Development of a Personal Digital Assistant-based (PDA) Hot-Mix Asphalt (HMA) Data Entry Program for Connecticut DOT “SUPERPAVE” Paving Projects

FINAL REPORT

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June 2005

HPR-2228

Report Number
2228-F-04-10

Connecticut Department of Transportation
Bureau of Engineering and Highway Operations
Office of Research and Materials

Keith R. Lane, P.E.
Director of Research and Materials

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. 2228-F-04-10	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle Development of a Personal Digital Assistant-based (PDA) Hot-Mix Asphalt (HMA) Data Entry Program for Connecticut DOT "SUPERPAVE" Paving Projects		**5. Report Date** May 2005 **6. Performing Organization Code** SPR-2228
7. Author(s) Richard C. Hanley, P.E		**8. Performing Organization Report No.** SPR-2228
9. Performing Organization Name and Address Connecticut Department of Transportation Office of Research & Materials Division of Research 280 West Street Rocky Hill, CT 06067-3502		**10. Work Unit No. (TRIS)** **11. Contract or Grant No.** CT Study No. SPR-2228 **13. Type of Report and Period Covered** Final Report September 2000 – June 2005
12. Sponsoring Agency Name and Address Connecticut Department of Transportation 2800 Berlin Turnpike Newington, CT 06131-7546		**14. Sponsoring Agency Code** SPR-2228

15. Supplementary Notes

A research project conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration (FHWA).

16. Abstract

The objective of this project was to develop and implement a PDA-based data collection system. This system would be an accurate, convenient and cost-effective alternative to traditional paper/pencil or computer spreadsheet data recording systems. The resulting system would be used in the daily operations of the Department's HMA quality inspection and assurance activities.

17. Key Words	**18. Distribution Statement**
Personal digital assistant, PDA, Palm computer, hot-mix asphalt, Superpave, testing	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA.

19. Security Classif. (Of this report)	**20. Security Classif.(Of this page)**	**21. No. of Pages**	**20. Price**
Unclassified	Unclassified	46	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

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ACKNOWLEDGEMENTS

The author wishes to acknowledge the support of both the Federal Highway Administration and the Connecticut Department of Transportation. The author wishes to acknowledge Ms. Michelle LaQuerre, Mr. Hiren Parmar and Ms. Jing-Rong Wang for their programming and training expertise, without whose computer programming expertise this project would have never been completed. The author also wishes to acknowledge Mr. John Whitbeck and the following Connecticut Department of Transportation inspectors: Mr. Michael Antoniak, Mr. Thomas Bauer, Mr. Andrew Bednar, Mr. Jonathan Boardman, Mr. Michael Cruess, Mr. Ronald DeMatties, Mr. James Doughty, Mr. Michael Emmerich, Mr. Stephen McDuell, Mr. Donald Noto and Mr. Shawn Smith.

METRIC CONVERSION

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

LIST OF ABBREVIATIONS AND ACRONYMS

ConnDOT	Connecticut Department of Transportation
Department	Connecticut Department of Transportation
FHWA	Federal Highway Administration
Graffiti™	Handwriting recognition used Palm PDA
HMA	Hot Mix Asphalt
IT	Information Technology
MatTest DB	Materials Testing Database, where all test results are maintained
Palm	PDA Manufacturer
Palm OS	Palm Corporation Operating System (Version 4.0)
PC	Personal Computer
QA	Quality Assurance
QC	Quality Control
PDA	Personal Digital Assistant handheld device
State Lab	Connecticut DOT Materials Testing Laboratory
SUPERPAVE	“SUperior PERforming Asphalt PAVEments”
TCO	Total Cost of Ownership
TLCO	Total Lower Cost of Ownership
Vendor Lab	HMA On-Site Laboratory maintained by vendor

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Hot-Mix Asphalt (HMA) Data Entry Program for

Connecticut DOT "SUPERPAVE" Paving Projects

INTRODUCTION

During 2001, the Connecticut Department of Transportation (ConnDOT) began a research project to evaluate Personal Digital Assistant (PDA) use in the daily operations of ConnDOT's Hot-Mix Asphalt (HMA) materials testing and quality assurance activities. It was believed the resulting system would be an accurate, convenient and cost-effective alternative to traditional paper/pencil or computer spreadsheet data recording systems. PDA's would not require the use of expensive portable computer equipment that was not hardened for the harsh construction environment. Finally, they would provide a structured data management process for synchronizing field and laboratory inspection data. This would be accomplished by automatically transferring field data into ConnDOT's Materials Testing Database (MatTest DB) and then correlating that data with laboratory data collected from the same projects.

Figure 1. Typical HMA Plant

In addition, inspector scheduling, job mix formula (JMF) and associated vendor data could be uploaded to a PDA for use by inspectors in the field.

BACKGROUND

Materials Testing services a large annual construction and maintenance program. Under existing processes, HMA testing was performed by state inspectors at field plants and at the Connecticut DOT Materials Testing Laboratory (State Laboratory). The inspector would perform tests, typically recording data on scrap paper during the testing process. Once completed, the inspector performed manual calculations using the raw data and transferred the results to the bubble sheet for data entry. Samples and bubble sheets were returned nightly to the State Laboratory in Rocky Hill, CT. The following business day, these samples would undergo additional testing at the Rocky Hill Facility, where the results would be coded on the associated bubble sheet in a similar manner to the process previously described. The resulting bubble sheet would then be scanned and the data incorporated into the master Materials Testing database.

Figure 2. Typical HMA Field Lab

PROBLEM STATEMENT

The testing, collection, recording and reporting of HMA test data is a very structured, manual process. There is a continuing need to improve Department processes. There was a need to examine whether the process could proceed more quickly and accurately through refinements in the data-recording and management portion of the process. Further automation was perceived to aid in complex calculations, provide better background information, synchronize field and office data collection, and improve communication and scheduling of HMA inspectors.

OBJECTIVES

The primary objective of this project was to develop and implement a PDA-based data collection system. The effort would examine the accuracy, convenience and cost-effectiveness of this alternative to traditional paper/pencil or computer spreadsheet data recording systems. If successful, the resulting system would be used in the daily operations of the Department’s HMA quality inspection and assurance activities.

METHODOLOGY

The project was divided into several phases as listed below:

1. A user needs statement of project features and functionality would be developed;
2. A technology review would be performed relating to the use of PDA’s in construction materials testing;
3. Evaluation criteria would be developed for selecting a PDA hardware and software platform for the development of software;
4. A systems analysis and review of the existing materials testing procedure would be performed;
5. The selected products would be used to develop a prototype system;
6. The system would be field-tested and modified per user requirements;
7. Implementation of the final version would be rolled out into full production, including the development of standard operating procedures; transitional support by Research personnel until appropriate technical, personnel and financial resources were obtained; and
8. A final report on the research would be authored and published.

PHASE 1 – USER NEEDS INVESTIGATION

From discussions with management, supervisory and line personnel, several needs were identified for project inclusion:

- Scheduling – scheduling a crew of almost a dozen inspectors for their next day's assignments was time-consuming. Each inspector had to be verbally contacted and instructions passed to him or her. Since ConnDOT had a large night paving operation, this posed several problems. First, it was both inconvenient for 2nd shift inspectors being scheduled by 1st shift supervisors. The supervisor would typically spend most of the last hours of his shift giving inspectors instructions for the coming shift. In addition, sometimes inspectors could not be contacted, so they might end up on the wrong job;
- Accuracy - Inspectors were manually performing calculations for several key fields of the inspection report, a process sometimes subject to error. The JMF for different paving jobs was typically different from project to project, or between multiple sources, or even changed part way through a job;
- Inspection Continuity & History – Already in data files were historical data about the vendor's performance, which inspector's could use but was not readily available to the inspector, i.e. previous test results, compliance problems, etc. It was proposed these data be uploaded for inspector usage. If an inspector was new or filling in on a job, they might not have access to data from previous days;
- Cost – the PDA technology possibly promised lower initial and operating system cost outlay than a fleet of portable computers. In addition, the equipment would be "interchangeable" such that if one unit broke, another unit could quickly and easily be placed into service; and

- Technology Assessment – the PDA technology had not been evaluated for Department usage. This project would identify the level of effort required to develop, maintain and operate PDA-based applications, as well as the product versatility and endurance in adverse conditions.

PHASE 2 - TECHNOLOGY REVIEW

A technology review was performed on PDA technologies. Many information sources had touted the advantages of PDA-based computer technologies. When the project was initiated, the PDA platform was a relatively new technology, having evolved during the late 1990’s. Two main technologies were available at that time, one offered by Palm Computer using the Palm Operating System (Palm OS) and one offered by Microsoft Corporation using Windows CE/Pocket PC operating systems. Each brand presented individual benefits and drawbacks (see Table 1). Ultimately, a Palm-based technology was selected. Ultimately, this quote from the November 5, 1999 issue of PC Magazine summed up the selection process:

> *Although many users admire the Windows CE … greater standard functionality compared with Palm devices, which is due to Windows CE’s built-in applications, larger memory capacity, and familiar Windows-like interface, the Palm-family devices boot faster, open applications and find data quicker, and have much longer battery life than their Windows CE counterparts.*

These comments summarized observations of the project staff.

Table 1. Palm vs. Windows CE Technology

	Palm	**Windows CE**
Hardware and Software Cost per User	$250/unit	$600/unit
Power Utilization Rate	9-12 hours/charge	4-6 hours/charge
Hardware Manufacturers	Palm, Handspring	Compaq, HP
Operating System	Version 4.0 – stable	Version 1.0 – unproven
Programming Environment	Satellite Forms, Pendragon Forms	Visual Basic (promised), Pendragon Forms

PHASE 3 – PDA EVALUATION CRITERIA

Since PDA's were new technology to the Department in 2001, a set of criteria relating to their relatively new technology, cost, maintenance, operation and organizational placement were developed. These are listed in Table 2. Evaluation of these criteria was performed by the project engineer, construction inspectors, managers and data processing personnel.

Table 2. PDA Evaluation Criteria

- Technological
  - PDA Hardware
    - Platform
      - Reliability
      - Durability
      - Screen Visibility
      - Screen Size
      - Overall Size
  - Software
    - Operating system
      - History
      - Stability
    - Development environment
      - Versatility
      - Ease of Development
    - Synchronization process
      - Complexity
      - Reliability
      - Recovery
- Manufacturer
  - History
  - Core Business Strategy
  - Financial Stability
- Financial
  - Initial Cost
  - Replacement Cost
  - Operational Cost
  - Total Cost of Ownership
- Organizational
  - Technical Support
  - Repair and Replacement

While evaluating units at the time of purchase, Department personnel visited local retailers to review each hardware platform. Ultimately, several factors led to the selection of the Palm platform:

- Initial and Replacement Equipment Cost – ConnDOT management wanted a platform that was not extremely expensive, so if the unit was lost or damaged the replacement cost would be minimal;
- Equipment and corporate performance record – this assessed the overall history of the company supplying hardware, along with its stability and innovative potential. The units ability to provide a stable operating system environment was also important;
- Total Lower Cost of Ownership (TLCO) – the concept of low-priced equipment was embraced, but the overall cost of ownership of the system was considered, as is presented in Table 3 and Appendix G:

Table 3. Total Cost of Ownership - Palm vs. Windows CE

	Palm	Windows CE
Hardware Cost per User	$250/unit	$600/unit
Software Fixed Cost (1 User)	N/C Runtime License $35 Print Utility	$200 Runtime Library $30 Print Utility
Software Marginal Cost (Each Additional User)	N/C Runtime License $35 Print Utility	$20 Runtime License $30 Print Utility
Support Software Cost Per Developer	$995/developer	$495/developer
Total Cost of Ownership (TCO)	$285/first user $285/additional user	$830/first user $650/additional user

Costs considered included software development, operating system licensing and maintenance, hardware upgrade/replacement, software development environment and development costs, host side licensing, and maintenance and enhancement costs; and

- Minimal Information Systems personnel support – during project design and continuing forward, Information Systems personnel were in short supply within the organization. The system should be simple and easy to use, with little or no maintenance and programmed routines for performing all operational and maintenance tasks.

Palm Corporation's Palm Pilot IIIc unit running the Palm Operating System (Palm OS) was chosen over Handspring, Compaq, HP, and several others of Pocket PC-based systems as the PDA hardware platform.

Figure 3. Palm IIIc PDA

Pumatech's Satellite Forms was selected as the PDA software platform. Primary selection factors included the lower initial cost of units; lowest Total Cost of Ownership (TCO); the robustness of Palm OS vs. the just-released Microsoft Pocket PC Operating System; and simplicity of systems development and management with the Satellite Forms platform. In addition, as development progressed, Satellite Forms was improved to support both Palm OS and Pocket PC platforms from the same application source code, thus improving its versatility.

PHASE 4 – SYSTEMS ANALYSIS/DESIGN FOR QUALITY CONTROL (QC) WORKFLOW

The task of systems analysis and design fell into several different areas. These included the following items:

1) Definition of a workflow accommodating Superpave testing procedures in the field and office for both data and HMA samples;
2) Creation of PDA-based field and laboratory data collection program to collect and calculate HMA sample data;
3) Development of Windows-based support programs to handle:
   a) inspector scheduling by office supervisors;
   b) background vendor data transfer from the MatTest DB to the PDA;
   c) updates to JMF tables by plant and job updates; and
   d) electronic communication between office and field personnel.
4) Synchronization of field data with corresponding laboratory data; and
5) Integration of field and laboratory data with the MatTest DB.

Discussion of workflow for HMA samples and data was the first item. To date, the Department had used the Marshall mold process to test field HMA samples but wanted to modify existing operations to handle an impending conversion to Superpave-related HMA testing procedures. Existing procedures for the Marshall testing methodology are described in the **BACKGROUND** section listed earlier in this document. The result was a workflow design that allowed the PDA program to track all data as it was acquired by field inspectors, transfer it back to the laboratory, correlate additional laboratory testing data, and save the results to the MatTest DB (see Figure 2). In addition, data for scheduling, vendor performance, JMF and other inspector communications would be uploaded to the PDA's. Ultimately, the systems design called for five major programming components. These were authored by Computer Science cooperative education students employed by the Department, and included the following:

- FieldData – PDA Program used by field inspectors to enter field test data and return to laboratory for next stage of data collection.
- FieldSetup – PC Program used by office supervisor to perform assignments and maintenance for field inspectors using FieldData.
- FieldTransferMultiuser - PC program used to support the synchronization of data with the field inspector PDA's.
- LabData – PDA Program used by laboratory personnel to retrieve test data for field samples and complete the testing sequence.
- LabTransfer - PC program used to support the synchronization of data with the laboratory personnel PDA and prepare data for final insertion into the MatTest database.

The first program component, FieldData, was a field data collection program for use by the inspectors in the field laboratories. It was designed to be a menu-driven, multiple-choice process where data were entered into the PDA program automatically and the required calculations were performed. The program also would make past vendor performance tests and JMF data available to the inspectors as needed. If any data element appeared out of spec, it was automatically highlighted on the PDA screen for investigation.

The second program component, FieldSetup, was for use by the inspection supervisory staff to schedule testing; review test findings; manage electronic data transfer between to the Testing Laboratory databases upon the inspectors return to the lab; and reformat data for electronic transfer to a Pending Test database upon the inspectors return to the lab. The program would also flag the returned sample as one that Laboratory personnel could now perform in-house testing upon since the sample was now physically returned to the Laboratory.

Also used in this synchronization sequence was the program called FieldTransferMultiuser. This program allowed the office supervisor to schedule inspectors for different plants, change JMF data, communicate electronically with the inspector and coordinate other inspection and testing activities.

Next, the LabData program was used by State Laboratory personnel to collect further test data on the HMA samples. This program, a modified version of the FieldData program, was designed such that test data already collected from the field could be retrieved from a Pending Test database, loaded into a PDA used by State Laboratory personnel where additional tests completed or previous test data reviewed, and the results downloaded into the Pending Test database where they would be incorporated into the MatTest database.

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Figure 4. Quality Control (QC) PDA Workflow

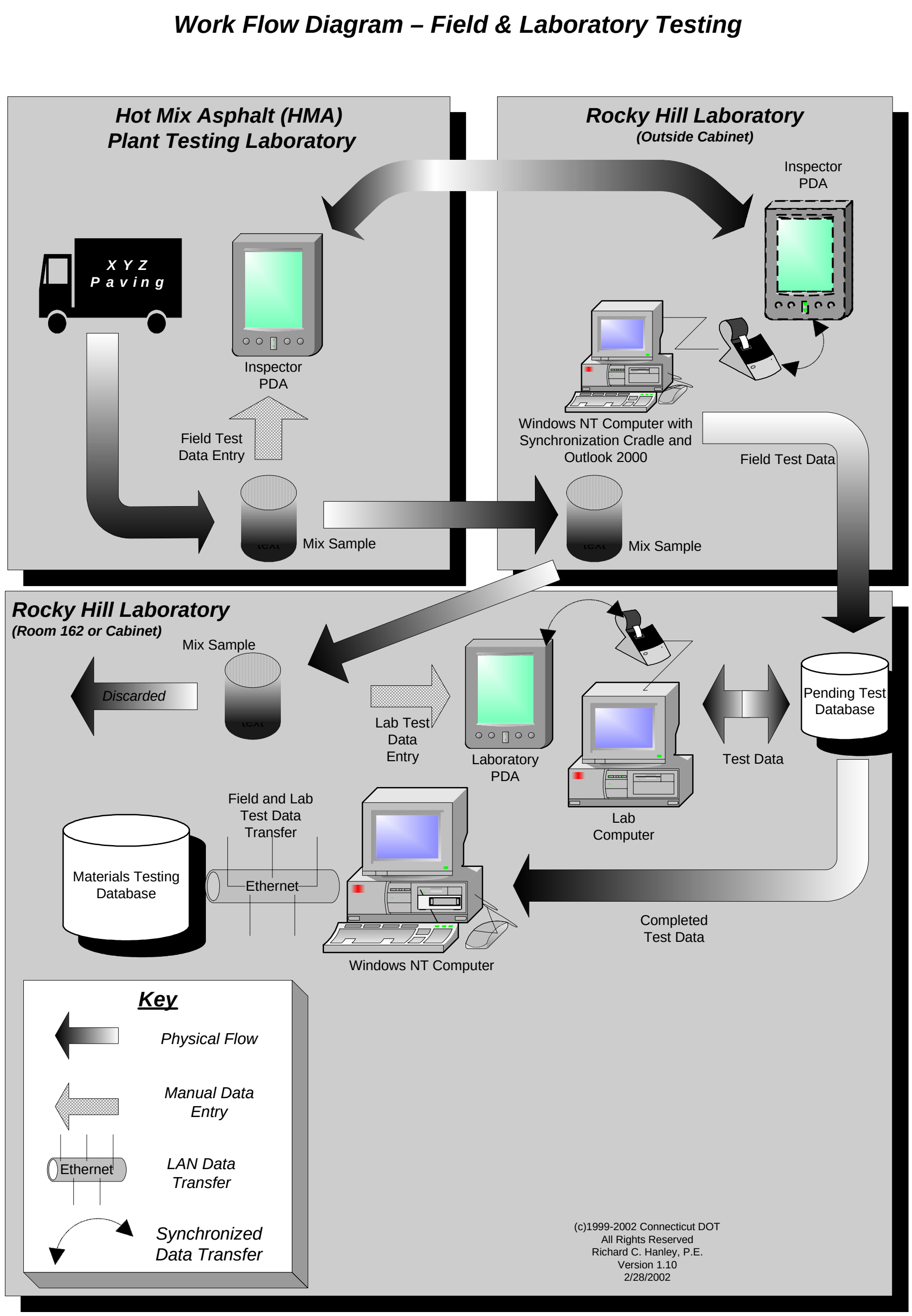

Figure 5. Workflow Schematic for FieldData PDA Program

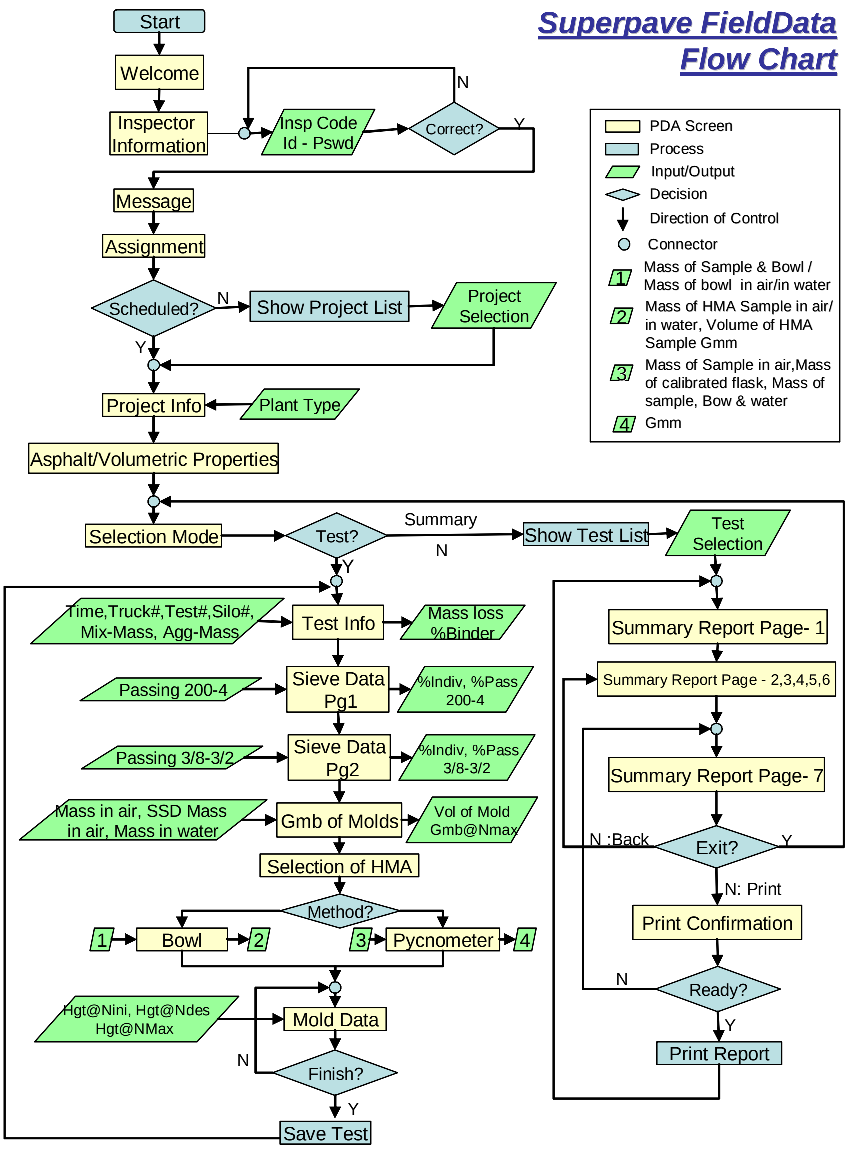

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Figure 6. Sample Data Entry Screens from FieldData PDA Program

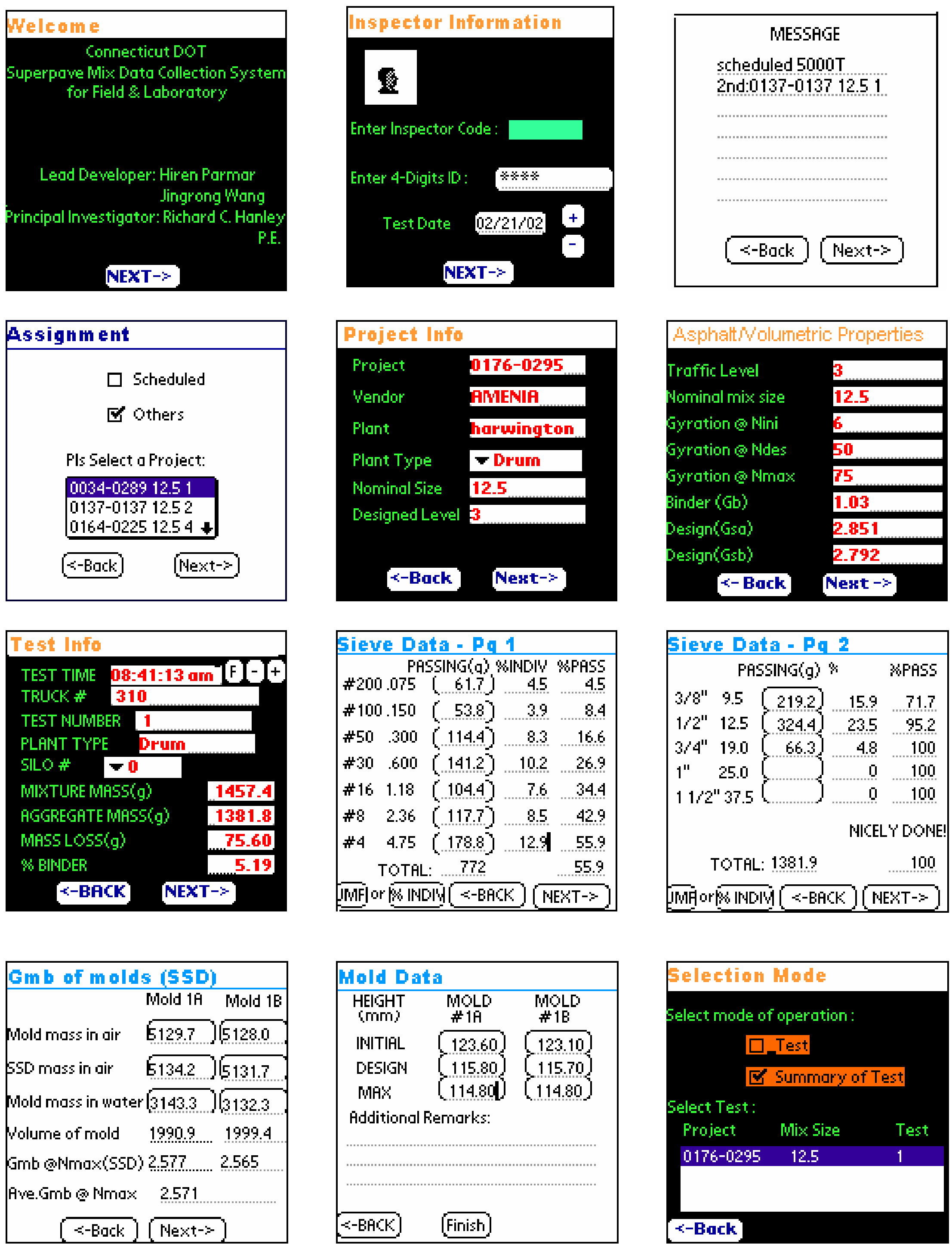
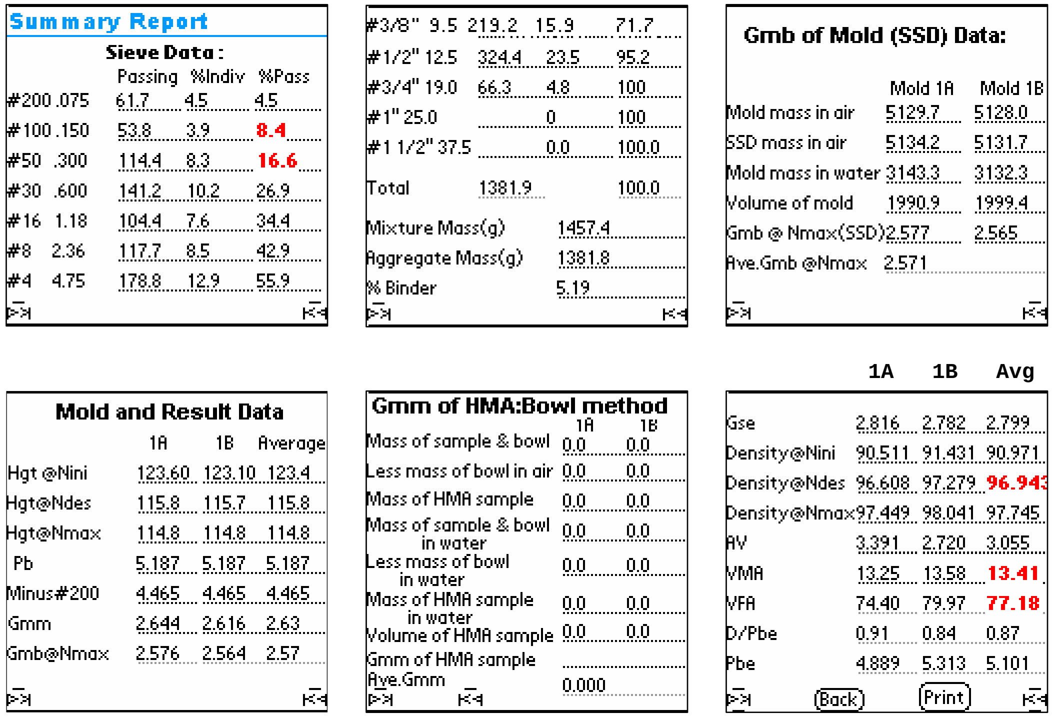


Figure 7. Sample Report Screens from FieldData PDA Program



Finally, LabTransfer was a PC program that would manage the synchronization of pending and completed tests between PDA and PC; and provide pending test data as well as results of previous tests for related projects to the PDA user. In addition, LabTransfer downloaded completed tests from the PDA and moved results to the MatTest database for inclusion into the master database.

Using these five software components, a prototype system was constructed by several IT cooperative education students employed by the Department’s Division of Research during the Summer of 2002. This system integrated the programmatic approach into the Palm IIIc hardware platform.

PHASE 5 – SYSTEM REDESIGN FOR QUALITY ASSURANCE (QA) WORKFLOW

As work progressed on the system during the summer of 2002, a revision to the Superpave testing process was proposed and adopted by Department management. This change switched the testing procedures from being Quality Control (QC) based to Quality Assurance (QA) based, which meant testing personnel assumed a supervisory role in the Laboratory portion of the testing process. Only a sample subset of laboratory tests performed by contractor personnel would be tested by the State. In addition to dramatically changing the workflow process for testing, the systems analysis and design for the PDA data collection process underwent major redesign.

In the redesign, almost the entire laboratory portion of the testing process was eliminated, since there was no longer a lab test for each field test (See Figure 6.) This included the LabData component of the software, and the FieldMultiuserTransfer and the LabTransfer components were integrated into one. Although very disruptive to the overall project progress, these changes were required to continue into the Prototype Testing phase of the project.

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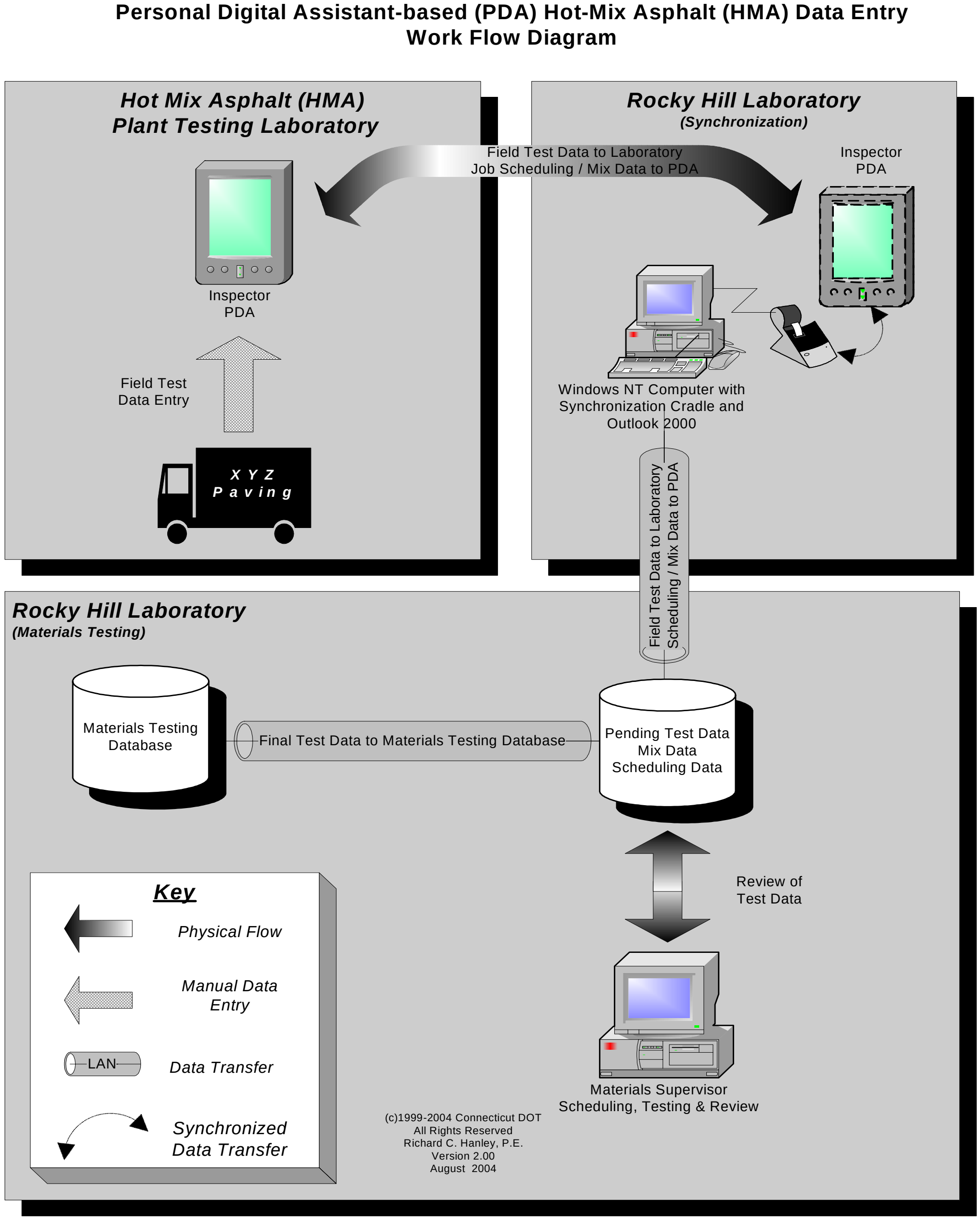
Figure 8. Quality Assurance (QA) PDA Workflow



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PHASE 6 – FIELD (BETA) TESTING

The testing began late in the summer of 2002 and ran through the fall. Several problems befell the field testing almost immediately, including:

- The PDA’s used Graffiti™ handwriting recognition technology to enter comments and some input. The lettering strokes used by Graffiti™ were not easily learned by the inspectors;
- The Palm hardware failed at an alarming rate, and eventually almost 50% of the units failed. Replacements were unavailable due to the changeover in the Palm handheld line, and new units were incompatible with the cradles purchased for the project;
- Personnel in the unit testing the Palm had taken a spreadsheet developed for internal laboratory testing and modified it for field inspectors using portable computers. Since the inspector’s computers could work with the more versatile spreadsheet, many reverted to the PC spreadsheets when the Palm equipment failed.

PHASE 7 - COMMENTS AND FEEDBACK

Project comments and feedback can be found in Appendices at the conclusion of this report. The inspectors did like the application software, but found the hardware environment and constraints cumbersome and troublesome.

PHASE 8 – IMPLEMENTATION

Upon completion of the system, ConnDOT chose not to implement the project for the 2003 paving season. Serious problems, some inherent to the technology or the organization, were identified. It was felt the combination of these made the probability of a successful implementation nearly impossible.

FINDINGS AND CONCLUSIONS

The following were conclusions derived from the project research:

Technical Problems

1) Hostile Field Conditions – the harsh field conditions that the PDA's were exposed in field laboratories, including dust, oils and solvents, in conjunction with questionable robustness of the Palm screens, were problematic during the field testing phase;
2) Equipment Durability – there were a high percentage of failures with the Palm IIIc units used in the project. Over 50% of the units failed at some time during the project. This particular unit has been discontinued, but serious questions remain about long-term reliability with the units;
3) Incompatible Model Upgrades - Palm Corporation's continually changing model line created obstacles to implementing a standard hardware platform. Older units could not be fixed when broken; only replaced with new units if under warranty. This caused a dilemma in that the synchronization cradles for the older units did not match the newer units, leaving no other option than to replace all units, an option not possible given the project budget;
4) Palm Handwriting System - the Graffiti™ handwriting recognition system was used for inspection comments, but this proprietary process was laborious for inspectors to learn and use. Many inspectors would have preferred an integrated keyboard in the unit; and,
5) Screen Issues - The Palm's small screen could not provide satisfactory spreadsheet-type displays that the inspectors requested for reviewing field data. In addition, although advanced for the time period of the study, the screen could not stand up to glare in outdoor situations or bright fluorescent lights.

Organizational Issues

1) Changing Project Objectives - the scope of the project, although well-defined at the start, suffered several changes during the course of the project. The Department, in its efforts to develop a process for testing and monitoring Superpave mixes, decided midway into the project to move from a Quality Control (QC) approach to mix testing to a Quality Assurance (QA) approach. This change eliminated any laboratory testing of mixes and necessitated the redesign of existing software and elimination of a major component for testing, ultimately reducing the utility of the software;
2) Personnel Resistance to Change – during the project development, the Materials Testing section had used Marshall-based testing of asphalt pavement samples for the last twenty years. The operational PDA system was to be a Superpave-based system only, a process unfamiliar to both contractor and State personnel. Unfortunately, much time and energy was spent simply discussing Superpave vs. Marshall concepts rather than evaluating the PDA system on its own merit;
3) No Change Incentive - during the field testing process, the operational unit requested that portable PC's be available to their personnel to handle other project-unrelated tasks beyond the project scope, such as email. Because these systems were readily available and their use was not restricted, there was no incentive to adopt a new system;
4) Lack of Information Technology Acceptance - the IT department was less than enthusiastic about embracing this technology, especially in the Palm platform. Since the software platform was not Windows-based, the IT group felt the project did not fall under their final level of control or expertise (Connecticut DOT used Microsoft software products). It was looked at as another device to support,

and was not based on any Windows technology that they could administer;

5) Operational Unit Bias - the unit testing the PDA application had, unbeknownst to the project personnel, taken a spreadsheet developed for internal laboratory testing and concurrently modified it for field inspectors using portable computers. Operational unit personnel told inspectors that selection of a PDA-based system would mean the future loss of portable computers. In addition, as an element of converting to AASHTO Site Manager software, many portable computers had already been purchased for inspectors, so the incentive to save equipment money was negated; and

6) No Long-Term Systems Support Path - the program developers for this project were cooperative education (Coop) students from local colleges. Shortly before the project was completed, Coop student funding was discontinued for budgetary reasons. This led to concerns about ongoing maintenance and support of the PDA program.

BENEFITS

Although the project results were not implemented at ConnDOT, the research was not without noteworthy findings. Benefits were found with software, hardware and process improvement. Identified benefits included:

1) Pumatech’s Satellite Forms – this development software was a viable platform for managing a fleet of PDA’s. Updates were straightforward, programming is object-oriented and the latest versions interfaced with standard Oracle databases. In addition, the program code would run on both Palm and Pocket PC-based systems;

2) Total Cost of Ownership (TCO) Valuation Process – this process was used in the hardware and software selection process. The amount expended on hardware to operate in harsh environments, as well as

software in a world of ongoing maintenance agreements and distribution licenses can add significantly to the ongoing system costs. Both the Palm OS and Satellite Forms platform offered affordable one-time licensing and run-time agreements; and,

3) Field Printers - the field printers selected for the project, Canon Bubblejet BJC-85, were well received by the inspectors and are now widely used by field personnel in conjunction with their portable computers.

IMPLEMENTATION OPTIONS AND RECOMMENDATIONS

Although the project findings were not implemented, periodic surveys of available PDA equipment should continue. In addition, the Department should review other labor-intensive field data entry processes that require supplemental field information for possible inclusion in future PDA data collection efforts.

NEXT STEPS

ConnDOT has completed its research effort in this project. It is anticipated that the baseline documentation and programming code will be released to the public domain. After this, no future work is planned related to this project. However, items of future interest might include:

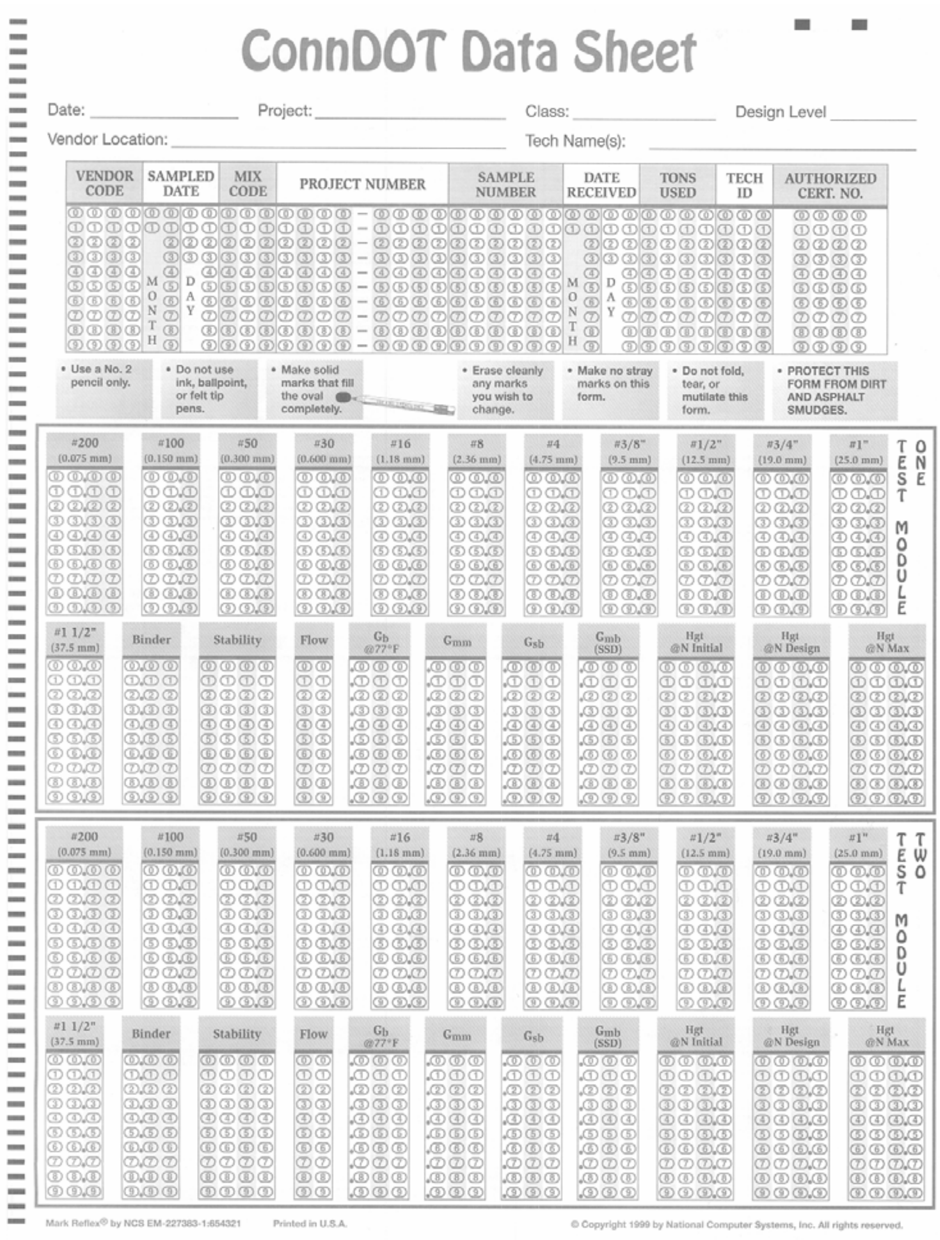
1) Reevaluation of PDA hardware platforms - new PDA designs now integrate keyboards, larger screens, cell phones, beepers and/or GPS receivers;
2) Reevaluation of the Graffiti™ handwriting process – a second generation of the Graffiti™ technology for handwriting recognition recognizes more standard pen strokes than the first generation software;

3) Reevaluation of the software platform – the Pocket PC operating system has been superseded by Windows 2003 Mobile and is now a viable and robust operating system. Palm OS has continued to retain market share, indicating both are viable PDA software technologies;
4) Evaluation of other technologies – several new technologies have become available since the PDA project inceptions. Tablet PC computers combine lightweight versatility, advanced handwriting recognition and touch-screen functionality with a fully-configured PC. Blackberry units combine PDA and email functionality and leave the user in contact with a distributed network in nearly real-time. Newer pocket cellphones have migrated to levels of versatility that offer remote data entry and PDA capability; and
5) Reassessment of PDA technology within ConnDOT - the replacement cycle for portable computers used by ConnDOT laboratory personnel offers periodic opportunities to revisit PDA technology and reconsider its application to the HMA QA function within ConnDOT.

REFERENCES

1. "Development of a Personal Digital Assistant-based (PDA) Hot-Mix Asphalt (HMA) Data Entry Program For "SUPERPAVE" Paving Projects – Preliminary Findings," Connecticut Department of Transportation, March 2004.
2. "First Looks: Hands-on Reviews of New Shipping Products," PC Magazine, November 5, 1999.
3. "White Paper: Palm and the Palm OS versus Pocket PC Mobile Solutions Deployment," The Gantry Group, L.L.C., May 2002.

APPENDIX A. Existing ConnDOT Bubblesheet for Test Reports



ConnDOT Data Sheet

Date: ________ Project: ________ Class: ________ Design Level ________

Vendor Location: ________ Tech Name(s): ________

VENDOR CODE | SAMPLED DATE (MONTH, DAY) | MIX CODE | PROJECT NUMBER | SAMPLE NUMBER | DATE RECEIVED (MONTH, DAY) | TONS USED | TECH ID | AUTHORIZED CERT. NO.

- Use a No. 2 pencil only.
- Do not use ink, ballpoint, or felt tip pens.
- Make solid marks that fill the oval completely.
- Erase cleanly any marks you wish to change.
- Make no stray marks on this form.
- Do not fold, tear, or mutilate this form.
- PROTECT THIS FORM FROM DIRT AND ASPHALT SMUDGES.

TEST MODULE ONE

#200 (0.075 mm) | #100 (0.150 mm) | #50 (0.300 mm) | #30 (0.600 mm) | #16 (1.18 mm) | #8 (2.36 mm) | #4 (4.75 mm) | #3/8" (9.5 mm) | #1/2" (12.5 mm) | #3/4" (19.0 mm) | #1" (25.0 mm)

#1 1/2" (37.5 mm) | Binder | Stability | Flow | Gb @77°F | Gmm | Gsb | Gmb (SSD) | Hgt @N Initial | Hgt @N Design | Hgt @N Max

TEST MODULE TWO

#200 (0.075 mm) | #100 (0.150 mm) | #50 (0.300 mm) | #30 (0.600 mm) | #16 (1.18 mm) | #8 (2.36 mm) | #4 (4.75 mm) | #3/8" (9.5 mm) | #1/2" (12.5 mm) | #3/4" (19.0 mm) | #1" (25.0 mm)

#1 1/2" (37.5 mm) | Binder | Stability | Flow | Gb @77°F | Gmm | Gsb | Gmb (SSD) | Hgt @N Initial | Hgt @N Design | Hgt @N Max

Mark Reflex® by NCS EM-227383-1:654321 Printed in U.S.A.

APPENDIX B. Existing ConnDOT Marshall Test Report

VG 4/9/98

TEST REPORT
BITUMINOUS MARSHALL QUALITY
MAT-051 Rev. 2/89

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION
LABORATORY DIVISION

____ of ____

Contract No.	53-169
Federal Aid No.	
Sample No.	
Kind of Material	Class 1
Source of Supply	
Location	
Sample Taken From	Truck
Location of	Plant
Sample by	MANN + Muszynski
District No.	1
Date Sampled	4-8-98
CONTRACT NUMBER (1–8)	0 0 5 3 0 1 6 9
SAMPLE NUMBER (9–16)	
MATERIAL NUMBER (17–21)	0 4 0 0 4
VENDOR NUMBER (22–26)	
DATE SAMPLED OR CAST (27–32)	0 4 0 8 9 8
DESTINATION CODE (39)	1
Where material will be used	Main St Glastonbury
Weather	Cldy
Temperature	50 - 65
Using Agency	Palazzo Const
Purpose	Top
UNIT OF MATERIAL	TONS 785 MT.
QTY REPRESENTED (43–48)	
UNIT OF MATERIAL (49–52)	T O N S
TESTING UNIT CODE (53)	3
DATE RECEIVED (55–60)	
STATUS ASSIGNED (74)	

TEST	TIME	TEMP	LAB NUMBER	ITEM NUMBER
#1	8:10	300		
#2	9:20	315		
#3	10:40	325		
#4	12:49	320		
#5	2:05	310		

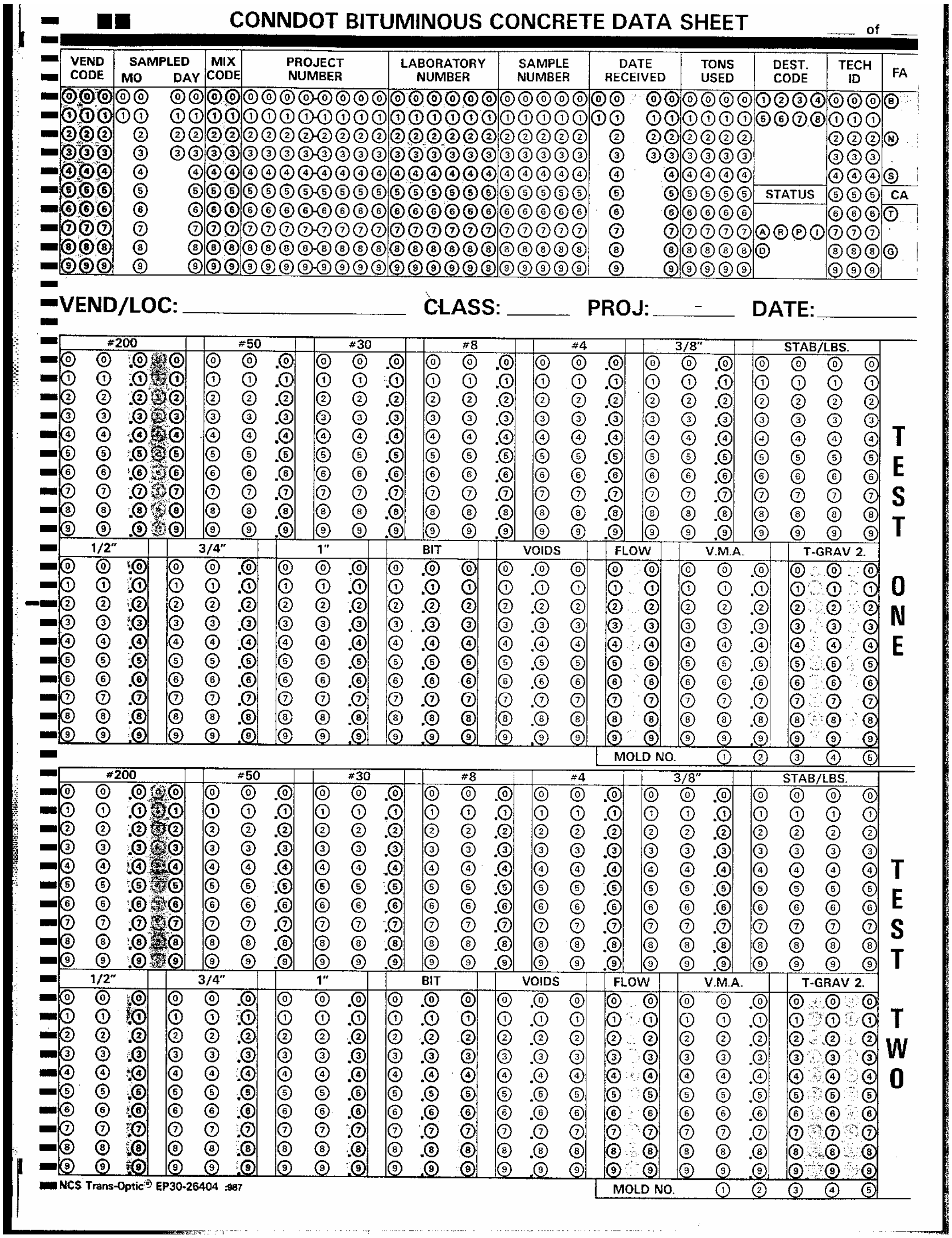
THEORETICAL SPECIFIC GRAVITY					
MOLD#	1P	2P	3P	4P	5P
TEMP.	295	295	290	290	285
BOWL#	1	2	3	4	5
Weight of Bituminous Concrete plus jar in air	2011.3	1884.1	1917.8	1964.2	1986.7
Less weight of jar	-400.7	-393.6	-406.2	-401.9	-402.1
Weight of Bituminous Concrete in air					
Weight of Bituminous Concrete plus jar in water (after 20 minutes under vacuum)	1068.2	941.0	1003.2	1036.9	1049.3
Less weight with water in jar	-67.2	-66.2	-68.0	-67.2	-67.4
Weight of Bituminous Concrete in water (after 20 minutes under vacuum)					
Weight of Bituminous Concrete in air					
Less weight of Bituminous Concrete in water	—	—	—	—	—
Volume of Bituminous Concrete					
Theoretical gravity equals Weight of Bituminous Concrete in air / Volume of Bituminous Concrete	1610.6 / 609.6	1490.5 / 565.7	1511.6 / 572.4	1562.3 / 592.6	1584.6 / 602.7
Weight of air (SSD)	1309.1	1482.0	1231.8	1363.4	1274.3
Less weight of mold in water	794.7	845.5	746.9	824.6	778.5
Volume of mold					
Actual gravity equals Weight of mold in air (Dry) / Volume of mold	1307.7 / 514.4	1399.8 / 556.5	1230.1 / 484.9	1362.0 / 539.4	1273.1 / 495.8
THEORETICAL GRAVITY	2.642	2.635	2.622	2.636	2.629
ACTUAL GRAVITY	-2.542	-2.515	-2.537	-2.525	-2.568
Difference	.100	.120	.085	.111	.061
% VOIDS	3.79	4.55	3.24	4.21	2.32
% Voids, asphalt	+13.58	+13.04	+14.10	+14.56	+14.58
Total voids, (VMA)	17.37	17.59	17.34	18.77	16.90
% Voids filled by ASP	78.18	74.13	81.31	77.57	86.27
FLOW	10	13	10	13	13
Stability, dial reading					
Stability X cor. factor	x1	2500 x.89	2460 x1.09	2710 x.93	2400 x1.04
Corrected Stability	2740	2225	2681	2520	2496

REMARKS
Coarse Agg: ½", ⅜" TR (Site)
Fine Agg: Screenings (")
nat'l sand (manchester)

Automation (1) Total Batch = 11985 lbs.
Check from (2) Total AC = 598 lbs. 4.99 %AC
Batch Ticket (3) Approved Production % AC 5.1

APPENDIX C. Original Paper Inspection Forms

Page 1


CONNDOT BITUMINOUS CONCRETE DATA SHEET ____ of ____

VEND CODE | SAMPLED MO DAY | MIX CODE | PROJECT NUMBER | LABORATORY NUMBER | SAMPLE NUMBER | DATE RECEIVED | TONS USED | DEST. CODE | TECH ID | FA

STATUS | CA

VEND/LOC: ____________ CLASS: ______ PROJ: ___-___ DATE: ________

#200 | #50 | #30 | #8 | #4 | 3/8" | STAB/LBS.

1/2" | 3/4" | 1" | BIT | VOIDS | FLOW | V.M.A. | T-GRAV 2.

MOLD NO. 1 2 3 4 5

TEST ONE

#200 | #50 | #30 | #8 | #4 | 3/8" | STAB/LBS.

1/2" | 3/4" | 1" | BIT | VOIDS | FLOW | V.M.A. | T-GRAV 2.

MOLD NO. 1 2 3 4 5

TEST TWO

NCS Trans-Optic® EP30-26404 :987

MAT-7 (NEW 2/95)

DEPARTMENT OF TRANSPORTATION
BUREAU OF ENGINEERING AND HIGHWAY OPERATIONS

Project #:	Vendor/location:		District:
Inspcctor:		Phone #:	Date Rec. lab use only
Production period (use estimate period) / / to / /			☐ 2 week ☐ monthly

DAILY LOG

DATE	CLASS	ESTIMATED CALL-IN	ACTUAL PRODUCTION	ITEM NUMBER	FIELD NOTES	LABORATORY USE	

B # _____ Class _______

LAB NUMBER	ITEM NUMBER	ITEM QUANTITY	ITEM UNIT	MATERIAL QUANTITY
				TONS
				TONS
				TONS
				TONS

B # _____ Class _______

LAB NUMBER	ITEM NUMBER	ITEM QUANTITY	ITEM UNIT	MATERIAL QUANTITY
				TONS
				TONS
				TONS
				TONS

B # _____ Class _______

LAB NUMBER	ITEM NUMBER	ITEM QUANTITY	ITEM UNIT	MATERIAL QUANTITY
				TONS
				TONS
				TONS
				TONS

B # _____ Class _______

LAB NUMBER	ITEM NUMBER	ITEM QUANTITY	ITEM UNIT	MATERIAL QUANTITY
				TONS
				TONS
				TONS
				TONS

DISTRIBUTION: ORIGINAL(White) to Central Laboratory DUPLICATE(Blue) to Project Records TRIPLICATE(Yellow) to District Coordinator

bitnew.doc/sr

M.04.03 - HOT MIX ASPHALT MIXTURES
MASTER RANGE
1999

PASSING (%)		CLASS 1 PG 64-28(k)	2 PG 64-28(k)	3 PG 64-28 (k)	4 PG 64-28 (k)	12 PG 64-28 (k)	5(f) MC-250(e)	5A(f) MC-250(e)	5B(f) MC-250(e)		TOLERANCE ± Percent
#200	75 µm	3-8(h)	3-8(h)	3-8(h)	0-5(h)	3-10(h)	0-2.5	0-2.5	0-2.5		2
#50	300 µm	6-26	8-26	10-30	5-18	10-40					4
#30	600 µm	10-32	16-36	20-40		20-60	2-15	2-15	2-15		5
#8	2.36 mm	28-50	40-64	40-70	20-40	60-95	10-45	10-45	10-45		6
#4	4.75 mm	40-65	55-80	65-87	30-55	80-95	40-100	40-100	40-100		7
1/4"	6.3 mm										
3/8"	9.5 mm	60-82	90-100	95-100	42-66	98-100	100	100	100		8
1/2"	12.5 mm	70-100	100	100		100					8
3/4"	19.0 mm	90-100			60-80						8
1"	25.0 mm	100									
2"	50.0 mm				100						
ASPHALT CEMENT -% (g)		5.0 – 6.5	5.0 – 8.0	6.5-9.0	4.0 – 6.0	7.5-10.0	6.0-7.5	6.0-7.5(i)	6.0-7.5(j)		0.4
TEMPERATURES–											
ASPHALT CEMENT	°C	163 max.	163 max.	163 max.	163 max.	163 max.	60-85	60-85	60-85		
	°F	325 max.	325 max.	325 max.	325 max.	325 max.	140-185	140-185	140-185		
MIXTURES	°C	129-163	129-163	129-163	129-163	135-163(a)	49-79	49-79	49-79		
	°F	265-325	265-325	265-325	265-325	275-325	120-175	120-175	120-175		
AGGREGATE	°C	138-177	138-177	138-177	138-177	138-177	38-79	38-79	38-79		
	°F	280-350	280-350	280-350	280-350	280-350	100-175	100-175	100-175		
VOIDS - %		3-6(b)	2-5(c)	0-4		0-5(b)					
STAB.	N. - min.	5300(d)	4500	4500		4500					
	(lb.)	1200	1000	1000		1000					
FLOW	(mm)	2-4	2-4	2-5		2-4					
	(in.)	.08 -.15	.08 -.15	.08-.18		.08 -.15					
VMA - % - min.		15(1):16(2)									

(1) Mixture with 5% or more aggregate retained on 19 mm (3/4 in.) sieve.
(2) Mixture finer than condition (1) above.
(a) 149 °C (300 °F) minimum after October 1.
(b) 75 blows (Marshall criteria).
(c) 3-6% when used for a roadway wearing surface.
(d) For divided roadways with 4 or more lanes, a stability of 6600 N (1500 lb.) is required.
(e) Contains an approved nonstripping compound.
(f) To help prevent stripping, the mixed material will be stockpiled on a paved surface and at a height not greater than 1.5 m (4 ft) during the first 48 hours.
(g) All producers shall add at least the minimum allowable percentage of asphalt cement to the mixes.
(h) The percentage of –75 µm (-200) mesh material shall not exceed the percentage of asphalt cement determined by extraction tests (AASHTO T 164, Modified; see Note 1).
(i) Polypropylene fibers, 9.5 mm to 12.5 mm (3/8-1/2 in.), added at the minimum rate of 3 kg (6 lb.) of fiber per metric ton (ton) of mix. Fibers shall be approved by the Assistant Manager of Materials Testing.
(j) Polyester Fibers, 6.3 mm (1/4 in.) added at the rate of 1.25 kg (2 ½ lb.) of fiber per metric ton (ton) of mix. Fibers shall be approved by the Assistant Manager of Materials Testing.
(k) As required by JMF for project.

APPENDIX D. Original Bituminous Test Result Report

Listing of Bituminous Test Results

From 09/01 to 09/01 For ALL Vendors 09/02/1999

VEND	MIX	DATE	#200	#50	#30	#8	#4	3/8	1/2	3/4	1	BIT	VOIDS	VMA	STAB	FLOW	GRAV	FA	CA	TECH	DST	REC'D	TONS	PROJECT	SAMPLE	LAB #	STATUS	TST
***			***																									
== JMF effec. 0111			5.0	16	25	44	58	74	92	98	100	5.5																
416	1	0901	4.55	16.7	24.9	44.6	57.7	76.1	91.9	100.0	100.0	5.79	4.23	18.6	2163	0.13	2.648	B	T	1	4	0901	0	0174-0283	0	0	A	1
416	1	0901	4.76	16.6	24.2	42.9	57.7	76.1	91.9	100.0	100.0	5.66	1.25	15.7	3016	0.16	2.641	B	T	1	4	0901	0	0174-0283	0	0	A	2
416	1	0901	4.87	18.0	25.7	43.8	56.3	75.2	92.7	100.0	100.0	5.82	2.12	16.9	2769	0.12	2.646	B	T	1	4	0901	0	0174-0283	0	0	A	1
416	1	0901	3.74	15.1	22.8	40.2	54.4	74.7	90.8	100.0	100.0	5.30	3.14	16.4	3016	0.12	2.643	B	T	1	4	0901	0	0174-0283	0	0	A	2
416	1	0901	4.98	16.8	24.3	42.6	56.5	74.8	93.2	100.0	100.0	5.50	2.04	16.0	3120	0.13	2.644	B	T	1	4	0901	0	0174-0283	0	0	A	3
416	1	0901	5.34	17.2	24.8	44.1	57.8	73.1	90.7	100.0	100.0	5.45	2.04	15.9	3586	0.16	2.652	B	T	1	4	0901	0	0174-0283	0	0	A	4
% PASSED mast__			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	33.33	100.00	100.00	66.67												
% PASSED JMF *			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00																

>>>>>>>>>>>>>>>>>>>>>>> Ytd passed mast: Class1 (44.4% ¦ 9) Class2 (80.0% ¦ 5) class3 (NO RECORDS) class4 (NO RECORDS) class12(NO RECORDS)
Last Ten: (44.4%) (80.0%) (NO RECS) (NO RECS) (NO RECS)
>>>>>>>>>>>>>>>>>>>>>>> Ytd passed jmf: Class1 (100.0% ¦ 9) Class2 (0.0% ¦ 5) class3 (NO RECORDS) class4 (NO RECORDS) class12(NO RECORDS)
Last Ten: (100.0%) (0.0%) (NO RECS) (NO RECS) (NO RECS)

VEND	MIX	DATE	#200	#50	#30	#8	#4	3/8	1/2	3/4	1	BIT	VOIDS	VMA	STAB	FLOW	GRAV	FA	CA	TECH	DST	REC'D	TONS	PROJECT	SAMPLE	LAB #	STATUS	TST
***			***																									
== JMF effec. 0803			5.0	15	26	40	50	74	92	98	100	5.4																
421	1	0901	3.66	15.1	25.7	39.1	47.9	73.5	97.1	100.0	100.0	5.28	3.84	16.2	1630	0.11	2.477	B	G	30	2	0901	0	0172-0311	0	0	A	1
421	1	0901	3.87	15.7	27.3	42.2	51.8	79.0	98.9	100.0	100.0	5.43	4.22	16.9	1804	0.11	2.490	B	G	30	2	0901	0	0172-0311	0	0	A	2
421	1	0901	4.47	16.3	27.6	41.6	50.4	74.4	98.6	100.0	100.0	5.36	2.98	15.6	1789	0.10	2.483	B	G	30	2	0901	0	0172-0311	0	0	A	3
421	1	0901	4.97	15.4	26.4	40.6	49.4	72.9	95.5	100.0	100.0	5.49	2.33	15.4	2496	0.14	2.489	B	G	30	2	0901	0	0172-0311	0	0	A	4
421	1	0901	3.28	16.0	27.9	41.3	49.4	74.0	98.3	100.0	100.0	5.42	4.19	16.8	1728	0.10	2.484	B	G	30	2	0901	0	0172-0311	0	0	A	1
% PASSED mast__			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	60.00	80.00	100.00	100.00												
% PASSED JMF *			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00																

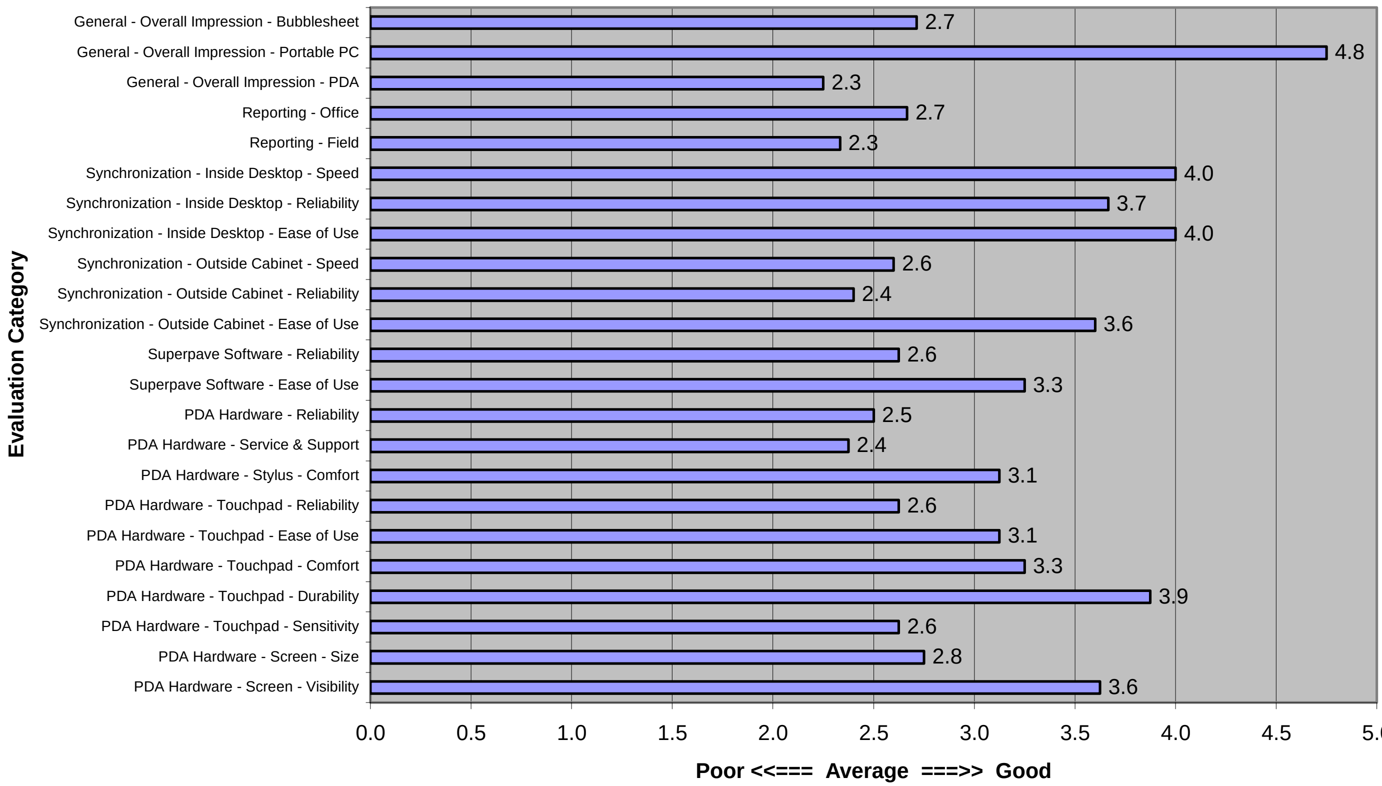
>>>>>>>>>>>>>>>>>>>>>>> Ytd passed mast: Class1 (70.0% ¦ 80) Class2 (70.5% ¦ 34) class3 (NO RECORDS) class4 (100.0% ¦ 2) class12(NO RECORDS)
Last Ten: (50.0%) (90.0%) (NO RECS) (100.0%) (NO RECS)
>>>>>>>>>>>>>>>>>>>>>>> Ytd passed jmf: Class1 (90.0% ¦ 80) Class2 (88.2% ¦ 34) class3 (NO RECORDS) class4 (100.0% ¦ 2) class12(NO RECORDS)
Last Ten: (50.0%) (90.0%) (NO RECS) (100.0%) (NO RECS)

VEND	MIX	DATE	#200	#50	#30	#8	#4	3/8	1/2	3/4	1	BIT	VOIDS	VMA	STAB	FLOW	GRAV	FA	CA	TECH	DST	REC'D	TONS	PROJECT	SAMPLE	LAB #	STATUS	TST
***			***																									
== JMF effec. 0701			5.0	14	25	42	55	74	92	95	100	5.5																
604	1	0901	4.31	17.5	27.5	40.7	52.5	73.7	93.5	100.0	100.0	5.83	2.17	16.8	2191	0.11	2.621	B	T	6	1	0901	0	0118-0140	0	0	A	1
604	1	0901	4.31	20.0 *	29.0	42.5	54.1	74.2	94.5	100.0	100.0	5.45	3.30	16.9	2361	0.10	2.639	B	T	6	1	0901	0	0118-0140	0	0	A	2
604	1	0901	4.51	19.8 *	29.2	43.9	56.1	76.7	94.2	100.0	100.0	5.94	2.71	17.6	2169	0.11	2.621	B	T	6	1	0901	0	0118-0140	0	0	A	3
% PASSED mast__			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	33.33	100.00	100.00	100.00												
% PASSED JMF *			100.00	33.33	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00																
== JMF effec. 0708			5.0	17	31	52	64	96	100	0	0	6.6																
604	2	0901	4.70	20.3	31.3	47.8	62.5	93.4	100.0	0.0	0.0	6.38	4.00	0.0	1986	0.11	2.602	B	T	6	1	0901	0	0042-0265	0	0	A	1
604	2	0901	4.60	19.8	29.1	44.3 *	59.2	93.1	100.0	0.0	0.0	6.13 *	3.16	0.0	2246	0.10	2.594	B	T	6	1	0901	0	0042-0265	0	0	A	2
604	2	0901	4.92	21.8 *	32.3	49.7	65.3	96.1	100.0	0.0	0.0	6.52	2.56	0.0	2049	0.12	2.575	B	T	6	1	0901	0	0042-0265	0	0	A	3

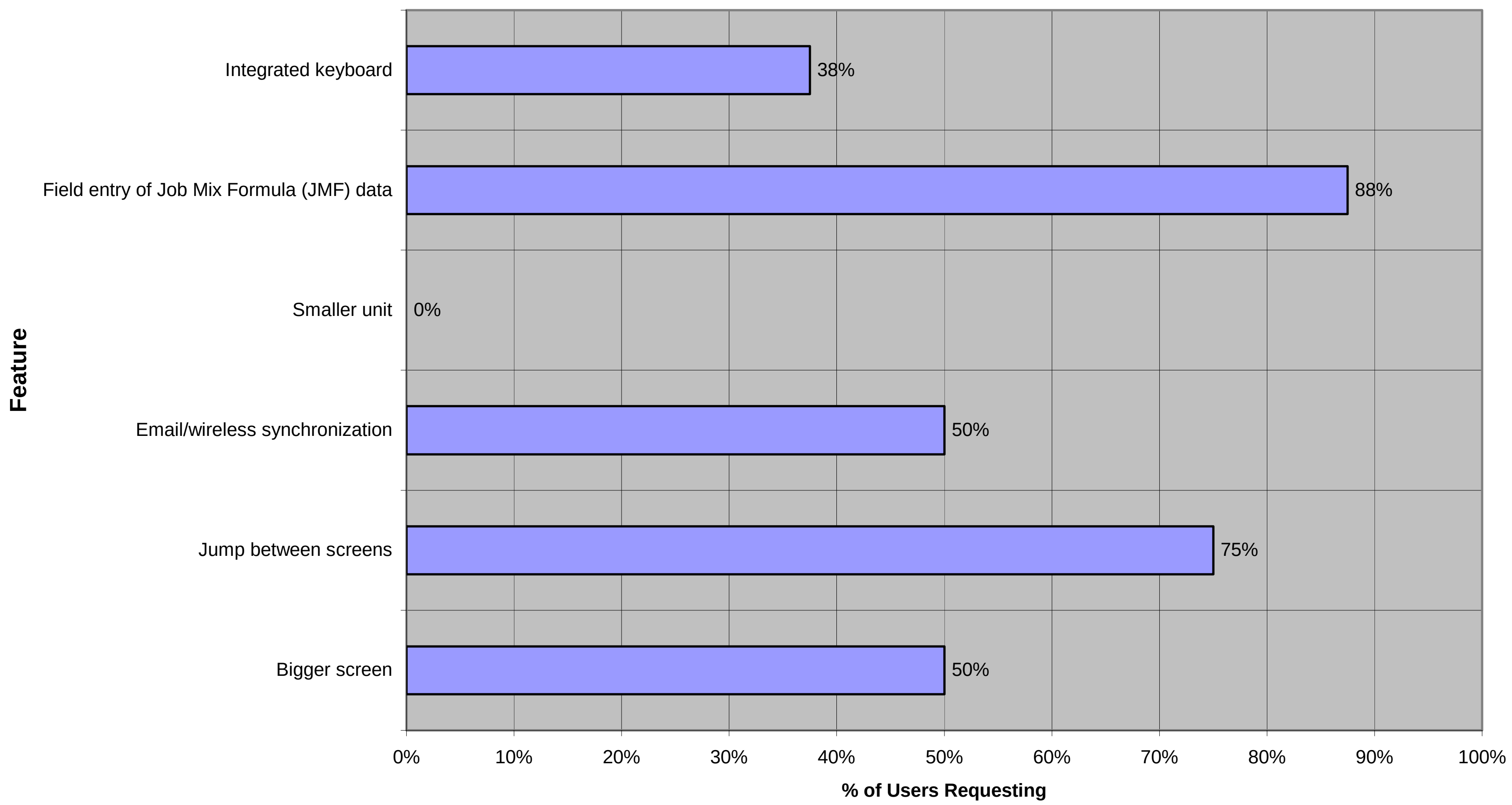
APPENDIX E. Inspector Questionnaire – Raw Scoring Data

				PDA Inspector Questionnaire - Inspector Scoring and Comments					
		Inspector #1	Inspector #2	Inspector #3	Inspector #4	Inspector #5	Inspector #6	Inspector #7	Inspector #8
Evaluation Criteria	***Average***								
PDA Hardware - Screen - Visibility	***3.6***	5	5	3	4	2	4	3	3
PDA Hardware - Screen - Size	***2.8***	5	2	1	3	2	4	3	2
PDA Hardware - Touchpad - Sensitivity	***2.6***	5	2	2	2	1	4	2	3
PDA Hardware - Touchpad - Durability	***3.9***	5	3	5	4	3	4	4	3
PDA Hardware - Touchpad - Comfort	***3.3***	5	3	3	3	2	4	3	3
PDA Hardware - Touchpad - Ease of Use	***3.1***	5	3	3	4	1	3	4	2
PDA Hardware - Touchpad - Reliability	***2.6***	5	1	4	2	1	2	4	2
PDA Hardware - Stylus - Comfort	***3.1***	5	3	2	4	2	3	3	3
PDA Hardware - Service & Support	***2.4***	3	2	3	4	1	3	1	2
PDA Hardware - Reliability	***2.5***	2	2	2	4	1	3	4	2
Superpave Software - Ease of Use	***3.3***	5	4	2	4	2	2	5	2
Superpave Software - Reliability	***2.6***	1	3	2	4	3	2	4	2
Synchronization - Outside Cabinet - Ease of Use	***3.6***	1	3	4	5			5	
Synchronization - Outside Cabinet - Reliability	***2.4***	1	2	3	3			3	
Synchronization - Outside Cabinet - Speed	***2.6***	1	3	4	4			1	
Synchronization - Inside Desktop - Ease of Use	***4.0***	5	3	4					
Synchronization - Inside Desktop - Reliability	***3.7***	5	3	3					
Synchronization - Inside Desktop - Speed	***4.0***	5	3	4					
Reporting - Field	***2.3***	3	2	2	3			1	3
Reporting - Office	***2.7***	3	3	2					
General - Overall Impression - PDA	***2.3***	5	2	2	3	1	1	2	2
General - Overall Impression - Portable PC	***4.8***	5	4	4	5	5	5	5	5
General - Overall Impression - Bubblesheet	***2.7***	1	2	3	3	4	3	3	
Feature	***% of Users Requesting***								
Bigger screen	***50%***			x	x	x			x
Jump between screens	***75%***	x	x	x	x	x			x
Email/wireless synchronization	***50%***			x	x	x		x	
Smaller unit	***0%***								
Field entry of Job Mix Formula (JMF) data	***88%***	x	x	x	x	x		x	x
Integrated keyboard	***38%***			x	x			x	
Comments		Used PDA 2x in 5 months		The PDA has some advantages, but overall its not a user-friendly. I do see uses in the field such as density testing.	Touchpad sensitivity varies widely between units; there is no place to put temperatures for mixer and molds; you can't see any volumetric cata until you hit test finished;don't like the fact you can not got to another screen until you ur your dry weight i				I found that using a laptop was much user-friendly than the PDA.

APPENDIX F. PDA Inspector Questionnaire – Evaluation Graph



APPENDIX G. PDA Inspector Questionnaire – Feature Requests Graph



APPENDIX H. Sample Formula Calculations Performed

Mass

- Mass Loss = Mixture Mass – Aggregate Mass
- Pb= $\frac{MixtureMass - AggregateMass}{MixtureMass} \times 100$
- %Ind= $\frac{Passing}{Total(PassingMass)} \times 100\%$
- %Acc= $\frac{SubTotal(Passing)}{Total(PassingMass)} \times 100\%$

Gmm Bowl Method:

A = Mass of HMA plus bowl in air

B = Mass of bowl in air

- X = A – B
- C = Mass of HMA plus bowl in water
- D = Mass of bowl in water (1 decimal place)
- Y = C – D (1 decimal place)
- Z = X – Y (1 decimal place)
- $Gmm = \frac{X}{Z} = \frac{MassOfHMAplusBowlInAir - MassOfBowlInAir}{(MassOfHMAplusBowlInAir - MassOfBowlInAir) - (MassOfHMAplusBowlInWater - MassOfBowlInWater)}$

Gmm Picnometer Method:

A = Mass of HMA in air

B = Mass of calibrated flask

C = Mass of Sample, Flask & Water

- Volume of Mix = A + B - C
- $$Gmm = \frac{A}{VolumeOfMix} = \frac{A}{A + B - C}$$
- $$Gmb@N\max = \frac{MoldMassInAir}{SaturatedMoldMass - MassOfMoldInWater}$$
- $$D1 = CorrectionFactor@Nd = \frac{Hgt@N\max}{Hgt@Ndes}$$
- $$D2 = CorrectionFactor@Ni = \frac{Hgt@N\max}{Hgt@Nini}$$
- $$D3 = PercentStone(Ps) = 100 - Pb$$
- $$Gse = \frac{100 - Pb}{(100/Gmm) - (Pb/Gb)} = \frac{D3}{(100/Gmm) - (Pb/Gb)}$$
- $$Gmb@Nd = Gmb@N\max * \frac{Hgt@N\max}{Hgt@Ndes} = Gmb@N\max * D1$$
- $$Gmb@Ni = Gmb@N\max * \frac{Hgt@N\max}{Hgt@Nini} = Gmb@N\max * D2$$
- $$Pba = \frac{(100 * Gb)(Gse - Gsb)}{Gsb * Gse}$$
- $$Pbe = Pb - \left(\frac{Pba * (100 - Pb)}{100}\right) = Pb - \left(\frac{Pba * D3}{100}\right)$$
- $$VA@Ndes = \frac{Gmm - Gmb * D1}{Gmm} * 100$$
- $$VMA@Ndes = 100 - \left(\frac{Gmb * D1 * D3}{Gsb}\right)$$

- $$VFA@Ndes = \left(\frac{VMA@Ndes - Va@Ndes}{VMA@Ndes} \right) * 100$$
- $$DENSITY@N\max = \frac{Gmb@N\max}{Gmm} * 100$$
- $$DENSITY@Ndes = \frac{Gmb@Ndes}{Gmm} * 100 = \frac{Gmb@N\max * D1}{Gmm} * 100$$
- $$DENSITY@Nini = \frac{Gmb@Nini}{Gmm} * 100 = \frac{Gmb@N\max * D2}{Gmm} * 100$$
- $$\#200/Pb = \frac{\#200\%Acc}{Pbe}$$

APPENDIX I. PDA TCO Comparison – Acquisition & Annualized Costs

Acquisition Costs

Device Profile Average Acquisition Price	Palm OS	Pocket PC	% Difference
Base Handheld Device Cost	$290.85	$549.72	52%
Total Add-ons: HW+SW	$169.30	$223.29	24%
Software Add-ons	$ 50.80	$107.95	53%
Hardware Add-ons	$118.50	$109.34	-8%
Total Handheld Device w/Add-ons	$460.15	$773.01	40%

Annualized Costs

TCO Cost Component Average Annualized Per Handheld	Palm OS	Pocket PC	% Difference
Air Time Services	$ 53.12	$ 58.62	1%
Software Distribution & Update Mgmt.	$ 7.99	$ 50.00	84%
IT Services	$ 25.55	$ 65.19	61%
Help Disk & Support	$ 68.51	$ 93.00	26%
Training	$ 26.32	$ 95.19	72%
Amortized Lifetime Device Cost w/Add-ons	$274.30	$413.76	34%
Total Handheld TCO	$455.78	$775.77	41%

Source: "White Paper: Palm and the Palm OS versus Pocket PC Mobile Solutions Deployment," The Gantry Group, L.L.C., May 2002.