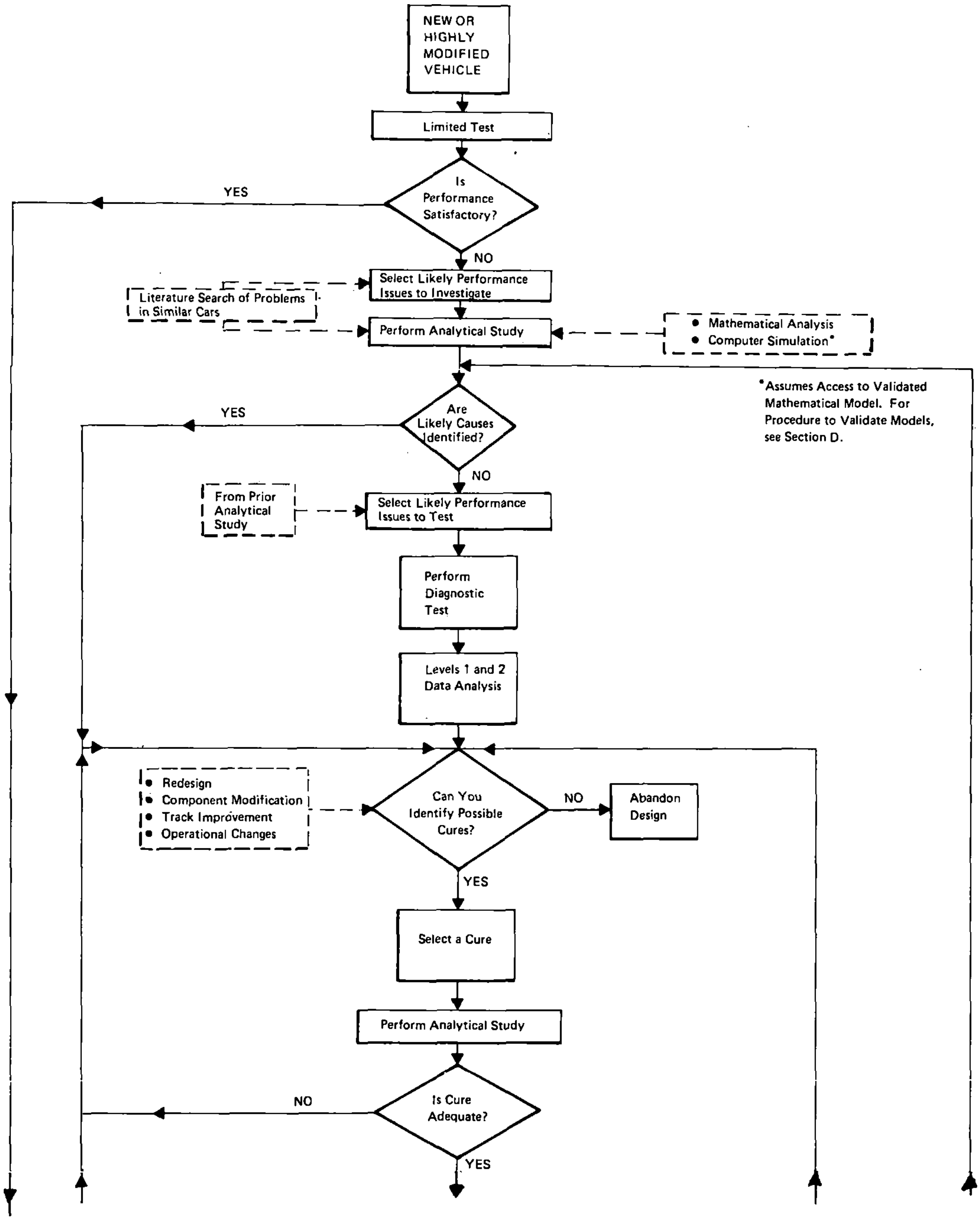


FIGURE 2–4 ASSESSMENT PROCEDURE FOR PROTOTYPE VEHICLE EVALUATION

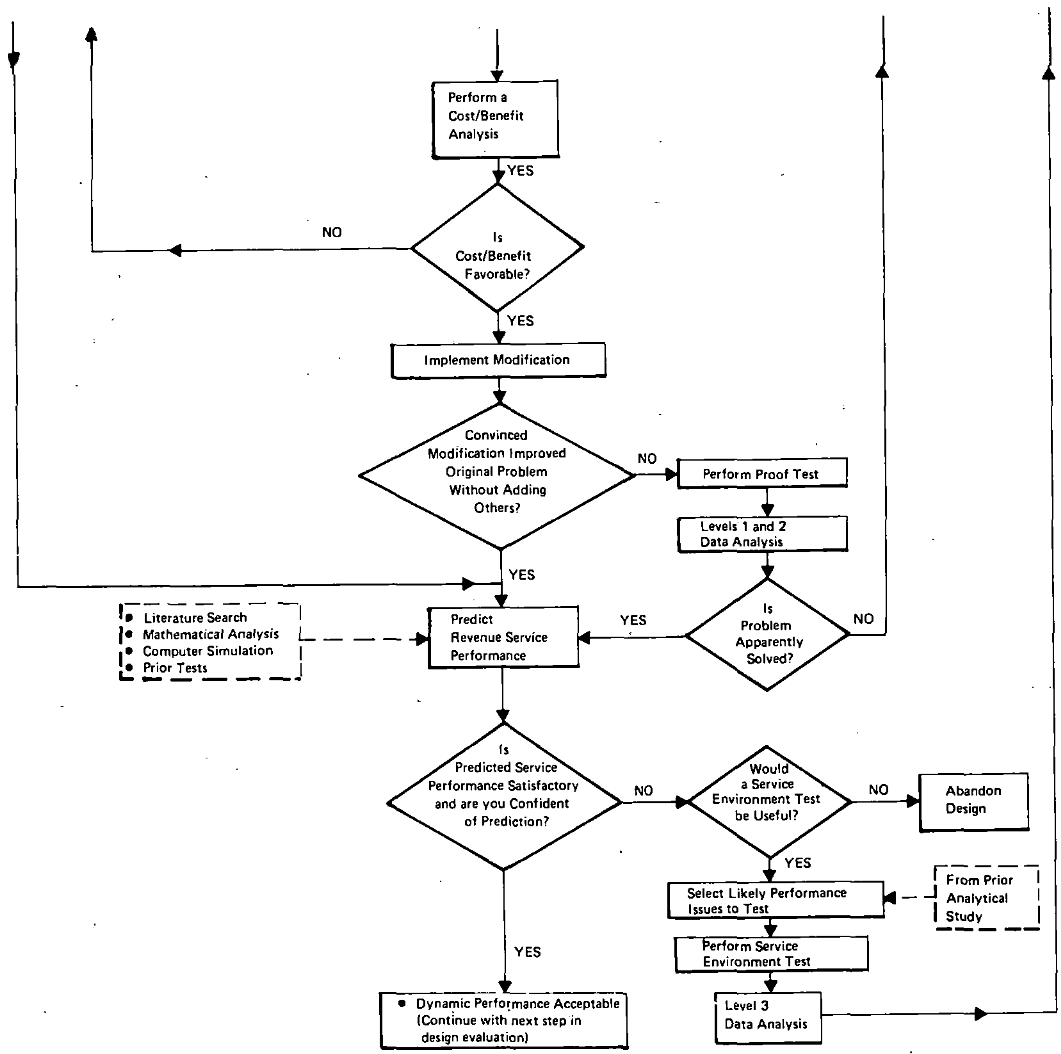


FIGURE 2–4 ASSESSMENT PROCEDURE FOR PROTOTYPE VEHICLE EVALUATION (CONT.)

2.3) can be used in this task. Also, a literature search of problems in similar cars can be of assistance (see Section A).

The next task involves the performance of an analytical study consisting of mathematical analysis and computer simulation (see Section C). If this study does not reveal the likely causes of the stability problem, a "Diagnostic Test" needs to be performed. Prior to performing the test, a final set of Performance Issues to be tested is established based on the analytical study. Then the Diagnostic Test is performed. The raw data from this test are processed according to Level 1 and 2 Data Analysis.

If, even after the test, possible cures to the problem are not identified, the design may be abandoned; otherwise, a cure is selected. If this cure is found to be adequate (based on an analytical study) and cost effective (based on a cost/benefit analysis), it is implemented. The vehicle is then treated as a modified vehicle as discussed in Subsection 2.2.1. That is, if the user is not convinced that the modification will correct the original problem without causing any other problems, then a Proof Test is performed. If, after the data analysis of the Proof Test data, the modification is found to be inadequate, another modification is introduced.

If possible cures to the problem are not identified after the test the design may be abandoned; otherwise, a cure is selected. If this cure is found to be adequate (based on an analytical study) and cost effective (based on a cost/benefit analysis), the cure is implemented. The vehicle is then treated as a modified vehicle as discussed in Subsection 2.2.1. When the user is convinced that the modification will correct the original problem without causing any other problems, then a Proof Test performed. If, after the data analysis of the Proof Test data, the modification is found to be inadequate, another modification is introduced.

After this task, if the user is satisfied with the predicted revenue service performance and is confident of the predictions, the procedure is assumed to be completed, and the design evaluation can progress further according to the industry practices. If, however, the revenue service prediction is not satisfactory, and/or the user is not convinced of the accuracy of the prediction, then the usefulness of a "Service Environment Test" should be considered. If a decision is taken to conduct this test, the Performance Issues to test are selected based on prior analytical study, and the test is performed. A Level-3 Data Analysis, consisting of techniques such as Regression Analysis and Probability Distribution Analysis, is performed. If the potential problems are identified after the data analysis, the complete procedure is repeated to remove the problems.

2.3 Assessment Objectives/Test Categories

The three test categories introduced in the previous subsection are further discussed in this subsection. These are Proof Test, Diagnostic Test, and Service Environment Test.

A Proof Test is performed to ensure that a vehicle modification has solved the problem for which it was made and that no new problems have been introduced by the modification. The test could be conducted as a part of a procedure addressing any of the three objectives, (i.e., Modified Vehicle Assessment, Vehicle Problem Diagnosis, or Prototype Vehicle Assessment). A Diagnostic Test, on the other hand, is conducted primarily to assist in finding the cause of a stability problem. It could, however, also be conducted to assess the performance of a new or highly modified car which is suspected of having a stability problem. Finally, a Service Environment Test is performed to ensure that a new or highly modified vehicle will perform adequately in the revenue service environment.

The Proof and Diagnostic Tests differ more in terms of comprehensiveness than content. A Proof Test is less comprehensive than a Diagnostic Test. The reason for this difference becomes apparent if one assumes that the information required to make a stability assessment is obtained from two sources:

- Information available from revenue service performance data, analytical studies and previous tests.
- Information required from the present vehicle test.

Since, before performing a Proof Test, significant information is available from the first source, the information required from a proof test itself is limited. However, much more information is required from a Diagnostic Test because there is a lack of information available prior to conducting the test. This difference generally leads to a Proof Test having fewer test runs, less instrumentation, less data analysis and a more specific test environment than a Diagnostic Test, as shown in the charts and tables provided later in the document in Section 3.

A Service Environment Test is generally similar in complexity to a Diagnostic Test, except the objectives are different. In a Diagnostic Test, the vehicle is known to have a problem based on prior information, which includes the revenue service record (in case of Diagnostic Assessment) or the limited test record (in case of Prototype Assessment). In a Service Environment Test, the vehicle is suspected of having a problem based on revenue service predictions. Also, unlike the planners of a Proof Test, the planners of a Diagnostic or Service Environment Tests may have only a limited knowledge of the reason for the problem. Thus, a comprehensive test should be conducted. A Service Environment Test may include testing on a revenue service track, whereas a Diagnostic Test can be conducted on a specially designed perturbed track or the Rail Dynamics Laboratory without interference to revenue operations (see Section F for the details of test sites available). In both tests, the vehicle is extensively instrumented and a large number of test runs are made.

These three Test Categories appear throughout the document. The test requirements for each Test Category are summarized in Section 3 and described in detail in the sections of the second part of the document.

2.4 Performance Issues

The ten Performance Issues addressed by the IAT are described below.

1. Hunting -- A form of self-excited oscillation of wheelset, truck or carbody that is also termed an "instability". It can arise on perfect track and self-excites once it is started. It is one of the most complex dynamic phenomena observed in the railroad environment, and a complete understanding of all the parameters affecting it does not exist. It is known, however, that many aspects of the design and wear characteristics of the trucks and the carbody are important, including specifically the design of the suspension system and the wear profiles of the wheels and rails. Hunting occurs in certain speed ranges, demarcated by "critical speeds". Often, the objective of the vehicle designer is to achieve critical speeds which lie outside the speed range in which the vehicle is expected to operate.

2. Twist and Roll -- A form of low-speed, externally excited, resonance-type oscillation in which the vehicle ocsillates about an axis parallel to the train. Twist refers to the torsional bending of the carbody, whereas roll refers to the rotational motion of the carbody around a longitudinal axis. This oscillation has historically been associated with cars with a high center of gravity, whose truck spacing lies in a fairly narrow range of lengths, while operating on track with staggered-joint, bolted-rail construction having "dipped" joints, or on newly installed, continuously welded rail with joint memory in the track support, or car induced "dipped" or low locations caused by car roll dynamics.

3. Pitch and Bounce -- Externally excited vertical oscillations of the body of the vehicle, caused by track goemetry variation. Pitch refers to the rotational motion of the carbody around a lateral axis whereas bounce refers to the motion in the vertical direction. Usually of greater concern for human comfort (as in locomotives) and lading damage (in freight cars), pitch and bounce occasionally contribute to derailments.

4. Yaw and Sway -- Externally excited transverse oscillations of the body of the vehicle, caused by track geometry variation. Yaw refers to the rotational motion of the carbody around a vertical axis, whereas sway refers to the motion in the lateral direction. These oscillations can be contributors to derailments by generating large lateral forces between wheels and rails, or when oscillations are coupled with light vertical wheel loads.

5. Steady-State Curving -- Large steady-state lateral forces may be generated between the rails and the wheels of the vehicle, even when track conditions are excellent. Contributing factors are trucks of large wheelbase on sharp curves, and inadequate maintenance of parts such as sidebearings and centerplates that may cause binding.

6. Spiral Negotiation -- Track warp, such as the spiral between tangent and curve, may cause loss of vertical contact between a wheel and rail, while large lateral wheel-rail forces are being generated. This phenomenon is typically associated with either improper track construction or maintenance such that the track is improperly superelevated, or with torsionally stiff and long carbodies, which are unable to accommodate the warp in the track, or contain insufficient sidebearing clearance or excessively stiff constant contact side bearings.

7. Dynamic Curving -- High lateral forces may be generated between wheel and rail as a result of geometric irregularities in a curve. Dynamic curving is still a relatively poorly understood phenomenon. High forces have been observed typically with vehicles that have high axle loads. Many other vehicle factors, not yet clearly identified, also play an important role.

8. Steady Buff and Draft -- When dynamic or locomotive brakes are applied, high compressive or "buff" forces can develop in the train. These buff forces cause an accordian-like buckling motion of the train during which cars may yaw (rotate about a vertical axis) or be pushed sideways, resulting in large lateral forces between wheels and rails. With light (empty) cars, high lateral to vertical force ratios may develop, eventually leading to derailment. This phenomenon occurs both on tangent and curved track, although its severity is greater on curved track. Also, if the locomotive is operating at high tractive effort while negotiating a curve -- for example, when climbing a gradient at low speeds -- high tensile or "draft" forces can develop in the train. These forces tend to straighten the train or "string-line" it, thus creating a tendency for cars to be derailed by being pulled to the inside of a curve.

9. Longitudinal Train Action -- A long train traversing undulating terrain may have some portions of it descending a gradient while other portions are ascending another. The descending portions are pulled forward by gravity while the ascending portions are pulled backward. In this manner, severe longitudinal oscillations of the train may develop, which can only partially be controlled by the train operator through the use of throttle and brakes. The longitudinal oscillation generates high buff and draft forces, which can result in derailment or in broken couplers. When a coupler breaks, the separation of cars in the consist will sever the airbrake line resulting in automatic application of the emergency brakes and the possibility of either a derailment or a collision between the two parts of the train.

10. Longitudinal Impact -- Whereas longitudinal train action involves oscillations of several cars, the issue of longitudinal impact concerns the behavior of one car (or locomotive or caboose) under the influence of a single impulsive buff loading encountered during car-to-car coupling or possibly occurring during a derailment scenario.

One of the first tasks in a Performance Assessment is to select one or more Performance Issues to be addressed which will provide the information necessary to resolve the problem. Careful selection of the Performance Issue is important, since it is too expensive and time consuming to test for all Performance Issues. This selection is based on the guidelines provided in Tables 2-2, 2-3, and 2-4.

Table 2-2 shows the effects of selected vehicle modifications on vehicle characteristics. As can be seen, some of the modifications affect more than one parameter. This is followed by Table 2-3 which shows the Performance Issues to be addressed based on the values of the various vehicle parameters. Certain parameters became important for each Performance Issue only when the value lies within or beyond a certain range. How to obtain the parameter values and a systematic procedure of determining the most important Performance Issues to be addressed for a particular vehicle is discussed in Section N (Vehicle Characterization). A further explanation of critical ranges and weighted effects of parameters is also provided in the same section.

Similarly, Table 2-4 provides information on the effects of consist characteristics on Performance Issues. As can be seen, the consist characteristics affect primarily the steady buff and draft, longitudinal train action and longitudinal impact. However, the car lengths may also affect steady-state curving, spiral negotiation and dynamic curving. Thus, in order to really aggravate vehicle behavior in these three Performance Issues, the test consist should have short cars coupled with long cars. This provides a guideline in developing the test consist for at least some of the Performance Issues.

TABLE 2-2: VEHICLE CHARACTERISTICS AFFECTED BY SELECTED MODIFICATIONS

	VEHICLE CHARACTERISTICS																													
	WHEEL		TRUCK									DRAFT GEAR		BODY																
MODIFICATIONS	Profile Concity		Total Shear Stiffness	Relative Axle Yaw Stiffness	Wheel Base	Truck Yaw Friction	Number of Axles	Yaw Moment of Inertia	Wheelset Weight	Braking Ratio		Long. Compressive Energy	Long. Energy Absorption	Truck Center Distance	Bounce Natural Frequency	Bounce Damping	Pitch Natural Frequency	Pitch Damping	Roll Natural Frequency	Roll Damping	Yaw Natural Frequency	Yaw Damping	Sway Natural Frequency	Sway Damping	Torsional Stiffness	Car Length	CG Height			
Centerplate						√																								
Side Bearing Type						√														√										
Axle Bearing Type			√	√																										
Suspension Spring															√		√		√											
Suspension Snubbers																√		√		√										
Coupler/Draft Gear												√	√																	
Carbody Material																									√					
Wheel Type	√								√																					
Radial Truck	√		√	√																										
Load Type															√	√	√	√	√	√	√	√	√	√			√			

√ = Vehicle characteristic affected by this modification.

TABLE 2-3: SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED VEHICLE CHARACTERISTICS

Vehicle Characteristics	Range (Footnotes are shown on the following page)	Performance Issues: Hunting	Twist & Roll	Pitch & Bounce	Yaw & Sway	Steady State Curving	Spiral Negotiation	Dynamic Curving	Steady State Buff & Draft	Longitudinal Train Action	Longitudinal Impact
Wheel											
Profile Conicity	≥AAR 1:20	✓									
	≤AAR 1:50					✓	✓	✓			
Truck											
Total Shear Stiffness	Low[1]	✓				✓	✓	✓			
Relative Axle Yaw Stiffness	Low[2]	✓									
	High					✓	✓	✓			
Wheel Base	≤8 ft.	✓									
	>8 ft.					✓	✓	✓			
Truck Yaw Friction	Low[3]	✓									
	High						✓	✓			
Number of Axles	1 or 2	✓									
	3					✓	✓	✓			
Yaw Moment of Inertia	<35,000 lb sec^2 in	✓									
	>45,000 lb sec^2 in						✓	✓			
Wheelset Weight	>5,000 lb						✓	✓			
Braking Ratio	High or Low[4]								✓	✓	
Coupler/Draft Gear											
Longitudinal Energy Absorption	<40,000 ft. lb.									✓	
Longitudinal Compressive Energy	<61,000 ft. lb.										✓
Body											
Truck Center Distance	39 ± 3 ft.		✓	✓	✓			✓			
	58 ± 3 ft.			✓	✓			✓	✓		
Bounce Natural Frequency	<6 Hz			✓				✓			
Bounce Damping	<0.2			✓				✓			
Pitch Natural Frequency	<6 Hz			✓				✓			
Pitch Damping	<0.2			✓				✓		✓	✓
Roll Natural Frequency	<3 Hz		✓					✓			
Roll Damping	<0.2		✓				✓	✓			
Yaw Natural Frequency	<3 Hz				✓			✓			
Yaw Damping	<0.2				✓			✓		✓	
Sway Natural Frequency	<3 Hz				✓			✓			
Sway Damping	<0.2				✓			✓		✓	
Torsional Stiffness	$>10^9$ lb in/rad						✓				
Car Length	>75 ft.						✓		✓		
Car Height	>90 inch		✓			✓	✓	✓			✓

✓ = Performance Issue is sensitive to Vehicle Characteristics in this range.

TABLE 2-3: SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED VEHICLE CHARACTERISTICS (continued)

<u>Notes</u>

1. Total Truck Shear Stiffness (in lb/ft)

	Freight		Passenger	
	Non-Steerable	Steerable	Non-Steerable	Steerable
Low	$<2\times10^7$	$<6\times10^5$	$<8\times10^4$	-
"Standard"	2×10^7	$6-9.75\times10^5$	$8\times10^4-1.3\times10^5$	3.0×10^6

- = Not Likely

2. Relative Axle Yaw Stiffness (in ft. lb/rad.)

	Freight		Passenger	
	Non-Steerable	Steerable	Non-Steerable	Steerable
Low	-	$<10^6$	$<2\times10^6$	$<8.5\times10^5$
High	$>10^8$	$>2\times10^6$	$>4\times10^6$	-
"Standard"	10^8	$10^6-2\times10^6$	$2\times10^6-4\times10^6$	8.5×10^5

- = Not Likely

3. <u>Truck Yaw Friction</u>

High means break-away torque >3.0 lb in/lb gross wt. on truck.

Low means break-away torque <1.5 lb in/lb gross wt. on truck.

4. <u>Net Braking Ratio (NBR)</u>

High means NBR > 10% gross or NBR > 30% empty

Low means NBR < 6.5% gross

TABLE 2-4. SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONSIST CHARACTERISTICS

CONSIST MAKE-UP	PERFORMANCE ISSUES: Hunting	Twist & Roll	Pitch & Bounce	Yaw & Sway	Steady-State Curving	Spiral Negotiation	Dynamic Curving	Steady Buff & Draft	Longitudinal Train Action	Longitudinal Impact
Light Cars at Head End	-	-	-	-	-	-	-	√	√	-
Heavy Cars vs. Light Cars	-	-	-	-	-	-	-	√	√	√
Short Cars Coupled with Long Cars	-	-	-	-	√	√	√	√	-	-
Very Long Cars	-	-	-	-	√	√	√	√	-	-
Alignment Control Present	-	-	-	-	-	-	-	√	√	-
Locomotives with Dynamic Braking	-	-	-	-	-	-	-	√	√	-

√ Performance Issue is sensitive to this consist characteristic.

\- Performance Issue is not sensitive to this consist characteristic.

SECTION 3

OVERVIEW OF TEST AND DATA ANALYSIS PROCEDURES

As described in Section 2, the IAT consists of a number of test and data analysis procedures, each designed to achieve a specific objective. These procedures are described further in this section.

Subsection 3.1 deals with Test and Data Analysis Requirements. These requirements are based on a fundamental assumption implicit in the IAT that the performance of a vehicle (or a consist) can be evaluated by providing "proper" inputs in a controlled environment and measuring "proper" outputs. The "proper" inputs in this case consist of track geometry variations (also called perturbations), track stiffnesses, speed and others, which would bring out the vehicle characteristics pertaining to the Performance Issue under investigation. These inputs are described in the form of Input/Run Matrices in Subsection 3.1.1, whereas the "proper" output variables (i.e., motion of vehicle, forces acting on track, and so on) are identified in Subsection 3.1.2. Next, the ways of measuring, storing and managing the output data are described in Subsection 3.1.3, and finally, the test sites which can provide the necessary inputs are identified in Subsections 3.1.4. As before, the details of all these aspects of the Test and Analysis Procedures are not provided in this part, rather, they are left to Part 2 of this document.

Subsection 3.2 deals with the nature and usage of Performance Indices, which, as mentioned before, provide a powerful tool for performing standardized and simple evaluation of the performance of a vehicle (or consist). Subsection 3.3 describes the use of the Reference Vehicles.

To facilitate its use, the information in this section is provided in the form of eight tables. Each table provides one piece of information related to test and data analysis procedures. They are organized in such a way that once the user has selected the Performance Issues and Test Categories (as described earlier in Section 2), all of the following information is readily available:

- Inputs (Control Variables);
- Outputs (Response Variables);
- Data Analysis Requirements;
- Instrumentation Requirements;
- Data Handling Requirements;
- Potential Test Sites; and

• Potential Performance Indices.

Although not detailed enough to carry out a test or analysis procedure, the information provided in this section is sufficient to develop a Test Plan Summary, as identified in the IAT Structure Block Diagram, Figure 2-1.

3.1 Test and Data Analysis Requirements

When a vehicle/consist is tested for a particular Performance Issue, certain "Excitation Inputs" are required in order to bring out the vehicle characteristics related to that Performance Issue. Only then can its performance be properly evaluated. A list of likely Excitation Inputs is provided in Table 3-1. This summary table, which is later expanded to form other tables in this subsection, also shows "Control Variables" which are the Excitation Inputs translated to parameters which can be controlled during a test. To properly excite a typical vehicle in the Performance Issue being studied, the Control Variables have to be in the ranges shown in the table.

The performance of a test vehicle under the above test conditions is measured in terms of "Response Variables" which consists of forces, accelerations, motions, and stresses as shown in Table 3-1. These Response Variables and Control Variables form the basic requirements for the Test and Data Analysis as discussed in the rest of this subsection.

Consistent with the format of this document, these requirements are described in three stages. The Overview provided in Table 3-1 is expanded in Subsections 3.1.1, 3.1.2, 3.1.3 and 3.1.4. The same information is also provided in Section E in Part 2 in a more user oriented format. In that section, the Test/Analysis Requirements for each combination of Performance Issue and Test Category are identified individually, so that a user interested in a particular combination can easily locate the appropriate information for that area of interest.

3.1.1 Input/Run Matrix

The sensitivity of each Performance Issue to various Control Variables is shown in Table 3-2. The Performance Issues which are generally insensitive to a control variable are indicated by a dash (--). For the others, a value is provided. In order to test the vehicles under a controlled environment, several Control Variables are set to fixed values (0 in many cases), and the others are varied in the specified ranges. The number of fixed Control Variables decreases, and the ranges of those which are varied increase as the Test Category is changed from Proof to Diagnostic and then to Service Environment.

As the table shows, four of the Performance Issues are tested on curves, the rest on tangent. Only two require grades; the rest should be tested on level ground. For the sake of standardization, the gauge

TABLE 3-1 OVERVIEW OF TEST REQUIREMENTS FOR EACH DYNAMIC PERFORMANCE ISSUE

Group	Performance Issue	Required Excitation Inputs	Key Response Variables	Control Variables	Anticipated Ranges of Control Variables
Tangent Track Response	1. Hunting	Tangent Lateral Transient	L/V; Wheel, Truck and Body Motions	Speed Lateral Displacement Amplitude; Rail Friction	30–130 mph 0.5"–2" 0.15–0.3
Tangent Track Response	2. Twist & Roll	Tangent Crosslevel Perturbations	Vertical Wheel Force; Roll Motion of Truck and Body	Wavelength of Perturbations; Amplitude of Perturbations; Phase of Perturbations; Speed	39', 78' 1"–3" (Crosslevel) Pure Crosslevel 10–80 mph
Tangent Track Response	3. Pitch and Bounce	Tangent Vertical Perturbations	Vertical Wheel Force; Pitch and Bounce Motion of Truck and Body	Wavelength of Perturbations; Amplitude of Perturbations; Phase of Perturbations; Speed	19', 39', 78' 2"–3" (Surface) in Phase (Zero Crosslevel) 10–80 mph
Tangent Track Response	4. Yaw and Sway	Tangent Lateral Perturbations	L/V; Yaw and Sway Motion of Truck and Body	Wavelength of Perturbations; Amplitude of Perturbations; Phase of Perturbations; Speed	19', 39', 78' 0.5"–5" in Phase (Pure Alignment) 10–120 mph
Curving Response	5. Steady State Curving	Uniform Curves	L/V	Curvature; Superelevation Speed; Rail Friction	1°, 2°, 5°, 10° 0"–6" 20–130 mph 0.15–0.3
Curving Response	6. Spiral Negotiation	Uniform Spirals	L/V; Truck and Body Motions	Rate of Change of Curvature; Rate of Change of Superelevation; Speed Rail Friction	0.005–0.3°/ft. 0.005"–0.05"/ft. 20–130 mph 0.15–0.3
Curving Response	7. Dynamic Curving	Curves with Lateral and Crosslevel Perturbations	L/V; Truck and Body Motions	Curvature; Superelevation; Type of Perturbations; Wavelength of Perturbations Amplitude of Perturbations; Phase of Perturbations Speed; Rail Friction	2°, 5°, 10° 0"–3" Alignment, Crosslevel 19', 39', 78' 1.5"–5" (Alignment), 0"–2" (Crosslevel) in Phase & Adjustable 10–80 mph 0.15–0.3
Train Action	8. Steady Buff and Draft	Uniform Curves and Steady Coupler Force	L/V; Coupler Angles	Terrain Curvature; Coupler Force Magnitude; Locomotive Acceleration & Deceleration Rates	Fixed Grade 0 to 2% 2°, 5°, 10° 0, ±250,000 lbs. –0.45 to 0.3 mph/s
Train Action	9. Longitudinal Train Action	Uniform Tangent and Dynamic Coupler Force	L/V; Coupler Forces and Angles; Longitudinal and Lateral Motion of Body	Locomotive Acceleration & Deceleration Rates Terrain	–0.45 to 0.3 mph/sec. Undulating
Train Action	10. Longitudinal Impact	Tangent Impact Force	Coupler Forces; Structural Stresses and Deformation; Body Longitudinal Motion	Impact Momentum	2000 ton–mph (6 million lb. ft./sec.)

Notes:
(1) L/V = Wheel and Truck L, V and L/V
(2) Motion measurements are generally = accelerations and displacements
(3) Inputs correspond generally to testing on track. For testing on RDL or using analysis, equivalent inputs can be determined (for example) wavelength of track perturbation can be converted to equivalent frequency for testing in RDL).

TABLE 3-2 SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONTROL VARIABLES

TEST CATEGORY: Proof

CONTROL VARIABLES	PERFORMANCE ISSUES: HUNTING	TWIST & ROLL	PITCH & BOUNCE	YAW & SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
1. NOMINAL TRACK GEOMETRY										
• Gauge, inch	56.5	--	--	--	56 - 57	--	56 - 57	56 - 57	56 - 57	--
• Curvature, degree	0	0	0	0	1° - 10°	1° - 10°	2° - 10°	2° - 10°	0	--
• Superelevation, inch	--	--	--	--	0 - 6	0 - 6	0 - 3	0 - 3	--	--
• Grade, percent	--	--	--	--	--	--	--	0 - 2	Variable	--
2. TRACK GEOMETRY IRREGULARITIES										
• Track Class	3-6	2	2	2	2 - 6	2 - 6	2 - 4	2 - 4	--	--
• Gauge Variable										
- Amplitude, inch	0	--	--	0	0	--	0	0	--	--
- Wavelength, ft.	0	--	--	0	0	--	0	0	--	--
• Alignment										
- Amplitude, inch	½ - 2	--	--	3	0	0	1.5 - 3	0	--	--
- Wavelength	0	--	--	39	0	0	19.5 - 78	0	--	--
• Crosslevel*										
- Amplitude, inch	--	2	--	--	0	0	2	0	--	--
- Wavelength, ft.	--	39	--	--	0	0	19.5 - 78	0	--	--
• Profile										
- Amplitude, inch	--	--	3	--	0	--	0	0	--	--
- Wavelength, ft.	--	--	19.5 - 39	--	0	--	0	0	--	--
3. TRACK STIFFNESS										
• Vertical Track, kips/in	--	>225	>225	--	--	>225	>225	--	--	--
• Lateral Rail, kips/in	--	--	--	>40	--	>40	>40	--	--	--
4. RAIL GEOMETRY										
• Profile	New	--	--	New	New	New	New	--	--	--

*Crosslevel can also be defined in terms of the Crosslevel Index (C.L.I.). A value of 0.3 is considered severe.

TABLE 3-2 SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONTROL VARIABLES (Continued)

TEST CATEGORY: Proof

CONTROL VARIABLES	PERFORMANCE ISSUES									
	HUNTING	TWIST & ROLL	PITCH & BOUNCE	YAW & SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
5. OPERATING CONDITIONS										
• Speed, mph Freight	30 - 115	10 - 30	10 - 30	10 - 30	20 - 115	20 - 115	10 - 65			
• Speed, mph Passenger	30 - 130	10 - 35	10 - 35	10 - 35	20 - 130	20 - 130	10 - 80	Variable	Variable	0 - 15
• Underbalance (ΔE), inch	--	--	--	--	0 - 8	Variable	0 - 8	Variable	--	--
• Acceleration/ Deceleration Rates, mph/s	0	--	--	--	--	--	--	-0.45 to 0.3	-0.45 to 0.3	--
• Longitudinal Forces, kips	--	--	--	--	--	--	--	up to ±250K	up to ±250K	--
6. ENVIRONMENT										
• Rail Surface Condition	Sanded,* Dry	--	--	Sanded, Dry	Sanded. Dry	Sanded, Dry	Sanded, Dry	Sanded, Dry	--	--

* Rail friction coefficient 0.15 to 0.3.

-- Performance Issue is generally not sensitive to this Control Variable.

TABLE 3-2 SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONTROL VARIABLES (continued)

TEST CATEGORY: Diagnostic

	PERFORMANCE ISSUES									
CONTROL VARIABLES	HUNTING	TWIST & ROLL	PITCH & BOUNCE	YAW & SWAY	STEADY STATE CURVING	SPIRAL NEGOTI-ATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDI-NAL TRAIN ACTION	LONGITUDI-NAL IMPACT
1. NOMINAL TRACK GEOMETRY										
• Gauge, inch	56.5	--	--	--	56 - 57	--	56 - 57	56 - 57	56 - 57	--
• Curvature, degree	0	0	0	0	1° - 10°	1° - 10°	2° - 10°	2° - 10°	0	--
• Superelevation, inch	--	--	--	--	0 - 6	0 - 6	0 - 3	0 - 3	--	--
• Grade, percent	--	--	--	--	--	--	--	0 - 2	Variable	--
2. TRACK GEOMETRY IRREGULARITIES										
• Track Class	3 - 6	2 - 4	2 - 4	2 - 4	2 - 6	2 - 6	2 - 4	2 - 4	--	--
• Gauge Variable										
- Amplitude, inch	0	--	--	0	0	--	0	0	--	--
- Wavelength, ft.	0	--	--	0	0	--	0	0	--	--
• Alignment										
- Amplitude, inch	0.5 - 2	--	--	1.5 - 3	0	0	1.5 - 3	0	--	--
- Wavelength	0	--	--	19.5 - 78	0	0	19.5 - 78	0	--	--
• Crosslevel										
- Amplitude,inch	--	1 - 2	--	--	0	0	2	0	--	--
- Wavelength, ft.	--	39 - 78	--		0	0	19.5 - 78	0	--	--
• Profile										
- Amplitude, inch	--	--	2 - 3	--	0	--	0	0	--	--
- Wavelength, ft.	--	--	19.5 - 39	--	0	--	0	0	--	--
3. TRACK STIFFNESS										
• Vertical Track, kips/in	--	>225	>225	--	--	>225	> 225	--	--	--
• Lateral Rail, kips/in	--	--	--	> 40	--	> 40	> 40	--	--	--
4. RAIL GEOMETRY										
• Profile	New	--	--	New	New	New	New	--	--	--

TABLE 3-2 SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONTROL VARIABLES (Continued)

TEST CATEGORY: Diagnostic

CONTROL VARIABLES	PERFORMANCE ISSUES: HUNTING	TWIST & ROLL	PITCH & BOUNCE	YAW & SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
5. OPERATING CONDITIONS										
• Speed, mph Freight	30 - 115	10 - 65	10 - 65	10 - 65	20 - 115	20 - 115	10 - 65			
• Speed, mph Passenger	30 - 130	10 - 80	10 - 80	10 - 80	20 - 130	20 - 130	10 - 80	Variable	Variable	15
• Underbalance (ΔE), inch	--	--	--	--	0 - 8	Variable	0 - 8	Variable	--	--
• Acceleration/ Deceleration Rates, mph/s	0	--	--	--	--	--	--	-0.45 to 0.3	-0.45 to 0.3	--
• Longitudinal Forces, kips	--	--	--	--	--	--	--	up to ±250K	up to ±250K	--
6. ENVIRONMENT										
• Rail Surface Condition	Sanded,* Dry	--	--	Sanded, Dry	Sanded, Dry	Sanded, Dry	Sanded, Dry	Sanded, Dry	--	--

* Rail friction coefficient 0.15 to 0.3.

-- Performance Issue is generally not sensitive to this Control Variable.

TABLE 3-2 SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONTROL VARIABLES (continued)

TEST CATEGORY: Service Environment

CONTROL VARIABLES	PERFORMANCE ISSUES: HUNTING	TWIST & ROLL	PITCH & BOUNCE	YAW & SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
1. NOMINAL TRACK GEOMETRY										
• Gauge, inch	56.5	--	--	--	56 - 57	--	56 - 57	56 - 57	56 - 57	--
• Curvature, degree	0	0	0	0	1° - 10°	1° - 10°	2° - 10°	2° - 10°	0	--
• Superelevation, inch	--	--	--	--	0 - 6	0 - 6	0 - 3	0 - 3	--	--
• Grade, percent	--	--	--	--	--	--	--	0 - 2	Variable	--
2. TRACK GEOMETRY IRREGULARITIES										
• Track Class	3 - 6	2 - 4	2 - 4	2 - 6	2 - 6	2 - 6	2 - 4	2 - 4	--	--
• Gauge Variable - Amplitude, inch	0	--	--	0	0	--	0	0	--	--
- Wavelength, ft.	0	--	--	0	0	--	0	0	--	--
• Alignment - Amplitude, inch	0.5 - 2	--	--	0.5 - 5	0	0	1.5 - 5	0	--	--
- Wavelength	0	--	--	19.5 - 78	0	0	19.5 - 78	0	--	--
• Crosslevel - Amplitude, inch	--	1 - 3	--	--	0	0	1 - 2	0	--	--
- Wavelength, ft.	--	39 - 78	--	--	0	0	19.5 - 78	0	--	--
• Profile - Amplitude, inch	--	--	2 - 3	--	0	--	0	0	--	--
- Wavelength, ft.	--	--	19.5 - 78	--	0	--	0	0	--	--
3. TRACK STIFFNESS										
• Vertical Track, kips/in	--	90 - 150 & > 225	90 - 150 & > 225	--	--	90 - 150 & > 225	90 - 150 & > 225	--	--	--
• Lateral Rail, kips/in	--	--	--	15-25 & >40	--	15-25 & >40	15-25 & >40	--	--	--
4. RAIL GEOMETRY										
• Profile	New, Worn	--	--	New, Worn	New, Worn	New, Worn	New, Worn	--	--	--

TABLE 3-2 SENSITIVITY OF PERFORMANCE ISSUES TO SELECTED CONTROL VARIABLES (Continued)

TEST CATEGORY: Service Environment	PERFORMANCE ISSUES									
CONTROL VARIABLES	HUNTING	TWIST & ROLL	PITCH & BOUNCE	YAW & SWAY	STEADY STATE CURVING	SPIRAL NEGOTI-ATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDI-NAL TRAIN ACTION	LONGITUDI-NAL IMPACT
5. OPERATING CONDITIONS										
• Speed, mph · Freight	30 - 115	10 - 65	10 - 65	10 - 115	20 - 115	20 - 115	10 - 65			
• Speed, mph · Passenger	30 - 130	10 - 80	10 - 80	10 - 120	20 - 130	20 - 130	10 - 80	Variable	Variable	5 - 15
• Underbalance (ΔE), inch	--	--	--	--	0 - 8	Variable	0 - 8	Variable	--	--
• Acceleration/ Deceleration Rates, mph/s	--	--	--	--	--	--	--	-0.45 - 3	-0.45 - 3	--
• Longitudinal Forces, kips	--	--	--	--	--	--	--	up to ±250K	up to ±250K	--
6. ENVIRONMENT • Rail Surface Condition	Sanded, Dry, Wet	--	--	Sanded, Dry, Wet	Sanded, Dry, Wet	Sanded, Dry, Wet	Sanded, Dry, Wet	Sanded, Dry, Wet	--	--

-- Performance Issue is generally not sensitive to this Control Variable.

for hunting is kept fixed at 56.5 inches even though hunting is sensitive to gauge variations.

The variations in gauge may not be required for any of the Performance Issues under consideration; yaw and sway and dynamic curving can generally be studied by providing just alignment perturbations. Hunting also requires alignment perturbations, but of a transient nature. Consequently, its wavelength is specified as zero (actually, very small). The amplitudes of perturbations in all cases are selected based on the class of the track on which tests are to be conducted. The Crosslevel Index mentioned in the table describes the properties of crosslevel perturbations as they affect a freight vehicle [Ref. 3-1]. It is defined as the root mean square of the deviation of crosslevel values from a 100 ft. moving average taken over a 400 ft. length of track.

Track stiffness is not an easily defined parameter. Both lateral and vertical track stiffnesses depend on a number of factors, all of which should be controlled while measuring the stiffnesses. Section H (Rail/Track Stiffness) provides details on how these stiffnesses should be measured. The values provided in Table 3-2 generally represent a "nominal" track when characterized under the following conditions:

Vertical Stiffness -- The value given (>225 kips/in.) represents static tangent track stiffness per rail at initial load of 12,000 lbs. (i.e., stiffness found by drawing a tangent on the force-deflection curve at 12,000 lb. load) of a track away from the joint region and in absence of an adjacent wheel.

Lateral Stiffness -- The value given in Table 3-2 (>40 kips/in.) represents the Lateral Stiffness of rail to a gauge-spreading type load (with zero lateral net force on the tie). This value has to be measured at zero vertical load in absence of another wheel close by and away from a joint. Also, this value is valid only up to lateral load of 4 kips. For a Service Environment Test, some runs on a track with lower lateral stiffness are also recommended, as shown in Table 3-2.

There is no clear descriptor for rail section geometry. Thus, the table identifies it as new rail for the Proof and Diagnostic Test and "new and worn rail" for the Service Environment Test.

Four Control Variables are provided under Operating Conditions. The speed at which a vehicle is tested depends on the amplitude of the perturbation provided on the track. Thus, the test at the higher speeds are to be conducted only if the perturbation amplitudes are near the low end of the range specified. Similarly, the speed on a curve should be such that the underbalance range is not exceeded. An underbalance of 8 in. is considered quite high, and a test at that level should be conducted only with extreme safety precautions.

The final Control Variable, the rail surface condition, may be quantified by rail friction coefficient. As yet, however, no reliable technique exists to measure the rail friction coefficient. Thus, this Control Variable is described by nonquantitative descriptors, such as "sanded", "dry" or "wet."

The Control Variables given in Table 3-2 are generally valid for any type of rail vehicles. However, as explained earlier, the Performance Issues of concern depend on the stability problem being addressed and the type of rail vehicle being tested.

3.1.2 Output

Table 3-3 shows the required Response Variables for each combination of Performance Issue and Test Category. This table was developed based on an understanding of the behavior of a vehicle/consist in a particular Performance Issue and of the Response Variables required to quantify this behavior for the purpose of stability assessment.

For example, for studying the twist and roll behavior of a vehicle, the user should always measure the roll acceleration of the body, and the relative displacements in the roll and bounce modes between one of the bolsters and the body. This is the minimum requirement. However, if the test category of interest is Diagnostic Test or Service Environment Test, the user needs to measure, in addition to the above, the vertical force on a wheel in the lead truck, the roll displacement of one of the trucks relative to the carbody, and the vertical displacement of a wheel relative to rail. Finally, for a Service Environment Test, the user should measure the vertical deflection of rail (relative to ground), and the vertical forces on all four wheels of the lead truck, in addition to all of the variables mentioned above.

As can be expected, a Diagnostic Test requires a larger number of Response Variables to be measured compared to a Proof Test, and a Service Environment Test requires a still higher number. This table forms the foundation on which the instrumentation requirements for each Test Category can be established.

Table 3-4 shows how the Response Variables, once measured, are to be analyzed. To continue the above example, the three Response Variables measured for a Proof Test to study the twist and roll behavior of a vehicle should be analyzed according to D1, or Level-1 Data Analysis Procedures. The typical analytical procedures to be used in the three levels of Data Analysis are shown below and are discussed further in Section J (Analysis Techniques).

TABLE 3-3 REQUIRED RESPONSE VARIABLES FOR EACH PERFORMANCE ISSUE

P = Proof Test
D = Diagnostic Test
S = Service Environment Test

RESPONSE VARIABLE	PERFORMANCE ISSUES: HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
• RAIL AND TIE DEFLECTIONS										
Either Rail – Lateral				S						
Either Rail – Vertical		S	S							
High Rail – Lateral					S	S	S	S		
High Rail – Vertical							S			
• WHEEL/RAIL INTERACTION FORCES										
Lead Truck: Total Truck – Lateral	DS			DS	PDS		PDS	PDS	PDS	
Lead Truck: Total Truck – Vertical	DS			DS	PDS		PDS	PDS	PDS	
Lead Axle (High/Low) Wheel – Lateral	DS			S	PDS		DS	DS		
Lead Axle (High/Low) Wheel – Vertical	DS	DS		S	PDS		DS	DS		
All Wheels – Lateral						DS	DS			
All Wheels – Vertical		S				DS	DS			
Trailing Truck: Total Truck – Lateral								PDS	PDS	
Trailing Truck: Total Truck – Vertical								PDS	PDS	
Lead Axle – Lateral					S		S			
Lead Axle – Vertical					S		S			
All Wheels – Lateral						DS				
All Wheels – Vertical						DS				
• BODY ACCELERATIONS AT C.G.										
Roll		PDS				DS	PDS			
Pitch			PDS				PDS			PDS
Bounce			PDS				PDS			PDS
Yaw	DS			PDS		DS	PDS			S
Sway	PDS			PDS		DS	PDS			S
Longitudinal									PDS	PDS
• BOLSTER DISPLACEMENT RELATIVE TO BODY										
Roll		PDS				DS	DS			
Bounce		PDS	PDS							PDS
• TRUCK FRAME ACCELERATIONS										
Leading Truck – Pitch										PDS
Leading Truck – Bounce										PDS
Leading Truck – Yaw	DS						S			
Leading Truck – Sway	PDS						S			
Leading Truck – Longitudinal										DS
• TRUCK FRAME DISPLACEMENT RELATIVE TO BODY										
Leading Truck – Roll		DS				DS	DS			
Leading Truck – Pitch			DS							
Leading Truck – Bounce			PDS							
Leading Truck – Yaw	DS			DS	DS	DS	DS			
Leading Truck – Sway	S			DS		DS	DS			
Leading Truck – Longitudinal										DS
• AXLE ACCELERATION										
Leading Truck – Lateral	DS			S						
• AXLE DISPLACEMENT RELATIVE TO TRUCK										
Leading Truck – Lateral	DS				S	S	S			
Leading Truck – Yaw	DS			S	S	S	S			
• WHEEL DISPLACEMENT RELATIVE TO RAIL										
Lead Truck, High Rail – Lateral	S			S	S	S	S			
Lead Truck, High Rail – Angle of Attack	S			S	DS	S	S			
Lead Truck, High Rail – Vertical		DS				PDS*	S			
• COUPLER FORCES										
Both Couplers – Vertical									DS	DS
Both Couplers – Axial								DS	DS	DS
Both Couplers – Lateral								DS	DS	DS
• COUPLER DISPLACEMENT										
Both Couplers – Vertical			PDS						DS	DS
Both Couplers – Axial								DS	DS	DS
Both Couplers – Lateral				PDS				DS	DS	DS
• STRUCTURAL STRESS										S
• DEFORMATION OF BODY										S

*All four wheels.

[box symbol] = Used in Performance Index (see Table 3-8)

TABLE 3-4 DATA ANALYSIS REQUIREMENTS FOR EACH PERFORMANCE ISSUE

TEST CATEGORY: Proof

RESPONSE VARIABLES		PERFORMANCE ISSUES									
		HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF & DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
Rail & Tie Deflection	Lateral										
	Vertical										
Wheel Forces	Lateral					D2					
	Vertical					D2					
Truck Forces (Side & Complete)	Lateral					D2		D2	D2	D2	
	Vertical					D2		D2	D2	D2	
Body Accelerations	Roll		D1					D1			
	Pitch			D1				D1			D1
	Bounce			D1				D1			D1
	Yaw				D1			D1			
	Sway	D2			D1			D1			
	Longitudinal									D1	D1
Bolster Displacement (Relative to Body)	Roll		D1								
	Bounce		D1	D1							D1
Truck Acceleration	Pitch										D1
	Bounce										D1
	Yaw										
	Sway	D2									
	Longitudinal										
Truck Displacement (Relative to Body)	Roll										
	Pitch										
	Bounce			D1							
	Yaw										
	Sway										
	Longitudinal										
Axle Acceleration	Lateral										
Axle Displacement (Relative to Truck)	Lateral										
	Yaw										
Wheel Displacement (Relative to Rail)	Lateral										
	Angle of Attack										
	Vertical						D1				
Coupler Forces	Vertical			D2							
	Lateral										
	Axial										
Coupler Displacements	Vertical										
	Lateral				D1						
	Axial										
Structural Stresses											
Deformation of Body											

D1 = Level 1 Data Analysis
D2 = Level 2 Data Analysis
D3 = Level 3 Data Analysis

TABLE 3-4 DATA ANALYSIS REQUIREMENTS FOR EACH PERFORMANCE ISSUE (continued)

TEST CATEGORY: Diagnostic

RESPONSE VARIABLES		PERFORMANCE ISSUES: HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF & DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
Rail & Tie Deflection	Lateral										
	Vertical										
Wheel Forces	Lateral	D2				D2		D2			
	Vertical	D2	D2			D2	D2	D2			
Truck Forces (Side & Complete)	Lateral	D2			D2	D2	D2	D2	D2	D2	
	Vertical	D2			D2	D2	D2	D2	D2	D2	
Body Accelerations	Roll		D1				D1	D1			
	Pitch			D1				D1			D1
	Bounce			D1				D1			D1
	Yaw	D2			D1		D1	D1			
	Sway	D2			D1		D1	D1			
	Longitudinal										D1
Bolster Displacement (Relative to Body)	Roll		D1				D1	D1			
	Bounce		D1	D1							D1
Truck Acceleration	Pitch										D1
	Bounce										D1
	Yaw	D2									
	Sway	D2									
	Longitudinal										D1
Truck Displacement (Relative to Body)	Roll		D1				D1	D1			
	Pitch			D1							
	Bounce			D1							
	Yaw	D2			D1	D1	D1	D1			
	Sway				D1		D1	D1			
	Longitudinal										D1
Axle Acceleration	Lateral	D2									
Axle Displacement (Relative to Truck)	Lateral	D2									
	Yaw	D2									
Wheel Displacement (Relative to Rail)	Lateral										
	Angle of Attack					D1					
	Vertical		D1				D1				
Coupler Forces	Vertical									D2	D2
	Lateral								D2	D2	D2
	Axial								D2	D2	D2
Coupler Displacements	Vertical			D1						D1	D1
	Lateral				D1				D1	D1	D1
	Axial								D1	D1	D1
Structural Stresses											
Deformation of Body											

D1 = Level 1 Data Analysis
D2 = Level 2 Data Analysis
D3 = Level 3 Data Analysis

TABLE 3-4 DATA ANALYSIS REQUIREMENTS FOR EACH PERFORMANCE ISSUE (continued)

TEST CATEGORY: Service Environment

RESPONSE VARIABLES		PERFORMANCE ISSUES									
		HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY BUFF & DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
Rail & Tie Deflection	Lateral				D3	D3		D3	D3		
	Vertical		D3	D3				D3			
Wheel Forces	Lateral	D3			D3	D3		D3	D3		
	Vertical	D3	D2		D3	D3	D3	D3	D3		
Truck Forces (Side & Complete)	Lateral	D3			D3	D3	D3	D3	D3	D3	
	Vertical	D3			D3	D3	D3	D3	D3	D3	
Body Accelerations	Roll		D3					D3			
	Pitch			D3				D3			D3
	Bounce			D3				D3			D3
	Yaw	D3			D3			D3			D3
	Sway	D3			D3			D3			D3
	Longitudinal									D3	D3
Bolster Displacement (Relative to Body)	Roll		D3					D3			
	Bounce		D3	D3							D3
Truck Acceleration	Pitch										D3
	Bounce										D3
	Yaw	D3						D3			
	Sway	D3						D3			
	Longitudinal										D3
Truck Displacement (Relative to Body)	Roll		D3					D3			
	Pitch			D3							
	Bounce			D3							
	Yaw	D3			D3	D3		D3			
	Sway	D3			D3			D3			
	Longitudinal										D3
Axle Acceleration	Lateral	D3			D3						
Axle Displacement (Relative to Truck)	Lateral	D3				D3		D3			
	Yaw	D3			D3	D3		D3			
Wheel Displacement (Relative to Rail)	Lateral	D3			D3	D3		D3			
	Angle of Attack	D3			D3	D3		D3			
	Vertical		D3				D3	D3			
Coupler Forces	Vertical									D3	D3
	Lateral								D3	D3	D3
	Axial								D3	D3	D3
Coupler Displacements	Vertical			D3						D3	D3
	Lateral				D3				D3	D3	D3
	Axial								D3	D3	D3
Structural Stresses											D3
Deformation of Body											D3

D1 = Level 1 Data Analysis
D2 = Level 2 Data Analysis
D3 = Level 3 Data Analysis

Level 1:

-- Simple statistics (mean, maximum, RMS, standard deviation, and such); and

-- Resonant Frequency Analysis (comparing the input frequencies to the vehicle resonance frequencies).

Level 2:

Level 1, plus

-- Threshold Exceedance Analysis (such as determining the longest time a variable exceeds a threshold value);

-- Frequency Spectral Analysis (such as power spectral densities of a variable); and

-- Damping Ratio Calculation.

Level 3:

Level 2, plus

-- Regression Analysis (such as curve fitting, extrapolation to revenue service environment); and

-- Probability Density Analysis (e.g., determining the probability of derailment in service environment based on test data).

As can be seen in Table 3-4, a Proof Test or a Diagnostic Test requires Levels 1 and 2 Data Analysis, whereas a Service Environment Test requires Level 3 Analysis. This is because the major purpose of conducting a Service Environment Test is to predict the service performance of a vehicle/consist, for which sophisticated statistical analysis provided by Level 3 is required. The other two test categories do not require this level of sophistication.

Similarly, all force measurements require Level 2 analysis because one is usually interested in performing a Threshold Exceedance Analysis of a force measurement [Ref. 3-2]. However, most acceleration and motion variables require Level 1 analysis. One exception is in the case of hunting: the tendency of a vehicle to hunt can best be discerned by studying the damping values of sway or yaw motions of body and/or truck. This means that a Level 2 Data Analysis is required for analyzing the motion data from a test for hunting.

As shown later in Subsection 3.2, some of the Response Variables are used for calculating Performance Indices which provide standardized representation of the stability performance of a vehicle or a consist.

The specific analysis techniques for these variables are identified in Table 3-8. However, as Tables 3-3 and 3-4 show, many of the Response Variables measured are not used in the calculation of the Performance Indices. The measurement of these variables is recommended because:

- They may be required for calculating Performance Indicies developed in the future; or

- They may be required by a trained analyst for further assessment of vehicle/track performance.

In either case, the specific analytical techniques cannot presently be identified. However, Section J has a table which can be used to select appropriate techniques for a given analysis objective.

3.1.3 Data Measurement Requirements

The Response Variables identified in Table 3-3 are measured using instrumentation having amplitude and frequency ranges shown in Table 3-5. Arrived at through experience gained in conducting tests over the past few years, these instrumentation requirements are conservative. Thus, even instruments not having such high amplitude and frequency ranges may also be adequate for many test programs, as discussed in Section K (Wayside and Onboard Instrumentation) of the second part of this document.

Finally, Table 3-6 shows the data handling requirements for each Performance Issue and each Test Category. The number of channels identified in this table for both onboard and wayside data acquisition systems represents pure channels (one for each variable) after preprocessing. Thus, for example, vertical wheel force is represented by one channel, although several raw channels may be required to create it from instruments. Also, synthesized channels, such as those recording L/V ratios, are not counted.

The number of quick look channels shown in the table includes those meant for ensuring safe conduct of the test as well as those for speed and Automatic Location Detector (ALD) (See Section K, Wayside and Onboard Instrumentation). Details on the safety channels can be found in Section E (Test Plan Summaries). For a test which addresses more than one Performance Issue, the total number of channels will generally be less than the sum of the number for all Performance Issues being addressed because of common Response Variables, which can be found in Table 3-3. In doing so, the five channels for speed, ALD, etc., and two quick look channels (generally speed and ALD) are to be treated as common channels.

3.1.4 Test Sites

Once the input and output requirements are established, the next

TABLE 3-5: SUGGESTED AMPLITUDE AND FREQUENCY RANGES FOR INSTRUMENTS

RESPONSE VARIABLE		MEASUREMENT TYPE	AMPLITUDE RANGE	FREQUENCY RANGE Hz
Rail & Tie Deflections	Lateral	Displacement	± 3"	0-100
	Vertical	Displacement	± 3"	0-100
Wheel Forces	Lateral	Force	±10-60kips	0-100
	Vertical	Force	0-60kips	0-100
Truck Forces	Lateral	Force	±20-120kips	0-100
	Vertical	Force	0-240kips	0-100
Body Accelerations	Roll	Accelerations	100°/Sec^2	0-10
	Pitch	Accelerations	100°/Sec^2	0-10
	Bounce	Accelerations	±2g	0-10
	Yaw	Accelerations	500°/sec^2	0-10
	Sway	Accelerations	±2g	0-10
	Longitudinal	Accelerations	±10g	0-10
Bolster Displn. (relative to body)	Roll	Displacement	±5°	0-10
	Bounce	Displacement	± 2"	0-10
Truck Accelerations	Pitch	Acceleration	±1000°/sec^2	0-50
	Bounce	Acceleration	±10g	0-50
	Yaw	Acceleration	±5000°/sec^2	0-50
	Sway	Acceleration	±10g	0-50
	Longitudinal	Acceleration	±10g	0-50
Truck Displn. (relative to body)	Roll	Displacement	±10°	0-10
	Pitch	Displacement	±10°	0-10
	Bounce	Displacement	± 6"	0-10
	Yaw	Displacement	± 5°	0-10
	Sway	Displacement	± 3"	0-10
	Longitudinal	Displacement	± 3"	0-10
Axle Acceleration	Lateral	Acceleration	±50g	0-100
Axle Displn. (Relative to truck)	Lateral	Displacement	± 1"	0-50
	Yaw	Displacement	± 2°	0-50
Wheel Displn. (Relative to rail)	Lateral	Displacement	± 3"	0-100
	Angle of Attack	Displacement	±10°	0-100
	Vertical	Displacement	± 2"	0-100
Coupler Forces	Vertical	Force	±50 kips	0-100 *
	Lateral	Force	±50 kips	0-100 *
	Axial	Force	±200 kips	0-100 *
Coupler Displacements	Vertical	Displacement	±20°	0-50 *
	Lateral	Displacement	±20°	0-50 *
	Axial	Displacement	12"	0-50 *
Structural Stresses		Stress	**	0-50
Deformation of Body		Displacement	**	0-50

*The frequency range is high, so that the peaks during impact can be measured adequately. For longitudinal train action, however, the frequency range could be reduced to 10 Hz.

**Depends on location.

TABLE 3-6: DATA HANDLING REQUIREMENTS FOR EACH PERFORMANCE ISSUE AND TEST CATEGORY

TEST CATEGORY: Proof

DATA HANDLING REQUIREMENTS	PERFORMANCE ISSUES									
	HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY STATE BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
<u>ONBOARD DATA ACQUISITION/STORAGE</u>										
• Number of Data Channels*	7	8	11	9	11	9	12	9	10	11
• Number of Quick Look Channels	4	3	5	5	4	3	6	4	4	7
• Frequency Range (Hz)	0-50	0-10	0-10	0-10	0-100	0-100	0-100	0-100	0-100	0-50
• Digital Sampling Rate (Hz)	100	20	20	20	200	200	200	200	200	100
<u>WAYSIDE DATA ACQUISITION/STORAGE</u>	---------------------------- NONE ----------------------------									
• Number of Data Channels										
• Number of Quick Look Channels										
• Frequency Range (Hz)										
• Digital Sampling Rate										

*Includes five channels for speed, Automatic Location Detector, temperature, and other funcamental data.

TABLE 3-6: DATA HANDLING REQUIREMENTS FOR EACH PERFORMANCE ISSUE AND TEST CATEGORY (continued)

TEST CATEGORY: Diagnostic	PERFORMANCE ISSUES									
DATA HANDLING REQUIREMENTS	HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY STATE BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
ONBOARD DATA ACQUISITION/STORAGE										
• Number of Data Channels*	19	14	12	13	13	26	22	21	22	25
• Number of Quick Look Channels	8	5	5	7	6	7	8	6	6	8
• Frequency Range (Hz)	0-100	0-100	0-10	0-100	0-100	0-100	0-100	0-100	0-100	0-50
• Digital Sampling Rate (Hz)	200	200	20	200	200	200	200	200	200	100
WAYSIDE DATA ACQUISITION/STORAGE	NONE									
• Number of Data Channels										
• Number of Quick Look Channels										
• Frequency Range (Hz)										
• Digital Sampling Rate										

*Includes five channels for speed, Automatic Location Detector, temperature, and other fundamental data.

TABLE 3-6: DATA HANDLING REQUIREMENTS FOR EACH PERFORMANCE ISSUE AND TEST CATEGORY (continued)

TEST CATEGORY: Service Environment	PERFORMANCE ISSUES									
DATA HANDLING REQUIREMENTS	HUNTING	TWIST AND ROLL	PITCH AND BOUNCE	YAW AND SWAY	STEADY STATE CURVING	SPIRAL NEGOTIATION	DYNAMIC CURVING	STEADY STATE BUFF AND DRAFT	LONGITUDINAL TRAIN ACTION	LONGITUDINAL IMPACT
ONBOARD DATA ACQUISITION/STORAGE										
• Number of Data Channels*	22	15	12	21	18	30	31	21	22	37**
• Number of Quick Look Channels	8	5	5	7	6	7	8	6	6	8
• Frequency Range (Hz)	0-100	0-100	0-10	0-100	0-100	0-100	0-100	0-100	0-100	0-50
• Digital Sampling Rate (Hz)	200	200	20	200	200	200	200	200	200	100
WAYSIDE DATA ACQUISITION/STORAGE										
• Number of Data Channels		10	10	10	4	4	20	4		
• Number of Quick Look Channels		6	6	6	4	4	8	4		
• Frequency Rate (Hz)		0-100	0-100	0-100	0-100	0-100	0-100	0-100		
• Digital Sampling Rate (Hz)		200	200	200	200	200	200	200		

*Includes five channels for speed, Automatic Location Detector, temperature, and other fundamental data.

**Assumes ten channels for structural stress and deformation.

step is to select a test site. Basically, a user has the following choices available:

- The test tracks at Transportation Test Center (TTC),
- The Rail Dynamics Laboratory (RDL),
- An existing track, and
- A modified track.

Also, the existing track may be a revenue service track or one which is not in use. For a modified track, the track characteristics may be changed to create a "perturbed track". From these options, the user should select the proper test site based on many considerations. The primary consideration is the ability of the test site to provide the input excitation described in Subsection 3.1.1, and in Table 3-2. This means that the test site should provide the required:

- Nominal Track Geometry (Curvature and Grade);
- Track Geometry Irregularities;
- Track/Rail Stiffness; and
- Rail Geometry (Head Profile).

In addition, the site should be able to run vehicles within the required speed range.

Often, the user may find the process is reversed. A test site is available, based on financial, logistic, or other consideration, and the input/output requirements are adjusted depending on the characteristics of the site.

With this background, Table 3-7 provides a guideline for selecting a proper test site for each combination of Performance Issue and Test Category. Included in the list of test facilities is SAFE (Stability Assessment Facility for Equipment), which has not been built; however its design is available in considerable detail [Ref. 3-3].

The table shows that one of the existing TTC tracks can be used to address all Performance Issues except longitudinal train action, to the extent curvature and grade are appropriate and assuming that the perturbations required to study twist and roll, pitch and bounce, yaw and sway, and dynamic curving will be installed on one of the test tracks by the user. The details of each appropriate test track at TTC are provided in Section F (Test Facilities).

The RDL located at TTC can also be used to study hunting, twist and roll, pitch and bounce, yaw and sway, and spiral negotiation. Of

TABLE 3-7: POTENTIAL TEST SITES FOR DIFFERENT PERFORMANCE ISSUES AND TEST CATEGORIES

PERFORMANCE ISSUE	TEST CATEGORY		
	Proof	Diagnostic	Service Environment
Hunting	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5
Twist and Roll	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5
Pitch and Bounce	1, 2, 4, 5	1, 2, 4, 5	1, 4, 5
Yaw and Sway	1, 2, 4, 5	1, 2, 4, 5	1, 4, 5
Steady State Curving	1, 3, 5	1, 3, 5	1, 3, 5
Spiral Negotiation	1, 2, 3, 5	1, 3, 5	1, 3, 5
Dynamic Curving	1, 4, 5	1, 4, 5	1, 4, 5
Steady Buff and Draft	1, 3, 5	1, 3, 5	1, 3, 5
Longitudinal Train Action	3	3	3
Longitudinal Impact	1, 3	1, 3	1, 3

Key:
1. An existing Transportation Test Center track.
2. Rail Dynamics Laboratory (RDL).
3. Existing Track (Class 1-6).
4. Modified Track.
5. Stability Assessment Facility for Equipment (SAFE) (not yet built).

these, hunting can be initiated on the Roll Dynamics Unit (RDU) in the RDL by providing appropriate inputs to the vehicle, whereas the other Performance Issues can be studied to a certain extent using the Vibration Test Unit (VTU) which is also located in the RDL. The capabilities of both these units are described in Section F (Test Facilities).

All of the Performance Issues which do not require perturbations (i.e., hunting, steady state curving, spiral negotiation, steady buff and draft, longitudinal train action, and longitudinal impact) can be addressed on an existing revenue track (or tracks) having the required track class, tangents, curves, spirals, grades, and track/rail stiffnesses. Those Performance Issues which do require perturbations can be addressed on these tracks after appropriate modifications are made. In Section F of Part II of the document, the modifications to the track required to address each Performance Issue are discussed under the subsection dealing with SAFE design. Hunting, as shown in Table 3-7, can be addressed with an unmodified track by operating the test vehicle until a perturbation initiates hunting. Alternatively, an intentional perturbation can be installed on a track to initiate hunting in the vicinity of a test zone.

Finally, SAFE, if built, can address all except the last two Performance Issues at <u>one location</u>. The benefits of having one comprehensive facility can be enormous:

- An existing track does not need to be modified every time the performance of a vehicle needs to be assessed.

- All of the resources required to run a test (test personnel, instrumentation system, data acquisition, storage/processing systems, power and other logistics, and so on) can be concentrated in one place instead of being spread on different test zones.

As mentioned earlier, Table 3-7 is based on the ability of various test sites to meet the primary requirements of a Performance Issue, i.e., those dealing with the input requirements. While selecting a test site, the other test requirements also are to be considered. These include:

- The power availability;

- The existing track condition,

  - condition of ties,
  - type of ties (wood or concrete),
  - condition of ballast;

- The disruption to the revenue traffic;

- The potential for third-party damage;
- The distance from a town;
- The accessibility (distance from a road);
- The season, weather conditions, temperature, and so on.

Generally, while going through the selection process, the user may find two or three potential sites where a test can be conducted. In this situation, the ultimate decision will be based on trade-offs among:

- The ability of the test site to meet the input requirements;
- The total cost of test; and
- The time in which the test could be completed.

3.2 Performance Indices

Performance Indices provide a simple and standardized representation of the stability performance of a vehicle or a consist. Consisting of selected response parameters processed in a specific manner, the Performance Indices can be used either for a comparative evaluation of a vehicle (or consist) or an absolute evaluation against a standard. They are developed to ensure that the results of a test can be interpreted by a user who is not thoroughly familiar with the vehicle/track interaction or the various Performance Issues involved. Also, being standardized, the Indices make the task of correlating results from different tests simpler. As such they represent a powerful tool to be used in the IAT.

The idea of using Performance Indices for vehicle safety assessment has been around for some time. Principal studies on this subject are summarized in References [3-4] and [3-5], the first of which is provided in Section I (Performance Indices). Some of these earlier ideas have been expanded in this document to meet the requirements of the IAT. The Performance Indices developed for the IAT share the following properties:

- They have strong positive or negative correlation with probability of derailment.
- They have unambiguous definition.
- Measuring them is clearly within the state-of-the-art.

For each Performance Issue, a number of Performance Indices have been identified. Some of them provide a more accurate representation of the derailment tendencies than others. Generally the Indices which are more difficult to measure are more accurate than those which are relatively easier to measure.

In order to ensure that the Performance Indices developed for the IAT can be applied to many different test conditions, they are first shown in terms of their elements. Then a method of combining these elements to form Performance Indices applicable to various test situations is described. Table 3-8 shows a list of elements of the Performance Indices developed for each Performance Issue.

As shown, a Performance Index consists of two parts: input and output. In general the performance of the vehicle is specified in terms of output for a given input, where the output is represented by Response Variables and the input consists of Control Variables which affect the vehicle performance for a particular Performance Issue.

The table shows that a threshold value is provided corresponding to each Control Variable. In general, the vehicle performance has to be evaluated at test conditions corresponding to each of these threshold values. For some Control Variables, however, ranges of values are provided. In these cases, the vehicle performance should be evaluated over the complete range of each such Control Variable.

Each Response Variable (expressed in the form of a prescribed statistic) also has a threshold value. If a vehicle, tested according to the Control Variables specified in the input part of the table, exhibits Response Variables which exceed (or are lower than, as the case may be) the threshold values, the vehicle may exhibit a dynamic problem in the form of the Performance Issue under consideration. Using this reasoning, a Performance Index is then constructed from its elements in the following manner:

For cases where the threshold is expressed as < some value

$$P.I. = \frac{\text{The highest Response Variable value obtained in the test}}{\text{Threshold of the Response Variable value}}$$

For cases where the threshold is expressed as > some value.

$$P.I. = \frac{\text{Threshold of Response Variable}}{\text{The highest Response Variable value obtained in the test}}$$

A Value of Performance Index < 1 then generally means that the vehicle would not suffer that Performance Issue, and a value > 1 means that there is a stability problem from the Performance Issue under consideration. Similarly, a vehicle exhibiting a higher Performance Index is generally worse in that Performance Issue than that exhibiting a lower Performance Index.

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES

Performance Issue: Hunting

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Alignment Kink	Amplitude	> 1/2"	Truck Lateral Acceleration	Damping (from time response)	>0.1	PDS
Speed	Mean	0-130 mph				
Rail Surface Condition	--	Sanded, Dry	Carbody Sway Acceleration	Damping (from time response)	>0.1	PDS
Loading	--	Loaded, Empty	Carbody Sway Acceleration	Peak	<0.55 g	PDS
Wheel Profile	--	Worn	Carbody Sway Acceleration	RMS	<0.1 g	PDS

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICFS (continued)

Performance Issue: Twist and Roll

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Crosslevel	C.L.I. [Ref. 3-1]	0.30	Carbody Roll Angle	Peak to Peak	<7°	PDS
Speed	Mean	Speed of peak response in operating range	Carbody-bolster relative roll	Peak to Peak	<4°	PDS
Loading	Center of Gravity	C.G. when fully loaded with worst case commodity	Vertical Wheel Force	Maximum Zero Force Duration	<0.5 sec.	DS
Track Vertical Stiffness	kips/inch deflection	90 - 150 & > 225	Wheel Unloading Index $\left(I = \frac{WL}{\left(\frac{WH}{3}\right)}\right)$ WL = vertical force on most lightly loaded wheel; WH = sum of vertical forces on three most heavily loaded wheels	Peak	<0.7	S

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Pitch and Bounce

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Profile	Profile Index*	??	Carbody Pitch angle	Peak to Peak	<2°	PDS
Speed	Mean	Speed of peak response in operating range	Carbody Bounce Acceleration at CG	Peak	<0.5 g	PDS
Loading	--	Empty, Loaded	Truck-car relative bounce displacement	Peak	<3"	PDS
Track Vertical Stiffness	kips/inch deflection	90 - 150 & > 225	Carbody-bolster relative bounce motion	Peak	<2"	PDS

*Undefined as yet, similar to Crosslevel Index. [Ref. 3-1]. See text for alternative.

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Yaw and Sway

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Alignment	Alignment Index*	??	Carbody Yaw Angle	Peak to Peak	<2°**	PDS
Speed	Mean	Speed of peak response in Operating Range	Carbody Sway Acceleration at CG	Peak	<0.5 g	PDS
Loading	--	Empty, Loaded	Truck Lateral Force	L_{95}	<60 kips	DS
Track Lateral Stiffness	kips/inch deflection	15 - 25 & ≥ 40	Truck L/V	$(L/V)_{95}$	<0.5	DS
Rail surface condition	--	Sanded, Dry				
Wheel Profile						

*Similar to Crosslevel Index but undefined as yet. See text for alternative.

**For 40' truck center distance. Proportionally lower for higher truck center distance.

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Steady State Curving

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Curvature	Mean	1° - 10°	Angle of attack of leading axle	Peak	<1°	DS
Superelevation	Mean	0 - 6"	Wheel Lateral Force (leading, high rail)	Mean	<20 kips	PDS
Speed	Mean	up to ΔE=8"	Wheel L/V (leading high rail)	Mean	<0.8	PDS
Wheel Profile		New, Worn				
Load	--	Loaded, Empty				
Rail Surface Condition	--	Sanded, Dry				

TABLE 3-8: ELEMENTS OF PEFFORMANCE INDICES (continued)

Performance Issue: Spiral Negotiation

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Rate of change of Curvature	Mean	0.3°/ft*	Truck Side L/V (all four sides)	$(L/V)_{95}$ of maximum	<0.6	DS
Rate of change of Superelevation	Mean	0.05"/ft*	Truck Side V (all four sides)	V_{95} of minimum	>0	DS
Length	--	Longer than the car length	Wheel unloading Index (see Rock & Roll Performance Indices)	Peak	<0.7	DS
Speed	Mean	Speeds up to ΔE=8"				
Track Lateral Stiffness	kips/inch	15 - 25 & > 40	Wheel Vertical Displacement relative to rail	Peak	<0.5"	PDS
Track Vertical Stiffness	kips/inch	90 - 150 & > 225				

*Lower threshold for a vehicle which is not going to operate on a mountainous terrain.

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Dynamic Curving

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Crosslevel, Profile and Alignment	Track Quality Index*	??	Wheel Lateral Force (leading high rail)	L_{95}	<20 kips	DS
Curvature	Mean	1° - 10°	Wheel L/V (leading high rail)	$(L/V)_{95}$	<0.8	DS
Superelevation	Mean	0° - 6"				
Wheel Profile		New, Worn	Truck Lateral Force (leading)	L_{95}	<60 kips	PDS
Load	--	Loaded, Empty	Truck L/V (leading)	$(L/V)_{95}$	<0.5	PDS
Rail Surface Condition	--	Sanded, Dry	Carbody Yaw Angle	Peak to Peak	<2°**	PDS
Track Lateral Stiffness	kips/inch deflection	15 - 25 & > 40	Carbody Roll Angle	Peak to Peak	<7°	PDS
Track Vertical Stiffness	kips/inch	90 - 150 & > 225				

*This as yet undefined Index includes crosslevel, profile and alignment indices. See text for alternative.

**For 40' truck center distance. Proportionally lower for longer distances.

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Steady Buff and Draft

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Curvature	Mean	2° – 10°	Truck Lateral Force (both trucks of a selected car)	Mean	<60 kips	PDS
Superelevation	Mean	0" - 2.5"				
Loading	--	Empty	Truck L/V (both trucks of a selected car)	Mean	<0.5	PDS
Rail Surface Condition	--	Sanded, Dry				
Grade	Mean	0-2%	Coupler Longitudinal Force (both couplers of a selected car)	Mean	<200 kips	DS
Braking Rate	Mean	-0.45 mph/s				
Acceleration Rate	Mean	0.3 mph/s	Coupler Lateral Angle (both couplers of a selected car	Mean	<20°	DS

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Longitudinal Train Action

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
			Truck Lateral Force (both trucks of a selected car)	L_{95}	<60 kips	PDS
Braking Rate	Mean	-0.45 mph/sec				
Acceleration Rate	Mean	0.3 mph/sec	Truck L/V (both trucks of a selected car)	$(L/V)_{95}$	<0.5	PDS
Terrain	--	Undulating				
			Coupler Longitudinal Force (both couplers of a selected car)	Peak	<200 kips	DS
			Coupler Lateral Angle (both couplers of a selected car)	Peak	<20°	DS

TABLE 3-8: ELEMENTS OF PERFORMANCE INDICES (continued)

Performance Issue: Longitudinal Impact

INPUT			OUTPUT			TEST CATEGORY
CONTROL VARIABLE	STATISTIC	STANDARD THRESHOLD	RESPONSE VARIABLE	STATISTIC	STANDARD THRESHOLD	
Speed of Impact	--	15 mph	Carbody Pitch Angle	Peak	<1°	PDS
Mass of Impacting Car	--	Loaded	Carbody-bolster relative bounce displacement	Peak	<2"	PDS
Mass of Impacted Car	--	Unloaded	Coupler Vertical Force	Peak	<50 kips	DS
Mass of Backup Car	--	Loaded				

As the table shows, several Control Variable statistics are not yet defined. They are:

- Profile Index,
- Alignment Index, and
- Track Quality Index.

Until they are defined and their threshold values determined, the corresponding Control Variables may be set according to the values shown in Table 3-2. These perturbation values should provide severe test environments for pitch and bounce, yaw and sway, and dynamic curving. Also, the threshold values of the response parameters are preliminary and are based on the existing knowledge. They are subject to change as more and more is learned about the Performance Issues under consideration. This, however, should not affect a comparative evaluation of two or more similar vehicles.

The Performance Indices can be, in some cases, evaluated for Control Variables which are less than threshold range. The obvious advantage is that the test has lower probability of derailment for lower Control Variable values. Generally, when the input-output relationship is reasonably linear, such non-threshold tests can be performed. The prime candidates for this are twist and roll, pitch and bounce, and yaw and sway, in which the body motion is more or less linearly related to the Control Variables that deal with track perturbations. For example, the relationship of the carbody roll angle to crosslevel perturbations (expressed in terms of Crosslevel Index) is reasonably linear. In this case, the Performance Index can be evaluated as:

$$\text{P.I.} = \frac{\text{The highest Response Variable value obtained in the test}}{\text{Threshold of the Response Variable value}} \times \frac{\text{Control Variable threshold value}}{\text{Control Variable value used in the test}}$$

The only recourse available in case the relationship between a Control Variable and a Response Variable for a Performance Issue is nonlinear, and the test has to be performed at a non-threshold value of the Control Variable, is to use some extrapolation method to estimate the value of the Response Variable corresponding to the threshold value of the Control Variable. In this case:

$$\text{P.I.} = \frac{\text{The extrapolated variable value of the Response Variable}}{\text{The threshold value of the Response Variable}}$$

The computer programs provided in Section C (Vehicle/Track Simulation Models) can help in such extrapolation.

Finally, the last column of the table shows the applicable test categories for each Performance Index. The Performance Indices, which are more complex to measure, but which are more accurate indicators of the vehicle performance, are generally used for the more comprehensive test categories (Diagnostic and Service Environment Tests); those less complex are used for a Proof Test.

3.3 Reference Vehicle Usage

The use of a vehicle which is regarded and maintained as a standard, against which other test vehicles and/or measured results can be compared, can supplement the other measurement techniques used in a test program conducted as a part of the IAT. Section O in Part 2 of the document deals with the development of a concept regarding such reference vehicles.

As discussed in Section O, the reference vehicles can be used to perform the following four functions:

- Track calibration;
- Test calibration;
- Baseline comparison; and
- Performance extrapolation to service condition.

Track Calibration: The use is intended to:

- Identify levels of track change which affect vehicle performance;
- Provide guidelines as permissible tolerances to track geometry; and
- Identify when and where track maintenance is required.

Test Calibration: The uses of a test calibration reference vehicle are:

- To identify changes in performance due to test conditions; and
- To develop factors for normalizing the test results.

The variations which this vehicle are designed to measure are those due to climate on the system at the time of the test. This vehicle can be included in the test consist to calibrate the effects of climate changes on the Performance Issues under investigation.

Baseline Comparison: A reference vehicle used for this purpose serves as a standard against which the performance of the vehicle under investigation can be compared. The Performance Indices identified in the preceding subsection can be used for such comparison. For the comparison to be valid, the reference vehicle has to be similar to the test vehicle and both vehicles should be tested under identical conditions.

Performance Extrapolation to Service Conditions: A reference vehicle can be used to assist in assessing the performance of a new or modified vehicle in revenue service. This can be accomplished in the following way:

- Conduct a baseline test for the test vehicle as well as the reference vehicle;

- Record reference vehicle performance under revenue service conditions; and

- Infer the performance of the test vehicle in revenue service.

Section 0 in Part 2 studies in detail the requirements for the reference vehicles which can provide the above services for each Performance Issue. The conclusions of this study are shown in Table 3-9. Finally, Table 3-10 summarizes the properties of ideal reference vehicles for each combination of Performance Issue and reference vehicle usage.

TABLE 3-9: CONCLUSIONS ON REFERENCE VEHICLE UTILITY

PI #	PERFORMANCE ISSUE	USE # 1 TRACK CALIBRATION	USE #2 TEST CALIBRATION	USE #3 BASELINE USE	USE # 4 EXTRAPOLATION TO SERVICE CONDITIONS
1	Hunting	Good use Weather important Light car Worn wheels Simple measure	Good use Maintenance important Light car Worn wheels Simple measure	Good use for similar vehicles Analysis available if cars differ Measure vehicle characteristics	Possible Measures test severity On board measures required
2	Twist and Roll	Good use Maintenance important Heavy car High center of gravity Simple measures	Good use to identify weather Heavy car High center of gravity Experimental	Good use for similar vehicles Analysis available if cars differ Measures to fit differences	Good use for similar vehicles Maintenance important Analysis desirable Measures simple for test severity
3	Pitch and Bounce	Good use Vary car weight Experimental Simple measure with spectral analysis	Good use Vary car weight Experimental to determine track compliance	Good use for similar vehicles Low priority issue	Good use for similar vehicle Low priority issue
4	Yaw and Sway	Complex use Weather important Maintenance important Measurements complex Analysis complex	Complex use Maintenance important Additional track measurements Analysis complex	Best used with analytic model Measurements complex	Best used with analytic model Measurements complex
5	Steady State Curving	Good use Weather important Direct simple measurement	Good use Simple or complex Fundamental measurement possible	Good use for similar vehicles Analysis available to extend to new vehicles	Not appropriate see dynamic curving
6	Spiral negotiation	Complex use Special vehicle maintenance and test runs in good weather	Complex use Difficult to analyze Experimental Combine with other issues	Complex use Not required for x-level Direct measure valid for test spiral only	Possible only with analytic model Complex use
7	Dynamic Curving	Complex use Analysis difficult Complex measurement Experimental	Good use Simple or complex Fundamental measurement possible	Possible only with similar vehicles or new analytic support	Not recommended without full analytic model support

Source: TASC

TABLE 3-10: FREIGHT REFERENCE VEHICLE CHOICE

PI #	PERFORMANCE	#	BODY				TRUCK		COMMENT
			WEIGHT	TCD	CG HEIGHT	COMPLIANCE	ROLL+ CONTROL	WHEEL PROFILE	
1	Hunting	1.1	Light	Long	Low	Flex	Free play	Worn	
2	Twist and roll	2.1	Heavy	39 ft	High	NC	Free play	New	Roll response
		2.2	Light	59 ft	NC	Flex	No play	NC	Twist response
3	Pitch and bounce	3.1	Medium	49 ft	Medium	NC	NC	NC	Pitch response
		3.2	Heavy	30 ft	High	NC	NC	NC	Bounce response
4	Yaw and sway	4.1	Heavy	59 ft	Medium	Flex	Free play	New	
5	Steady state curving	5.1	Light	NC	Low	NC	No play	New	
6	Spiral negotiation	6.1	Light	Long	NC	Rigid	No play	New	
		6.2	Heavy	Long	NC	Rigid	No play	New	For track Stiffness
7	Dynamic curving	7.1	Heavy	39 ft	High	NC	Free play	New	
		7.2	Medium	NC	Medium	NC	Free play	New	For track and length variation

NC - Not critical to this issues.

+Body to bolster (S.B.; CPEP, etc.)

Source: TASC

REFERENCES -- SECTION 3

3-1 Lee, H.S. and Weinstock, H., "A Rail Car Harmonic Roll Response to Periodic Track Crosslevel Variations," Report No. WP-743-C-15-075, Transportation Systems Center, December, 1979.

3-2 Boghani, A.B., Palmer, D.W., and Nayak, P.R., "Perturbed Track Test: Results of Data Analysis," prepared by Arthur D. Little, Inc., for the Transportation Systems Center, under Contract No. DTRS-57-80-C-00111, Task 2, August, 1981.

3-3 Boghani, A.B., Nayak, P.R., and Palmer, D.W., "Safety Assessment Facility for Equipment (SAFE), Test and Analysis Methodology Options," Volumes 1 and 2," prepared by Arthur D. Little, Inc., for the Transportation Systems Center, Contract No. DOT-TSC-1671, January, 1980.

3-4 Jeffcoat, R.L, Griffin, J.W., and Vinje, E.W., "Performance Indices for Derailment Prediction," prepared by The Analytic Sciences Corporation for the Transportation Systems Center, September, 1978.

3-5 Ramachandran, P.V., El Madany, M.M., and Tsai, N.T., "Dynamic Response of Freight Vehicle Systems -- A Performance Characterization," ASME Paper 81-RT-4, April, 1981.

SECTION 4

TYPICAL EXAMPLE FOR PERFORMING AN ASSESSMENT

This section deals with an example of performing vehicle stability assessment using the IAT. The purpose of this subsection is to highlight several key aspects of the IAT and outline the sequence of events a user will follow in assessing the dynamic performance of a vehicle. Developing a complete test plan for the hypothetical example is a major effort which is considered beyond the scope of this document.

In this example, it is assumed that a type of 100-ton hopper car has been involved in a number of derailments. The objective of the assessment is diagnosing the problem and implementing a solution. Being a "Diagnostic Assessment," the procedure to be used in this case is the one shown in Figure 2-3. As dictated by the procedure, the first step is to confirm that a problem truly exists. This is done using the accident investigation technique described in Section B (Accident History Investigation).

A review of the accident investigation reports reveals that a large majority of accidents happen on tangent tracks at intermediate speeds. Also the tracks on which accidents have happened incorporate low staggered joints and/or alignment perturbations. The fact that the accidents happened only under definite circumstances reinforces belief in the existence of the problem. Also, based on this review, the symptom matrix (Table B-2 in Part II of the document) points to twist and roll and yaw and sway as likely candidates for the investigation which follows.

This contention is supported by an evaluation of the vehicle characteristics which are measured using the techniques described in Section N (Vehicle Characterization). The ranges of these characteristics fall (say) within ranges for both twist and roll and yaw and sway, although a relatively high yaw damping seems to indicate that twist and roll is the more likely cause of accidents. Similar conclusions are arrived at using a computer model from those identified in Section C (Vehicle/Track Simulation Models), and from the literature review of the pertinent literature obtained using the information provided in Section A (Resources Available for Investigating Performance Issues). Here, it is assumed that the model selected (and available) is validated within the range of interest. Thus, Section D (Model Validation) does not need to be consulted.

Since no one cause is definitely identified, it is decided to perform a Diagnostic Test for both twist and roll and yaw and sway. The first task to be performed before conducting the test is to develop a Test Plan. While developing the Test Plan, it is useful to expand the test objectives in great detail. In fact, a memorandum can be developed at this stage which shows explicitly how the test data would be analyzed, once the test is completed, and what the final results of the test would look like. There are two advantages of doing this:

- The test objectives are expressed in a form which is specific enough to eliminate any chance of misunderstanding by the various parties involved in the test; and

- The crucial data channels (the malfunction of any of which warrants halting the test) are identified.

The preparation of the Test Plan requires a number of tasks to be performed. First, Table 3-2 provides the test conditions which simulate the worst environment as far as the twist and roll and yaw and sway performance of the vehicle is concerned. These conditions are:

- Perturbations

  -- crosslevel, 1 in. to 2 in. amplitude, 39 ft. and 78 ft. wavelengths (for twist and roll)
  -- Alignment, 1.5 in. to 3 in. amplitude, 19.5 ft., 39 ft., and 78 ft. wavelengths (for yaw and sway)

- Track Class

  -- 2 and 4

- Track/Rail Stiffness

  -- vertical, >225 kips/in (track stiffness at 12 kips vertical load)
  -- lateral, >40 kips/in (rail stiffness at 0 vertical load)

  Subsection 3.1.1 and Section H, (Rail/Track Stiffness) provides details on how these stiffnesses should be measured.

- Speed

  -- 10-65 mph

- Rail Surface Condition

  -- sanded, dry

A quick survey of the available test facilities (see Section F, Test Facilities) shows that the best option would be to create perturbations on an out-of-service track of the railroad using the designs suggested for the proposed SAFE track for the issues under investigation.

Next, the Response Variables to be measured (found from Table 3-3) are identified as:

- Total truck lateral force;
- Total truck vertical force;
- Lead axle vertical force;
- Body roll, yaw and sway accelerations;
- Bolster to body roll and bounce displacements;
- Truck frame to body roll, yaw and sway displacements;
- Vertical wheel displacement; and
- Lateral coupler displacement.

Corresponding instrumentation characteristics are picked from Table 3-5 and the actual instrumentation is selected from the information provided in Section K (Wayside and Onboard Instrumentation). The onboard instrumentation includes:

- Two instrumented wheel sets (for truck and axle lateral and vertical forces);
- Accelerometers (for carbody accelerations);
- Potentiometers (for bolster to body and truck to body relative displacements as well as for coupler displacement);
- A video camera (for vertical wheel displacement); and
- Automatic Location Detector (ALD) and speed measurement instruments.

The data acquisition requirements are based on Table 3-6, which indicates that for the two Performance Issues under consideration, a total of 27 channels need to be handled in a 0-100 Hz range at a digital sampling rate of 200 Hz. Out of these, 12 will be "quick look" channels. Table 3-3 shows that these two Performance Issues share no common channels for a Diagnostic Test, except those recording speed, ALD, etc. Thus, the final number of channels to be recorded and to be provided for "quick look" reduces only to 17 and 10, respectively.

The safety criteria for the test is based on information provided in Section E (Test Plan Summaries). The variables to be studied to ensure a safe test are:

- Vertical wheel force, time duration at zero value;
- Truck lateral force;
- Truck L/V;
- Carbody roll angle;
- Carbody yaw angle; and
- Wheel/rail vertical displacement.

All of these channels are included in the list of quick look channels, as can be expected.

The test plan includes, in addition, the identification of the analysis techniques from Table 3-4 and Performance Indices from Table 3-7. As shown in Table 3-4, all of the Response Variables will be processed according to Levels 1 and 2 data analysis using techniques described in Section J (Analysis Techniques). The results will be used to generate the Performance Indices incorporating the following elements (see Table 3-7):

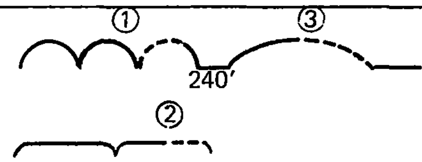
- Carbody roll angle;
- Carbody-bolster relative roll angle;
- Carbody wheel force;
- Carbody yaw angle;
- Carbody sway acceleration at Center of Gravity (C.G.);
- Truck lateral force; and
- Truck L/V.

Once the Test Plan incorporating all of the above information is prepared, the next task is to produce a document incorporating the test details.

The Test Details document provides the detailed design of the perturbation. For a Diagnostic Test to evaluate twist and roll, and yaw and sway, the SAFE design in Section F (Test Facilities) requires test sections with perturbation design shown in Figure 4-1. These sections can be laid in two test zones, one simulating Class 2 track and other, Class 4 track. The Class 2 track should include:

- Six cycles of 39 ft. wavelength, 2 in. amplitude crosslevel perturbations;

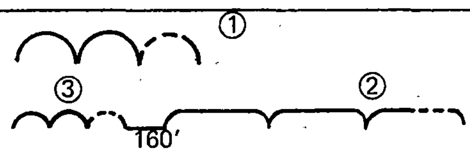
Crosslevel Perturbations

Class	Pictorial Representation
2	
4	

Subsection	Perturbation Characteristics					Length	Class	Recommended
No.	Type	Ampl.** in.	Wavelength ft.	Vertical Stiffness Kips/inch	No. of Cycles	ft.		Max. Speed MPH
1	Crosslevel	2	39	>225	6	240	2	30*
2	Crosslevel	1	78	>225	5	390	4	65*
3	Crosslevel	2	78	>225	5	390	2	30*

**Peak to peak amplitude with zero mean value.

Alignment Perturbations

Class	Pictorial Representation
2	
4	

— — represents cycles not shown

Subsection	Perturbation Characteristics					Length	Class	Recommended
No.	Type	Ampl. in.	Wavelength ft.	Lateral Stiffness Kips/inch	No. of Cycles	ft.		Max. Speed MPH
1	Alignment	3	39	>40	6	240	2	30*
2	Alignment	1.5	78	>40	5	390	4	65*
3	Alignment	1.5	19½	>40	8	160	4	65*

*Speeds and/or perturbation characteristics which exceed FRA Track Safety Standards would require a waiver on in-service track. Special safety precautions should also be exercised on out-of-service and test tracks.

FIGURE 4-1 PERTURBATION DESIGN FOR THE ILLUSTRATIVE EXAMPLE

- Five cycles of 78 ft. wavelength, 2 in. amplitude crosslevel perturbations; and
- Six cycles of 39 ft. wavelength, 3 in. amplitude alignment perturbations.

The Class 4 test track should include:

- Five cycles of 78 ft. wavelength, 1 in. amplitude crosslevel perturbations;
- Five cycles of 78 ft. wavelength, 1.5 in. amplitude alignment perturbations; and
- Eight cycles of 19.5 ft. wavelength, 1.5 in. amplitude alignment perturbations.

Both test tracks should have vertical stiffness of >225 kips per inch and lateral stiffness of >40 kips per inch. Also, the test speed should be kept less than 30 mph on the Class 2 track and less than 65 mph on the Class 4 track. Speeds and/or perturbation characteristics which exceed FRA Track Safety Standards would require a waiver on in-service track. Special safety precautions should be exercised on out-of-service and test tracks.

The perturbations can be constructed based on information provided in Section G (Track Geometry Perturbations), and the instructions for changing, measuring and maintaining rail/track stiffness are provided in Section H (Rail/Track Stiffness).

The instrumentation details are finalized (Section K, Wayside and Onboard Instrumentation), the data acquisition/storage system is designed, and field test plans are developed as shown in Section M. The use of a reference vehicle is prescribed based on information given in Section O.

Once the test details are worked out, the track is prepared according to plans, and tests are run over the prepared track. The field test plans provided in Section M are used in running the test.

The data from the test are converted to Performance Indices as described in Section 3.2. Suppose the results show that the values of the Performance Indices for twist and roll are closer to one (1) than those for yaw and sway, the vehicle is confirmed to suffer from twist and roll and adequate cures are contemplated.

For the sake of the hypothetical example, assume that the cure selected requires increasing somehow the damping in the side bearings. The first task in determining the adequacy of the cure is to run an analytical model (preferably the same one used before) and determine from the results if the cure will improve the twist and roll characteristics of the vehicle. If this first hurdle is passed successfully, a cost/benefit analysis is performed in order to ensure that the solution is not too expensive. This can be done by comparing the net present value of the yearly expenses of the derailments which the proposed modification is likely to prevent with the expenses of fabrication, installing, and maintaining the additional damping devices.

Next, at this stage, if the user is convinced that the proposed modification will improve the vehicle's twist and roll performance, without deteriorating its performance in any other Performance Issue, the modifications are implemented, and the hopper cars are returned to service. If, however, the user is not convinced, a Proof Test is planned.

For the Proof Test, the test plan is substantially smaller than that for the earlier test. For example, the test would be performed only on a track incorporating 39 ft. wavelength crosslevel perturbations. Also, the Response Variables to be measured and processed reduce to:

- Body roll motion, and
- Body to bolster roll and bounce relative displacements.

Comparing the Performance Indices obtained from this test with those obtained for the unmodified vehicle reveals the effectiveness of the modification. If, the modification is not found to be adequate, a new modification (such as reducing the C.G. height somehow or increasing the suspension stiffness substantially) is evaluated by subjecting it to the same process.

The assessment is considered complete when an adequate modification is found and implemented.

SECTION 5

SYSTEM STANDARD NOMENCLATURE

In the past, difficulties have been experienced in utilizing the data from previously run tests, partly because nomenclature has not been standardized for describing various aspects of a test. The IAT will permit improvement in this situation and contribute to a growing body of information concerning vehicle stability. This section describes an attempt to identify the various test aspects which can be standardized and proposes standardizations for each aspect.

Table 5-1 summarizes the various test aspects which can be standardized. They are then discussed in the following subsections.

5.1 Test Site

The test site should be described in terms of maps, charts, and drawings introduced in a sequence of increasing detail as shown in Figure 5-1. The most general of these should be a region map which identifies the location of major cities, towns around the test site, railroad tracks and mileposts. This should be followed by a track chart which shows the test area in terms of mile posts, overall track geometry, and structures (grade crossings, bridges, etc.). In the example shown, the test area is made up of two test zones. There is no need to separate a test area into zones, unless they are separated by at least a mile or they are located on different tracks altogether.

The next chart in Figure 5-1 shows the details of the test site, which includes a schematic of the test zones, reference mileposts for each test zone, and major structures along the site. As can be seen, Test Zone A has two test sections, Sections 1 and 2 (numbered in the direction of increasing milepost numbers), whereas Test Zone B has only one test section, Section 3. Generally, each test section differs from others in one or more major attributes, such as the type of perturbations, curvature, track stiffness, and so on. The location of each test section from the pertinent reference milepost, in feet, is given in this chart.

The next chart shows the details of a particular test section. As shown in Figure 5-1, each test section may be further divided into subsections (to be identified as Subsections 1-1, 1-2, and so on), each having, say, perturbations with different amplitudes or wavelengths, but having the same track stiffness, curvature and/or perturbation type. The exact shape of perturbations need not be shown in this chart; a schematic representation should suffice. However, the locations of each perturbation from the beginning of the section should be provided in terms of number of joints and in feet. For this purpose, the joints should be counted on the right rail, (i.e., the rail on the right hand side while facing in the direction of increasing milepost numbers), and should be numbered sequentially in the same

TABLE 5-1: TEST ASPECTS WHICH CAN BE STANDARDIZED

TEST SITE

- AREA MAP
- TRACK CHART
- SITE OVERVIEW
- TRACK STRUCTURES
- TRACK GEOMETRY
- TRACK COMPLIANCE
- INSTRUMENTATION LOCATIONS
- TEST EVENTS LOCATIONS

TEST CONSIST

- CAR IDENTIFICATION
- CAR EQUIPMENT
- CONSIST CONFIGURATIONS

ONBOARD INSTRUMENTATION

- TRANSDUCER DEFINITIONS
- CAR LAYOUT
- INSTALLATION DETAILS
- CHANNEL ASSIGNMENTS

WAYSIDE INSTRUMENTATION

- TRANSDUCER DEFINITIONS
- INSTRUMENTATION LOCATIONS
- INSTALLATION DETAILS
- CHANNEL ASSIGNMENTS

TEST CONDUCT

- SUMMARY OF TEST EVENTS
- AMBIENT ENVIRONMENT
- RUN SEQUENCE

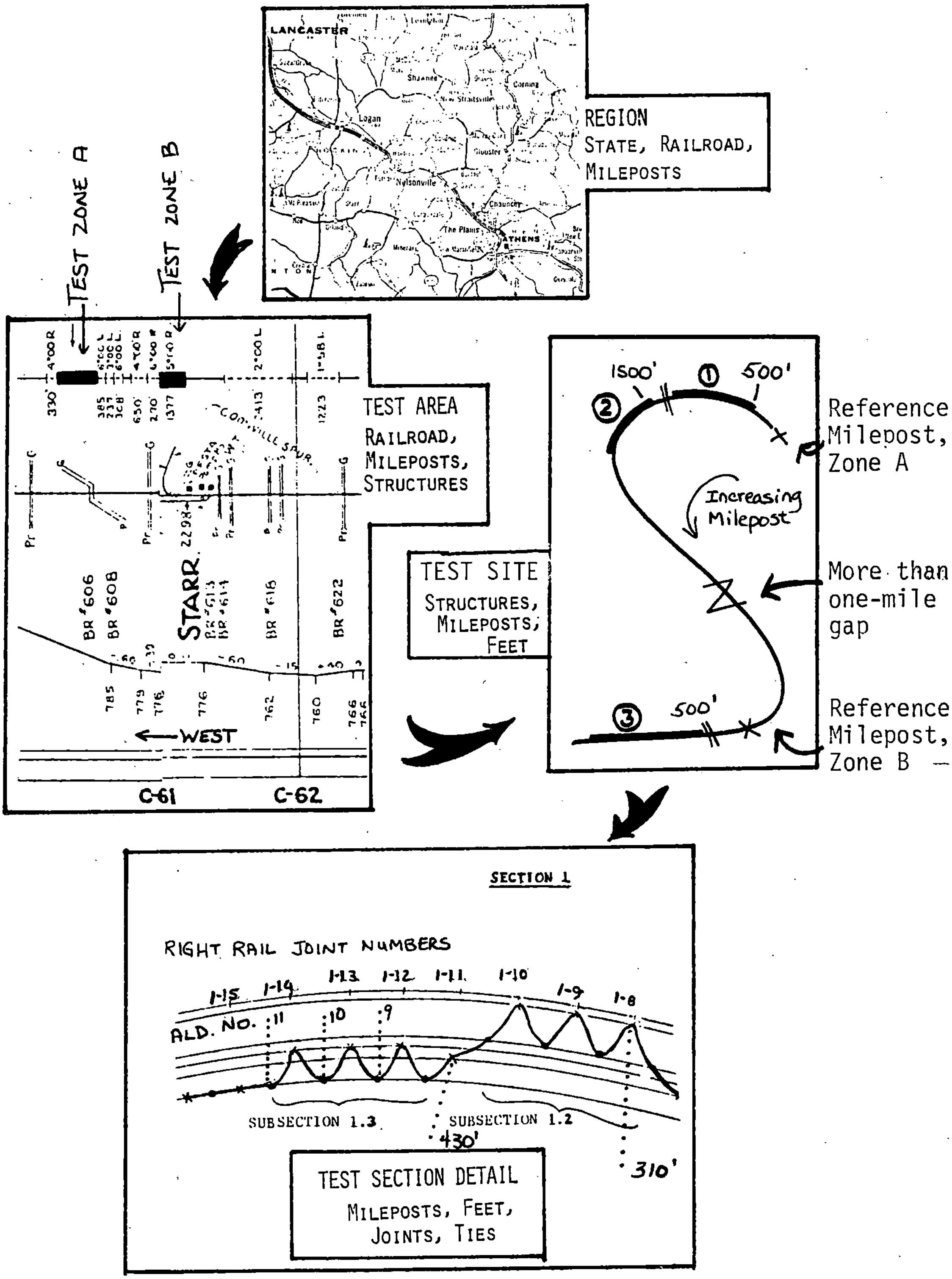


FIGURE 5-1: TEST SITE IN INCREASING DETAIL

direction. The section number should appear in front of each joint number to prevent any confusion.

This chart should also show the location of each automatic location detector (ALD) target, any wayside instrument distributed along the test site and places where track stiffness measurements are made. The ALDs and dynamic gauge displacement transducers should be numbered sequentially in the direction of increasing milepost numbers, so that there are no duplicates in the complete test site. The locations of stiffness measurements (which are to be performed according to instructions provided in Section H, Rail/Track Stiffness) should also be numbered sequentially.

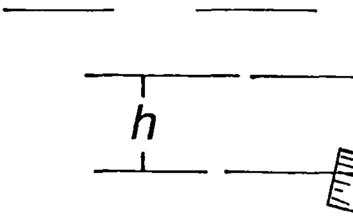
The characteristics of the perturbations should be defined next. Figure 5-2 clearly shows the track geometry parameters which can be varied to create perturbations. The details of the perturbations should be provided in a manner shown in Figures 5-3 and 5-4. The following key points should be observed:

- The exact shape of perturbation (e.g., sinusoidal, piece-wise linear, rectified sine, etc.) should be shown in this chart.

- The amplitude is to be specified in terms of "peak-to-peak" amplitude, i.e., maximum parameter value minus minimum parameter value. Thus, for example, ½ in. shims gives rise to ½ in. amplitude profile perturbations, whereas the same shims create 1 in. amplitude crosslevel perturbations. As shown in Figure 5-4, a similar distinction can be made in specifying the alignment and gauge perturbation amplitudes. This, of course, is true if both rails, and not just one rail, are bent to create perturbations.

- The nominal lines should be shown in the figure displaying perturbation details. These take the form of nominal tangent or curve lines in the figure showing gauge or alignment perturbations and nominal deviation line in that showing profile or crosslevel perturbations. The distance from the nominal line to the inner part of the perturbation (in case of gauge and alignment perturbations) or to the bottom part (in case of profile and crosslevel perturbations) is termed offset. The value of the offset is negative in the examples shown in Figures 5-3 and 5-4.

- The right and left rails should clearly be identified. As mentioned earlier, the right rail is on a person's right while facing the direction of increasing mileposts. If the perturbations are on a curve, the inner and outer rails should also be identified.



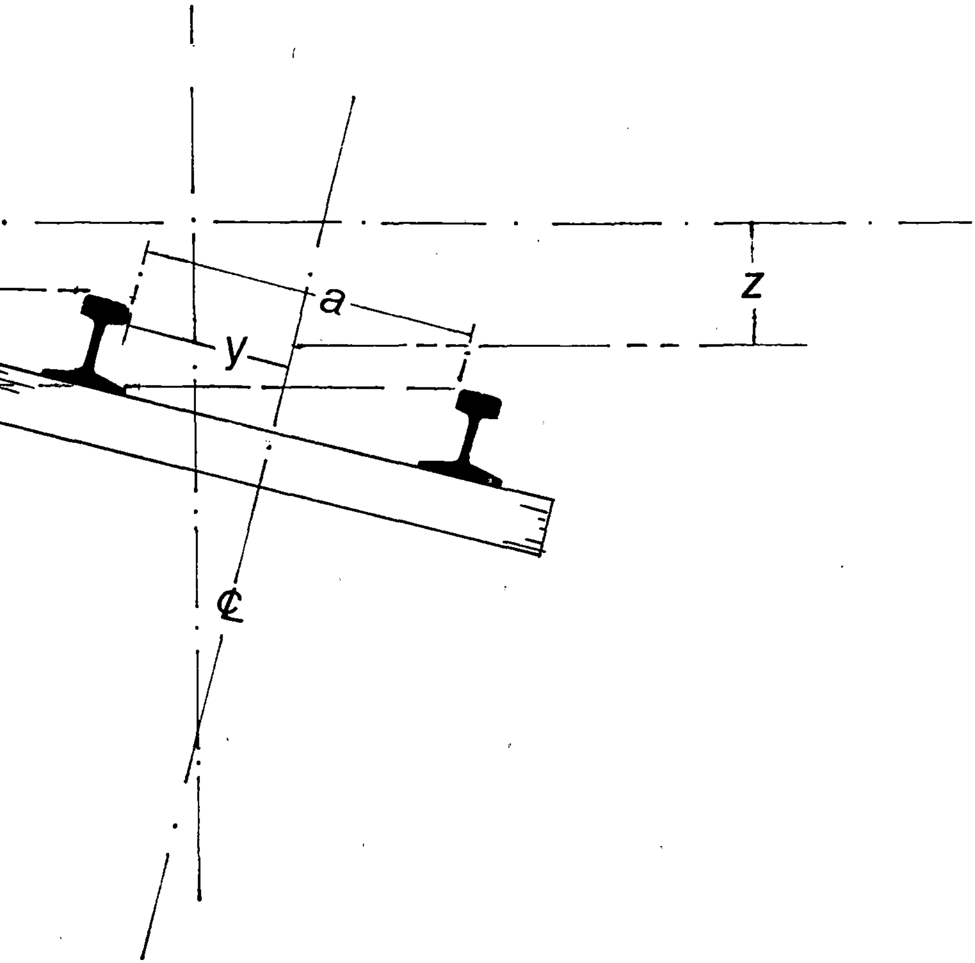
z = Profile

y = Alignment

h = Crosslevel

a = Gauge

FIGURE 5-2:



TRACK GEOMETRY PARAMETERS

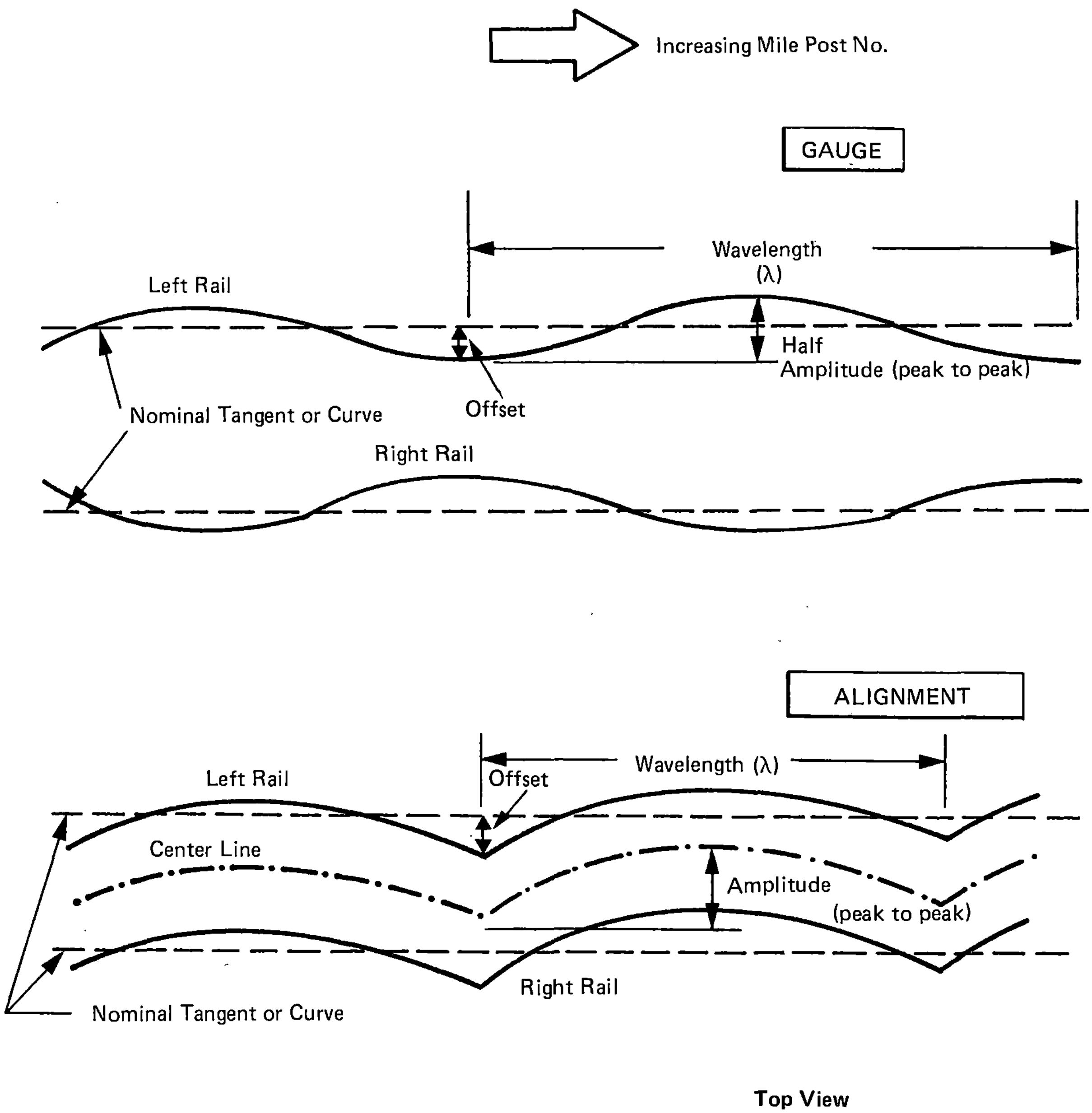


FIGURE 5-3 SPECIFYING PERTURBATION CHARACTERISTICS, GAUGE AND ALIGNMENT

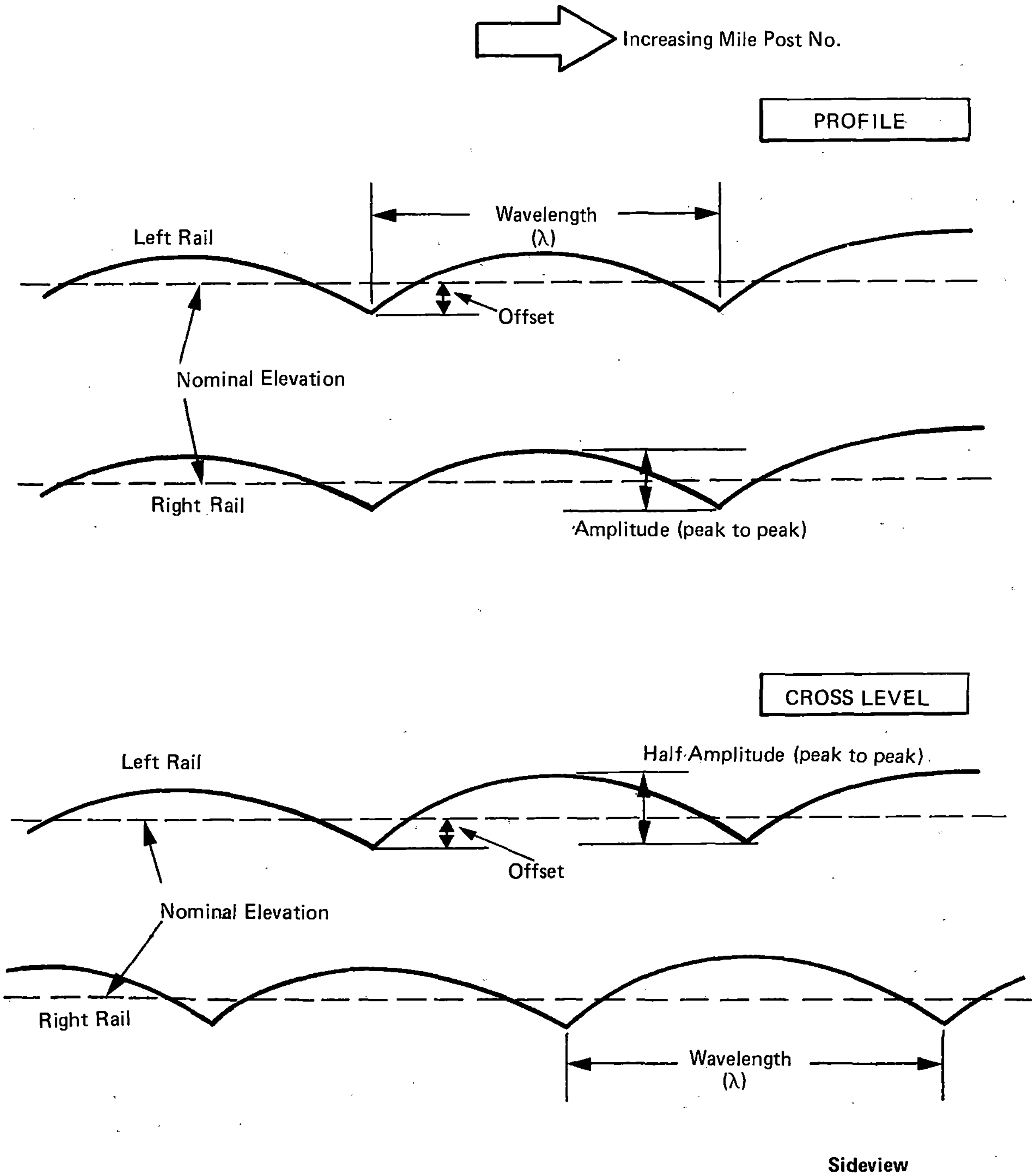


FIGURE 5-4 SPECIFYING PERTURBATION CHARACTERISTICS, PROFILE AND CROSSLEVEL

- The perturbation wavelength should also be specified. Special care should be exercised in crosslevel perturbations where shims appear once every half wavelength.

Finally, the location of each test event should be provided in terms of test sections on which the test is run.

5.2 Test Consist

The description of a test consist should include a side view schematic of each configuration showing the car identification numbers, car orientation, axle numbers, axle orientation, and right and left rails (see Figure 5-5). The head-end of the consist should be labeled as such, and the A and B ends of each car should be identified. Axle numbers are chosen based on incremental numbering from the head-end of the primary consist configuration. This numbering is henceforth firmly associated with that particular wheelset. Other consist configurations will not change the number assigned to these wheelsets. The addition of cars will add new axle numbers to the consist, even though the resulting sequence may not be continuous.

The wheels on individual axles will be named in the following way: Facing the B-end of the car, the wheels on the right side will become R1, R2, R3, and R4, whereas those on the left side will become L1, L2, L3, and L4. Added to this will be the designation of the vehicle they belong to. Thus, in Figure 5-5, 5R4, 5R3, 5R2 and 5R1 will refer to the wheels on Axles 21, 22, 23, and 24, when seen from the side of the right rail. Once each wheel is identified this way, they will continue to be designated by the same identification number, even if the axle orientations are changed or the axles are swapped with other axles in the consist. This is described in detail in Section M (Field Test Planning) of Part II.

The identification number of each vehicle should include its primary orientation. Thus, the locomotives in Figure 5-5 will be labeled as Vehicles 1F and 2B, whereas the cars will be labeled as Vehicles 3A, 4B, 5A, 6A, 7A, and 8A.

The consist description should include a table, similar to Table 5-2, summarizing the key properties of each vehicle. This table can also include information such as CG height, clearances, and so on, depending on the Performance Issues being addressed by the test. One particularly confusing aspect in retrieving information from the past test reports is determining the direction in which the consist was facing and the direction in which it traversed the test sections. Thus, for each test run, the facing and moving directions should be specified. The facing direction should be specified as I--facing increasing milepost numbers or D--facing decreasing milepost numbers, and the moving direction should be specified as F--forward or B--backward.

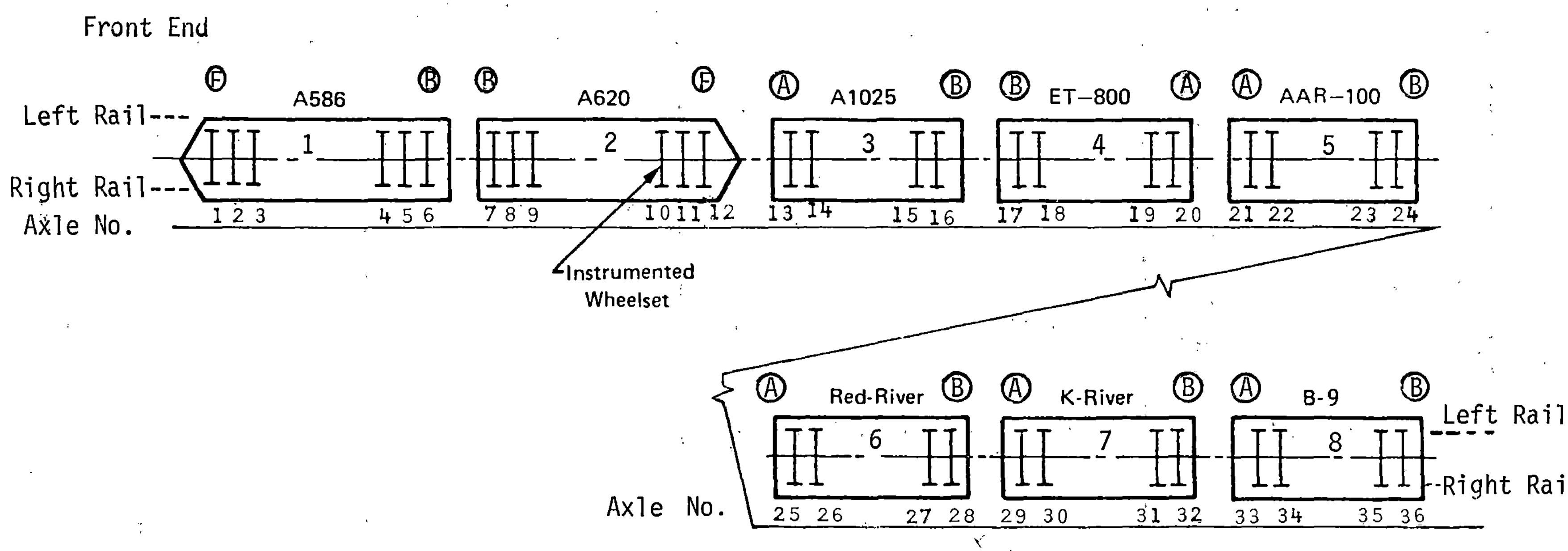


FIGURE 5-5: TEST CONSIST NOMENCLATURE

TABLE 5-2: TYPICAL CONSIST CONFIGURATION

CAR NO.	DESCRIPTION	RAILROAD CAR IDENTIFICATION NO.	LOADED/EMPTY	TRUCK TYPE	AXLE NO.	WHEEL PROFILE
1F	Locomotive		-	HTC	1	New AAR 1/20
					2	
					3	
					4	
2B	Locomotive		-	HTC	5	
					6	
					7	
					8	
3A	100 T Hopper		Loaded with Coal	Barber S-2-HD	9	Worn CN
					10	
					11	
					12	
4B	100 T Hopper		Empty	Barber S-2-HD	13	New CN
					14	
					15	
					16	
•	•	•	•	•	•	•
•	•	•	•	•	•	•
•	•	•	•	•	•	•
•	•	•	•	•	•	•

Note: Additional information on each vehicle, such as car height, clearances, truck center distance, wheel base, car length, etc., should also be provided as needed.

5.3 Onboard Instrumentation

The definitions of most onboard transducers are unambiguous and therefore not clarified here. Section K describes the various instruments which can be used as part of the IAT.

The location of each instrument should be provided in a manner shown in Figure 5-6. In addition, the X, Y, and Z coordinates of each instrument, referenced to some convenient location, such as "A" end centerpin for the X, Y coordinates and railhead for the Z coordinate, should be provided in a manner shown in Table 5-3.

The data acquisition/recording channels are assigned to transducers in a numerical sequence starting from channel No. 1. Usually, the miscellaneous channels, such as speed, time, and so on, are assigned the last few channel numbers. These channels should have the same identification number throughout the test, even if some of them are discarded and new channels are added as the test progresses. Also, if some channels are synthesized (such as L/V ratios) for "quick look" from other channels, they should be assigned separate numbers and their relationships with the other channels explicitly identified. Finally, each data stream recorded should be preceded by the channel identification number so that they can readily be identified, even if their locations on the recording devices are changed.

Corresponding to each channel number the shortened name or acronym of a transducer may be used. This shortened name or acronym would indicate the location and type of transducer, as shown in Figure 5-6. If such a scheme is used, each shortened name or acronym should be defined explicitly somewhere in the report. A suggested standardization of acronyms is provided in Table 5-4.

Finally, some standardization is required in specifying the directions of various accelerations, displacements, and forces. Figure 5-7 provides some suggestions in this regard.

5.4 Wayside Instrumentation

The standardization of wayside instrumentation information is similar to that for the onboard instrumentation. The definition of each wayside instrument to be used in the IAT is provided in Section K (Wayside and Onboard Instrumentation) and therefore, is not repeated here. The same section also provides installation details.

The location of local wayside instruments (such as rail and tie displacement transducers) should be specified in a manner shown in Figure 5-8. The following information should be included in this chart:

- The tie and crib numbers (with associated section number), counting from the beginning of the section;

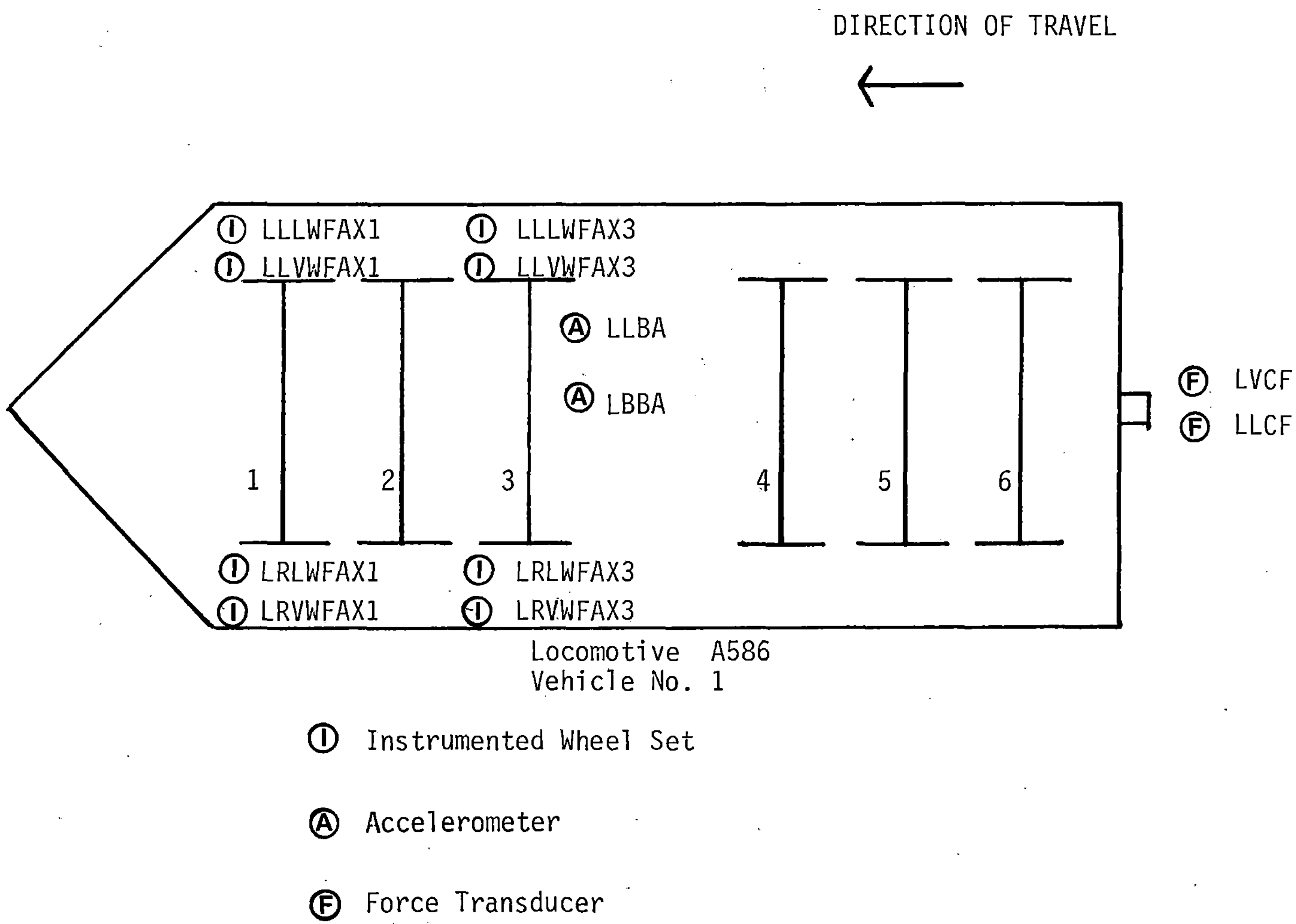


FIGURE 5-6: TYPICAL ONBOARD INSTRUMENTATION LAYOUT

TABLE 5-3: TYPICAL SPECIFICATION OF COORDINATES OF INSTRUMENTATION LOCATIONS

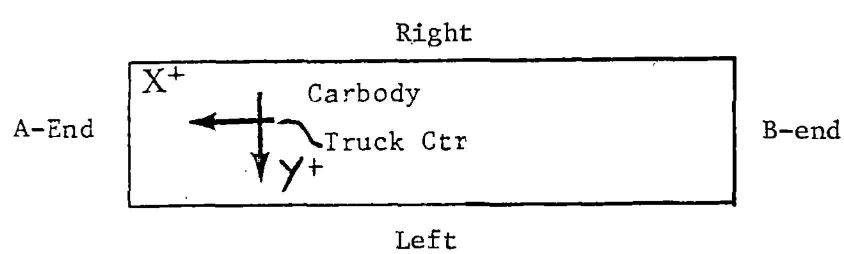
CAR #4

CHANNEL** NUMBER	DESCRIPTION	LOCATION (INCHES)*		
		X	Y	Z
30	Vertical Carbody Acceleration (Mid. A)	0	0	+56.75
31	Vertical Carbody Acceleration (Rt. A)	0	-54.0	+42.50
32	Vertical Carbody Acceleration (Mid. B)	-486	0	+56.75
33	Lateral Carbody Acceleration (Mid. A)	0	0	+42.50
34	Lateral Carbody Acceleration (Mid. B)	-490	0	+42.50
35	Lateral Truck Frame Acceleration (Lt. A1)			
36	Lateral Truck Frame Acceleration (Lt. A2)			
37	Vertical Truck Frame Acceleration (Lt. A1)			
38	Vertical Truck Frame Acceleration (Lt. A2)			
39	Vertical Truck Frame Acceleration (Rt. A1)			
40	Vertical Truck Frame Acceleration (Rt. A2)			
41a	Truck Yaw ("A" End)	+56.5	-13.5	+25.5
41b	Truck Yaw ("A" End)	+9.0	-22.5	+22.0
43a	Vertical Suspension Displacement (Lt. A)	-2.0	+49.0	+16.5
43b	Vertical Suspension Displacement (Lt. A)	-2.25	+49.0	+1[illegible].0
46a	Vertical Suspension Displacement (Rt. A)	-2.5	-50.0	+16.0
46b	Vertical Suspension Displacement (Rt. A)	-2.5	-50.0	+[illegible].75
45a	Carbody Roll Displacement (Lt. A)	+4.5	+53.0	+37.50
45b	Carbody Roll Displacement (Lt. A)	+4.5	+50.5	+10.00
44a	Carbody Roll Displacement (Rt. A)	+4.0	-50.5	+37.25
44b	Carbody Roll Displacement (Rt. A)	+4.0	-49.0	+10.00
51	Carbody Roll Gyro (Mid. A)	+9.5	-7.0	+49.00
53	ALD (Lt. A)			

*X and Y relative to "A" end center pin (positive as shown below)

Z relative to top of rail head (positive is up)

**a - transducer; b - string attachment



Plan View

TABLE 5-4: STANDARDIZED ACRONYMS FOR EACH CHANNEL OF THE ONBOARD INSTRUMENTATION

L L VWF AX4

Vehicle (if needed)

L = Locomotive
P = Passenger/Baggage Car
H = Covered Hopper
G = Gondola
T = Tanker
F = Flat Car
B = Box Car
O = Open Hopper
S = Stock Car

Side (if needed)

L = Left
R = Right
(Primary Orientation)

Variable

LWF = Lateral Wheel Force
VWF = Vertical Wheel Force
LTF = Lateral Truck Force
VTF = Vertical Truck Force

RBA = Roll Acceleration of Body
PBA = Pitch Acceleration of Body
BBA = Bounce Acceleration of Body
YBA = Yaw Acceleration of Body
SBA = Sway Acceleration of Body
LBA = Longitudinal Acceleration of Body

RBD = Roll Displacement of Bolster*
BBD = Bounce Displacement of Bolster*

PTA = Pitch Acceleration of Truck
BTA = Bounce Acceleration of Truck
YTA = Yaw Acceleration of Truck
STA = Sway Acceleration of Truck
LTA = Longitudinal Acceleration of Truck

RTD = Roll Displacement of Truck*
PTD = Pitch Displacement of Truck*
BTD = Bounce Displacement of Truck*
YTD = Yaw Displacement of Truck*
STD = Sway Displacement of Truck*
LTD = Longitudinal Displacement of Truck*

LAA = Lateral Axle Acceleration

LAD = Lateral Axle Displacement**

LWD = Lateral Wheel Displacement
AWR = Wheel Angle of Attach
VWD = Vertical Wheel Displacement

VCF = Vertical Coupler Force
LCF = Lateral Coupler Force
ACF = Axial Coupler Force

VCD = Vertical Coupler Displacement
LCD = Lateral Coupler Displacement
ACD = Axial Coupler Displacement

Location (if needed)

AXn = Axle n
A = A end
B = B end

No acronyms can be specified for structural stresses and deformation of body.

*Relative to body.
**Relative to truck.

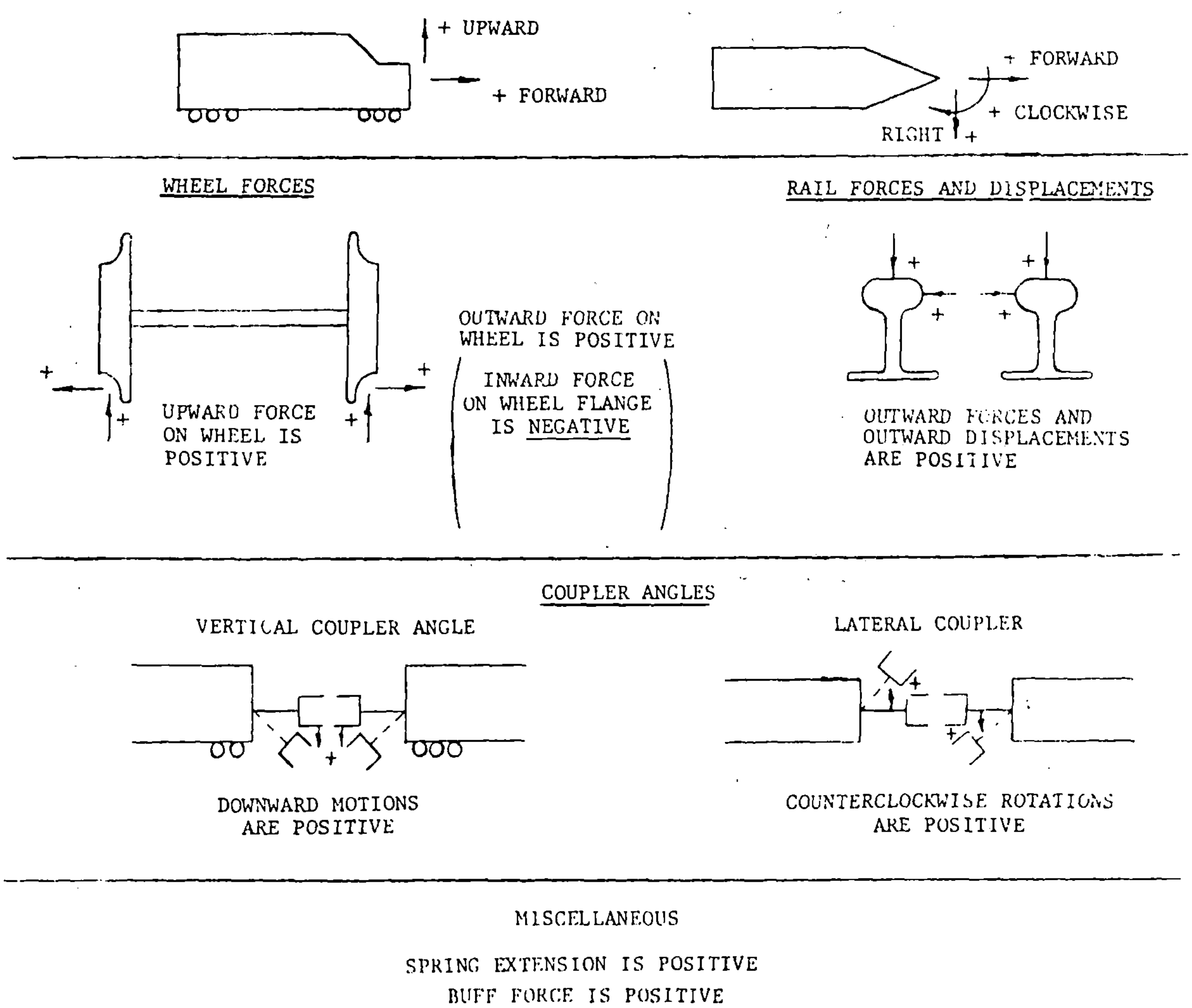
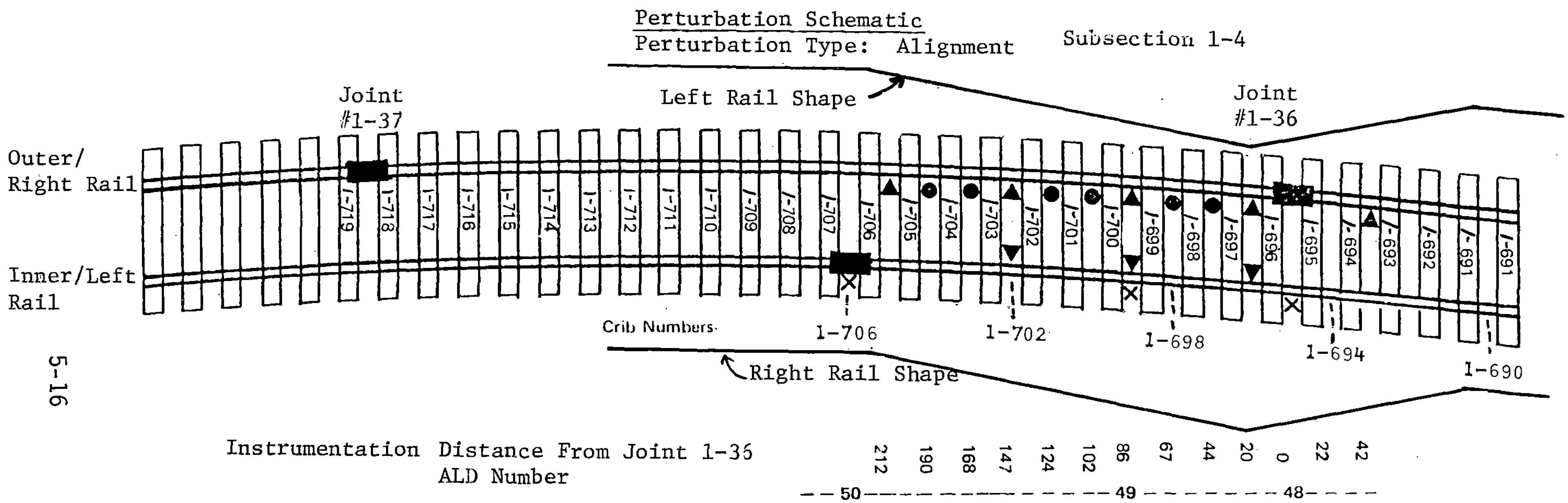


FIGURE 5-7: SUGGESTED SIGN CONVENTIONS



Legend:

▲ Rail Head Vertical Deflection;

● Rail Head Lateral Deflection: and so on.

X ALD Target

FIGURE 5-8: TYPICAL WAYSIDE INSTRUMENTATION LAYOUT

- A schematic of the perturbation;
- The identification of nearby joints and ALD targets; and
- The distance of each instrument in inches from a reference joint.

The symbols used for each wayside instrument should be clearly defined.

Once again, the assignment of channel numbers should follow the same rules as in the case of onboard instrumentation. The acronyms to be used for channel identification can follow the suggestions provided in Table 5-5.

5.5 Test Conduct

The summary of test events should include the conditions under which a test run was made and the observations on the vehicle/track behavior which may be of use in interpreting the test data. Also, if an unplanned run was made, the reason for making it should be clearly provided. It is important to note the ambient environment, in terms of temperature, wind, rain, snow, and so on, because it could have a significant effect on the interpretation of results.

The run sequence should be identified in the following manner:

XX	YY	ZZ	-60	IF
Month No.	Day No.	Run No.	Test Speed	Facing and Moving Directions

Using a separate run number for each run is preferable, even though it may be very slightly different from the other runs.

TABLE 5-5: STANDARDIZED ACRONYMS FOR EACH CHANNEL OF WAYSIDE INSTRUMENTATION

L LTD T 1-45

Side	Variable	Location	Number
L = Left	LTD = Lateral Tie Deflection	T = Tie	Identification No. of Tie or Crib
R = Right	VTD = Vertical Tie Deflection	C = Crib	
	LRHD = Lateral Rail Head Delfection		
	VRHD = Vertical Rail Head Deflection		
	LRBD = Lateral Rail Base Deflection		
	VRBD = Vertical Rail Base Deflection		
	DGW = Dynamic Gage Widening		
	LRF = Lateral Rail Force*		
	VRF = Vertical Rail Force*		

*Not in the list of suggested instrumentation in Table 3-3.

SECTION 6

SUMMARY OF PART II SECTIONS

The sections provided in Part 2 of the document describe many aspects of the IAT in more details. A summary of each section is provided below.

A. Resources for Investigating Performance Issues

This section incorporates a listing of literature pertinent to each Performance Issue. The literature includes reports and technical papers that describe each Performance Issue and reports that summarize various test and analysis programs related to vehicle/track interaction. A table of Performance Issues versus pertinent references is provided to guide the user to the correct information on an issue of interest.

The intent of this section is to provide the user not only with the benefit of the experience of other researchers, but also with the required information on the state-of-the-art in the field of rail vehicle dynamics. This information could be valuable in interpreting the symptoms of a dynamic problem and in identifying which Performance Issues to be aware of while testing a new or modified vehicle.

B. Accident History Investigation

This section first presents how the accidents are currently being investigated. Second, a method of identifying common factors in a series of accidents is presented. A way of relating these factors to the symptoms common to accidents caused by each Performance Issue is then proposed, followed by the identification of the Performance Issues which potentially could be causing the accidents under investigation. Such information is crucial in applying the IAT, because the analysis and tests that follow this investigation can then be directed toward only these few potential Performance Issues instead of toward all ten of them.

C. Vehicle/Track Simulation Models

A compendium of practically all computer models developed in the United States -- and some elsewhere -- is provided in this section. For each computer model, vital information is given, such as the vehicles for which it was developed, the model class, the number of degrees of freedom, the extent of present usage, the hardware it has been run on, the availability of users' manual, and the extent of validation. To make this information user-oriented, separate tables are provided for models applicable to each Performance Issue. In additional, applicable information on the track models is also made available.

As shown earlier in the IAT structure diagram (Figure 2-1), an analysis using a computer simulation model can reveal much information about the dynamic performance of a vehicle over a track with given characteristics. Such information can be crucial in planning a test program and in the overall dynamic performance assessment.

D. Rail Vehicle Model Validation

Unless a computer model is validated in the range of interest, no confidence can be placed in its predictions. Thus, this section which deals with what mathematical model validation is and how it can be performed is important to the use of the computer models for vehicle performance assessment and, thereby, to the success of the IAT. In order to make it user oriented, this section provides extensive information on how to use existing test results for performing validation and on how to design tests for the same objective. Appropriate examples are given to illustrate the key techniques.

E. Test Plan Summaries

This section consists of test plan summaries for each combination of the ten Performance Issues and the three Test Categories. Easy-to-use tables provide valuable information, such as, the test sites to be used, Control Variables, Response Variables, data handling requirements, Performance Indices and safety criteria. Although much of this information is available in the tables in Section 3, the information in Section E is in an easier to use format.

F. Test Facilities

The user has a number of options for conducting tests prescribed by the IAT. They can be conducted on a revenue service track, either modified or unmodified, or they can be run on industry owned test tracks. Often, however, the cost of modifying a track and providing the support needed to conduct test programs could exceed that of conducting the test at the Transportation Test Center (TTC) in Pueblo, Colorado, which is setup for conducting a variety of rail vehicle/ consist tests.

This section describes the following test facilities available at TTC for the investigation of conventional railroad vehicles:

-- The Rail Dynamics Laboratory (RDL), which includes the Vibration Test Unit (VTU), and the Roll Dynamics Unit (RDU);

-- The Facility for Accelerated Service Testing (FAST);

-- The Railroad Test Track (RTT);

-- The Train Dynamics Track (TDT);

-- The Precision Test Track;

-- The Turn Around Track (Balloon Loop); and

-- The Impact Track.

In addition, Section F provides the details of the proposed Stability Assessment Facility for Equipment (SAFE). This last facility has not yet been built, but its detailed design is available. The information provided in this section, and additional details available from the Transportation Systems Center (TSC) can assist the user in developing a test facility which may not be as comprehensive as SAFE but which will include its appropriate components.

G. Track Geometry Perturbations

This section deals with irregularities (or perturbations) that can intentionally be installed in a track to provide the test vehicle with sufficient excitation to bring out its dynamic characteristics, which is generally the intent of a test done under the IAT. Included in the description in this section are methods of creating alignment, crosslevel, and profile perturbations and of measuring and maintaining them. Past tests where such perturbed tracks have successfully been used are referenced.

H. Rail/Track Stiffness Measurements, Variations, and Simulations

Like track geometry, the vertical and lateral stiffnesses of rail/track have significant effects on some of the Performance Issues addressed by the IAT. Thus, the stiffnesses have to be closely controlled and accurately measured during a test program. This section describes how this can be done.

I. Performance Indices

As discussed in Subsection 3.2, Performance Indices provide a standardized and simple way of interpreting vehicle performance data. The candidate Performance Indices provided in that subsection were obtained from many sources, one of which is a document included in this section. This document outlines methods used in deriving Performance Indices, identifying the most suitable Indices for each Performance Issue and estimating their accuracies.

J. <u>Analysis Techniques</u>

The raw data gathered during a test program must be processed before they can be interpreted. Many analysis techniques which can be used to process the data are described. Typical among these techniques are simple statistics (mean, rms, etc.), resonant frequency analysis, threshold exceedance analysis, frequency spectral analysis, regression analysis, and probability distribution analysis. With these techniques, a user can develop Performance Indices and other measures required to assess the performance of a vehicle using the IAT.

K. <u>Wayside and Onboard Instrumentation</u>

Although the Response Variables to be measured and the characteristics required of instruments designed to measure them are discussed in Section 3 of this part, the details of the instruments are included in this section. Described here are the onboard and wayside instruments commonly used for measuring the various vehicle/track displacement forces and accelerations. The calibration and installation techniques for each instrument are also provided. Finally, other relevant instruments, such as the Automatic Location Detector, (ALD), are described.

L. <u>Data Management</u>

A summary of the data management requirements associated with a test program is provided in this section. Usually a test program results in the generation of a large amount of data which, unless managed properly, would make the task of interpreting the data very difficult. Highlighted in this section are the pitfalls to be aware of while developing a data management system.

M. <u>Field Test Planning</u>

This section provides a detailed and systematic plan for designing and implementing the IAT field test programs. The basic approach is to provide the user with a progressively more detailed breakdown of constituent subtasks or test planning activities (i.e., starting with an overall flow diagram, the user will be able to quickly access the appropriate planning area and planning detail necessary). Where appropriate, specific examples of the type of information required for each planning stage are included.

The structure for this section is based upon an overall planning diagram which depicts the major activities required to successfully plan and integrate a field test program. This overall planning diagram is presented at the front and back of the section so that it can be easily referred to when needed.

The purpose of the overall planning diagram is to show the <u>primary</u> interrelationships between basic elements or activities. This procedure permits factoring out common elements, aids in assessing resource requirements, allows critical paths and decision points to be identified, and also provides the structure for a management plan through identification of the major coordination requirements.

As part of the approach to developing a systematic plan for addressing vehicle/track interactive field testing, each of the larger tasks or basic blocks of the planning diagram are broken down into constituent subtasks (activities) which are more amenable to precise definition. Each block has been assigned a reference number which provides a mechanism for defining the interrelationships between subtasks. The detailed subtask breakdowns are presented in respective sections.

N. Vehicle Characterization

Table 2-3 in Section 2 of this part shows how Performance Issues to be addressed can be identified if one knows the characteristics of a vehicle. This section describes how such characteristics can be measured, and provides a technique to systematically identify the Performance Issues of interest for a given set of characteristics. Discussed in this section are ways of obtaining information on vehicle weight; center of gravity height; truck bending and shear stiffness; vehicle torsional flexibility; truck yaw moment of inertia; body natural frequencies and damping; and so on.

O. Reference Vehicle Usage

The study provided in this section examines the utility and choice of reference vehicles, particularly freight vehicles, for track and test calibration, baseline comparison and extrapolation to service conditions. A fundamental set of measurable characteristics is identified from which needs for maintenance and instrumentation are defined. Reference vehicle uses are considered for seven performance issues: hunting, twist and roll, pitch and bounce, yaw and sway, steady-state curving, spiral negotiation, and dynamic curving. The advantages in reference vehicle use are assessed against the cost of fundamental measurement of the significant system variables. The study identifies a minimum of four freight cars representative of the present fleet of freight vehicles and appropriate to the Performance Issues discussed. It is concluded that the variety of locomotive and passenger vehicle designs requires an independent assessment for the choice of a reference vehicle for each.

One of the key aspects of a test performed under the IAT is that of providing controlled inputs to the test vehicle. A reference vehicle used and selected as described in this section will assist in achieving this objective.

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