DATA MANAGEMENT AT THE NATIONAL AIRPORT PAVEMENT TEST FACILITY (NAPTF)

By:
Charles A. Teubert
Galaxy Scientific Corporation
2500 English Creek Ave., Bldg. C
Egg Harbor Twp., NJ 08234-5562
(609) 645-0900, chuck.teubert@galaxyscientific.com
Fax: (609) 645-2881

David R. Brill
FAA William J. Hughes Technical Center
Airport Technology Research and Development Branch
AAR-410
Atlantic City International Airport, NJ 08405
(609) 485-8555, david.brill@tc.faa.gov
Fax: (609) 485-4845

Qingge Jia
Galaxy Scientific Corporation
(609) 485-5427 qingge.ctr.jia@tc.faa.gov
Fax: (609) 485-4845

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ABSTRACT

The Federal Aviation Administration's (FAA) National Airport Pavement Test Facility (NAPTF) began operation at the William J. Hughes Technical Center in April 1999. The quantity of data produced by this facility is estimated at 25 gigabytes per year. An important aspect of data management for the project was the implementation of a relational database system to receive the processed data. The Microsoft™ SQL Server™ 7.0 database not only facilitates quick retrieval of specific data sets, but also provides worldwide access to NAPTF data via the World Wide Web (WWW).

In the current NAPTF configuration of nine test pavements, data is acquired, processed, stored, and disseminated from over one thousand individual sensors using three data collection systems interconnected by wire and wireless local area networks (LANs). A description is given of the data flow from the acquisition, processing, population, and dissemination of the NAPTF database.

KEYWORDS

Data Acquisition, Database, Data Flow, Dissemination, Dynamic Data, NAPTF, Population, Processing, Static data, SQL Server.

INTRODUCTION

The National Airport Pavement Test Facility (NAPTF) is fully enclosed and contains nine instrumented test pavements (test items) that are 60 feet wide and total 900 feet in length. The rail-based test vehicle has two loading carriages that can be configured for up to six wheels per carriage with loads up to 75,000 pounds per wheel and is programmed for a controlled aircraft wander simulation [1].

Presently there are 1050 sensors installed in the pavement test items recording environmental and dynamic pavement responses in support of NAPTF operations. The quantity of data produced by this facility is estimated at 25 gigabytes per year and falls into four major categories:

Static Data. Each of the six flexible pavement test items has approximately five temperature and three moisture sensors to measure the environmental conditions of the pavement structure at different levels. Each of the three rigid-pavement test items has a similar amount of temperature and moisture sensors plus approximately ten resistance sensors to identify when the econocrete base (for the Portland Concrete Cement (PCC) slabs) cracks. The data from these sensors can be sampled every minute; however, in the current configuration, data are collected continuously at hourly intervals.

Dynamic Data. Each of the six flexible pavement test items has three sets of dynamic sensors consisting of multidepth deflectometers (MDDs), pressure cells (PCs), and asphalt strain gages (ASGs) that measure the pavement response to vehicle loads in each traffic lane and one MDD located midway between the traffic paths. Each MDD is an array of seven deflection gages located at depths ranging from 6 to 125 inches.

Each of the three rigid-pavement test items has three sets of dynamic sensors consisting of concrete strain gages (CSGs) and joint gages (JGs) that measure the pavement response to vehicle loads in each traffic lane and one joint gage located midway between the traffic lanes. Collection of the above data is triggered by vehicle movement on the test items at a sampling rate of 20 Hz (one sample per 0.05 sec). Approximately three data files are created for each test item for each vehicle pass.

Test Vehicle Data. Test Vehicle monitoring systems collect time; vehicle position along the track; skew moment, load and tire temperature ("log file") and carriage wander positions, module vertical positions and tire inflation pressure ('additional log") for each of the six modules for all vehicle operations. The sampling rate is also 20 Hz and vehicle log files are created every 10 minutes.

Other Data. Two falling weight deflectometer (FWD) devices were used to collect pavement data. A KUAB Model 150 with a segmented 12" loading plate and a pulse width of 27-30 milliseconds, provided by Engineering & Research International (ERI) equipment, was used for the initial evaluation of pavement uniformity, prior to traffic testing. The FAA is currently using a KUAB Model 240 heavy weight deflectometer (HWD) also configured with a 12" loading plate and a 27-30 milliseconds pulse width for ongoing pavement evaluations. These data are manually entered into the database; only asphalt item data are currently loaded into the database.

Summary and detailed data on Pavement Condition Index (PCI) surveys and Structural Condition Index (SCI), including the distresses and deduct values used to determine the indexes, will soon be manually entered into the database.

In November 2001, the NAPTF database exceeded 45 gigabytes and contained 9,631,172 dynamic data records representing 39,946 vehicle passes, 1,746,828 static data records, and 4,607 FWD tests.

SENSOR INFORMATION

An integral element of the data collection and processing system requires tracking of sensor identification, location, calibration data, installation information, and status. During construction of the test facility, a Microsoft™ Access™ database was created to facilitate the tracking of all sensor information and is used by personnel maintaining the instrumentation systems. It contains the sensor/gage ID, type, test item location, x, y, z coordinate location, computer and channel number, calibration information, status, and associated comments. The intersection of the western edge of the pavement test items and the centerline is defined as the origin. The x-direction is along the pavement centerline the y-direction is perpendicular to the pavement centerline and is positive in the southern direction. The z direction is positive beneath the surface. The test vehicle's north carriage is designated "carriage 1" and the south carriage is "carriage 2. " The three load modules on carriage 1 are designated load modules 1-1, 1-2, and 1-3 respectively. Load module 1-1 faces east, tire A is closest to the centerline. The three load modules for carriage 2 are similarly designated. Figure 1 depicts the test vehicle carriage/module nomenclature and coordinate system used to identify test vehicle and senor locations.

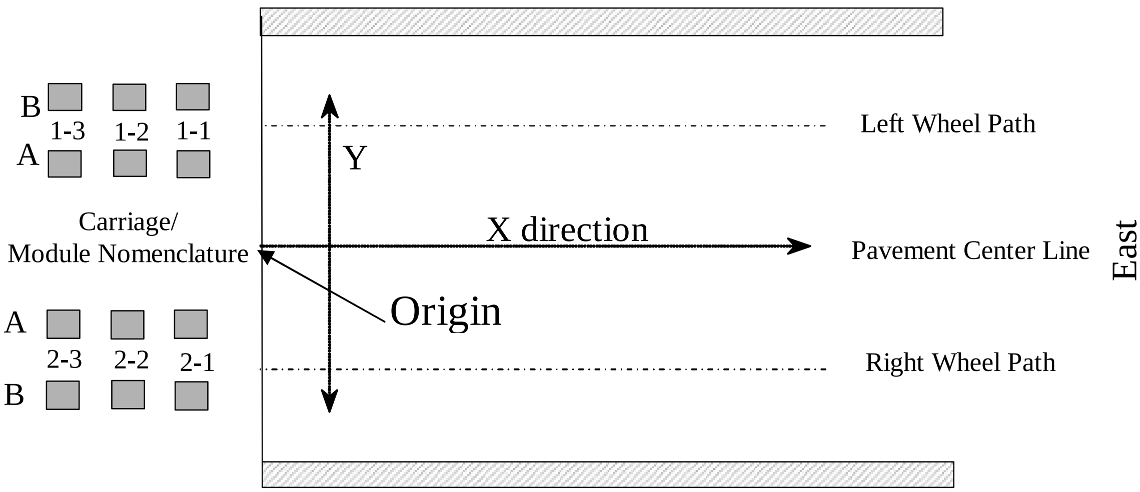

Figure 1. Coordinate Reference and Module Nomenclature

The sensor identification and location information contained in Access™ database depicted in figure 2 is used to create and update the signal processing units (SPUs) and MUX tables in the Microsoft™ SQL Server™ 7.0 NAPTF database. The calibration data and gage status information provide input for the data processing software.

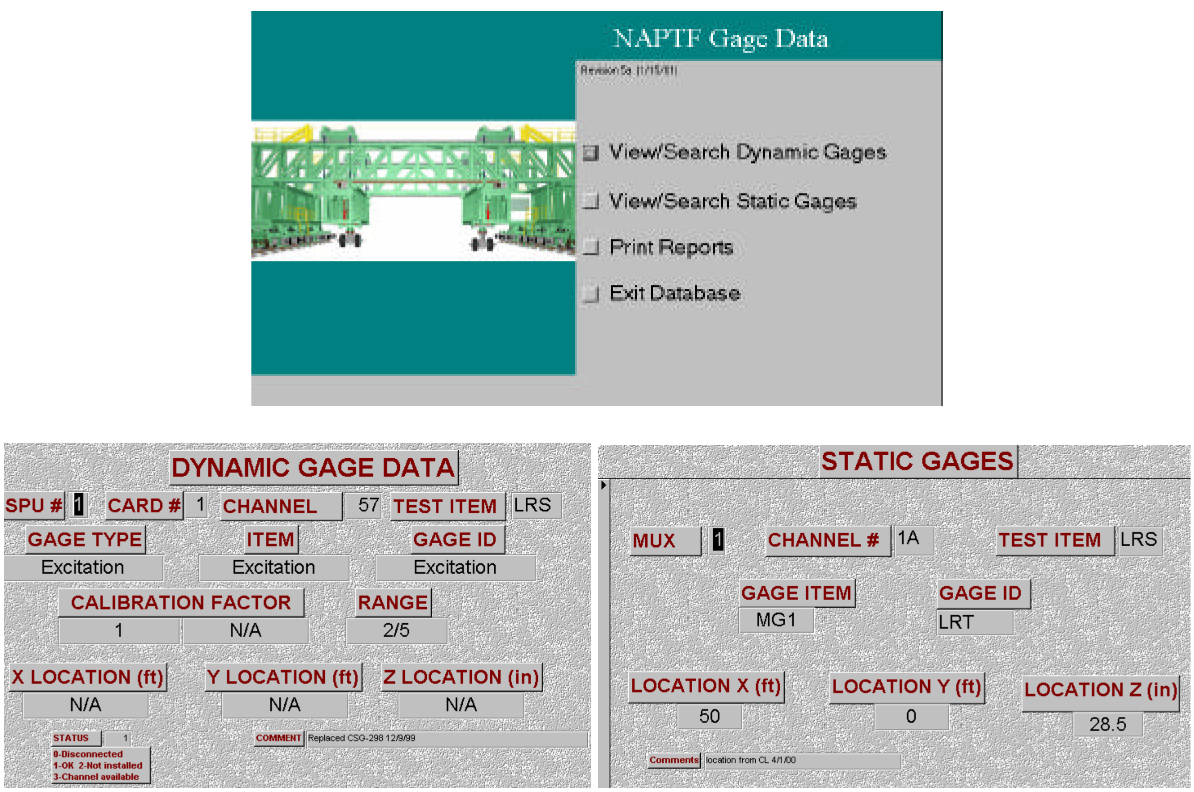

Figure 2. Sensor Information Database

DATA COLLECTION, PROCESSING, ARCHIVING, STORAGE, AND DISTRIBUTION

Figure 3 reflects the connectivity required to support the data collection, processing, archiving, storage and distribution of NAPTF data. The signal processing units and test vehicle computer are located in the test building, however, they can be monitored and/or remotely operated from the control room, located in the administrative building.

The SPUs are networked to the sensor control computer, "Main, " via a wire local area network (LAN). They can be remotely operated using remote control utility software. The test vehicle control computer, "NAPTV2, " is networked to the test vehicle control computer, "NAPTV1," via a wireless radio frequency (RF) link. The remaining control room computers; signal processing computer, "Data PC," data retrieval computer, "Archive PC"; and database server computer, "DBSEVR," are networked peer to peer. The test vehicle computer is used as the master clock to synchronize the system time.

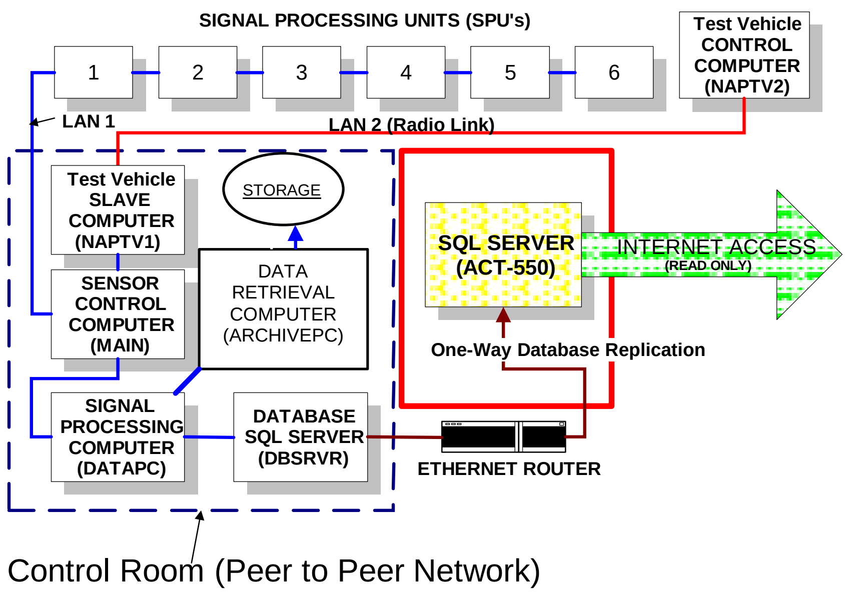

Figure 3. Data Collection, Processing, Archiving, and Distribution

DATA COLLECTION

Each of the sensors that respond to the test vehicle loads are monitored by one of six Hewlett Packard VXI Mainframe SPUs shown in Figure 4. Each SPU has a 133-MHz Pentium computer system card and three 64 channel scanner analog to digital converter (ADC) cards. Each rigid-test item has a dedicated SPU. Each pair of flexible test items (on a given strength subgrade) has a dedicated SPU. The system is capable of sampling at 100 KHz. However, the data sampling rate for the current operation is 20 Hz. Although monitored continuously, the response data from the sensors are only recorded when the SPUs are triggered on. This can be done manually from the sensor control computer "Main" in the control room for system checks and evaluation, however, the test vehicle is the primary trigger for dynamic data collection.

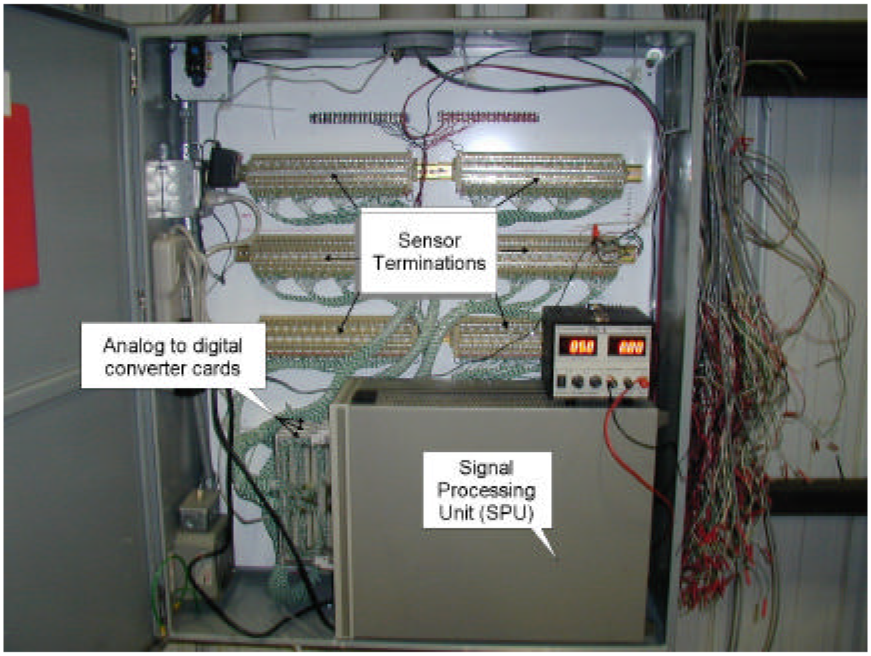

Figure 4. Sensor Terminations and Signal Processing Unit

A reflector is located on the test vehicle and infrared (IR) emitter-detector pairs are located between the rails that the test vehicle traverses. As the test vehicle moves, the vehicle reflector passes over the IR sensors, causing them to generate trigger pulses for an associated SPU to record data. The IR sensors can be moved in the longitudinal direction so that the recording time for the associated SPU can be varied. Figure 5 depicts the areas where the SPUs and IR sensors are located.

Figure 5. Test Vehicle, IR Sensor, and SPU Locations

When an ON trigger signal is detected, the SPU opens a binary file and stores the incoming data. When an OFF trigger signal is detected, the SPU stops storing the incoming data and closes the file. Three binary files are created for each vehicle pass by each triggered SPU and reflect the date/time, SPU number, A/D converter card number, and pass number in the filename. For example, sensor data for the fifth vehicle pass on February 14, 2000, would be recorded in three files on SPU1 as:

14 Feb 2000 ,08 -36 -07, s1c1p5.bin
14 Feb 2000 ,08 -36 -07, s1c2p5.bin
14 Feb 2000 ,08 -36 -07, s1c3p5.bin

The vehicle pass number only reflects the number of passes recorded by the SPU since it was last "booted", it does not reflect a total pass number. Each triggered SPU would have a similar set of three files; therefore, one vehicle pass on all nine test items would generate 18 SPU files.

Unlike the SPUs, when the test vehicle monitoring system is turned on, all data is recorded continuously. Both vehicle "log" and "additional log" files in ASCII format are created every 10 minutes. Test vehicle log and additional log filenames also reflect the date and time the file was created, formatted as YYYYMMDDHHMM. Vehicle log and additional log files associated with the above SPU files would have filenames like:

200002140830.log
200002140830 Additional Data.log

Vehicle operations and sensor responses can be monitored in real-time using the vehicle slave computer "NAPTF1" and a quick check software program running on "DataPC" for viewing and printing to a Microsoft Word™ document. The monitoring program displays sensor voltage output in relation to time, not vehicle location. However, since the vehicle log files are only created every 10 minutes, the data can only be processed in no less that 10 minute intervals.

DATA PROCESSING

Since the NAPTF uses two independent dynamic data collection systems (sensor and vehicle) recording at a rate of 20 samples per second, subsequent processing is necessary to provide the vehicle to sensor relationship and reduce the amount of overall data to a useful amount that can be accessed from an on-line database. The dynamic data are processed with a Visual Basic computer program, developed in-house. This program is similar to the data processing program for the runway instrumentation at the Denver International Airport described in reference [2]. The principal functions of the program are:

1. Read the binary data files produced by the sensor and vehicle data collection systems.

2. Converts sensor output voltages to engineering units according to calibration constants contained in the sensor information database.

3. Filter the data (where necessary).

4. Compute and display relevant sensor data, including sensor names, the magnitude of the primary peak, and the time at which the primary peak occurs.

5. Calculate the peak responses for all sensors and screen the peak responses to determine which peak values and peak records should be stored in eh database.

6. Plots a time-history of sensor responses (sensor record) for each traffic event.

7. Generate a SQL file for transferring the processed data to the NAPTF database.

8. Provide complete automatic processing of a batch of traffic events stored in a specified directory structure.

All vehicle movements and sensor responses can be viewed with the dynamic processing program. Figures 6 and 7 depict the program in a manual mode.

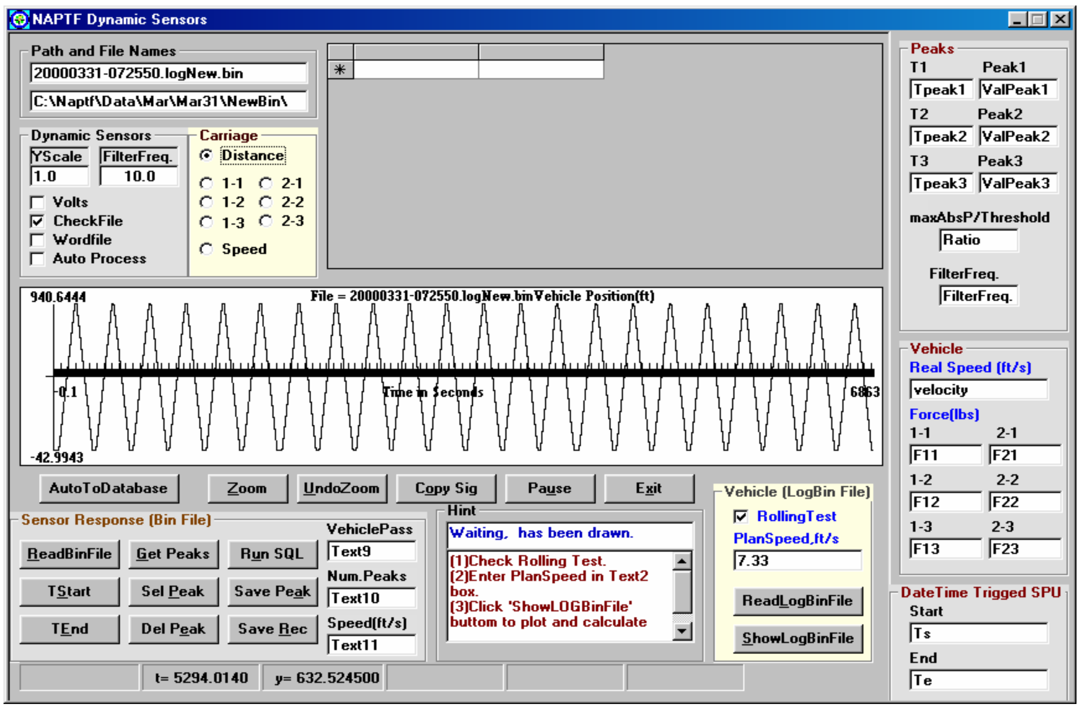

Figure 6. Vehicle Log File (Vehicle Movement of 44 Passes)

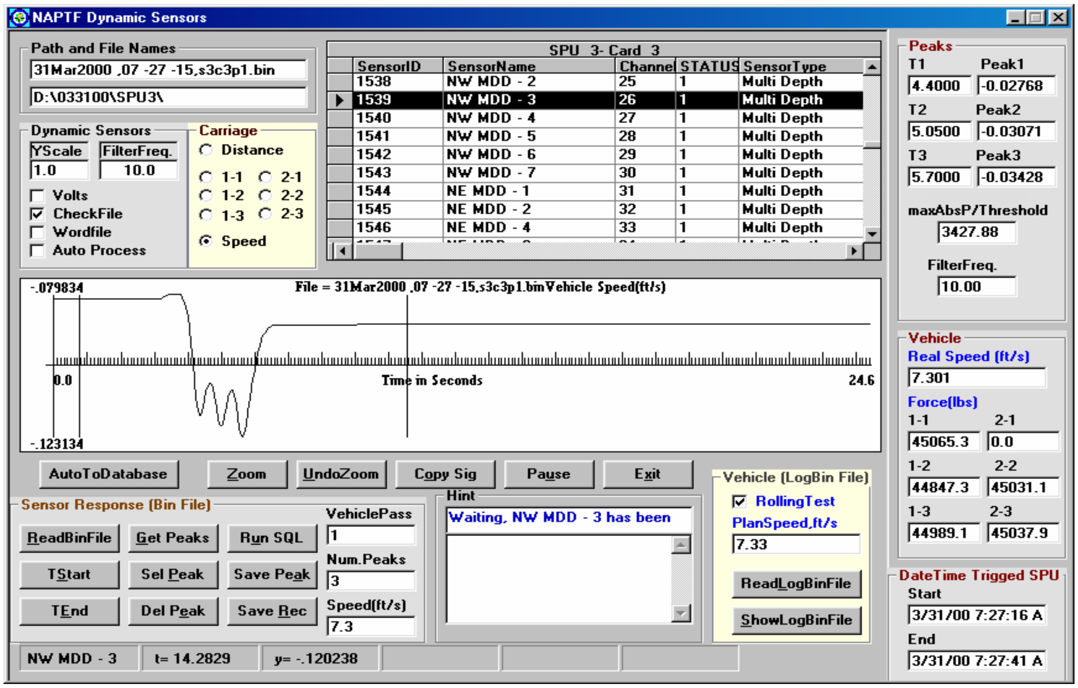

Figure 7. Dynamic Sensor Events (Multidepth Deflectometer Selected) for One Vehicle Pass

The most difficult procedure in the data processing effort is to collect and arrange all of the sensor files associated with the test vehicle operation to support analyses. As previously addressed, there are nine pavement test items which can (and have been) be trafficked independently. Therefore, each of the test items has a different number of vehicle passes associated with them. In order to distinguish vehicle movements between vehicle “passes” or “repetitions” on a particular test item, a vehicle traffic table was created to keep track of all vehicle “events” defined as the movement of the vehicle under load during traffic tests, regardless of the test item it traverses. Thus, the master key that establishes all of the relationships within the NAPTF database is the event number and all events are stored in the “Traffic” table.

For each event, the vehicle and SPU data is synchronized using the SPU trigger start and stop times (stored in the dynamic_data table), since the exact position of the vehicle is known, and a zero reference is created for calculating sensor response to vehicle location. The sensor responses are converted to engineering units using the sensor status and calibration factors read from a sensor database (SPU table) and the excitation voltages recorded during data acquisition. Figure 8 [3] represents the response of a concrete strain gage during one pass (event number 9) of the vehicle. The left and right ends of the curve correspond to the start and stop trigger times converted to a zero reference. Although the entire sensor event lasted 21 seconds not all of the recorded data is needed.

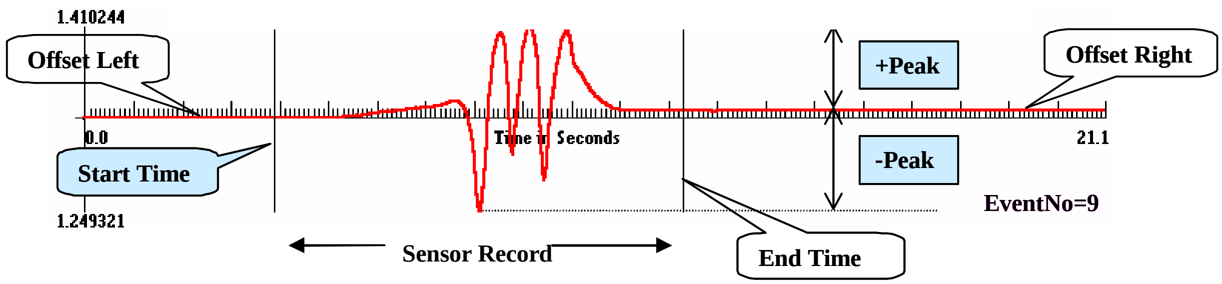

Figure 8. Sensor Event Reduced To Sensor Record

During automatic processing, the entire response is divided into three segments. The left and right segments indicate the sensor response as the vehicle approaches the sensor location and after the vehicle has passed the sensor location respectively. Their average responses are listed in “Offset Left” and “Offset Right” columns in Figure 9.

Sensor-ID	Test Item	Event Number	Record Start Time	Record End Time	Starting Vehicle Location x, ft	Ending Vehicle Location x, ft	Offset Left	Offset Right	Peak1 Time	Peak1	Peak2 Time	peak2	Peak3 Time	Peak3
CSG-265	HRS-1	9	2/14/00 09:58:36	2/14/00 09:58:44	627.53	689.1	1.33	1.337	5.2	0.0736	4.15	-0.088	0	0

Figure 9. Dynamic Table Sensor Record

The center segment contains the peak responses of the sensor when the vehicle is closest to the sensor location. The length of this part is about 40% of the length of the entire time history for this example (calculated as 20% either side of the first peak), but varies somewhat in other records depending on the type of sensor and its location in the test item. All data points from this section are saved as a sensor record stored as a comma delimited text string that can be downloaded and graphed. Since sensor records vary in length, the first value of the record identifies the total number of points in the record and the second value in the record identifies the time interval between samples.

The record start and end times are actual (local); however, the peak times are referenced from the zero reference and are computed from the Offset Right value in order to indicate a “recovered” response when there is permanent deformation between the Offset Left and Offset Right values. All additional information needed to analyze the dynamic data, such as the load magnitude and gear configurations, are read directly from the vehicle log files and are stored in linked database tables.

DATA ARCHIVING

The SPU data files are initially stored on the hard disks of the SPU computers. During automatic processing, a software program on the “ArchivePC” computer moves them and the vehicle log files to a daily directory each time the log files are created (every 10 minutes). During automatic processing, the files are read by the data processing software and then manually transferred to CD-ROM for safe keeping at a later time. If all test items are being trafficked, enough files are created to fill a CD-ROM each day. Two additional copies of the data are made for semiautomatic processing and quality control.

DATA STORAGE

As indicated above, all raw (preprocessed) data is written to CD-ROM. Reference and processed data is organized and stored in 13 database tables as follows:

Reference tables

Distress - Lists the standard distress types used to determine pavement condition index (PCI) and structural condition index (SCI).

Gear - Contains information about the configured loads, including number of tires per carriage, applied tire loads (nominal), and tire spacings (dual and tandem).

MUX - Contains information about the static sensors, including sensor type and location. (MUX refers to the multiplexer units, which acquire the static sensor data.)

SPUs - Contains information about the dynamic sensors, including sensor type and location. (SPU refers to the 6 *signal processing units*, which acquire the dynamic sensor data.)

Test_Item - Contains engineering data about the pavement test items, including the pavement type (rigid or flexible), layer thicknesses, and materials.

Track - Identifies the north and south carriage positions corresponding to the nine wander tracks.

Wander - Lists the track numbers and carriage positions corresponding to each sequence number in the wander pattern.

Recorded/processed data tables

Dynamic_data - Contains dynamic sensor responses, including peak values and full dynamic records.

Static_data - Contains hourly temperature and moisture readings.

Traffic - Contains information about the vehicle passes, including start and end times for each load event, gear configuration, applied loads (actual), and wander position. This is the master table for all traffic events.

<u>Survey data tables</u>

FWD - Contains falling-weight deflectometer (FWD) test data. FWD tests are conducted periodically on NAPTF test items to monitor changes in the pavement structural properties.

PCI_summary - Contains summary data on PCI surveys conducted on the test items.

PCI_survey - Contains detailed data on PCI surveys, including the distresses and deduct values used to determine the PCI.

Figure 10 depicts the relationship(s) of the NAPTF database tables.

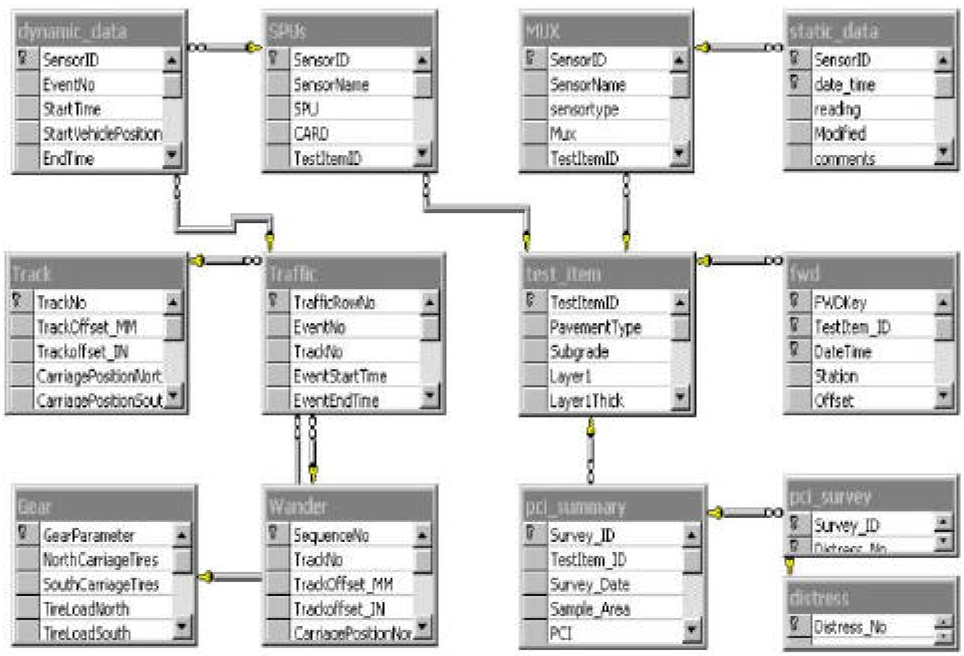

Figure 10. NAPTF Database Table Relationships

DATA DISTRIBUTION

Since the control room computers have access to the test vehicle and the triggering of the SPUs, in the test area, the control room network is isolated from all other networks at the Federal Aviation Administration (FAA) William J. Hughes Technical Center and are only accessible from the control room. Additionally, the FAA William J. Hughes Technical Center requires all Internet servers to be protected by a firewall and located inside an area designated the DMZ.

The computer that stores the NAPTF database "DBSRVR" is connected to a FAA Internet server, inside the DMZ, with a one-way connection via a router and the database residing on DBSRVR is replicated on the Internet server. Access to the Internet server requires a username and password to logon and a special port to replicate the database. Several Sequential Query Language (SQL) procedures actually do the replication by synchronizing the two databases automatically. Replication can be initiated manually but it is scheduled to automatically occur weekly. The data can then be accessed via the FAA, Airport Technology Research and Development Branch website: http://www.airporttech.tc.faa.gov/NAPTF. Through this website, users can query by forms, as depicted in Figure 11, or manually query the database with SQL.

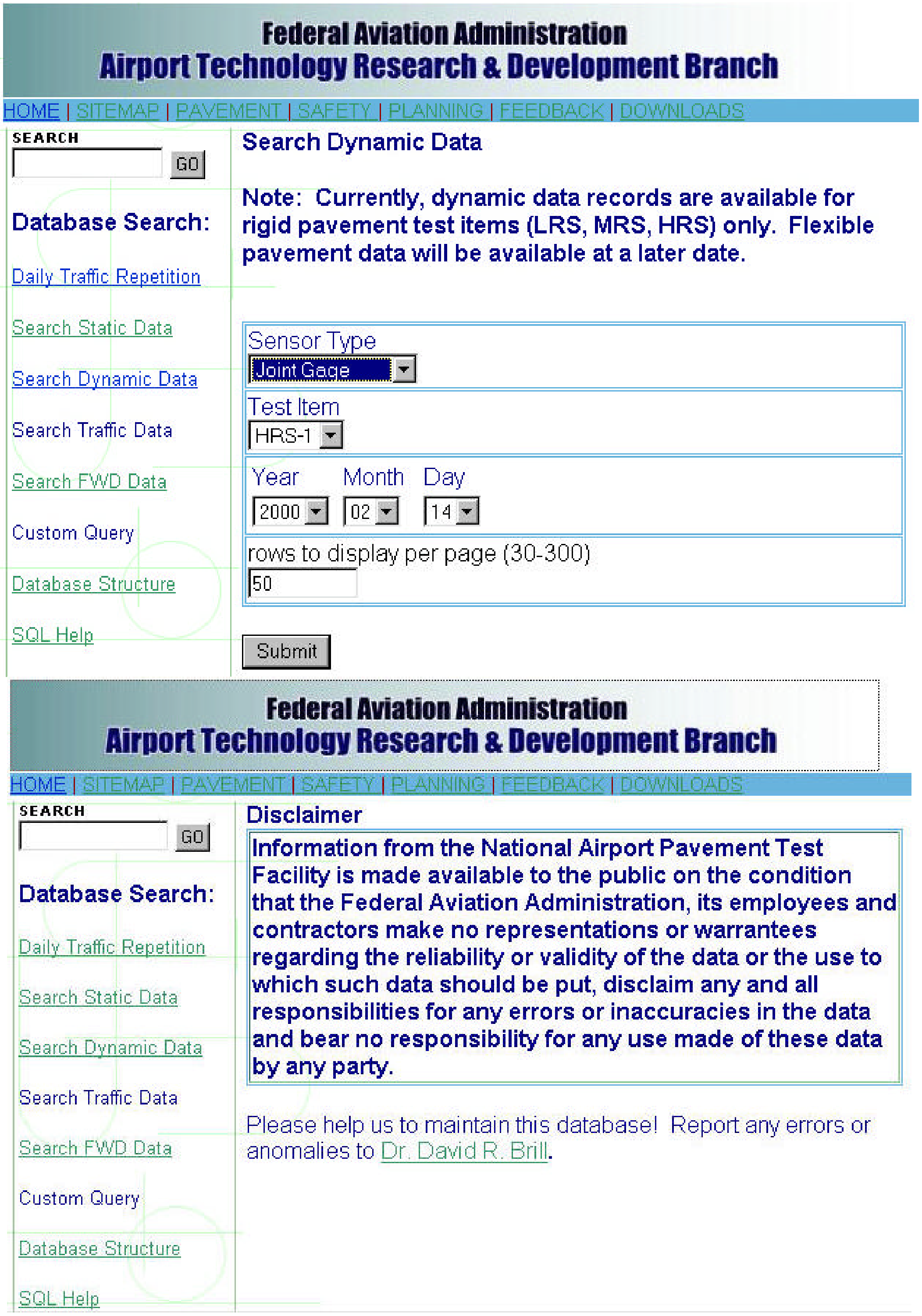

Figure 11. Data Distribution Via FAA Website

SUMMARY

The NAPTF is comprised of three major data acquisition systems that independently collect a substantial amount of environmental, test vehicle, and pavement response information. The data from each of these systems must be properly acquired, organized, processed, correlated, stored, and disseminated to a multitude of researchers worldwide to support the FAA's airport pavement research program. A description of the FAA's program, full-scale test facility, and information management efforts can be accessed from the Internet at www.airporttech.tc.faa.gov/naptf.

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