5. EQUIPMENT EVALUATION

A guiding concept for this project has been to test and evaluate the system components under realistic conditions, on vehicles in revenue service. That concept implies that the primary purpose of the vehicles is to generate revenue – make money – for their operators, and that collection of data is only an important secondary purpose. One consequence of that priority has been that the vehicles are occasionally unavailable for data download or equipment inspection.

In addition, the conditions of U.S. Xpress revenue service often led to situations where instrumented tractors were not connected to instrumented trailers in spite of good intentions of dispatchers and schedulers. It was intended that the U. S. Xpress vehicles be dedicated to a particular customer who hauls freight between a terminal in Ohio and a terminal in Georgia on a regular basis. Under such circumstances, the six instrumented trailers could in principle be swapped among the three instrumented tractors and almost always be connected to allow trailer data collection. It took quite a while to persuade the yard operators that this connection of instrumented tractor and trailer mattered; therefore, in the early days of the project, the instrumented trailers were somewhere else most of the time. On the contrary, Praxair had no such problem. The Praxair tractor for this test was also a special vehicle, and the tractor and trailer stayed together except for brief maintenance periods.

Trailer-to-tractor communication remains a problem, though there is evidence that the industry is addressing it. One version of multiplexing data onto power leads for the trailer is receiving widespread testing, and dedicated short range radio frequency technology also has advocates. Fiber optics appears to have a number of significant advantages such as ample bandwidth and RFI immunity, but at least for this project, it had connector weaknesses that outweighed the advantages. For fleets that routinely use whatever tractor is available to pull whatever trailer is loaded and ready to go, connecting and disconnecting is a fact of life subject to all the rigors of the over-the-road environment. When the data communication problem is "solved," estimation of as-loaded roll stability will be an attractive value-added feature.

Because of the problems experienced with the tractor-trailer communications, there is some rationale for positioning instrumentation only in the tractor. The interesting possibility of sensing trailer stability from tractor-based instruments is intriguing, but remains a challenging research-and-development effort as far as we know. There were promising preliminary results at UMTRI,[7] but there are no published reports of a subsequent study at this time.

The connector problems of fiber optics should be less severe for tractor-trailer combinations that stay coupled, as our Praxair vehicle did. However, another sort of connector problem plagued the Praxiar data collection efforts. Board connections internal to the on-board computer and/or port connections on attached devices appear to have been the cause(s) of the serious problem of intermittent data logging. Such connection problems are already being attacked by vendors; the

[7] Private communication from C. B. Winkler, 9 November 2000.

simple expedient of integrating functions onto the main computer board can make computers sufficiently reliable. The ability to know a vehicle's location precisely is valuable for many reasons, and GPS receiver functions can certainly be integrated into vehicle computers as the marketplace develops.

One additional problem occurred with the U.S. Xpress trucks after several months of data collection. In November 2000, the on-board computer "crashed." Although a final diagnosis of the cause of the failure is not known at this time, it is possible that the operating system (Windows 98) was affected by the shut-down procedures. Because the computer on-off switch was connected to the ignition switch, the shut-down procedures were not "graceful."

In summary, although equipment problems occurred for both trucking partners, the problems are being addressed, and it appears that the issues can be resolved.

6. EVALUATION OF THE ACCURACY AND TIMELINESS OF THE DATA

GPS data can now provide real-time vehicle position and can be used to support driver warning, although this was not the case during the entire project. The detailed analysis given in Section 4.6 shows that the original GPS data from U. S. Xpress trucks, collected almost entirely before SA was turned off, were not always precise enough to support driver warning. Data collected near Knoxville, Tennessee, showed a standard deviation of hundreds of feet. A truck traveling at 81 feet per second travels slightly over 400 feet in 5 seconds. Five seconds of advance warning is a time interval of the order of magnitude that one might want to give a driver, in order to allow the driver to recognize the warning and take appropriate action. Failure to measure location/time-to-hazard with enough precision would make it difficult to avoid both false-negative and false-positive errors.

However, even before SA was stopped, it was possible to collect "good" GPS data. GPS data collected near Cincinnati, Ohio, by U.S. Xpress trucks during the same period show a standard deviation of only a few feet. The U.S. Coast Guard broadcasts differential corrections that allow ships to correct GPS receptions for various errors, including SA.[8] These Coast Guard corrections cover the U. S. Coasts and the Mississippi and Ohio River valleys. Cincinnati is within range of these broadcasts, and Knoxville is not.

Fortunately for prospective civilian users of GPS location equipment, the deliberate errors of SA have gone away. The available precision of the GPS is illustrated by recent data collected by Praxair, which show a standard deviation of less than five feet. Clearly, such precision can support determination of a vehicle's proximity to a sharp curve. Likewise, in combination with the trucks' on-board measurements of lateral acceleration, such measurements can determine *with precision* those highway locations where vehicles are routinely subjected to forces that could overturn them. Indeed, with that sort of precision, it becomes feasible to infer the lane of travel on a multilane highway, information that could be useful in estimating the likelihood that a vehicle will indeed take an approaching exit ramp.

This project originally included plans to use signals from beacons to provide precise reference distance to a critical portion of a hazardous curve. However, roadside beacon technology is relatively expensive and somewhat inconvenient to use and maintain. Now that GPS has sufficient precision to determine a vehicle's proximity to an upcoming sharp curve, it is no longer useful or necessary to employ any auxiliary information from, for instance, the timing of signals from roadside beacons. A map database can contain precise locations of sharp curves and their lateral acceleration demands, and an approaching vehicle can determine how far away the curve is. With knowledge of the vehicle's speed, acceleration, and roll stability, an on-board computer can project the speed in the turn and can warn the driver if action is required. Beacons perhaps are still useful for transient hazards like weather and traffic/work-zones, but fixed hazards such as sharp curves need not be identified by expensive roadside hardware.

[8] U.S. Coast Guard, http://www.uscg.mil/hq/g_cp/comrel/factfile/Factcards/DGPS.html.

As discussed above, the instrumentation can generate the required “bad-curve” database. Based on the limited data analyzed so far, it appears that measured lateral acceleration and weight transfer are reasonable and correlated, and that they can be related to road speed and location. That combination of data could be stored in a database for use by other drivers. As an alternative to collection of a great deal of truck data, the required data (with required precision and accuracy) could easily be collected by special vehicles with accurate speed sensors. If no mapping industry leader steps forward, the data collection could be accomplished by trucking companies themselves following the procedures of this project.

Trailer data also appear to be useful for rollover risk estimation. Instrument drift and temperature dependence apparently can be estimated and compensated, but a periodic calibration check would give more confidence. Significant engineering remains before such systems are robust enough for the rigors of over-the-road trucking, but we have demonstrated that such a system could give drivers advance warning of potential rollover.

7. CONCLUSIONS

Using data collected by U.S. Xpress and Praxair from trucks in revenue service, ORNL analyzed the data and evaluated the data collection equipment. ORNL received ten data files between June 2000 and late January 2001. Procedures were established for transferring the data to ORNL, loading it into appropriate databases, and performing the analyses using a GIS tool.

Trailer-to-tractor communication remains a problem; however, the solution to this problem is certainly forthcoming.

Trailer data can be used to indicate truck roll stability. Instrument drift and temperature dependence apparently can be estimated and compensated for, but a periodic calibration check would give more confidence.

The data collected by the truck-trailer instrumentation can generate a “bad-curve” database. Based on the limited data analyzed so far, it appears that measured lateral acceleration and weight transfer are reasonable and correlated, and that they can be related to road speed and location. That combination of data could be stored in a database for use by other drivers.

The data analysis indicates that GPS data are extremely accurate. Analysis also indicates that the data collected by the truck and the trailer can be used effectively to provide a warning system for drivers.

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APPENDIX A

SDL:
STABILITY DATA LOGGER

SDL
Stability Data Logger
Version 1.1.20
5/08/00
John Bate

This document describes the overall operation of the SDL program. It is written in VB 6.0. Its main purpose is to accept GPS (Global Positioning System) data, J1708 (truck data bus) data, and Trailer instrumentation data (from stress and strain gauges attached on the trailer).

For DEMO MODE:
1. “Demo Display” is shown on the Startup and Graphs screens.
2. The G forces and weight of the trailer is listed as “uncalibrated”
3. The VORAD Collision Warning is just text.
4. The data shown on the debug display is real.
5. To prevent distracting the driver the system screen saver was set to blank after 1 minute. The system is still operating and data can still be collected.

The Startup Screen

The first screen seen when starting up the application includes real time display of the G forces and weight of the truck.

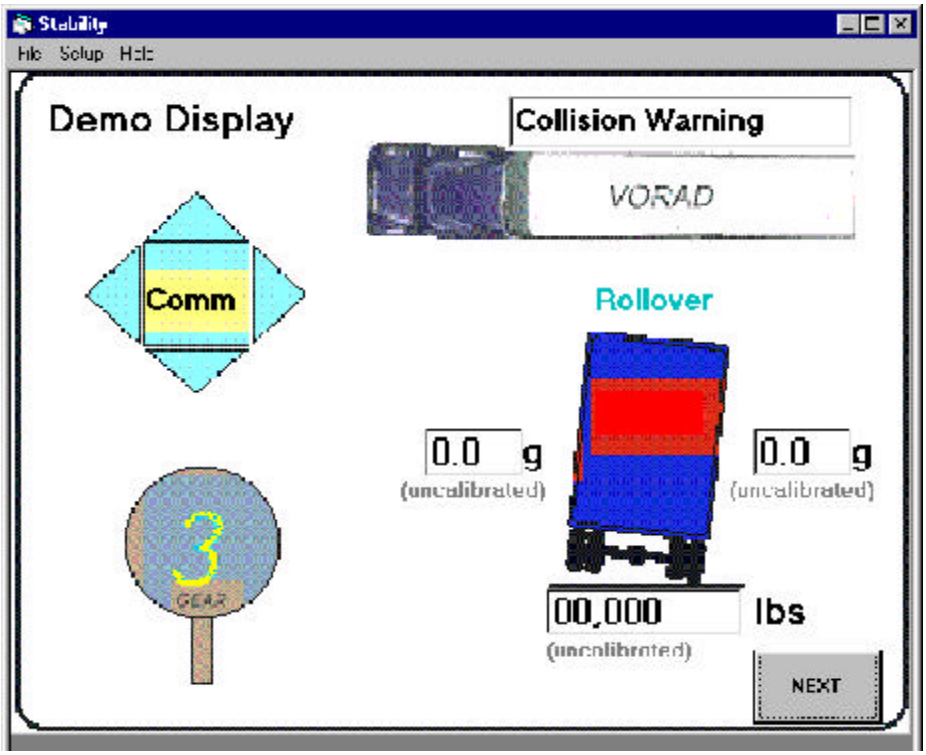


Figure 1. Startup Screen

The “NEXT” button switches to the debug screen.

Monitor Screen

The next screen is shown in Fig. 2. The “Data Monitor Enables” frame is 8 text boxes used when debugging the data collection hardware. It displays data as seen by the RODL after data filtering has taken place. The three check boxes control the display of that particular data in the text boxes. The checkboxes do not control the logging of the data, only the display. Any data destined for the log file will be displayed here. If all check boxes are unchecked then the display will not update. Typical operation will be to enable one checkbox, view the data, decide on what data is wanted in that group, then set the filters accordingly (in the Setup dialog boxes described later.

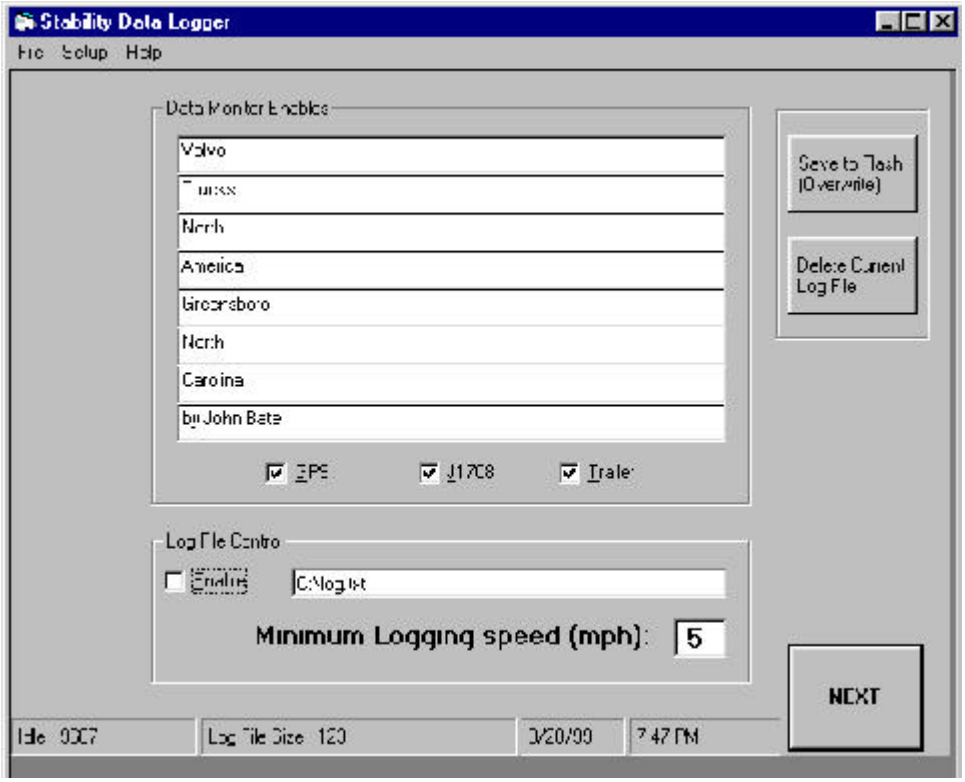


Figure 2. Main Screen

The “Log File Control” frame displays the log file currently in use as well as the enabled status. If the Enable button is checked then the system will log to the file. The log file path cannot be changed when the system is logging.

To edit the log file the Enable button must be unchecked.

The Minimum Logging Speed (mph) indicates at which speed the vehicle must reach before logging will start.

The two buttons “Save to Flash (overwrite)” and “Delete Current Log File” are used when transferring the log file database to another computer. The system must not be logging data (Enable unchecked) for this to work. “Save..” expects a flash PCMCIA disk to be inserted into the second PCMCIA slot in the top of the onboard computer. The log file is copied to “E:\log.txt” on the flash disk. “Delete…” deletes the onboard computer’s log file. This should be done after the

file has been copied to the flash disk. This button is enabled only if logging is disabled.

The status bar at the bottom of the main screen is updated once per second. It displays a performance indicator (Idle) and Log File status.

The idle number is an indicator as to how much free idle time the system has. The smaller the number the more processing it is doing and the less idle time it has.

The log file size and status is also displayed. This segment may also display the status of another path: (directory, read-only, illegal file).

The “NEXT” button switches to the Graphs screen (this has been disabled, however the screen still exists)

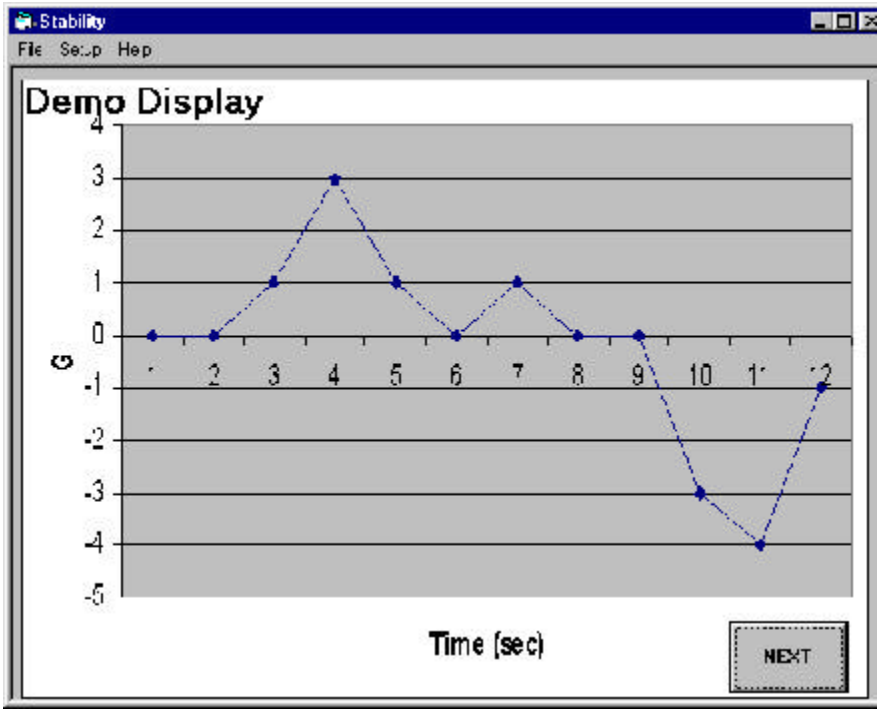


Figure 3. Graphs Screen

Graphs Screen

The Graphs screen is for demo purposes only. Data graphs can be included in this application and this is an example (**it is not displayed in the current version**).

Trip Screen / ID Buttons

The Trip screen allows the user to record 4 identifiers for the driver, the vehicle, the trailer, and the load.

The Start Trip button causes all identifiers to be stored in the current log file along with a “Start” and time and date message. The Stop Trip stores the word “Stop” and time and date. The system will always log these two buttons but may not log anything else if logging is not enabled. Logging is controlled by the log enable button, not by these buttons.

The “NEXT” button switches to the Startup Screen.

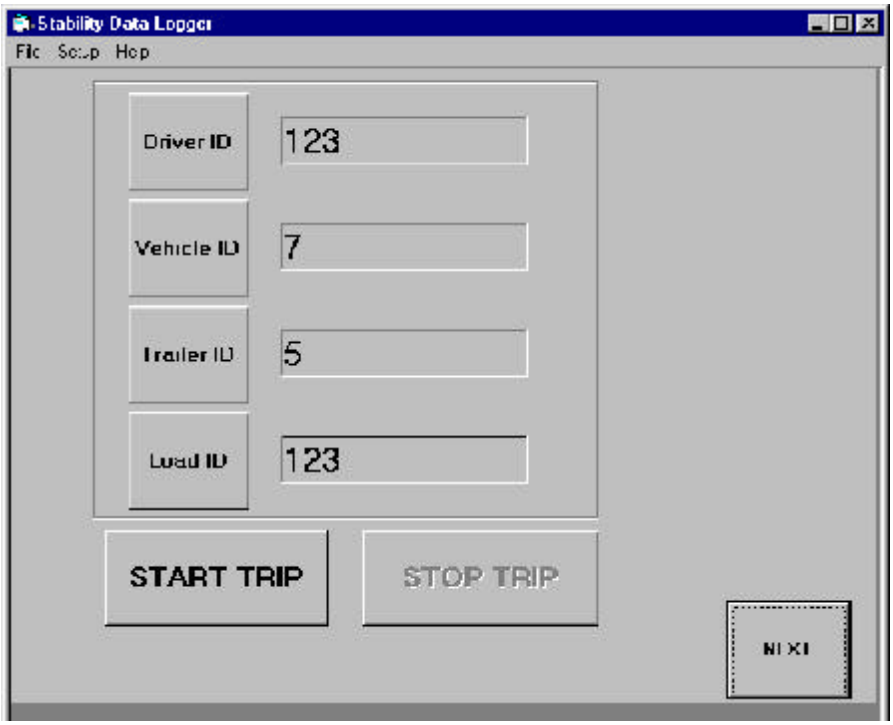


Figure 4. Trip Screen

If pushed the ID buttons display the number entry panel. Pushing a number will clear out the current number and start a new number. Push Clear to clear the display, push Enter to save the current number. Empty ID fields are allowed.

Figure 5. Number Entry Panel

Setup->GPS

Figure 6 shows the GPS Port Setup dialog box.

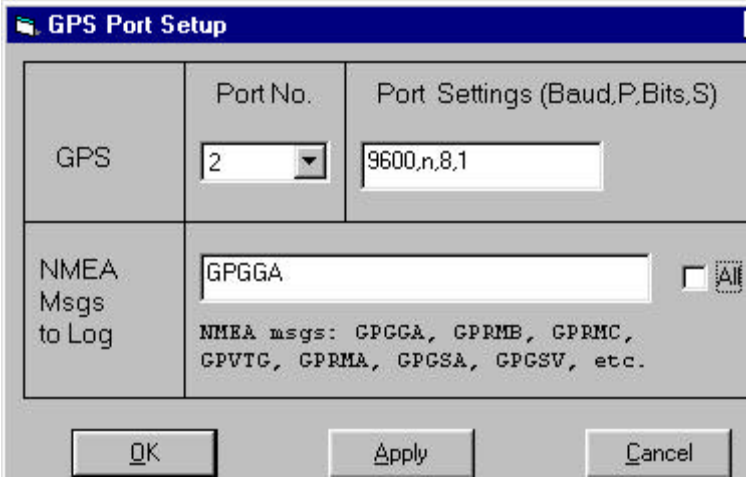


Fig. 6 GPS Port Setup

GPS ports 1-8 are available. Typical GPS devices (NMEA 0183 compatible) are configured with 9600, No parity, 8 bits, and 1 stop bit.

The “NMEA Msgs to Log” field is strictly text. Enter the NMEA message name (not case sensitive) that you want to allow through the filter. This message will be displayed on the main screen as well as logged (if enabled). Separate multiple names by spaces or commas. The program is looking only for a string match of the incoming NMEA name to anything in the setup filter. Checking the “All” box will cause all messages to be displayed (if enabled) and logged (if enabled)

The GPS device is provided by Trimble Inc. Any NMEA 0183 compatible differential GPS system will work.

Setup->J1708

Figure 7 shows the J1708 Setup dialog box.

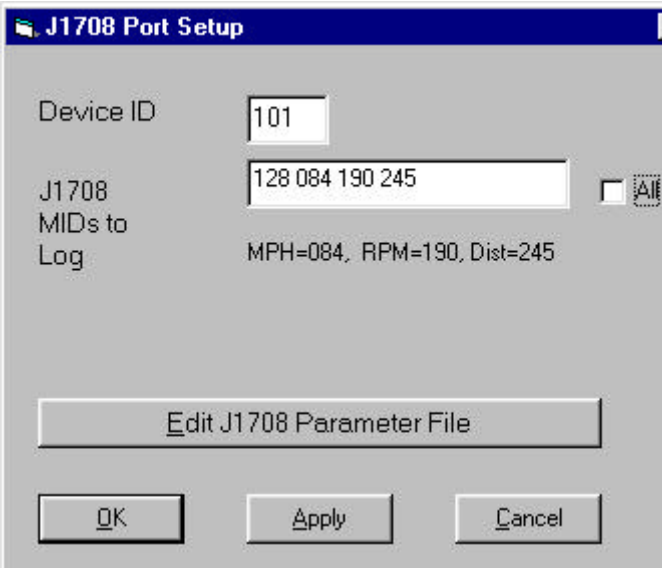


Figure 7. J1708 Setup

Selecting a Device ID causes the system to lookup the port parameters in the proper section of the J1708 parameter file. This file MUST be set up correctly in order to operate.

The “J1708 MIDs to Log” text box accepts the MIDs and PID. The system can handle up to 10 MIDs, each with 10 PIDs (10 x 10 array). There is not a lot of error checking here so follow the format. Spaces separate MID from PIDS, semicolons separate MIDS. “*” means to accept everything and log it (if enabled).

MID PID PID…..;MID PID;MID *;MID PID

Example:

144 23 56 67;165 34 45;86 *

This example shows that the user wants to log PIDS 23, 56, and 67 from MID 144, PIDS 34 and 45 from MID 165, and ALL PIDS from MID 86.

Checking the “All” box will cause the system to log ALL PIDS from ALL MIDS that are seen on the J1708 bus. The filter settings are ignored.

The DPA II J1708 adapter is manufactured by Dearborn Group. They also provide the RP1210 Windows 95/98 compatible DLL. Other adapters will work as long as the proper RP1210 DLL is provided and the source code updated to link

to the proper RP1210 compatible DLL. The actual RP1210 API calls will remain the same.

Setup Trailer

Trailer link setup includes setting up the read, message output, and averaging rates as well as selecting which channels to log.

Checking “All” box causes the system to log the data in raw format only. By selecting individual channels the system will log the data in a more natural form if format is known.

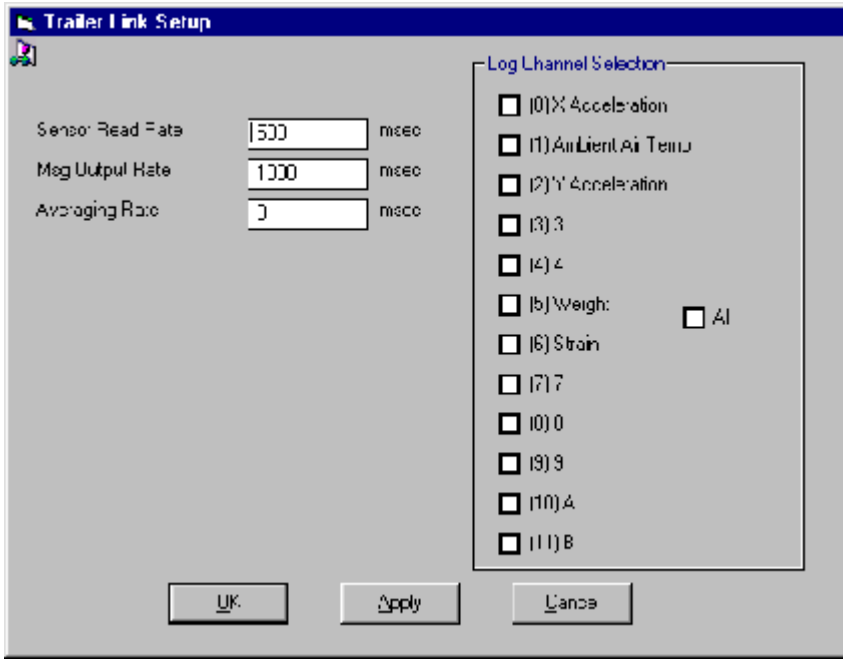


Figure 8. Trailer Setup Screen

Troubleshooting

There are a few points of possible failure. Figures 9 and 10 display two (of the many) dialog boxes that might show up.

Figure 9. J1708 connection

Figure 10. GPS Setup

Figure 9 shows that the J1708 DPA II is not responding. This may be that the adapter is not powered, connected, the Device ID is incorrect, or the parameter file is incorrect.

If the J1708 Data Monitor checkbox is enabled and there is no display check the adapter, device id, and or the parameter file. Also ensure that the J1708 filter is set up correctly.

Figure 10 shows that the GPS port is not available. Ensure that the port is available and that the GPS receiver is attached.

If the GPS Data Monitor checkbox is enabled and there is no display then ensure that the device is powered on, connected, and that the GPS filter is set correctly.

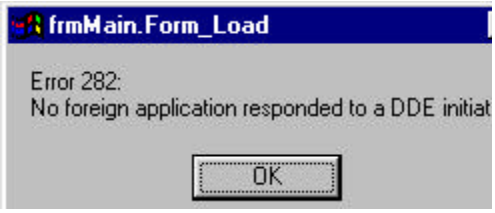


Figure 11. No DDE channels open

Figure 11 above shows examples when this program was not able to communication with the LMS network server. Possible problems were that the LMS server did not invoke, it crashed, or that this application invoked before the server was ready.

Log File format

The log file is a ASCII CSV formatted text file. The system will log data whenever the speed of the vehicle is greater than the minimum and logging is enabled.

The log file format consists of a letter (case sensitive) followed by the data, all comma deliminated.

In most cases the system will log incoming data whenever the data has changed.

The J1708 data bus is continuously broadcasting the current values for a number of vehicle states. To keep the size of the log file to a reasonable size the speed and rpm are only logged as follows:

Speed (S): must change by 2 mph
RPM (R): must change by 50 rpm

The GPS data will consist of one NMEA message per line. GPS data is logged all the time (if the speed is greater than minimum and logging is enabled). GPS data contains the UTC time used to time sync other log file data.

Following the GPS data will be vehicle speed, engine rpm, and outside temperature if they have changed (if data is not logged then either the J1708 or trailer setup is incorrect, or the data has not changed).

For performance reasons the vehicle speed, engine rpm, and outside temperature are logged and/or displayed only if the GPS data is logged (about once per second).

The trailer data is logged when it changes (if the speed is greater than minimum and logging is enabled).

The log file data is as follows:

3,<data>
Raw channel 3 data, currently unassigned or reserved
4,<data>
Raw channel 4 data, currently unassigned or reserved
7,<data>
Raw channel 7 data, currently unassigned or reserved
8,<data>
Raw channel 8 data, currently unassigned or reserved
9,<data>
Raw channel 9 data, currently unassigned or reserved
A,<data>{ TC \l4 "}
Raw channel 10 data, currently unassigned or reserved
B,<data>{ TC \l4 "}
Raw channel 11 data, currently unassigned or reserved

#,<comment string to end of line>{ TC \l4 "}
Trip start, stop, date – logged only if the Start or Stop trip buttons have been pushed.

I,<driver id>,<vehicle id>,<trailer id>,<load id>{ TC \l4 "}
Logged when the Start button has been pushed.

G,<UTC>,<latitude>,<N or S>,<longitude>,<E or W>,<Signal Quality>
G,142326.000,3604.788390,N,07958.179359,W,1
Logged approximately each second.

This data begins with “G” as the first character followed by UTC (hhmmss.ss,latitude*100,N or S, longitute*100,E or W, GPS quality (0=invalid, 1=GPS fix, 2=DGPS fix).

O,<odometer in miles>{ TC \l4 "}
O,45711.3
Logged about every 10 seconds.

Q,<Strain gauge in volts, (.02055mv/micro strain)>{ TC \l4 "}
Q,0.003
Logged about 10/sec (or as set up on Trailer setup screen)

R,<RPM>{ TC \l4 "}

R,1143
Logged about 1/sec

S,<Speed in MPH>{ TC \l4 "}
S,65
Logged about 1/sec

T,<all 12 channels of comma separated trailer data>{ TC \l4 "}
T,0.04,-1.56,….
Logged when “All” checked on Trailer setup

C,<outside air temp in C>{ TC \l4 "}
C,25
Logged about 1/sec

X,<X lateral acceleration (right(+)/left(-)) in Gs>{ TC \l4 "}
X,-0.4
Logged about 10/sec (or as set up on Trailer setup screen)

Y,<Y longitudinal acceleration (fore(+)/aft(-)) in Gs>{ TC \l4 "}
Y,1.01
Logged about 10/sec (or as set up on Trailer setup screen)

W,<weight at back axle of trailer in pounds>{ TC \l4 "}
W,9780
Logged about 10/sec (or as set up on Trailer setup screen)

Installation Instructions

First time loading:

1. Run Programs->Hampshire Touch screen alignment.
2. 7Insert SDL install flash card. Run setup.exe
3. Navigate to Program files\Stability Data Logger, Run 1210.exe and install RP121032.dll
4. Remove SDL flash card.
5. Select rodl.exe, RMB, Send to Desktop, center it on screen, change the name to “Stability Data Logger”

6. Add RODL.exe to Start->Taskbar Startup, name it “Stability Data Logger” (target: C:\Program files\Stabilty Data Logger\RODL.exe)
7. Ensure that the Startup menu has the LMS server in it (target: C:\echelon\lm_dde\lmsrvr.exe /NB /e OAKRIDGE, start in: c:\echelon\lm_dde)
8. Reboot and verify that the Volvo Startup logo, the LMS server, and the Stability Data Logger execute at boot time.
9. Set task bar to Auto Hide
10. [as needed] Set J1708 ID to 101 or 102
11. [as needed] Set GPS Port to 2 or 1, set Baud rate (Raytheon@4800, Trimble@9600, 8,N,1)
12. Exit the data logger
13. Set Screen Saver to “Blank Screen” and Wait time to 1 minutes.

Second time loading:

1. Insert SDL flash card.
2. Copy RODL.exe to c:\Program files\Stability Data Logger
3. Remove SDL flash card.

Data Download

To copy the log file off the truck PC:

1. Disable logging (uncheck the log file Enable). The “Save…” and “Delete…” buttons are activated. If the logging screen is not available then push “Next” until you get the logging screen. If you still never see it then first cycle to the Trip screen. Enter the password number 13363932000 as the driver ID. Push “Next”.
2. Unscrew two screws and remove the truck’s dashboard cover (located just above the ashtray).
3. Insert flash disk storage card to the extra slot on the PC, taking care not to disturb the attached cables.
4. Push the “Save…” button.
5. [Optional] Verify that file was transferred with Windows Explorer
6. Remove flash disk card.
7. Push the “Delete…” button. Verify that the log file size changes.
8. [Re] Enable logging (check the Enable button). Log file size should now be zero.
9. Reinstall cover.
10. Verify correct operation.

Installation Modification

02/02/00 Stefan Jansson

This note describes how to modify the SDL installation to allow for two PCMCI adapters being used simultaneously. In the existing installation all interrupts are used by the existing devices and no interrupt is available for the second PCMCI card. Two modifications have to be performed: The first is in the computer BIOS configuration and the second in WINDOWS device driver settings.

Connect a keyboard to the computer. The plastic cover on the standard connector might have to be trimmed back 1/8" for full engagement.

BIOS modifications:

1. Start or restart the computer.
2. Press "Delete" during boot up to access the BIOS setup menu.
3. Select "Integrated Peripherals".
4. Disable "Onboard Parallel Port".
5. Disable "Built in CPU Audio".
6. Press "ESC" to exit this menu.
7. Select "Save & Exit Setup"
8. Answer "y" to "Save to CMOS"

WINDOWS modifications:

1. Let WINDOWS start up.
2. Exit the Data Logger Program and go to the Desktop.
3. Select "START", "SETTINGS", "CONTROL PANEL"
4. Start the "SYSTEMS" application.
5. Select the "Device Manager" menu.
6. Select "Ports (COM & LPT)" from the list.
7. Click on the "+" in the front to see the individual ports.
8. Select the "ECP Printer Port".
9. Click on properties
10. Check "Disable in this hardware profile"
11. Click on "OK"
12. Repeat step 9-11 for "PCI Bridge", under "Other Devices".
13. Repeat step 9-11 for "PCI Multimedia Audio Device, under "Other Devices"
14. Repeat step 9-11 for "Vadem PCI Compatibility PCMCI Controller", under "PCMCI Sockets"

15. Click on “OK” and exit the “Device Manager”.
16. Exit the “Control Panel”.
17. Reboot the computer

Note: Some of the devices in 12-14 might not be present.

APPENDIX B

INTERNET FILE TRANSFER PROCEDURE

Internet File Transfer Procedure

Initial FTP Client Setup
These instructions assume the use of either version 4 or higher of Microsoft Internet Explorer or Netscape. FTP clients are not restricted to these browsers, but they are suggested because they convenient, free, and readily available.

1. **Find the FTP Site**
   Double-click on the Internet browser icon on the desktop (Internet Explorer or Netscape). Type in the following appropriate site name in the **Address** or **Location** box
   ftp://PraxAir@128.219.40.110 …then press the **Enter** key.
   ftp://USXpress@128.219.40.110 …then press the **Enter** key.
   Type in your password (passwords are case sensitive).
   If given a choice, click on your directory (folder) name.

2. **Make an Easy Way to Return to this Site**
   Create a desktop shortcut for this location using the following steps:
   Click and hold the icon in or in front of the left side of the **Address** or **LOCATION** box.
   Drag this icon to your desktop to create a shortcut for the **FTP site**. (Leave the **FTP site** window open.)
   Drop (release the button you are holding) the icon on the desktop.

3. **Start Uploading the Data File**
   Click on the **Start** button (on your task bar); click **Programs**, and then click **Windows Explorer**. On the left side of the Windows Explorer window, click on the appropriate drive and click and continue clicking on the folder(s) until you reach the folder that contains the file to be uploaded. On the right side of the Windows Explorer window, click, hold down the mouse, and drag the file to be uploaded to the Internet Explorer (the **FTP site**) window. If a small pop-up window appears follow the directions (usually push the YES button to transfer the file).

4. **Finish Uploading the Data File**
   When you see the file appear on the **FTP site**, click on the word **File** in the upper left-hand corner of your browser and then click on **Close** to end your session.

5. **Notify the FTP Manager that a New File is Available**
   Send an e-mail to truettlf@ornl.gov and note that a new file was successfully uploaded. Mention the file name and any other information that may make this data file different than any other. For example, "The file 2000_July_15.txt was just successfully uploaded to the FTP site on 128.219.40.110. This file is different from the previous file in that (fill in the blank, e.g., trailer data is missing)."

For routine use of FTP for file transfer, double-click on the **FTP site icon** on your desktop.

Follow Steps 3-5.
Start Uploading the Data File
Finish Uploading the Data File
Notify the FTP Manager that a New File is Available

APPENDIX C

VISUAL FOXPRO PROGRAM CODES

Visual FoxPro Program Codes

I. Program to separate US Xpress truck trips

```
*******
*
*       GETUSEXP.PRG
*
*******
        Set talk off
        Close all
        Clear
        If FILE('log.txt')  && Does file exist?
                gnErrFile = FOPEN('log.txt',12)  && If so, open read-write
        Else
                gnErrFile = FCREATE('log.txt')  && If not, create it
        Endif

        If gnErrFile < 0  && Check for error opening file
                Wait 'Cannot open or create output file' WINDOW NOWAIT
        Else  && If no error, write to file
                * =FWRITE(gnErrFile, 'Error information to be written here')
        Endif

        Use \trkrover\originaldata\UsExpAdd.dbf in 0 alia tt
        Sele tt
        Zap
        xxno = 0
        xyno = 0
        xwno = 0
        xqno = 0
        xsno = 0
        xrno = 0
        xcno = 0
        xjno = 0
        xono = 0
        xino = 0
        xoold = 0
        xcount = 0
        xl = 0
        ytime = 0
        xgps = ""
        xlold = 0
        xo = -98.00
        yo = 39.0
        xd = 0
        xdateold = date()
        xdatenew = date()
        xcumdist = 0
        xcumtime = 0
        Dimension gps(9)
```

```
Do whil not feof(gnErrFile)
    xtxt = fgets(gnErrFile)
    x1 = substr(xtxt,1,at(',',xtxt,1)-1)
    Do case
        Case x1 = "X"  && lateral  Acc
                xxno = xxno + 1
                repl xv with xv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "Y"  && Longitudinal  Acc
                xyno = xyno + 1
                 repl yv with yv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "W"  && Weight
                xwno = xwno + 1
                 repl wv with wv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "Q"  && Strain
                xqno = xqno + 1
                repl qv with qv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "S"  && Speed
                xsno = xsno + 1
                repl sv with sv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "R"  && RPM
                xrno = xrno + 1
                repl rv with rv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "C"  && Temperature
                xcno = xcno + 1
                repl cv with cv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "J"  && No Idea
                xjno = xjno + 1
                repl jv with jv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "O"  && Odometer
                xono = xono + 1
                xdo = val(substr(xtxt,3,7)) - xoold
                xoold = val(substr(xtxt,3,7))
                repl ov with ov + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "I"  && Driver ID
                xino = xino + 1
                repl iv with iv + substr(xtxt, at(',',xtxt,1)+1,len(xtxt)-at(',',xtxt,1))
        Case x1 = "G"  && "$GPRMC"
                Repl tt.xno with xxno,  tt.yno with xyno, tt.wno with xwno
                Repl tt.qno with xqno, tt.sno with xsno, tt.rno with xrno
                Repl tt.cno with xcno, tt.jno with xjno, tt.ono with xono, tt.ino with xino
                xcount = xcount + 1
                 For n = 2 to 8
                    gps(n) = substr(xtxt, at(',',xtxt,n-1)+1,at(',',xtxt,n)-at(',',xtxt,n-1)-1)
                Endfor
                gps(n) =substr(xtxt, at(',',xtxt,n-1)+1,len(xtxt)-at(',',xtxt,n-1))

                Sele tt
                Appe blan
                Repl tt.tod with gps(2)
                xn = -1.0 * (val(substr(gps(5),1,3))+val(substr(gps(5),4,7))/60)
```

```
                yn = val(substr(gps(3),1,2))+val(substr(gps(3),3,7))/60
                Do gcdist with xn,yn,xo,yo,xd
                Repl tt.long with xn, tt.lat with yn, tt.idist with xd
                xo = xn
                yo = yn
                xtime = val(substr(gps(2),1,2))*3600+val(substr(gps(2),3,2))*60+;
                        val(substr(gps(2),5,2))
                z = xtime - ytime
                If z < 0
                        z = z + (60*60*24)
                Endif
                xcumdist = xcumdist + xd
                xcumtime = xcumtime + z
                xhr = substr(str(int(z/3600)+100,3),2,2)
                xmn = substr(str(int((z-int(z/3600)*3600)/60)+100,3),2,2)
                xse = substr(str(mod(z,60)+100,3),2,2)
                xitime = xhr+xmn+xse
                Repl tt.itime with xitime

                if z > 600 and ((abs(xn + 83.781908 ) < 0.05 and ;
                   abs(yn - 39.435725) < 0.05) or (abs(xn + 84.374952 ) < 0.05 and ;
                   abs(yn - 33.653563) < 0.05))
                   xl = xl + 1
                   xgps = gps(2)
                   xcumdist = 0
                   xcumtime = 0
                   xcount = 0
                   delete
                Endif

                Repl tt.xrec with xcount, tt.cumdist with xcumdist
                xhr = substr(str(int(xcumtime/3600)+100,3),2,2)
                xmn = substr(str(int((xcumtime-int(xcumtime/3600)*3600)/60);
                        +100,3),2,2)
                xse = substr(str(mod(xcumtime,60)+100,3),2,2)
                Repl tt.cumtime with xhr+xmn+xse, tt.runid with xl
                ytime = xtime
                xxno = 0
                xyno = 0
                xwno = 0
                xqno = 0
                xsno = 0
                xrno = 0
                xcno = 0
                xjno = 0
                xono = 0
                xino = 0
        Otherwise
    Endcase
Enddo
```

```
Repl tt.xno with xxno, tt.yno with xyno, tt.wno with xwno, tt.qno with xqno
Repl tt.sno with xsno,  tt.rno with xrno, tt.cno with xcno, tt.jno with xjno
Repl tt.ono with xono, tt.ino with xino

=FCLOSE(gnErrFile)  && Close file
Set talk on
        Return
```

II. Programs to estimate angles, speed, and accelerations from GPS data

```
*******
*
*       GTANG.PRG
*               To estimate turning angles
*
*******
        ang = 0
        do xgtang with 0,0,0.5,-.87,ang

        procedure xgtang
        parameter x1,y1,x2,y2,ang
        d = ((x2-x1)**2 + (y2-y1)**2)**.5
        if d = 0
                ? "d is zero"
                 retu
        endif
        ax = acos((x2-x1)/d)/pi()*180
        ay = asin((y2-y1)/d)/pi()*180
        do case
                case  0 <= ax and ax <= 90 and  0 <= ay and ay <= 90
                        ang = ax
                case  90 <= ax and ax <= 180 and  0 <= ay and ay <= 90
                        ang = ax
                case  90 <= ax and ax <= 180 and  -90 <= ay and ay <= 0
                        ang = 180 - ay
                case  0 <= ax and ax <= 90 and  -90 <= ay and ay <= 0
                        ang = 360 + ay
        endcase
        rele x1,y1,x2,y2,ang,d,ax,ay
        endproc

*******
*
*       GETSPEED.PRG
*               To estimate speeds
*
*******
        close data
        set talk off
        use work2x
        go top
        store dlongitude to y1
        store dlatitude to x1
        store time to mtime
        store int(mtime/10000) to hr1
        store int(mtime/100)-hr1*100 to minute1
        store mtime-hr1*10000-minute1*100 to second1
        store (hr1*60+minute1)*60+second1 to time1
        skip
```

```
do while not eof()
        store dlongitude to y2
        store dlatitude to x2
        store time to mtime
        store int(mtime/10000) to hr2
        store int(mtime/100)-hr2*100 to minute2
        store mtime-hr2*10000-minute2*100 to second2
        store (hr2*60+minute2)*60+second2 to time2
        store recno() to thisone
        store 0 to mdist
        do gcdist with y1,x1,y2,x2,mdist
        mspd=60*60*mdist/(time2-time1)
        repl record thisone-1 ornlspeed with mspd
        goto thisone
        store dlongitude to y1
        store dlatitude to x1
        store time to mtime
        store int(mtime/10000) to hr1
        store int(mtime/100)-hr1*100 to minute1
         store mtime-hr1*10000-minute1*100 to second1
        store (hr1*60+minute1)*60+second1 to time1
        if not eof()
           skip
        endif
enddo
repl ornlspeed with mspd
set talk on
Return

Proc gcdist
*  This procedure requires two geo-coded locations
*  and calculate the great circle distance in mile
*  and stored in GRTCIR
*
parameter LONGF,LATF,LONGT,LATT ,grtcir
grtcir = 0

* LATF,LONGF,LATT,LONGT, SNGL
phi1 = 0
phi2 = 0
theta = 0
omega = 0
half = 0.5
one = 1.0
one03 = 1.0033
p16 = 0.0016
p50= 0.0050
cosp1 = 0
cosp2 = 0
costh = 0
denom = 0
```

```
        factor = 0
        piconv = 0.01745329251994329576923 7
        rearth = 6367650.0

        * DABS,DBLE,DCOS,DARCOS
        phi1 = (latt - latf) * piconv
        phi2 = (latt + latf) * piconv
        theta = (longt - longf) * piconv
        denom = phi1+theta
        costh = cos(theta)
        cosp1 = cos(phi1)
        cosp2 = cos(phi2)
        omega = half * (cosp1 * (costh + one) + cosp2 * (costh - one))
        if omega > one
                Omega=one
        endif
        if omega < -one
                Omega=-one
        endif
        factor=one

        if abs(denom) < 0.0000000001
        else
                Factor = (theta * (one03 -cosp2*p16) + ;
                        Phi1 * (one - cosp2 *p50)) / denom
                If factor < 0.95 .or. Factor > 1.05
                        Factor=one
                Endif
        endif
        grtcir = acos(omega) * rearth * factor / 1609
        endproc


*******
*
*       CALCACC.PRG
*               To estimate lateral and longitudinal accelerations
*
*******
        para fname

        set talk off
        set deci to 6
        use &fname
        go top
        stor ornlspeed/3600 to s1
        skip
        do whil not eof()
                stor ornlspeed/3600 to s2
                 stor angle-90 to theta
                if angle<90
```

```
                    stor 270+angle to theta
          endif
*
stor (s2*sin(dtor(theta))-s1)*5280/32 to my
stor s2*cos(dtor(theta))*5280/32 to mx
repl x with mx, y with my
stor s2 to s1
skip
enddo
set talk on
return
```

APPENDIX D

STRAIN GAGE VERIFICATION

Strain Gage Verification Test

Method – Impose reproducible stresses on the trailer suspension and record the measured strain for comparison with other trailers and with records of the measurement for the trailer currently being tested.

Frequency – every six-to-eight weeks or a similar convenient interval.

Equipment required – tractor and (empty) trailer with data acquisition system installed; ramp capable of supporting the weight of the trailer safely, jack capable of lifting rear end of trailer till tandems are off the ground.

Procedure – On a level lot, drive the rig so that the tandem on one side of the trailer rides up onto the ramp and the tandem on the other side remains on (or just off) the pavement. Pause for a few seconds while the trailer wheels are on the top of the ramp. Then drive off the ramp. Repeat for the other side. Collect data during the drive onto the ramp, the pause at the top, and the drive off the ramp (total of a minute or less per side?).

With the jack, lift rear end of trailer till wheels are just off the ground. Measure strain gage readings with wheels just off the ground.

Download the data for transmission to ORNL for analysis.

Explanation – What we're trying to do with the ramps is to make first one side of the trailer suspension and then the other side take essentially all of the trailer weight. That will put a strain – first one way and then the opposite – in the suspension torque tube and check out the full-scale readings of the instrumentation. It's useful to keep the tractor and trailer lined up straight, so the tractor suspension has a consistent effect on the measurement.

What we're doing with the jack is making sure the strain in the torque tube is zero, by lifting the wheels so they just hang, and support no weight. That will check out the zero readings of the instrumentation.

If we repeat these measurements under essentially the same conditions at various times during the project, we can estimate how much the instruments might be drifting.

The web address of the ORNL data-download site is

ftp://128.219.40.110/

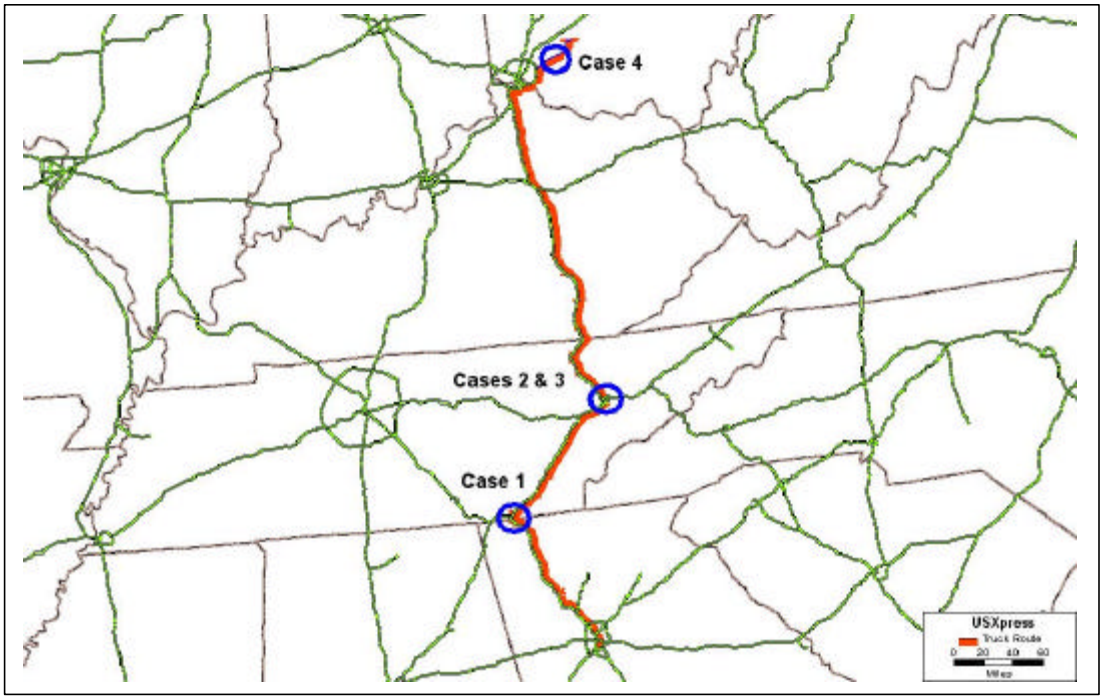
Files can be transferred to this site by standard drag-and-drop techniques.

APPENDIX E

CASE STUDIES OF LATERAL ACCELERATION IN SELECTED CURVES ALONG I-75

Case Studies of Lateral Acceleration in Selected Curves along I-75

Analyses of truck data for four specific locations along the corridor traveled by U.S. Xpress trucks were conducted to examine lateral accelerations at four curves along I-75. The figure below is a map that shows where each of these cases is located.



Locations of the four curves discussed in the case studies.

For each of the four cases, two graphs are presented. The first graph in each set shows lateral accelerations measured (in g) by the trailer instrument. The second graph of each set is a comparison of the "measured" lateral acceleration (i.e., reading from the instrument mounted on the trailer) and the "estimated" value (from GPS readings of time and location). The calculation assumes a "flat" roadway surface. It also contains "noise" due to stops (long time-gap with small location change) or some other reasons (short time-gap with big location change). Overall, the "measured" value is about half of the "estimated" value which indicates that the roadway design (e.g., elevation of roadway) at the location is doing a proper adjustment to reduce the impact from the turning force to the truck.

CASE 1. INTERSECTION OF I-24 AND I-75 NEAR CHATTANOOGA, TENNESSEE

The I-75/I-24 interchange at Chattanooga, Tennessee, was investigated. Typically, I-75 traffic from Georgia would take a turn of about 85E (1,000 feet turning radius) to the right at this I-75/I-24 junction before continuing to travel northbound. Case 1 – Figure 1 displays a Digital Orthophoto Quadrangles map by U.S. Geological Survey (USGS) at this area. A digital orthophoto is a digital image of an aerial photograph in which displacements caused by the camera and the terrain have been removed. It combines the image characteristics of a photograph with the geometric qualities of a map. The truck trajectory based on the onboard GPS reading is shown as a polyline in this figure. Lateral acceleration measurements collected from a northbound truck trip on I-75 are also shown. These lateral acceleration measurements have been adjusted to correct bias from instrument drift.

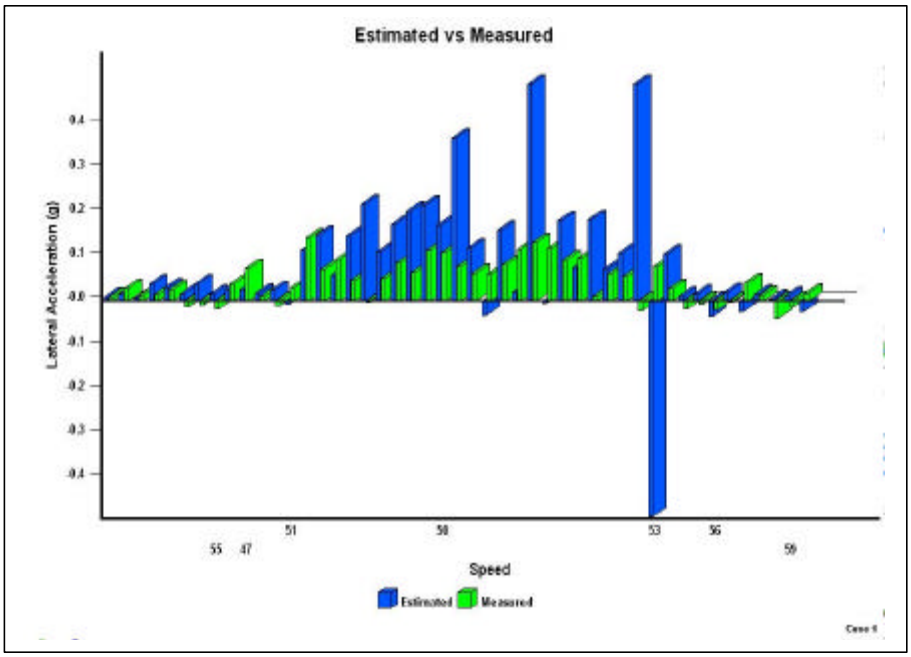
Case 1 – Figure 1. Lateral accelerations measured at the I-24/I-75 junction near Chattanooga, Tennessee.

These lateral acceleration readings range from -0.15g to +0.15g, where g is the earth gravity acceleration. Lateral acceleration should be near zero when a truck is traveling along a straight line. Its value can be negative or positive depending on the direction of a turn. In this figure, the size of a lateral acceleration measurement is reflected by the width of the line at that location. In order to have a thematic map that is sensitive to positive and negative values, the width of the line is drawn from the center and extended toward either side of the polyline, depending on the sign of the lateral acceleration. For example, a line would be drawn from the center and extended toward the right side of the polyline if the value of a lateral acceleration is positive (shown in yellow). The width of this line

would be proportional to the magnitude of that lateral acceleration. Note that the color light blue is used to indicate negative values in these maps.

Case 1 – Figure 1 shows that the onboard accelerometer recorded a significant increase in lateral accelerations when the truck negotiated the curve. The truck sustained the highest lateral acceleration (-0.16g) when it reached the "crown" of the curve. Further review of speed variations from this truck revealed that the truck was traveling at normal highway speed (around 65 mph) before reaching the curve. When it arrived at the curve, it decelerated and then reduced its speed to around 53 mph at the "crown" of the curve. The truck accelerated at a slower pace after coming out from the curve and resumed its normal highway speed.

A comparison of estimated and measured lateral accelerations for this location is presented in Case 1 – Figure 2. Lateral accelerations recorded by the accelerometer (i.e., measured) are shown in yellow. The estimated values calculated from the on-board GPS data as described previously are shown in blue. It is apparent that both series contain random variations in the data. Despite such random noises, one can still detect a general trend that estimated lateral accelerations are higher than those recorded by the trailer-mounted instrument. The difference is greatest when the truck is at the "crown" of the curve. At that point, the estimated lateral acceleration is over 60% higher than the recorded value.



Case 1 – Figure 2. Comparison of measured and estimated lateral accelerations for Case 1.

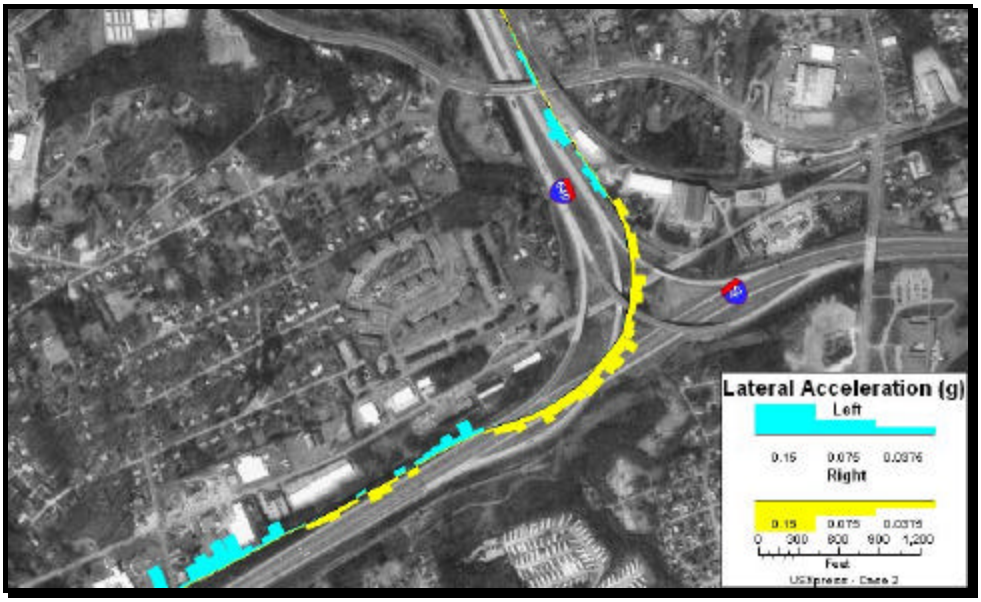
As stated previously, the estimation procedure used in this study assumed the truck was traveling on a flat surface. Therefore, a certain part of the difference between the estimated and the measured lateral acceleration can be viewed as an effect of the pavement geometry. A properly designed highway pavement should have super-elevation to facilitate negotiating the curve. It should be noted that the GPS receiver is mounted on the tractor and the accelerometer is mounted on the rear axle of the trailer. This would also contribute to the difference between the estimated and the measured lateral acceleration.

CASE 2. JUNCTION OF I-640 AND I-75 IN KNOXVILLE, TENNESSEE

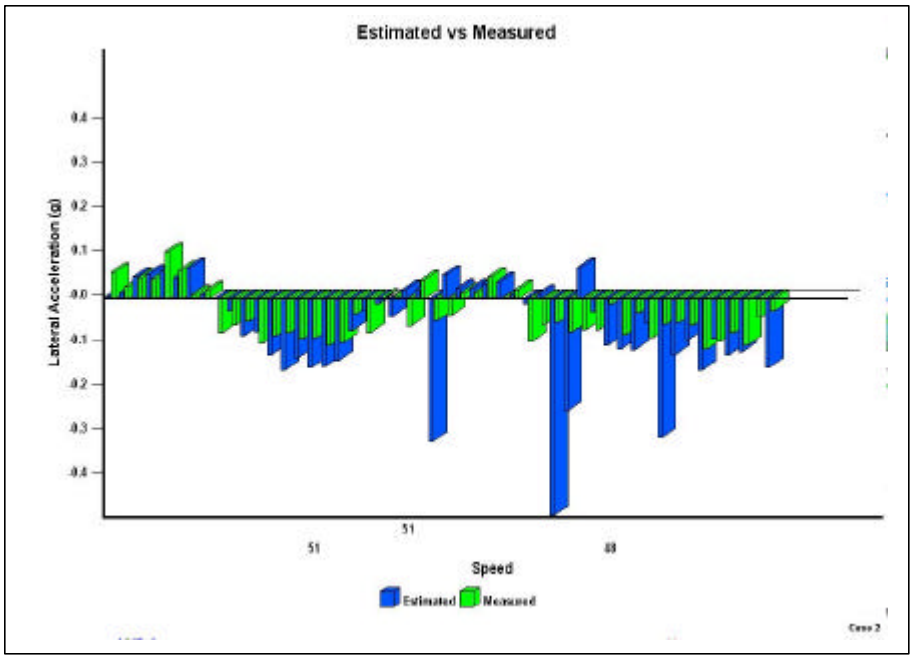
Case 2 – Figure 1 depicts the lateral accelerations recorded by the onboard accelerometer at the I-75/I-640 junction in Knoxville, Tennessee. The radius of this curve is approximately 1,150 feet, which is similar to the curve section at the I-75/I-24 interchange (see Case 1). The truck sustained its highest lateral accelerations (close to 0.1g) when it traveled at the “crown” section of this curve. The lateral accelerations sustained at this curve section are lower than those sustained at the curve of I-75/I-24 interchange.

This figure also shows that the truck sustained a series of positive, negative, and positive lateral accelerations before it actually entered into the “crown” section of this curve. This pattern of lateral accelerations might be caused by lane switching. The truck speed profile for this curve section is generally lower when compared to that around the I-75/I-24 interchange. This is consistent with lower lateral accelerations the truck sustained around this curve section. That is, a slower speed translates into a lower angular velocity and, thus, induces a lower centrifugal force that produces a smaller lateral acceleration.

Case 2 – Figure 2 presents the comparison of estimated and measured lateral accelerations for this curve section. It is apparent that there are quite a few outliers in the lateral accelerations estimated based on the GPS information (in blue). However, as in Case 1, the estimated values are higher than those that are measured. In other words, highway pavement at this curve section also has a super-elevation feature.



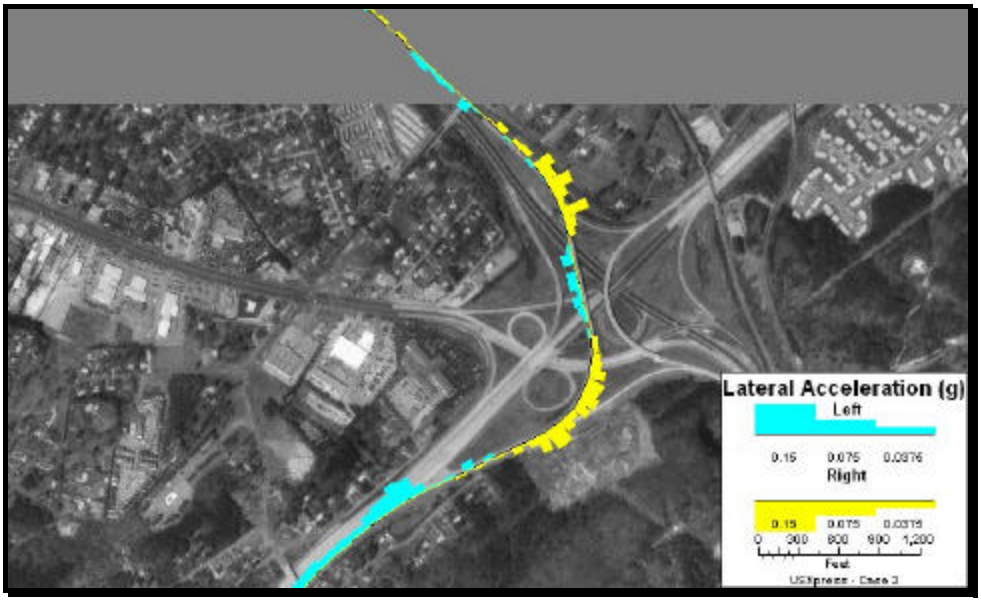
Case 2 – Figure 1. Lateral accelerations measured at the I-640/I-75 junction near Knoxville, Tennessee.



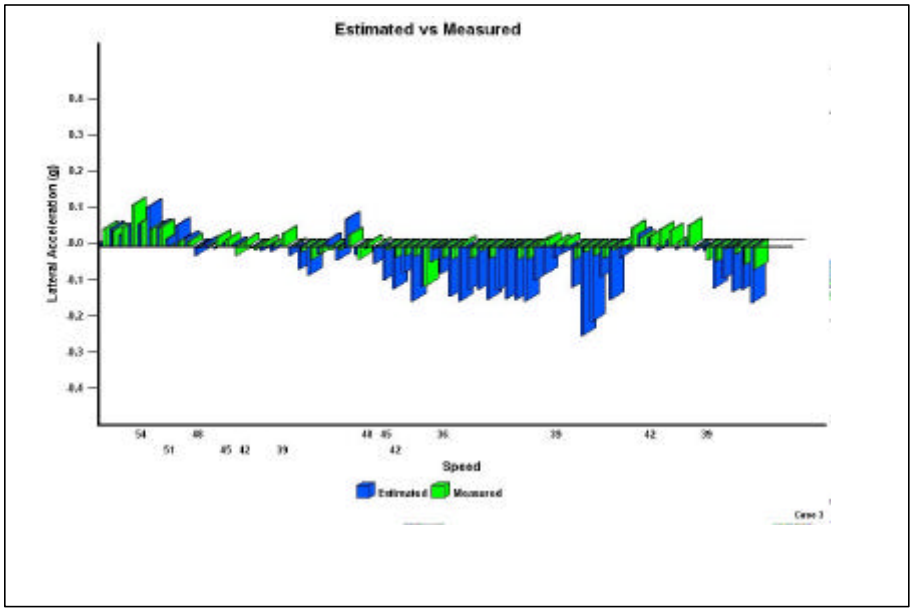
Case 2 – Figure 2. Comparison of measured and estimated lateral accelerations for Case 2.

CASE 3. JUNCTION OF I-640, I-275, AND I-75 INTERCHANGE IN KNOXVILLE, TENNESSEE

Case 3 – Figure 1 and Case 3 – Figure 2 display the lateral accelerations at the I-640/I-275/I-75 interchange, also in Knoxville, Tennessee. The major difference between this curve section and the curves of Cases 1 and 2 is that its turning radius is smaller (only about 725 feet). The highest lateral acceleration recorded by the onboard accelerometer at the "crown" section of this curve is around 0.11g. However, the truck slowed down to 45 mph to negotiate this smaller curve. The lateral accelerations estimated from the GPS data are much higher than those recorded by the onboard accelerometer.



Case 3 – Figure 1. Lateral accelerations measured at the I-640/I-75/I-275 junction near Knoxville, Tennessee.



Case 3 – Figure 2. Comparisons of measured and estimated lateral accelerations for Case 3.

CASE 4. "S" CURVE ON STATE ROUTE 28 NEAR BLANCHESTER, OHIO

The previous three cases focused on curves at intersections on interstate highways. The following case is an example of truck lateral acceleration on a state highway system. Case 4 – Figure 1 and Case 4 – Figure 2 display lateral accelerations at an "S" curve of State Route 28 just outside Blanchester, Ohio. This case provides a rare opportunity for studying truck lateral accelerations with respect to a "S" curve. The turning radius for these two curve sections are about 315 feet each, which are much smaller than those measured at the previous curves.

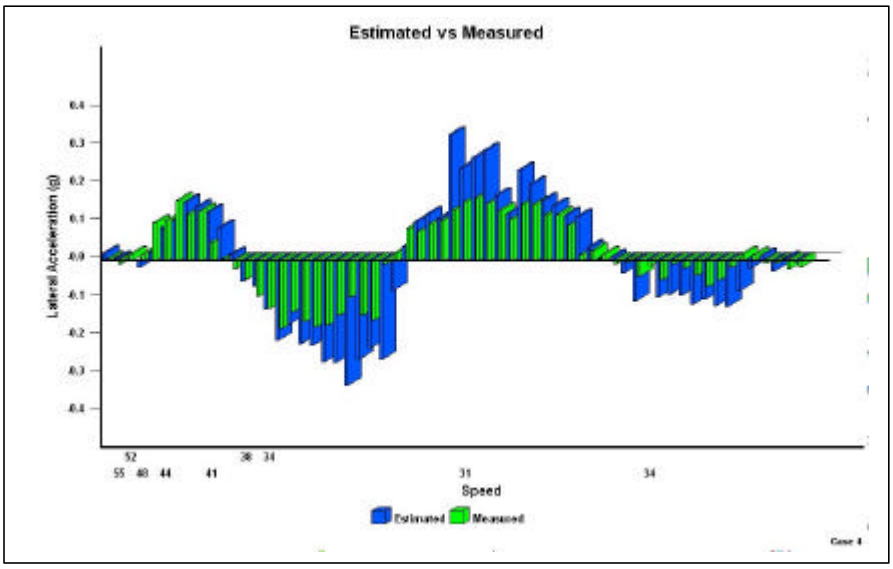
Also, the speed profile for this "S" curve is lower. The truck traveled at a speed around 50 mph as it approached the curve. As in Cases 1-3, the truck decelerated rapidly when it was a short distance away from the curve and slowed down to 35 mph when it was in the first "crown" section of the "S" curve. The truck continued to decelerate further and slowed down to 31 mph when negotiating the "crown" section of the second curve. The truck then resumed a speed of about 42 mph after it came out of the "S" curve.

The lateral accelerations recorded by the onboard accelerometer registered readings as high as 0.24g when the truck was in the "crown" section of the first curve of the "S." As the truck was slowing down and going to the "crown" section of the second curve of the "S," the lateral acceleration recorded was lower with the highest reading at 0.18g.

Different from a simple curve section, the truck sustained significant lateral accelerations just before, and also after, the "S" curve. At least at this particular location, two patterns

were apparent. Super-elevation features were present at both “crown” sections of the “S” curve; however, no super-elevation was present on highway pavements just before and after the “S” curve.

Case 4 – Figure 1. Lateral accelerations measured at an “S”-shaped curve near Blanchester, Ohio.



Case 4 – Figure 2. Comparison of measured and estimated lateral accelerations for Case 4.