Heavy Truck
Crash Avoidance Research Support
—Vehicle Dynamics—

A Plan for Conducting An LCV Operational Field Test

Interim Technical Report

C. B. Winkler
S.E. Bogard
M. A. Bowen

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Mr. Robert Clarke of NHTSA served as the Contracting Officer's Technical Representative on this project.

16. Abstract

This report presents a plan for conducting operational test of longer combination vehicles (LCVs) equipped with antilock braking systems (ABS) and double-drawbar dollies (C-dollies). The document identifies five commercial trucking fleets to participate in the study. Detailed plans for acquiring the necessary hardware and retrofitting the test vehicles are included. Plans for operational (maintenance, reliability, etc) and performance data gathering and analysis are included. An itemized financial plan is presented. PERT and Gantt charts are appended.

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INTRODUCTION

This document reports on the primary results of IQC TASK 1, "Planning to Conduct LCV Operational Test," Contract No. DTNH22-92-D-07003, Project No. NRD-01-2-07572. The LCV operational test that we are planning is one element of the LCV tests mandated by Congress in the 1991 ISTEA. DOT is obligated to report to Congress on the results of the test by December 18, 1994.

The objective of the test, to which this document is addressed, is to "evaluate the stability enhancing characteristics, practicality/reliability, maintenance costs and (fleet) personnel reactions to ABS,...and double-drawbar dollies...." To do this we will equip a sample of seventeen double- and triple-trailer LCVs in actual commercial service with ABS and with double-drawbar dollies (C-dollies), and will monitor their performance for a period of about one year. Both the sample size and the time period are small relative to the ambitions of the test, but both are unavoidable due to fiscal limitations and the congressional reporting date.

As originally conceived, the study task was composed of seven sub tasks. They are:

1) Assessment of the Outside Partners
2) Planning for Meaningful Operational Tests
3) Planning for Data Processing
4) Devising a Complete Equipment Plan
5) Obtaining Preliminary Agreement from Partners
6) Planning for Management of the Field Test
7) Preparation of the Test Plan Report

The task has recently been modified to include an eighth sub task:

8) Development of a Prototype Instrumentation System

This report deals with the first seven tasks. An additional report will be delivered at a later date dealing with the instrumentation system.

While the subjects above provide convenient categories for identifying the requirements of the total plan, in fact, the elements are heavily interrelated. We will address each of the subjects itemized, but in a format more conducive to presenting the plan as a congruous whole than would result from an itemization of the sub task subjects. Following an overview of the project plan, we will address its five major elements— the managerial plan, the equipment modification plan, the operational (paper) data gathering and analysis plan, the performance (electronic) data gathering and analysis plan, and the fiscal plan.

Finally, the seven subjects listed have not received equal emphasis to date. Nor would it be accurate to say that the plan is *final.* The LCV study conceived is a very ambitious project, particularly in view of the severe time limitations imposed by the congressional mandate. The study will require major contributions of effort from many organizations outside of UMTRI; it will require the acquisition of a wide range of hardware at very substantial cost and in a very timely fashion. The careful coordination of effort and logistical support of and for all of the players in the project will be key to a satisfactory result. Accordingly, this planning project has very definitely focused on the overall organization, management, and fiscal elements of the plan. Generally, the more technical subjects of the sub task listing have been dealt with to the level required by the organizational plan. Technical subjects will be developed in more detail in the coming months, and the managerial aspects of the plan will, of necessity, be revised throughout the entire program to meet the unforeseen needs of the various participants.

AN OVERVIEW OF THE LCV TEST PROGRAM

The LCVs to be studied are operated by five commercial truck fleets based in Portland, Oregon and Boise, Idaho, and operating in the states of Washington, Oregon, Idaho, Nevada, and Utah. This choice of fleets and location is generally mandated by the simple fact that this area, the northwestern states, is the center of LCV use due to the peculiarities of state road usage laws. The fleets are:

Albertson's, a grocery chain centered in Portland
Fred Meyer, a grocery chain centered in Portland
Payless Drug Stores, a drug store chain centered in Portland
Silver Eagle, a regional common carrier centered in Portland
Shopko, a discount department store chain centered in Boise

The study will track 17 "vehicles"— seven Rocky Mountain doubles and 10 triples. The definition of vehicles, as used here, requires explanation. In this study, a vehicle is the collection of tractors, dollies, and semitrailers that service a single route or "haul" within a fleet's operation. While only one tractor is required to do this, many extra trailers and dollies may be needed. The best example is a triple-trailer vehicle that might service three retail stores from a central warehouse facility. A casual observer might believe that this vehicle would require three trailers. However, to insure high productivity from the tractor and driver, this vehicle would require as many as nine trailers: for each of three stores, one trailer at the warehouse being loaded, one at the store being unloaded, and one on the road. Through a number of variations on scenarios such as this, our 17 vehicles are composed of 17 tractors, 28 double-drawbar dollies, and 88 semitrailers. Depending on a fleet's operations, a single vehicle may make from 1 to 5 trips a week ranging from 350 to 1500 miles per trip. (Routes are shown on the map appended to this report.) According to the current plan, we will track these vehicles for approximately 50 weeks (49 to 52 depending on the test launch date of the fleet).

Figure 1 outlines the situation as regards the number of vehicles (doubles and triples) provided by each fleet, individual units needed, mileage accumulated, and two efficiency ratings. The mileage numbers derive from the estimates of trips and trip mileage provided by the fleets. Trailer efficiency is the number of vehicles (tractors) times the *standard* number of trailers (two for doubles, three for triples) divided by the trailers required. This number, times miles per week, is trailer mileage efficiency. According to this plan, the 17 vehicles will accumulate approximately one million miles— 425,000 by doubles and 575,000 by triples.

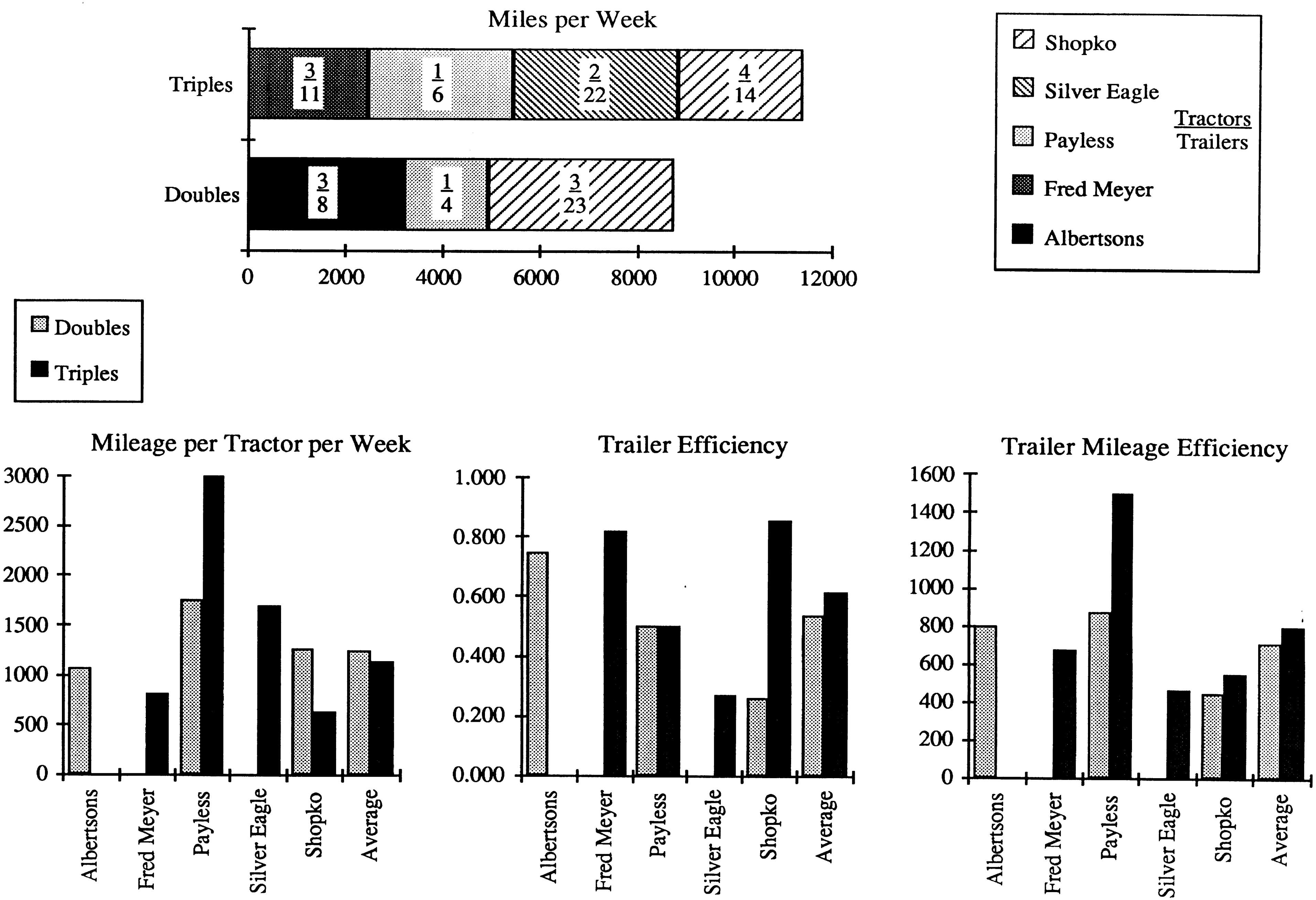

Figure 1. Overview of the study vehicles, fleets, and mileages

Of the fleets to be monitored, one currently uses C-dollies, three use ABS on their tractors, and none use ABS on dollies or trailers. Thus, a major, early task in this study is the acquisition of ABS and C-dolly equipment and the retrofitting of the test vehicle units with this hardware. In the same general activity, we must acquire and install the instrumentation packages needed to monitor vehicle performance over the year-long test period. The combined installation tasks imply very substantial physical alteration of units requiring two major garage facilities and several days per unit.

The retrofitting and instrumentation process introduces a number of new partners. ABS will be acquired from the three primary U.S. suppliers, Bendix (Allied Signal), Midland-Grau, and Rockwell/WABCO. C-dollies and associated hitching hardware will come from the only significant U.S. supplier of C-dollies, Independent Trailer & Repair (Independent Trailer). Besides their role as hardware suppliers, these companies will provide training, service, and technical expertise throughout the study. Vehicle Monitor Corporation (VMC) will supply the instrumentation systems. Instrumentation packages belonging to the government and used in a previous ABS study[1] will be substantially modified as required for this new application. (That process is, in fact, proceeding now under the eighth sub task of this planning study.) VMC will also be a continuing partner providing training, equipment maintenance, and data monitoring services. Finally, the facilities of Fruehauf Trailer Corporation in Portland and Western Trailer Service in Boise will do the bulk of the tractor and trailer retrofitting work, and Freightliner Corporation will retrofit ABS to the few tractors that will require this activity. These organizations fit the two special requirements of the study— the facilities and willingness to accomplish the very substantial undertaking quickly, and acceptability vis-a-vis the fleets that are donating their vehicles to the program. Figure 2 shows an overview of the relationships between and flow of material among the various players during the retrofitting activity.

Once the vehicles are equipped (that activity currently scheduled to be completed in the July-August, 1993 time period), their performance will be monitored for a period of one year. With respect to the monitoring of physical performance by the instrumentation system, data will be downloaded as the vehicle arrives at the central terminal after each trip. The instrumentation system will be configured such that this is a simple task, handled by the driver. The data will be delivered to a computer in the fleet office and will be automatically forwarded to VMC and UMTRI by phone line that evening. Both organizations will initially analyze the data to insure continuing integrity of the ABS and instrumentation system. Ongoing analysis to evaluate stability qualities of the vehicle will

[1] Klusmeyer, LF, et al. *An in-service evaluation of the reliability, maintainability, and durability of antilock braking systems (ABS) for heavy truck tractors.* Report number 03-2467. Southwest Research Institute. San Antonio. March 1992.

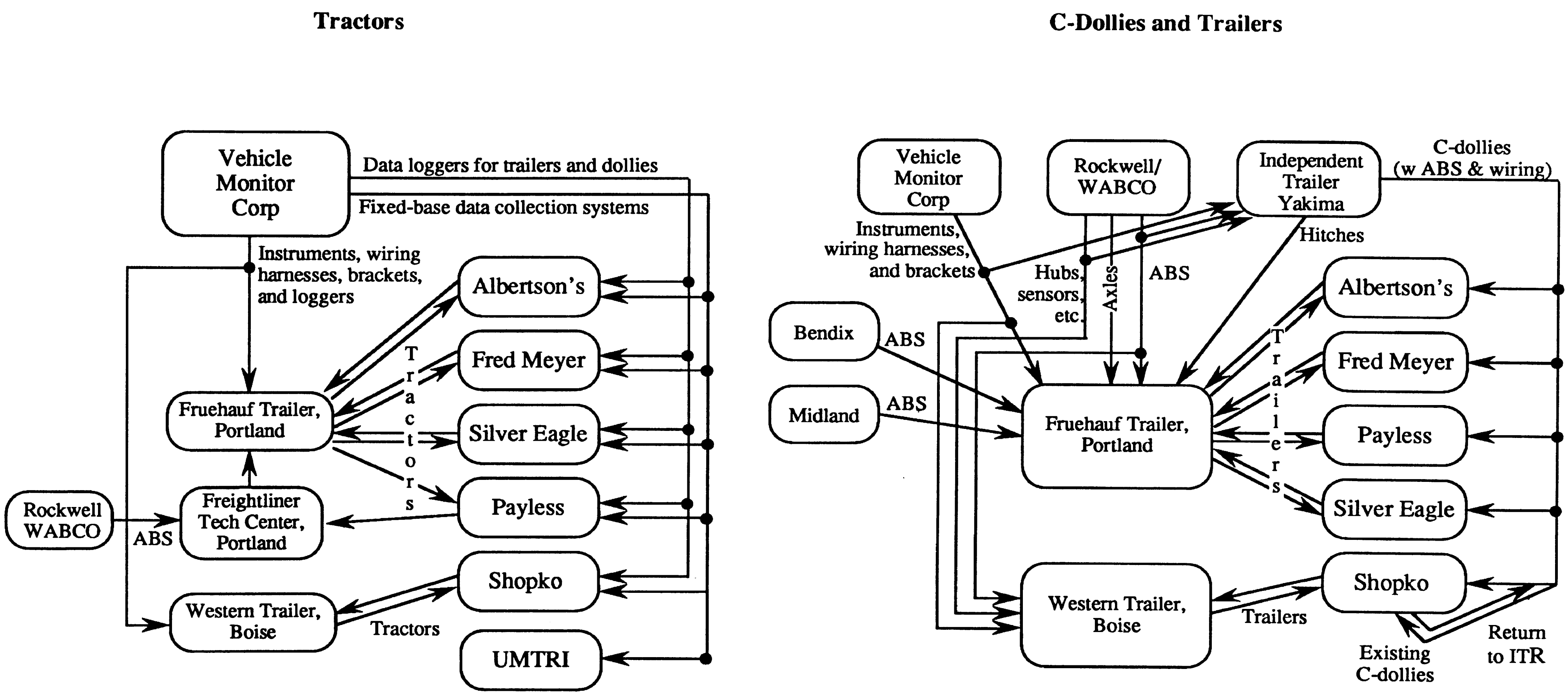

Figure 2. A simple flow diagram of the acquisition and retrofitting phase

be done by UMTRI. With respect to fleet operations data, UMTRI will collect maintenance, driver response and other appropriate data from each fleet on a weekly basis. UMTRI will have an employee (our west coast liaison) on location in Portland to perform this task for the four fleets located there. Maintenance data for the Boise fleet will be forwarded through the corporate home office (Green Bay, Wisconsin). The west coast liaison will visit the Boise location periodically, and UMTRI personnel will make similar visits to Green Bay as needed. These data will also be scrutinized immediately to insure continuing validity, and will be analyzed in a cumulative fashion throughout the study year. Data collection is expected to cease by July 1, 1994. A final report will be completed and delivered to the COTR by September 15, 1994.

A simplified overview of the project schedule and personnel plan is presented in figure 3. (The personnel efforts shown include those already planned for sub task 8.)

UMTRI is aware of difficulties in the previously mentioned ABS study, which resulted from the failure to monitor and analyze incoming data continuously for validity, consistency, and appropriateness. We also understand fully how that can happen when other activities at the research organization demand immediate attention and create pressure to put off the relatively routine tasks of an ongoing long-term data gathering process. We take this potential problem quite seriously.

Accordingly, UMTRI intends to staff this project, in part, with employees hired specifically for this project. We have already brought in Mr. M. Anthony Bowen. The plan has Tony serving as the Engineering Manager for this program. Early in the project, he will oversee and coordinate the logistics of the retrofitting activity. Later, he will ensure the steady, continuing operation of the data collection process, as well as expedite our response to any "emergencies." To date, Tony has played the major role in developing the managerial plan. A second special project employee will be a full time computer analyst, who will perform the routine daily data processing. It is most important to isolate this person from daily demands of other projects. Finally, we will hire an individual in the Portland area as the west coast liaison. He will serve as a junior engineering manager on site. He will be a coordinator during the retrofitting period, and will be responsible for both continuing fleet data collection in Portland and "emergency" services throughout the program. He will be provided with secretarial assistance in Portland. Regular UMTRI staff will also participate. Robert Ervin will be Project Director, and Chris Winkler will be Principal Investigator. They will receive substantial aid from Research Associate Scott Bogard. Other members of the UMTRI staff will play smaller support roles.

This discussion has presented a simplified review of a very complicated undertaking. A more accurate impression of the complexity involved is conveyed by the PERT and Gantt

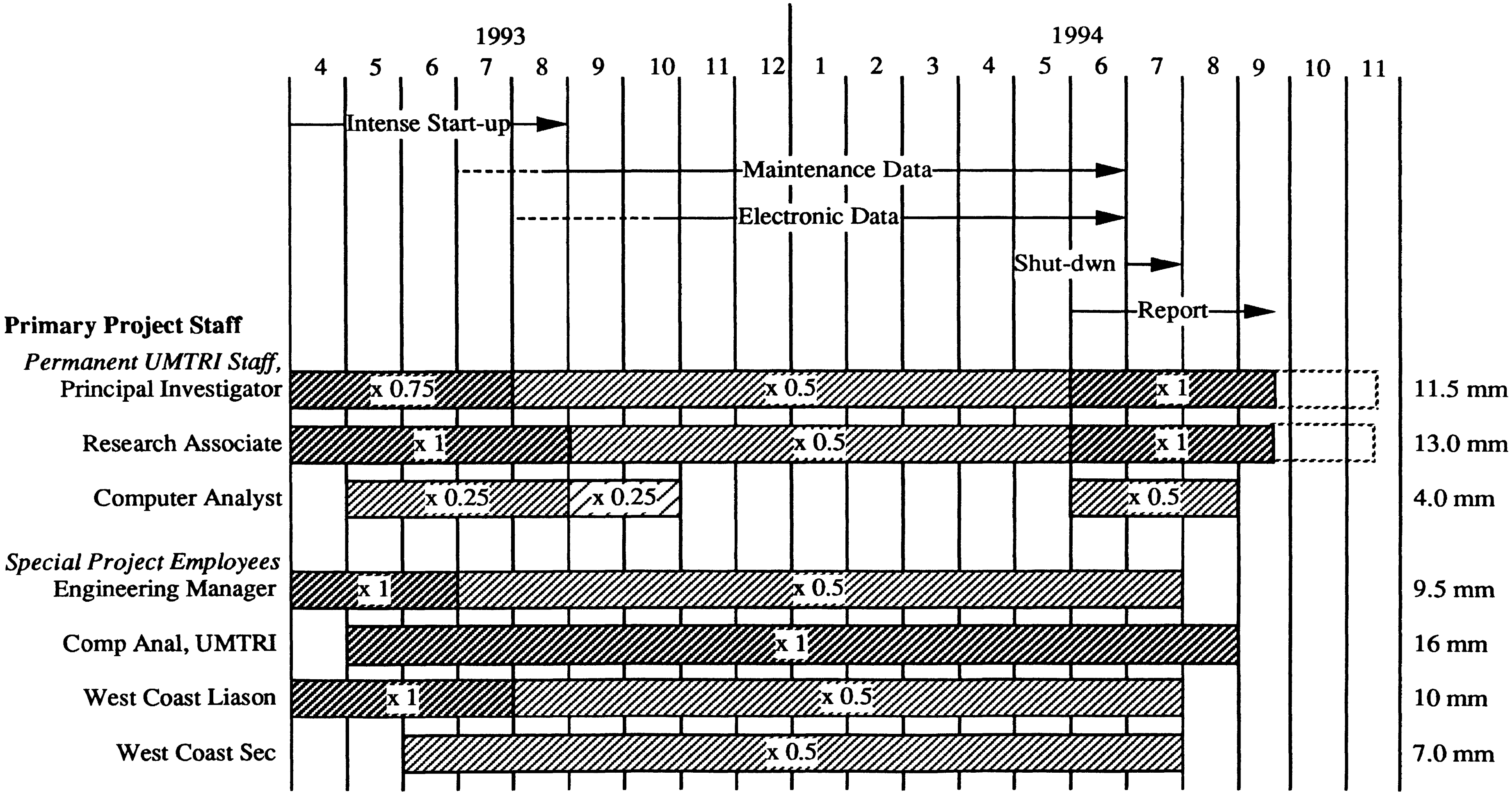

Figure 3. A simplified project schedule and staffing plan

charts, which are appended to this report. Those charts are the primary embodiment of the managerial plan at this time. A brief narrative description of that plan follows.

PROGRAM MANAGEMENT

Management of the LCV Operational Field Test Project involves several distinct activities:

— Planning
— Expediting
— Evaluating
— Problem Solving
— Reporting

These activities will be accomplished by two part-time employees, an Engineering Manager at UMTRI and a West Coast Liaison in Portland, Oregon.

PLANNING

During the Planning phase, currently in progress, a road map of the project is developed, communicated to all partners, and refined to achieve the optimum flow of work. The plan starts with the project objective:

> "Evaluate the stability enhancing characteristics, practicality/reliability, maintenance costs, and driver/mechanic/fleet personnel reactions to ABS on an entire unit (tractor, dollies, and trailers) and double-drawbar dollies in multiunit, double and triple trailer combinations with weights over 80,000 pounds."

An end point of September 15, 1994, has been established for delivery of the Final Technical Summary and Final Report to the National Highway Traffic Safety Administration.

In view of the established end date, the primary planning objectives are:

1) To ensure that actions are planned that will yield the desired results, and
2) To complete the vehicle preparation phase of the project as quickly as possible so as to maximize the length of the field test and, thereby, the quantity of relevant data.

The planning process starts by dividing the project into major phases. For this project, these include:

1) Planning
2) Procurement (of hardware and instrumentation)
3) Preparation of Tractors

4) Preparation of Trailers
5) Preparation of Double-Drawbar Dollies
6) Training
7) Launch of Operational Testing
8) Installation of Instrumentation
9) Field Testing
10) Data Analysis - for both maintenance/reliability and instrumentation data
11) Reporting

These phases are then broken down into smaller tasks, as required, and responsibilities, durations and costs are defined or estimated. A project management computer program is being used for this activity. The result is a flow chart, or model, for the entire project. This model is then used for "what if" iterations to develop the optimum work plan.

The management planning process is based on a PERT network of the project. This network planning process provides a number of significant advantages:

- Enables development and display of the planned work sequence before accurate time estimates are known
- Shows responsibilities, interrelationships and dependencies
- Helps keep key elements from being overlooked
- Allows rapid analysis of effects of alternative actions on the end result
- Helps identify potential problems so that solutions can be developed
- Helps improve communications by providing better understanding among players - everyone knows what needs to be done, and when
- Shows effects of slippages on downstream activities

The key to use of PERT planning is identifying the critical path through the network, then taking action to improve timing of activities on the critical path. This is a continuing effort during the life of the project.

The current draft of the schedule/PERT chart for this project is included with this report. It must be emphasized that this is a working document, not a completed plan. It will not be finalized until UMTRI's proposal has been approved by NHTSA and the contract awarded for the Operational Field Test. The award date is on the critical path for the project and, therefore, affects timing of all activities.

The portion of this chart that deals with the preparation phrase of the project has been sent to all proposed suppliers and partners for review. It is expected that this review will result in changes in activity content and timing, and may result in changes in the work flow logic. These changes will be incorporated in a refined version of the schedule chart, which will then be reviewed in planning meetings with the fleets and suppliers during March, as part of the "Planning to Conduct Operational Tests" project, and finalized upon award of the contract.

Several points are of interest regarding this preliminary plan:

1) Preparation of instrumentation is on the critical path. Indeed, instrumentation data loggers will not be available for the initial launch of operations with ABS and double-drawbar dollies. Early start-up of instrumentation development is essential. The current schedule shows this development starting February 24, 1993, based on prior NHTSA approval of the "Request for Contract Modification of Planning to Conduct Operational Tests." It should be noted that the instrumentation plan was recently revised to eliminate spread spectrum radio communication as part of the instrumentation package, and impact of this decision on instrumentation timing has not been considered in this schedule.

2) There are currently parallel critical paths through the equipment preparation phase, one through trailer preparation and one through fabrication of the double-drawbar dollies. The first path is controlled by delivery of axles to be used in rebuilding of existing trailers to include ABS. The double-drawbar dolly path may be established by availability of instrumentation hardware, but review of this path has not been completed.

3) This schedule chart assumes two separate activities designed to provide comparison data so that the effect of ABS and double-drawbar dollies can be evaluated:

   a) Identification in each fleet of similar comparison vehicles/combinations (in similar service) without ABS and double-drawbar dollies, and regular collection of maintenance/reliability data on those units, and

   b) Operation of the participating vehicles/combinations (with ABS and double-drawbar dollies) on a part-time basis with A/pintle hook dollies so that instrumentation data can be collected for comparison to the double-drawbar (C-train) configuration.

   Neither of these plans has been fully developed at this time.

4) Planning to date has been based on a July 1, 1994, test completion date, in order to provide a final report to NHTSA by September 15, 1994, adjusting the duration of test operation at each fleet and the duration of the activity "Process and Analyze Electronic Data" to meet this target. In other words, data collection is squeezed between the equipment and instrumentation preparation phases and the reporting phase. A major objective of the planning activity is to make the electronic data collection portion of the project as long as possible.

5) Timing for all activities is on the basis of Duration (work days) and Elapsed Time (calendar days). The current schedule is based on the UMTRI calendar of five day work weeks and 11 holidays per year. Special calendars, such as six day work weeks, can be used for individual participants. A change of calendar could obviously improve timing.

The Gantt bar chart version of this schedule is also included for reference.

EXPEDITING

This activity, which continues throughout the project, is basically a scheduling and follow-up task. It involves constant communication with all partners to make sure that project tasks will be achieved on schedule. This task will be accomplished both from UMTRI and in the field, by a West Coast Liaison engaged by UMTRI for the duration of the project. The West Coast Liaison's duties will include:

— Scheduling of tractor, trailer, and dolly preparation
— Expediting and problem solving during the preparation phase
— Planning, scheduling, and delivery of appropriate training to fleet personnel
— Weekly follow-up on operational testing, and collection of maintenance and reliability data
— Problem identification, investigation, and resolution, concerning both technical and task problems, including possible near-miss or accident events

EVALUATION

Evaluation of progress will occur on a continuing basis during the project. Data will be collected on progress and performance, including timing, costs, and status/results. These data will be compared to the plan and variances/gaps will be identified. These variances will be analyzed and corrective action taken, if possible, to bring the project back to plan. Schedule changes will be determined and communicated if corrective action will not eliminate the variance.

PROBLEM SOLVING

Problem solving tasks have been mentioned in preceding paragraphs. Problem solving of several types may be necessary to address potential problems:

— Activities aren't being completed on schedule
— ABS or double-drawbar dollies malfunction
— Maintenance/reliability data are incomplete
— Operational testing is interrupted by equipment problems, weather, etc.

— Operational problems are encountered, including possible near-miss or accident events

Action will be taken to address these and other problems as rapidly as possible. UMTRI and the West Coast Liaison will play key roles in this problem solving, but suppliers and fleets will be involved as appropriate.

REPORTING

Periodic status reports to all partners will be issued during the project. A number of report formats are available in project planning software, and these will be used as appropriate. Reports will be issued at least quarterly to NHTSA.

SUMMARY

Program management will be provided during the Operational Field Test Project in order to get the job done to specification, on time and on cost. A plan will be developed and executed that will maximize the amount of operational testing data.

EQUIPMENT MODIFICATION

INTRODUCTION

The five test fleets selected for this study do not currently use ABS-equipped trailers and dollies, and, with one exception, do not use double-drawbar dollies. Existing equipment must be modified to provide ABS and double-drawbar capability. This modification will be accomplished during the preparation phase of the project.

Double-drawbar dollies are not currently used in four of the five fleets, so new dollies will be procured for these fleets. These dollies will be built with ABS.

Preparation/modification of tractors, trailers, and dollies will also include installation of supplemental power wiring for the ABS system and instrumentation installed for this study. The power wiring will consist of added heavy gage power and ground wires on all equipment to ensure adequate voltage for ABS operation, an issue of particular concern for the last unit in the train. Tractor modification will include installation of a relay to boost brake circuit voltage, and installation of a special heavy gage umbilical.

Instrumentation will include ABS control unit (ECU) current sensors, brake chamber pressure sensors, additional wheel speed sensors at each wheel, lateral and longitudinal accelerometers, and a data logger to gather and store data from the sensors and accelerometers. Current plans are to accomplish instrumentation at the time other modifications are made, except for installation of data loggers. Data loggers will be installed at each fleet after completion of all preparation work and launch of the operational testing of the modified LCV units.

TRACTORS

All tractors identified for the study are ABS equipped, except for two tractors in the Payless Drugs fleet. ABS will be installed on these tractors at the Freightliner Technical Center.

Tractor modification, to include the supplemental power wiring and the instrumentation system, will be accomplished at Fruehauf Trailer in Portland for ten tractors from Portland area fleets, or at Western Trailer in Boise for seven tractors from the ShopKo Stores fleet.

TRAILERS

Trailers make up the largest part of the preparation job, involving 88 trailers from the five fleets. The modification job splits logically into two pieces: (1) the Portland area fleets (51 trailers), and (2) the ShopKo Stores fleet (37 trailers) in Boise.

Portland Area Fleets

The Portland area trailer modifications will be accomplished at Fruehauf Trailer. Modification will include:

1) Installation of replacement axles equipped for ABS;
2) Installation of ABS control units, modulator valves, wheel sensors, and wiring;
3) Installation of supplemental power harnesses for ABS and instrumentation;
4) Installation of instrumentation sensors, accelerometers and wiring, making provision for later installation of data loggers;
5) Installation of hitches for double-drawbar dollies, including appropriate reinforcement; and
6) Installation of hubometers on trailers from the Albertson's and Fred Meyer fleets (other fleets are already equipped with hubometers).

Boise/ShopKo Stores

The ShopKo modifications differ in two significant ways from the Portland work:

1) The ShopKo trailers have air suspension and the axles are welded in place, so they cannot be easily changed. Axles will be modified by installing hubs with ABS tooth rings, rather than replaced.
2) ShopKo currently uses double-drawbar dollies, so the hitch installation step is not necessary on these trailers.

Modification is otherwise similar to the Portland trailer modification.

ShopKo is purchasing three new trailers with ABS for the study, so only supplemental wiring and instrumentation will be required for these units.

DOUBLE-DRAWBAR DOLLIES

Twenty-four new double-drawbar dollies are required for this study.[2] These will be built by Independent Trailer. These units will be built with ABS and with heavy gage power wiring to support the ABS system and the instrumentation required for this study.

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[2] Twenty-four dollies will be purchase; two will be delivered to VRTC in East Liberty, Ohio.

Independent Trailer will also install dolly instrumentation, including extra wheel speed sensors, air chamber pressure sensors, ABS current sensors, and provision for data loggers.

Six existing dollies from the ShopKo fleet will be used in this study. Independent Trailer will retrofit these dollies with ABS systems, supplemental power wiring for ABS and instrumentation, and the special instrumentation system.

TRAINING

It is essential that fleet personnel understand the effects of ABS and double-drawbar dollies on combination operation, that they understand the instrumentation system and its operation, and that they understand the objectives of the operational test project and the importance of their contributions to the study. Accordingly, three training sessions are anticipated:

1) ABS Characteristics and Maintenance
2) Double-drawbar/C-Dolly Characteristics
3) Instrumentation and Data Collection (will include driver feedback and maintenance/reliability data)

SUMMARY

An equipment preparation and modification plan has been developed that involves 17 tractors, 88 trailers and 28 double-drawbar dollies in five fleets. This preparation phase will also include training of fleet personnel. Timing is dependent upon final contract award by NHTSA. Preliminary estimates, subject to revision after detailed review, indicate that this phase of the project will take approximately four months to accomplish.

OPERATIONAL DATA COLLECTION AND ANALYSIS

A major goal of this study is to report on the reliability, maintenance costs, and fleet (driver/mechanic) reaction to Antilock Braking Systems and C-dollies employed in Long Combination Vehicle operations. To accomplish this the work orders, maintenance forms, and driver's inspection reports from the dedicated units (tractor, trailers, and dollies) within the five participating fleets will be collected and analyzed. Data will also be collected on an equal number and distribution of control units, allowing comparison studies between ABS and non-ABS vehicles and between A- and C-dollies.

The study will include a variety of ABS sensor/modulator configurations from the three U.S. suppliers (Rockwell WABCO, Bendix, and Midland-Grau). For each supplier, and as a group, the repair and maintenance records will be analyzed to determine:

- ABS start-up costs for unit type (these are expenses incurred during the start-up period, due to installation oversights or other problems; they do not include the cost to buy ABS or the initial installation cost);
- general ABS maintenance costs for unit type for the duration of the study;
- the power reliability of the stop lamp circuit for ABS on all the units of an LCV (although this is a relatively short field test, the frequency of power related problems will be closely monitored; this information may provide some insight to the critical power issues of maintaining ABS on LCVs);
- the effect of ABS on the cost and operation of other systems (tires, brakes, electrical, pneumatic, etc.) on each of the unit types; and
- the response and opinion of mechanics and drivers to the ABS. Particular attention will be given to driver reports on near miss or accident events.

C-dollies used in this study will be supplied by Independent Trailer. Independent Trailer is the only significant supplier of C-dollies in the U.S. In order to examine the reliability, maintenance costs, and fleet personnel reaction to these dollies, maintenance records will be analyzed to determine:

- the cost to maintain the C-dolly and how maintenance costs compare to those for the traditional pintle-hitch dolly (particular attention will be paid to tire wear and maintenance costs due to the steering mechanism of the C-dolly);
- the effect of C-dollies on the maintenance costs of other vehicle components and systems;

— the response and opinion of the fleet spotting person with respect to the C-dolly (this person is responsible for connecting the trailers and dollies in the distribution center);
— the response and opinion of mechanics with respect to the C-dolly;
— the response and opinion of drivers with respect to the C-dolly. An evaluation of LCV maneuverability and trailer/dolly hookup will be sought, along with general on-the-road comments about the C-dolly.

An effective data collection plan will be incorporated into the record-keeping systems of the participating fleets in order to compile these costs and responses. This plan must be comprehensive enough that all the necessary information is captured, but cannot unnecessarily burden the fleets. The process of defining the plan and collecting the data throughout the test period is detailed in sections on Phase 1 through Phase 3 below.

PHASE 1 - PLAN DESIGN, FLEET INPUT, AND PREVIOUS RECORDS

The first phase will consist of three separate tasks. The first is to make a preliminary design for collection of the paper data from the fleets. Second, a trip to each fleet will be made to discuss the plan and get comments from the fleets. Third, extensive data samples from each fleet will be collected.

Plan Design

The paper data processing system will be similar to the one used in DOT Rept. HS 807 846, "An In-Service Evaluation of the Reliability, Maintainability, and Durability of Antilock Braking Systems (ABS) for Heavy Truck Tractors." In this study, the maintenance tracking was based on the system, subsystem, and component categories established by the American Trucking Associations' Vehicle Maintenance Recording System (VMRS). For each unit in the study (both ABS-equipped and control unit), the maintenance records will be frequently screened to determine the following: a) fleet name and unit number, b) repair date and unit mileage, c) repair order number, d) nature of the repair (adjust/inspect, repair/replace), e) labor hours, f) type and quantity of parts used, and g) comments about the repair. This information will be transferred onto a predefined maintenance data input sheet (MDIS), effectively standardizing the maintenance records across all the participating fleets. Two additional forms may be included with the standard maintenance forms from each fleet. One is an ABS report that details any problems with the ABS system and how they were resolved. The second is additional tire data (tread depth) to closely monitor tire wear. This information, along with a copy of the driver's trip log, and the driving condition sheet (detailing the weather for a trip) will be faxed, mailed, or electronically transferred to UMTRI for processing. Schematically, the details of the plan are shown in Figure 4.

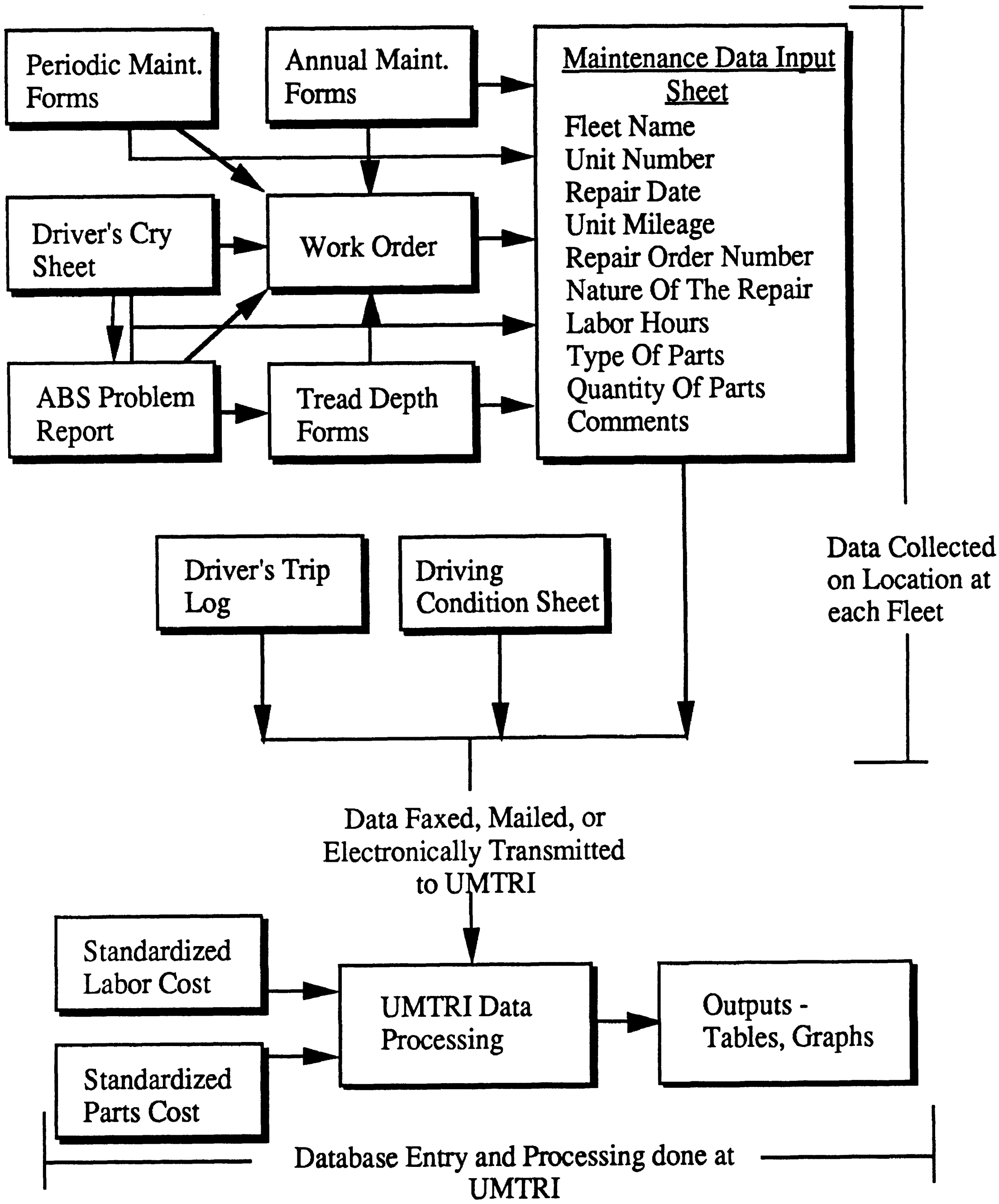


Figure 4. Maintenance Data Collection Plan

Some of the forms shown in Figure 4 are not part of the fleet's existing maintenance system. Part of this initial planning phase will be to create and define these forms.

Fleet Input

One of the initial tasks of phase 1 will be to visit the five fleets to get a detailed look into their record-keeping system. This is a ten day trip for one person, spending two days at each of the five fleets. (This will also include time in Green Bay, where ShopKo maintains its records.) A meeting with the pertinent maintenance people within each fleet will be held during the trip to discuss the best way to implement the data collection plan within their existing records system. Each fleet will undoubtedly have different record-keeping methods for maintaining their units. It will be important to work with each fleet to learn what will or will not work within their system. The goal is to capture consistent maintenance data across the fleets, even if the final data collection methods are not the same within each fleet. Special attention will also be made to the consistency of the data collection process across the five fleets. This will help avoid possible correlation between thoroughness of data collection and higher maintenance costs.

During or prior to the trip, the fleets will be asked which units would best serve as control vehicles. In some fleets these vehicles will not be operating on the same routes as the test units. The selection of these units is important in order to minimize the number of variables.

This trip will also serve to initiate, introduce, and bring up to speed UMTRI's West Coast Liaison. During the study it will be the Liaison's job to collect the maintenance data at each fleet and transfer it to UMTRI for processing. It will be important that this person be familiar with all the appropriate fleet personnel since he will serve as our representative when problems and questions arise.

Gather Previous Years Data

During the trip UMTRI personnel and the West Coast Liaison will gather the previous year's maintenance data for some, if not all, of the test units. This information will be used to work out any problems that may exist with the collection plan for each fleet. Three of the five fleets are currently using hubometers on their trailers. (All fleets monitor the mileage of their tractors.) Having the previous year's maintenance history for these units may also be useful when drafting the final report. If the data are thorough, it may be possible to address the possibility that monitoring the maintenance of a fleet will affect the quality of the maintenance on the various units.

PHASE 2 - PLAN IMPLEMENTATION, TRAINING, AND DATA COLLECTION

The second phase addresses the startup and collection events that will occur at UMTRI. The first task will be to set up the system within UMTRI to handle and process the data as they arrive. This phase will also includes the hiring and training of a dedicated person to insure that data are processed as they arrive at UMTRI.

Plan Implementation

The data that were collected on the fleet trip outlined in phase one will be used. Using this information, a database to manage all the data will be designed. This may involve the purchase of a database program for this purpose or, if sufficient, existing software may be used. This decision may be based on the database program used in DOT Rept. HS 807 846, "An In-Service Evaluation of the Reliability, Maintainability, and Durability of Antilock Braking Systems (ABS) for Heavy Truck Tractors."

Data Processing Specialist

UMTRI will hire and train a dedicated person to process the maintenance data as they arrive. This will guarantee a quick response to problems found by data analysis. UMTRI will supply necessary hardware and software for this person to do the data processing.

Collect Maintenance Data

This task includes the collection and processing of the data as they arrive at UMTRI during the study. This task also includes provisions for five trouble-shooting trips, by one UMTRI person, to visit the fleets. These are short, two-day trips to handle any crises that arise after the study begins.

PHASE 3 WRITE FINAL REPORT.

The last phase of the paper data collection plan is to generate the maintenance and fleet comment section of the final report. This activity will begin before the last data are collected due to the time considerations of this study.

PERFORMANCE DATA GATHERING AND ANALYSIS

OVERVIEW

The test vehicles will be instrumented in order to monitor vehicle behavior as influenced by the ABS and C-dollies throughout the test year. The interest in ABS implies an interest in monitoring brake performance parameters, while the C-dolly hardware indicates interest in the lateral response of the vehicle. Appropriate instruments will be provided on each of the test vehicle units to provide data to monitor these characteristics.

As noted in the introduction, we expect to gather data over approximately one million miles of vehicle travel. The majority of these miles will be covered with the vehicles equipped with C-dollies and with ABS systems active. This is deemed necessary in order to obtain sufficient operational data on the new systems. (As noted in the *Operational Data* section of this report, data for conventionally-equipped vehicles will be gathered from previous years and from similar vehicles in the fleet.) To obtain comparison data in the *performance regime*, it will be necessary to operate the instrumented fleet vehicles with conventional A-dollies for some period of time. Viewing this problem only, a 50-50 split would be desirable. But given the interest in operational data, we plan for a considerably smaller percentage of the total time to be dedicated to comparison data. The precise split remains to be determined in consultation with the COTR.

It is a basic premise of the instrumentation plan that the system must be configured to (1) minimize the perturbation it will cause in fleet operations and (2) be of maximum, long term durability. Given the constant interchange of trailers that takes place in the fleet operations, this means, first and foremost, that each unit's instrument package must be self contained. During the planning process, we considered a radio link to provide interunit communications. This would have been advantageous for two reasons: (1) interunit communication would allow a single data down-load point in the tractor cab for each vehicle; (2) events sensed on one unit could trigger data recording on all units. Unfortunately, this system has been judged to be too great a burden on the project in terms of cost, development time, and risk.

The alternate system is composed of individual instrument packages for each unit and a simple card reader devices for down-loading data. In this system, data will be down-loaded by the driver upon the making or breaking of the vehicle (adding or removing trailers). To do this, he will plug a hand-held device, containing a data card, into the data loggers located on each of the units of the vehicle. Later, when he has returned to the central fleet terminal and is completing his paper work in the drivers' office, he will insert the data card into a computer. Overnight, that computer will automatically forward the data to computers at the offices of UMTRI and VMC. Time and ID stamps included in the data, along with the normal paper records maintained by the fleets, will allow matching data records of individual units during post processing.

The data records downloaded will include summary data of the normal performance of the vehicle unit during the trip. This will generally be either in the form of histograms revealing the distribution of severity of performance measures, or in the form of event counts. The other form of data will be continuously recorded data, triggered by the occurrence of unusually severe events. This data recording will be similar to an aircraft crash recorder, although recordings may be made of less-than-catastrophic events.

On receipt of all electronic data, VMC and UMTRI will perform a preliminary analysis to monitor the condition of the instrumentation and ABS systems. VMC is expected to maintain data records for a relatively brief time for this purpose only. UMTRI will maintain and archive the data throughout the program and perform the continuing data analyses.

INSTRUMENT SYSTEM REQUIREMENTS

VMC will be requested to deliver on-vehicle loggers and data-card readers, transducers (exclusive of antilock wheel speed transducers), wiring harnesses, fixed-base computers with data-card readers and modems, data cards and any other associated hardware, software, and supplies as required to equip:

17 tractors (plus 2 spares)
28 C-dollies (plus 2 spares)
88 trailers (plus 3 spares)
5 fleet terminal fixed-base sites
1 UMTRI receiving site (software only)

The on-vehicle systems will provide for sensing and recording the following performance related data signals:

Tractors:

1) Accelerations. One longitudinal (Ax) and one lateral (Ay) acceleration. (Frame mounted accelerometers.)
2) Wheel speeds. (Up to 6.) (Sensors to be provided by UMTRI.)
3) ABS voltage and warning light. (One pair of signals per tractor.)
4) ABS modulator current. (Up to 6 in number.)
5) Brake treadle valve pressure.
7) ABS modulator pressure. (Up to 6.)

Trailers:

1) Acceleration. One lateral (Ay) acceleration. (Frame mounted accelerometer.)
2) Wheel speeds. (Up to 4.) (Sensors to be provided by UMTRI.)
3) ABS voltage and warning light. (One pair of signals per trailer.)
4) ABS modulator current. (Up to 2 in number.)
5) Brake line pressure.
6) ABS modulator pressure. (Up to 2.)

Dollies:

1) Wheel speeds. (2) (Sensors to be provided by UMTRI.)
2) ABS voltage and warning light. (One pair of signals.)
3) ABS modulator current. (1)
4) Line pressure transducer. (1)
5) Modulator pressure. (1)
6) Steering action. (1) (A binary signal indicating the presence or absence of steering activity.)

Each down load of data from a logger will create a data file. The file will be identified according to the vehicle unit/logger that produced it and through appropriate time stamping. Each file will contain output data in several forms. These are:

— Summary Data
— Special Event Logging
— Significant Event Recording

Summary Data

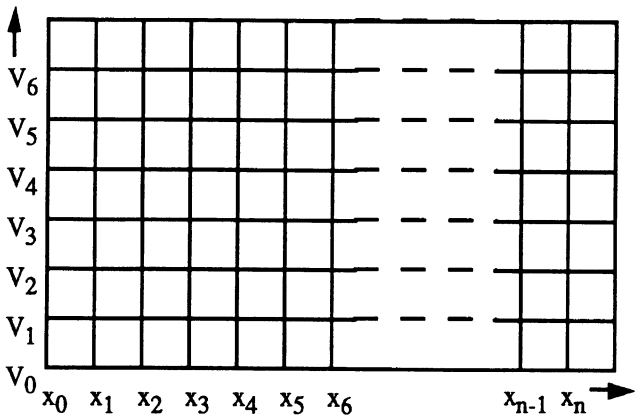
Summary data outputs for each trip will include:

Histograms
- Brake Pressure (tractors only)
- Longitudinal acceleration (tractors only)
- Type 1 (during braking) lateral acceleration
- Type 0 (during non-braking) lateral acceleration
- Modulator events
- Wheel lock events

Lateral Acceleration PSD
Braking Event Count

Histograms

Histograms are generated, on a per trip basis, for five variables of interest, namely, brake pressure, longitudinal acceleration, lateral acceleration, modulator-event cycle counts, and wheel-lock cycle counts. Histograms of pressure and accelerations are two dimensional, with one dimension being vehicle velocity and the other being one of the three variables of interest. That is, the histogram "bins" are a two dimensional matrix, as implied by the figure below. Histograms of modulator activity and wheel lock are one dimensional.



Where:

$V_0 = 5$ mph,
$V_1 = 15$ mph,
$V_2 = 25$ mph,
$V_3 = 35$ mph,
$V_4 = 45$ mph,
$V_5 = 55$ mph,
$V_6 = 65$ mph,

and are determined at the onset of braking. The x_is refer to values of the variables of interest.

The following discussion describes the various histograms to be produced.

Brake Pressure Histogram. Brake pressure histograms are generated from the *treadle pressure* transducer signal on the *tractor* during brake applications (brake light signal high). The values defining the cells in the pressure dimension are:

$x_0 = 0$ psi	$x_6 = 15$ psi
$x_1 = 2.5$ psi	$x_7 = 17.5$ psi
$x_2 = 5$ psi	$x_8 = 20$ psi
$x_3 = 7.5$ psi	$x_8 = 25$ psi
$x_4 = 10$ psi	$x_9 = 35$ psi
$x_5 = 12.5$ psi	$x_{10} = 50$ psi

This implies a 7x12, or 84-cell, matrix.

The pressure histogram data for each cell consists of the total time during which the condition of the cell was satisfied and a brake application was in progress (brake light signal high). (Alternatively, cell data may be expressed as a fraction of total time of braking if total braking time is maintained as an additional variable.)

Deceleration Histogram. Deceleration histograms are generated from the *longitudinal accelerometer* transducer signal on the *tractor* during brake applications (brake light signal high). The values defining the cells in the deceleration dimension are:

$x_0 = 0$ g	$x_6 = 6$ f/s^2
$x_1 = 1$ f/s^2	$x_7 = 7$ f/s^2
$x_2 = 2$ f/s^2	$x_8 = 8$ f/s^2

$x_3 = 3\ f/s^2$ $x_9 = 9\ f/s^2$

$x_4 = 4\ f/s^2$ $x_{10} = 11\ f/s^2$

$x_5 = 5\ f/s^2$ $x_{11} = 13\ f/s^2$

This implies a 7x12, or 84-cell, matrix.

The deceleration histogram data for each cell consists of the total time during which the condition of the cell was satisfied and a brake application was in progress (brake light signal high). (Alternatively, cell data may be expressed as a fraction of total time of braking if total braking time is maintained as an additional variable.)

Type 1 Lateral Acceleration Histogram. Type 1 lateral acceleration ($T1A_y$) histograms are generated from the *lateral accelerometer* transducer signals on all vehicle units, respectively, during brake applications (brake light signal high). (That is, a separate histogram is produced for the tractor and each trailer.) The values defining the cells in the acceleration dimension are:

$x_0 = 0\ g$ $x_6 = |6|\ f/s^2$

$x_1 = |1|\ f/s^2$ $x_7 = |7|\ f/s^2$

$x_2 = |2|\ f/s^2$ $x_8 = |8|\ f/s^2$

$x_3 = |3|\ f/s^2$ $x_9 = |11|\ f/s^2$

$x_4 = |4|\ f/s^2$ $x_{10} = |13|\ f/s^2$

$x_5 = |5|\ f/s^2$ $x_{11} = |15|\ f/s^2$

This implies a 7x12, or 84-cell, matrix. (Alternatively, a larger matrix could be maintained that distinguishes positive and negative values. Grouping can be done in post processing, and there may be some asymmetry of interest.)

The lateral acceleration histogram data for each cell consists of the total time during which the condition of the cell was satisfied and a brake application was in progress (brake light signal high). (Alternatively, cell data may be expressed as a fraction of total time of braking if total braking time is maintained as an additional variable.)

Type 0 Lateral Acceleration Histogram. Type 0 lateral acceleration ($T0A_y$) histograms are generated from the *lateral accelerometer* transducer signals on all vehicle units, respectively, during periods of *no brake application* (brake light signal *low*). Except for the difference in braking status, the $T0A_y$ and $T1A_y$ histograms are similar.

Modulator Event Histograms. A particular modulator event may be characterized as including one, two, three, etc. modulator cycles. (Counts can be initiated to zero (1) on the occurrence of a brake light status transition, and (2) after x seconds.) This 3-bin histogram is meant to be simply an accounting of the number of one-cycle, two-cycle, and more-than-two cycle modulator events. One histogram per trip per modulator is to be generated. Counts are made only when velocity exceeds 5 mph. (We are assuming here that more-than-two cycle events will be considered *major* events and will be recorded.)

Wheel-lock event histograms. A single wheel-lock cycle may be characterized by the length of time the wheel remains locked. This histogram is meant to be simply an accounting of the number of lock-up cycles that occur within the four duration ranges defined by the following time values (the high end of the upper range being unbounded).

$x_0 = 0$ sec	$x_2 = 1$ sec
$x_1 = 0.5$ sec	$x_3 = 2$ sec

One histogram per trip per wheel is to be generated. Counts will be made only when velocity exceeds 5 mph.

Lateral Acceleration PSD

A lateral acceleration PSD is generated from the *lateral accelerometer* transducer signals on *all* vehicle units, respectively, during periods of *no brake application* (brake light signal *low*). PSD output data are to be similar in form to the histogram data, in that they are based on a two dimensional matrix of bins. One dimension is defined by ranges of forward velocity; the second dimension is defined by signal frequency bands. In the case of the PSD data, there are only four velocity ranges of interest defined by the four boundary values $V_0 = 35$ mph, $V_1 = 45$ mph, $V_2 = 55$ mph, and $V_3 = 65$ mph. (As implied by the previous figure, the high-velocity range has no upper bound.) Seven frequency bands of interest are defined by the following eight frequencies. (Here, all seven ranges are bounded.)

$f_0 = 1.33$ hz,	$f_4 = 0.36$ hz,
$f_1 = 0.80$ hz,	$f_5 = 0.31$ hz,
$f_2 = 0.57$ hz,	$f_6 = 0.27$ hz,
$f_3 = 0.44$ hz,	$f_7 = 0.24$ hz,

This implies a (4x7) 28-bin cell matrix.

The data content of each bin is proportional to the relative power of the lateral acceleration signal integrated over the total non-braking time period of the trip, in a manner consistent with the ranges of the bin.

Braking Event Count

This review statistic is the number of brake applications made during the trip when velocity exceeds 5 mph.

Special Event Logging

Fail safe light events

This review statistic is the number of occurrences of fail safe light activity, logged as in the previous ABS study.

Pressure differential events

This review statistic is the number of occurrences of pressure differential events, logged as in the previous ABS study.

Significant Event Recording

(Significant braking or handling events may take place separately, but often may take place simultaneously. The rules for recording braking-only or handling-only events would certainly be different —braking not requiring as large lead-time recording as handling— and could result in more efficient memory use than will result from what is described here. However, the program complexity required for consistently making the proper decision, given that braking and handling triggers would never occur simultaneously, does not seem warranted, since memory capacity is likely to be very plentiful. The actual significance of the event and the appropriate trimming of the data recorded can be accomplished in post-processing.)

All data signals are to be recorded continuously during the course of a significant event. A significant event starts on the occurrence of a special event trigger condition. A significant event is ended by the establishment of the special event ending condition. The data record for a significant event starts ten seconds previous to the start trigger and ends two seconds after the end condition.

The special event trigger condition is defined by any of the following occurrences, simultaneous with a vehicle velocity in excess of 10 mph:

1) Treadle pressure in excess of 50 psi for more than 0.3 sec,
2) Longitudinal deceleration in excess of 13 f/s^2 for more than 0.3 sec,
3) Lateral acceleration in excess of 8 f/s^2 for more than 0.3 sec,
4) A more-than-2-cycle brake modulation, or
5) A more-than-2-second wheel lock event

The special event end condition is defined by the occurrence of:

1) The passage of 10 seconds since the trigger condition occurred;
2) The vehicle speed dropping to < 3 mph;
3) The simultaneous occurrence of the following conditions for 2 seconds:

   Treadle pressure less than 10 psi,
   Longitudinal deceleration less than 4 $f/s^{2,}$
   All lateral accelerations less than 3 $f/s^{2,}$
   No modulator on, and
   No wheel lock.

INSTRUMENT SYSTEM DEVELOPMENT

Instrument system development has just begun in earnest under sub task 8 of this planning study. The critical time lines of this project (see the appended PERT chart) are so tight that it was determined in November that we simply could not wait until full completion of the plan to move forward with development of the instrument system. Sub task 8 will include the development of a prototype system and installation of that system on a triple trailer vehicle at NHTSA's test facility in Ohio for checkout and debugging. More detail is available in the *Request For Contract Modification* submitted to NHTSA in December, 1992.

As one of the first actions of the main study, we will undertake a planning trip to the Portland/Boise sites to finalize details of the data systems and other hardware installations as needed for the peculiarities of each fleet's vehicles. (This will be combined with the planning trip mentioned in the *Operation Data* section of this report.) UMTRI, VMC, and other hardware supplier personnel will visit each of the fleet facilities together to work out the details of hardware installation.

Results of this trip will allow VMC to begin production of instrumentation wiring harnesses and other elements of the system, even though complete prototyping will not have been completed. This *parallel engineering* process is necessary due to the extremely tight time line requirements.

After the full prototype system has been developed and checked out, VMC will produce the large numbers of data loggers required for the program.

DATA PROCESSING

In the larger view, data processing will begin in the fleet terminal yard as the driver down-loads data from the several vehicle units. In this process, the logger mounted on each of the vehicle units will write its data onto a magnetic card. The driver will insert that card into a computer in the fleet's office which, in turn, will transmit the data to UMTRI and VMC for processing. All of the hardware and software required for this process will be part of the system developed by VMC.

Both VMC and UMTRI will review the data on receipt to determine the operational status of the instrumentation system and the ABS system. This is to take place on a daily basis as the data are received. VMC will maintain the data records in house only as required for this purpose, discarding the data within a few weeks of receipt.

UMTRI will archive all electronic data for the long term and will perform the analyses required for evaluation of vehicle performance. This will continue throughout the test program.

An initial task in the data analysis will be the matching of various vehicle unit data files into groupings corresponding to vehicle trips. Trailers are continually dropped and added to the vehicle in the field. At this moment it remains a matter of system development as to how the configuration of the vehicle at any moment will be reconstructed. The options being considered are broad. The driver could be asked to download all data each time a unit is removed or added, thereby keeping all data files properly grouped from the beginning. Given that the fleets are volunteers, this may be excessive. It may also lead to much lost data if drivers are not attentive. At the other end of the range, downloading would occur only at the central terminal at the end of a trip. This would mean that data files from a common trip would be forwarded to VMC and UMTRI several days apart. Post processing computer programs would be written to sort the files by time and date stamps into the appropriate groupings. A similar range of options (from highly driver-dependent to highly automated) exists for identifying the ordering of individual units within a vehicle. (That is, which trailer is first; which is second; etc.?) Decisions on these details will be made during the system prototyping phase of this task. Development of the computer programs that will automate this processing clearly must await establishment of the final form of the system.

Braking and ABS system performance numerics derived from the analysis will follow the form of those developed in the previous ABS study.[3] Some will be improved to avoid the "false signal" phenomenon experienced in that study. Much of the thinking to date on those items has been implied in the discussion of the instrumentation system requirements.

Analysis of the influence of C-dollies on vehicle stability will concentrate on the lateral acceleration signals. Histograms will be developed to show the relative strength and the quality (frequency content) of the lateral motions of the first, second, and third trailers of vehicles equipped with A-dollies and C-dollies. Results will be interpreted in terms of our understanding of the underlying physics of the vehicle. These results will be supplemented by counts of dolly steering action.

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[3] Klusmeyer, LF, et al. *An in-service evaluation of the reliability, maintainability, and durability of antilock braking systems (ABS) for heavy truck tractors.* Report number 03-2467. Southwest Research Institute. San Antonio. March 1992.

FISCAL PLAN

As part of this planning project, we have estimated the cost of conducting the LCV operational test program as it has been described here. The total cost of the program as envisioned is $2.66M. Of this total, $0.29M is currently funded under the Planning Study task ($0.08M for sub tasks 1 through 7 and $0.21M for sub task 8), leaving $2.37M. An accounting of the various elements that lead to this latter figure follows.

PERSONNEL

Personnel	*Rate per (man mon)*	*Time (man mon)*	*Total*
Project director*	$17,492.22	1.25	$21,865
Principal investigator*	$14,788.26	10.75	$158,974
Research scientist*	$17,325.18	1.5	$25,988
Research scientist*	$16,067.16	0.5	$8,034
Research associate*	$8,367.66	12.65	$105,851
Engineering manager†	$9,500.40	9.3	$88,343
Programmer/analyst†	$5,329.62	16	$85,274
Programmer/analyst*	$5,329.62	4	$21,318
Engineering liaison†	$9,500.40	10	$95,004
Mechanical technician*	$6,839.94	0.5	$3,420
Electronics technician*	$5,475.78	1.5	$8,214
Secretary*	$5,534.94	2	$11,070
Graphics artist*	$6,660.72	0.5	$3,331
Total Time		62.65	
Total SW&B w indirect			$636,686

* UMTRI staff member

† Special project employee.

Equipment, Supplies, and Services

Item	*Vendor*	*$Amount* *Task 1*	*Task 2*	*Task 3*	*Task 4*	*Total*	*Indirect cost (52%)*
Equipment							
Instrument system	Vehicle Monitor Corp		526,565			526,565	(no indirect
ABS systems and parts	Rockwell/WACBO	164,860				164,860	charges on
C-dollies and hitches	Independent Trailer	444,476				444,476	equipment)
ABS systems and parts	Midland Grau	4,600				4,600	
ABS systems and parts	Bendix	3,600				3,600	
Reimbursement, new trailer ABS	Shopko	3,600				3,600	
Reimbursement, new tractor ABS	Kenworth	6,420				6,420	
3 Syquest drives, UMTRI	Mac&More			3,062		3,062	
PC 486 computer, UMTRI			3,000			3,000	
Laptop computer, West coast				3,000		3,000	
Fax machine, West coast	Liese Office Supply			1,200		1,200	
Subtotals		627,556	529,565	7,262		1,164,383	
Supplies and Services, vehicle outfitting							
Tractor retrofitting, Portland	Fruehauf Trailer Service	10,500	10,500			21,000	10,920
Trailer retrofitting, Portland	Fruehauf Trailer Service	99,476	33,159			132,635	68,970
Instrument recovery, Portland				24,250		24,250	12,610
Tractor retrofitting, Boise	Western Trailer Service	7,250	7,250			14,500	7,540
Trailer retrofitting, Boise	Western Trailer Service	38,885	12,962			51,846	26,960
Instrument recovery, Portland				7,680		7,680	3,994
Tractor ABS retrofiting	Freightliner corp	9,000				9,000	4,680
ABS systems and parts	Midland Grau	500				500	260
ABS systems and parts	Bendix	500				500	260
Hubs for Shopko trailers	Budd Company	12,000				12,000	6,240
Trailer power		8,750				8,750	4,550
Umbilicals		1,500				1,500	780
Tractor power		850				850	442
Warning lights		880				880	458
Hubometers (80@35)		2,800				2,800	1,456
S & S, UMTRI office							
32 Syquest cartridges	Mac&More			1,900		1,900	988
Telephone Service (data links)	Sprint			3,700		3,700	1,924
Mail Costs		200	200	1,500	100	2,000	1,040
Misc ($200 * 17)		400	400	2,200	400	3,400	1,768
S & S, West coast liaison							
West coast sec. ($14.89 *174*.5*14)	Kelly Girl			18,136		18,136	9,431
Phone service ($150 * 17 + $300)		500	500	1,850		2,850	1,482
Car mileage (500 * 17 * $0.275)		500	500	1,338		2,338	1,216
Misc		100	100	400		600	312
Subtotals		194,591	65,570	62,954	500	323,615	168,280
Total Expenditures		822,147	595,135	70,216	500	1,487,998	168,280

Travel Expenses

Task	Purpose	No. of Trips	No. of Persons per Trip	No. of Days per Trip	Cost per Trip: Airfare per Person	Cost per Trip: Car Rental	Cost per Trip: Per diem per Person	Totals
1a	*West Coast Representative, Misc Trouble shooting*							
	Portland, Boise	2	1	2	$600	$80	$170	$1,700
								$1,700
1c	*Maintaenance Data Planning trips*							
	Detroit, Portland, Boise, Green Bay, Detroit *	1	1	10	$1,690	$400	$1,130	$3,220
	Detroit, Green Bay, Detroit	1	1	1	$600	$40	$50	$690
	Fleet Equipment Planning Trip							
	Detroit, Portland, Boise, Green Bay, Detroit *	1	2	5	$1,450	$40	$530	$4,000
								$7,910
2b	*Instrument instalation assist and review trips*							
	Detroit, Portland, Detroit	2	2	4	$1,180	$160	$410	$6,680
	Detroit, Boise, Detroit	1	2	2	$1,120	$80	$170	$2,660
								$9,340
3a	*Fleet Education*							
	Detroit, Portland, Detroit.	4	1	2	$1,180	$80	$170	$5,720
	Detroit, Boise, Detroit.	1	1	2	$1,120	$80	$170	$1,370
	Primary Data Gathering							
	Misc. trouble shooting							
	Detroit, Portland, Detroit.	5	1	2	$1,180	$80	$170	$7,150
	West Coast Representative, Regular Monthly							
	Portland, Boise	12	1	1	$600	$40	$50	$8,280
	UMTRI Representative, Regular Bi-monthly							
	Detroit, Green Bay	6	1	1	$600	$40	$50	$4,140
								$26,660
4	*Briefiings, Wash. DC*							
	Detroit, Washington D.C.	2	2	2	$700		$170	$3,480
								$3,480
Total Direct Cost								$49,090
Indirect Cost (52%)								$25,527

Per diem Basis:
$50 per day and $70 per night.

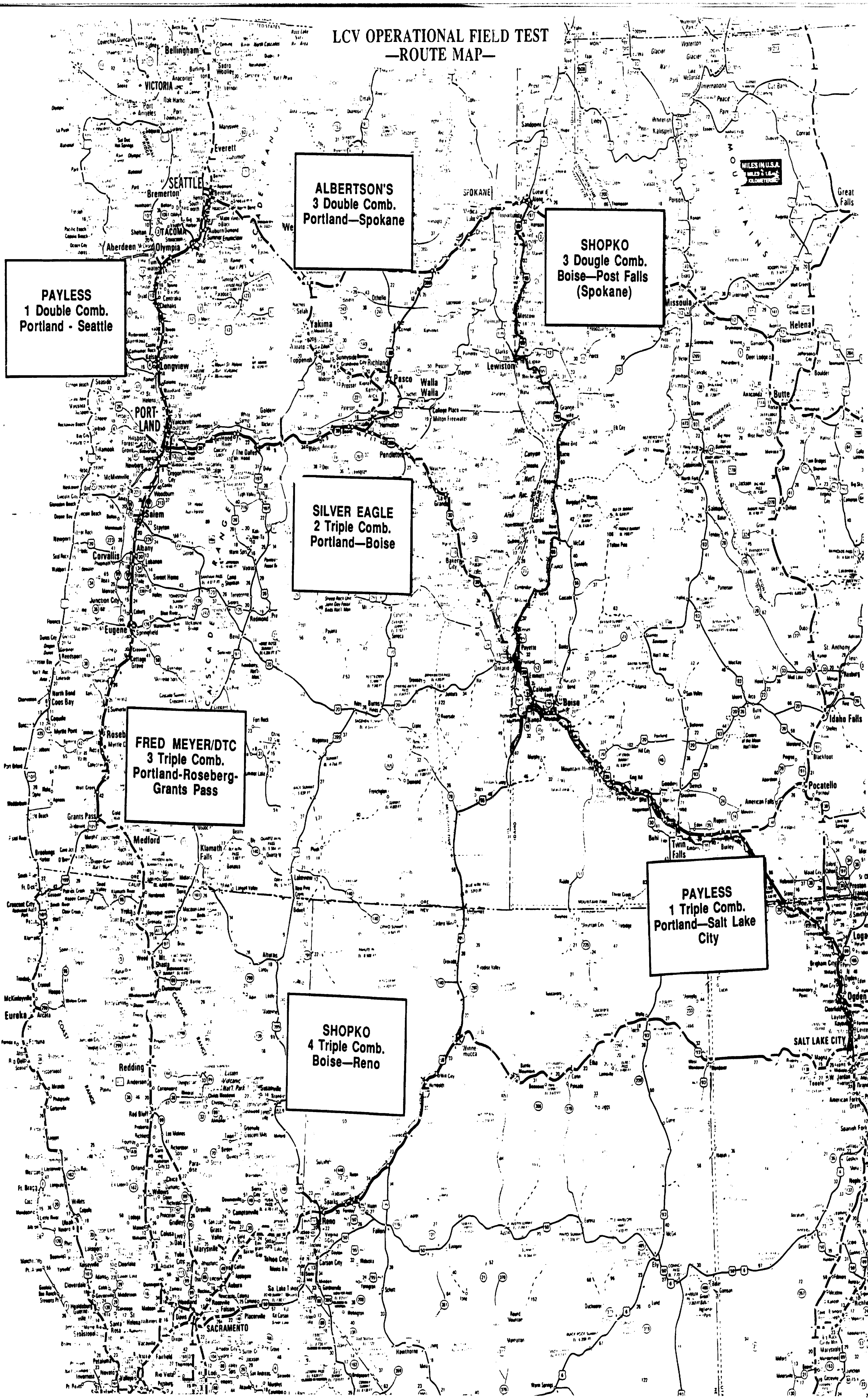
Car Rental Basis:
$40 per day

* Simultaneous trip. Car rental expenses combined.

Airfare Basis (one way fares):

Detroit	—	Portland	$590
Detroit	—	Boise	$560
Detroit	—	Green Bay	$300
Detroit	—	Wash., D.C.	$700
Portland	—	Boise	$300
Boise	—	Green Bay	$500

LCV OPERATIONAL FIELD TEST —ROUTE MAP—



LCV Operational Test Program Plan — Gantt Chart