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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Director of Research and Materials
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**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.

**Key Words**
Personal digital assistant, PDA, Palm computer, hot-mix asphalt, Superpave, testing

**Distribution Statement**
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**Supplementary Notes**
A research project conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration (FHWA).
DISCLAIMER

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Neither the U.S. Government nor the State of Connecticut endorse products or manufacturers. Trade or manufacturer names appear herein only because they are considered essential to the objective of this document.
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## METRIC CONVERSION

### SI* (MODERN METRIC) CONVERSION FACTORS

#### APPROXIMATE CONVERSIONS TO SI UNITS

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<td>yd³</td>
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<td>cubic meters m³</td>
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**NOTE:** volumes greater than 1000 L shall be shown in m³

#### APPROXIMATE CONVERSIONS FROM SI UNITS

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<td>Celsius °C</td>
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<td>kPa</td>
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*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**

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

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

Figure 1. Typical HMA Plant
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.

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.

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<tr>
<th>Hardware and Software Cost per User</th>
<th>Palm</th>
<th>Windows CE</th>
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<tr>
<td>Power Utilization Rate</td>
<td>9-12 hours/charge</td>
<td>4-6 hours/charge</td>
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<td>Hardware Manufacturers</td>
<td>Palm, Handspring</td>
<td>Compaq, HP</td>
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<td>Operating System</td>
<td>Version 4.0 - stable</td>
<td>Version 1.0 - unproven</td>
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<td>Programming Environment</td>
<td>Satellite Forms, Pendragon Forms</td>
<td>Visual Basic (promised), Pendragon Forms</td>
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</table>

Table 1. Palm vs. Windows CE Technology
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 unit's 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>
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<tr>
<th></th>
<th>Palm</th>
<th>Windows CE</th>
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<tbody>
<tr>
<td><strong>Hardware Cost per User</strong></td>
<td>$250/unit</td>
<td>$600/unit</td>
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<tr>
<td><strong>Software Fixed Cost (1 User)</strong></td>
<td>N/C Runtime License $35 Print Utility</td>
<td>$200 Runtime Library $30 Print Utility</td>
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<tr>
<td><strong>Software Marginal Cost (Each Additional User)</strong></td>
<td>N/C Runtime License $35 Print Utility</td>
<td>$20 Runtime License $30 Print Utility</td>
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<td><strong>Support Software Cost Per Developer</strong></td>
<td>$995/developer</td>
<td>$495/developer</td>
</tr>
<tr>
<td><strong>Total Cost of Ownership (TCO)</strong></td>
<td>$285/first user $285/additional user</td>
<td>$830/first user $650/additional user</td>
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</table>

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.

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

Work Flow Diagram – Field & Laboratory Testing

(c)1999-2002 Connecticut DOT
All Rights Reserved
Richard C. Harvey, P.E.
Version 1.10
2/28/2002
Figure 5. Workflow Schematic for FieldData PDA Program
Figure 6. Sample Data Entry 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

Personal Digital Assistant-based (PDA) Hot-Mix Asphalt (HMA) Data Entry Work Flow Diagram

Key
- Physical Flow
- Manual Data Entry
- Data Transfer
- LAN Data Transfer
- Synchronized Data Transfer

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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


### APPENDIX A. Existing ConnDOT Bubblesheet for Test Reports

#### ConnDOT Data Sheet

<table>
<thead>
<tr>
<th>VENDOR CODE</th>
<th>SAMPLED DATE</th>
<th>MIX CODE</th>
<th>PROJECT NUMBER</th>
<th>SAMPLE NUMBER</th>
<th>DATE RECEIVED</th>
<th>TONS USED</th>
<th>TECH ID</th>
<th>CERT. NO.</th>
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<td>001</td>
<td>1234</td>
<td>567</td>
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<td>5678</td>
<td>123</td>
<td>45</td>
<td>23</td>
<td>B</td>
<td>C</td>
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- Use a No. 2 pencil only.
- Do not use ink, ballpoint, or felt-tip pens.
- Make solid marks that fill the oval completely.
- Erase only the areas you wish to change.
- Make no sharp marks on this form.
- Do not fold, tear, or mutilate this form.

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- Made by Nodak® and used only with permission.
- Printed in U.S.A.
-  © Copyright 1998 by National-Computer Systems, Inc. All rights reserved.
## APPENDIX B. Existing ConnDOT Marshall Test Report

<table>
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<tr>
<th>Test Report</th>
<th>Relevant Data</th>
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<tbody>
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<tr>
<td>Mix Number</td>
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<td>Type of Material</td>
<td>Class I</td>
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<tr>
<td>Origin</td>
<td>Palazzo Coast</td>
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<td>Type of Test</td>
<td>Marshall Test Report</td>
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<tr>
<td>Test Date</td>
<td>4/9/98</td>
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### THEORETICAL SPECIFIC GRAVITY

| Weight of Bituminous Concrete plus pumice in air | Lb. | 20.1 |
| Weight of Bituminous Concrete in air | Lb. | 19.8 |
| Weight of Bituminous Concrete plus pumice in water | Lb. | 19.7 |
| Weight of Bituminous Concrete in water | Lb. | 19.6 |
| Volume of Bituminous Concrete | Cu. ft. | 0.194 |
| Theoretical specific gravity | | 0.948 |
| Volume of asphalt | Cu. ft. | 0.194 |
| Volume of pumice | Cu. ft. | 0.194 |
| Theoretical specific gravity | | 0.948 |

### THEORETICAL GRAVITY

| Weight of material | Lb. | 167.2 |
| Volume of material | Cu. ft. | 0.194 |

### ACTUAL GRAVITY

| Theoretical gravity | 0.948 |
| Actual gravity | 0.948 |
| Difference | 0.0 |

### Voids

- Total Voids, %Voids: 3.29
- Voids, air filled: 3.29
- Voids, water filled: 3.29
- Voids, total: 3.29

### Flow

| Flow number | 22.2 |

### Stability

| Stability factor, AS | 1.9 |
| Stability factor, MS | 1.9 |

### Density

| Density | 2.70 |

### Estimating

- Marine ratio: 1.9
- Marshall factor: 1.9
- Maximum Marshall: 26.54
- Estimated Marshall: 26.54

### Field Test

- Mix Design Method: 21.3%
- Marshall Spec, S concrete
- Mix Design Method: 21.3%}

### Referee's Notes

- Referee's Signature: [Signature]
- Referee's Notes: [Notes]
APPENDIX C. Original Paper Inspection Forms

CONNDOT BITUMINOUS CONCRETE DATA SHEET

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<thead>
<tr>
<th>VEND</th>
<th>LOC</th>
<th>MIX</th>
<th>PROJECT</th>
<th>LABORATORY</th>
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<th>DATE</th>
<th>TONS</th>
<th>DEST</th>
<th>TECH</th>
<th>FA</th>
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VEND/LOC: ___________________________ CLASS: _______ PROJ: _______ DATE: _______

<table>
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<th>TEST ONE</th>
<th>TEST TWO</th>
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</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
<td>3/4&quot;</td>
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</table>

| MOLD NO. | 0 | 0 | 0 | 0 |

<table>
<thead>
<tr>
<th>TEST ONE</th>
<th>TEST TWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
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| MOLD NO. | 0 | 0 | 0 | 0 |
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<th>CLASS</th>
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### B #  Class

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**DISTRIBUTION:** ORIGINAL (White) to Central Laboratory  DUPLICATE (Blue) to Project Records  TRIPLE (Yellow) to District Coordinator
## M.04.03 - HOT MIX ASPHALT MIXTURES
### MASTER RANGE
#### 1999

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<td>1 PG 64-28(h)</td>
<td>12 PG 64-28 (h)</td>
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<tr>
<td>#200 75 µm</td>
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<tr>
<td>#50 300 µm</td>
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<tr>
<td>#8 600 µm</td>
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<td>#8 8.36 mm</td>
<td>28-50</td>
<td>40-64</td>
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<tr>
<td>#4 4.75 mm</td>
<td>40-65</td>
<td>55-80</td>
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<tr>
<td>1/4&quot; 6.3 mm</td>
<td>50-70</td>
<td>65-90</td>
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<tr>
<td>3/8&quot; 9.5 mm</td>
<td>60-82</td>
<td>90-100</td>
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<tr>
<td>1/2&quot; 12.5 mm</td>
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<td>100</td>
</tr>
<tr>
<td>3/4&quot; 19.0 mm</td>
<td>90-100</td>
<td>100</td>
</tr>
<tr>
<td>1&quot; 25.0 mm</td>
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<td>100</td>
</tr>
<tr>
<td>2&quot; 50.0 mm</td>
<td>100</td>
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</tr>
</tbody>
</table>

### 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
- 5.0 - 7.5

### TEMPERATURES

- ASPHALT CEMENT
  - C
  - F
  - MIXTURES
  - C
  - F
  - AGGREGATE
  - C
  - F

### Voids - %
- 3-6(b)
- 2-5(c)
- 0-4
- 0-5(g)

### STAB.
- N, - min.
- (lb.)
- 5300(c)
- 4500
- 4000
- 3000
- 1200
- 1000
- 1000
- 1000

### FLOW
- (mm)
- (In.)
- 2-4
- 0.8 - 1.5
- 2.4
- 0.8 - 1.5

### VMA - % - min.
- 150(150)

### Notes:
1. Mixture with 5% or more aggregate retained on 19 mm (3/4 in.) sieve.
2. Mixture finer than condition (1) above.
3. From 6000 N (1500 lb.) is required.
4. Contains an approved non-slip compound.
5. 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 40 hours.
6. Polyester fibers, 6.3 mm (1/4 in.) added at the rate of 1.25 kg (2 1/2 lb.) per metric ton (ton) of mix. Fibers shall be approved by the Assistant Manager of Materials Testing.
7. As required by JMF for project.
### APPENDIX D. Original Bituminous Test Result Report

#### Listing of Bituminous Test Results

| YIELD | RCT | DATE | R200 | R50 | R20 | R8 | S | J/0 | 1/2 | 1/4 | 1 | BRT | V505S | VMA | INDEX | FLOW | GRAP | FA | CH | TEEN | DIS | REC'D | TIME | PROJECT | SAMPLE | LAB | 8 | STATUS | 1ST |
|-------|-----|------|------|-----|-----|----|---|---|---|---|---|---|-----|------|-----|-------|------|------|---|---|------|----|------|------|--------|------|-----|---|-------|----|
|       |     |      |      |     |     |    |   |   |   |   |   |   |     |      |     |       |      |     |   |    |      |    |      |      |         |      |     |   |       |    |
| YIELD | RCT | DATE | R200 | R50 | R20 | R8 | S | J/0 | 1/2 | 1/4 | 1 | BRT | V505S | VMA | INDEX | FLOW | GRAP | FA | CH | TEEN | DIS | REC'D | TIME | PROJECT | SAMPLE | LAB | 8 | STATUS | 1ST |

#### Notes

- YIELD: Yield of bituminous material in percent.
- RCT: Roll Calorimeter Test Result.
- DATE: Date of test.
- R200, R50, R20, R8: Composition of bituminous material.
- S: Softening point.
- J/0, 1/2, 1/4: Penetration values.
- BRT: Bitumen Recombination Test.
- V505S, VMA, INDEX: Bitumen characteristics.
- FLOW: Flow number.
- GRAP, FA, CH, TEEN, DIS, REC'D, TIME, PROJECT, SAMPLE, LAB: Additional test details.
- 8, STATUS, 1ST: Test status and additional information.

#### Additional Details

- YIELD passed test: YIELD passed test results are indicated.
- Class: Bituminous class classification.
- Test: Type of test performed.
- REC'D: Record status.
- TIME: Time of test.
- PROJECT: Project reference.
- SAMPLE: Sample identification.
- LAB: Laboratory reference.
- 8, STATUS, 1ST: Additional test status and information.

---

VI
## APPENDIX E. Inspector Questionnaire – Raw Scoring Data

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Inspector #1</th>
<th>Inspector #2</th>
<th>Inspector #3</th>
<th>Inspector #4</th>
<th>Inspector #5</th>
<th>Inspector #6</th>
<th>Inspector #7</th>
<th>Inspector #8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>3.6</td>
<td>3.9</td>
<td>3.3</td>
<td>3.1</td>
<td>2.8</td>
<td>2.4</td>
<td>2.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>

### PDA Hardware

- **Screen - Visibility**: 3.6, Inspector #1; 3.9, Inspector #3; 3.3, Inspector #7; 3.1, Inspector #8
- **Size**: 2.8, Inspector #2; 2.6, Inspector #4; 2.4, Inspector #6; 2.3, Inspector #8
- **Touchpad - Sensitivity**: 2.6, Inspector #1; 3.9, Inspector #3; 3.3, Inspector #7; 3.1, Inspector #8
- **Durability**: 3.9, Inspector #1; 3.0, Inspector #3; 3.4, Inspector #4; 3.4, Inspector #6
- **Comfort**: 3.3, Inspector #1; 2.8, Inspector #2; 3.4, Inspector #3; 3.3, Inspector #7
- **Ease of Use**: 3.1, Inspector #1; 2.5, Inspector #2; 2.2, Inspector #3; 1.3, Inspector #4
- **Reliability**: 2.6, Inspector #1; 3.8, Inspector #2; 2.2, Inspector #3; 1.2, Inspector #4

### PDA Hardware - Stylus

- **Comfort**: 3.1, Inspector #1; 2.4, Inspector #2; 2.3, Inspector #3; 1.9, Inspector #4

### PDA Hardware - Service & Support

- **Ease of Use**: 2.4, Inspector #1; 3.0, Inspector #2; 2.2, Inspector #3; 1.3, Inspector #4

### PDA Hardware - Reliability

- **Ease of Use**: 2.5, Inspector #1; 2.3, Inspector #2; 2.2, Inspector #3; 1.3, Inspector #4

### Superpave Software

- **Ease of Use**: 3.3, Inspector #1; 2.3, Inspector #2; 2.3, Inspector #3; 1.3, Inspector #4

### Synchronization

- **Outside Cabinet - Ease of Use**: 3.6, Inspector #1; 2.7, Inspector #2; 2.6, Inspector #3; 1.3, Inspector #4
- **Outside Cabinet - Speed**: 2.6, Inspector #1; 3.7, Inspector #2; 3.7, Inspector #3; 2.7, Inspector #4
- **Inside Desktop - Ease of Use**: 4.0, Inspector #1; 3.7, Inspector #2; 3.7, Inspector #3; 2.7, Inspector #4
- **Inside Desktop - Speed**: 4.0, Inspector #1; 3.7, Inspector #2; 3.7, Inspector #3; 2.7, Inspector #4

### Reporting

- **Field**: 2.7, Inspector #1; 3.7, Inspector #2; 3.7, Inspector #3; 2.7, Inspector #4
- **Office**: 2.7, Inspector #1; 3.7, Inspector #2; 3.7, Inspector #3; 2.7, Inspector #4

### General

- **Overall Impression - PDA**: 4.8, Inspector #1; 4.5, Inspector #2; 4.5, Inspector #3; 4.5, Inspector #4
- **Overall Impression - Portable PC**: 4.8, Inspector #1; 4.5, Inspector #2; 4.5, Inspector #3; 4.5, Inspector #4
- **Overall Impression - BubbleSheet**: 2.7, Inspector #1; 2.7, Inspector #2; 2.7, Inspector #3; 2.7, Inspector #4

### Feature

<table>
<thead>
<tr>
<th>Feature</th>
<th>% of Users Requesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bigger screen</td>
<td>50%</td>
</tr>
<tr>
<td>Jump between screens</td>
<td>75%</td>
</tr>
<tr>
<td>Email/wireless synchronization</td>
<td>50%</td>
</tr>
<tr>
<td>Smaller unit</td>
<td>0%</td>
</tr>
<tr>
<td>Field entry of Job Mix Formula (JMF) data</td>
<td>88%</td>
</tr>
<tr>
<td>Integrated keyboard</td>
<td>38%</td>
</tr>
</tbody>
</table>

### Comments

- **Used PDA 2x in 6 months**
- **The PDA has some advantages, but overall it is not 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 mixers and molds; you can’t see any volumetric data until you hit test finished; don’t like the fact you can not go to another screen until you enter your dry weight.**
- **I found that using a laptop was much user-friendly than the PDA.**
APPENDIX F. PDA Inspector Questionnaire – Evaluation Graph

![Evaluation Graph]

- **Evaluation Category**: General - Overall Impression - Bubblesheet
- **Evaluation Category**: General - Overall Impression - Portable PC
- **Evaluation Category**: General - Overall Impression - PDA
- **Evaluation Category**: Reporting - Office
- **Evaluation Category**: Reporting - Field
- **Evaluation Category**: Synchronization - Inside Desktop - Speed
- **Evaluation Category**: Synchronization - Inside Desktop - Reliability
- **Evaluation Category**: Synchronization - Inside Desktop - Ease of Use
- **Evaluation Category**: Synchronization - Outside Cabinet - Speed
- **Evaluation Category**: Synchronization - Outside Cabinet - Reliability
- **Evaluation Category**: Synchronization - Outside Cabinet - Ease of Use
- **Evaluation Category**: Superpave Software - Reliability
- **Evaluation Category**: Superpave Software - Ease of Use
- **Evaluation Category**: PDA Hardware - Reliability
- **Evaluation Category**: PDA Hardware - Service & Support
- **Evaluation Category**: PDA Hardware - Stylus - Comfort
- **Evaluation Category**: PDA Hardware - Touchpad - Reliability
- **Evaluation Category**: PDA Hardware - Touchpad - Ease of Use
- **Evaluation Category**: PDA Hardware - Touchpad - Comfort
- **Evaluation Category**: PDA Hardware - Touchpad - Durability
- **Evaluation Category**: PDA Hardware - Touchpad - Sensitivity
- **Evaluation Category**: PDA Hardware - Screen - Size
- **Evaluation Category**: PDA Hardware - Screen - Visibility
- **Evaluation Category**: Synchronization - Inside Desktop - Speed
- **Evaluation Category**: Synchronization - Inside Desktop - Reliability
- **Evaluation Category**: Synchronization - Inside Desktop - Ease of Use
- **Evaluation Category**: Synchronization - Outside Cabinet - Speed
- **Evaluation Category**: Synchronization - Outside Cabinet - Reliability
- **Evaluation Category**: Synchronization - Outside Cabinet - Ease of Use
- **Evaluation Category**: Superpave Software - Reliability
- **Evaluation Category**: Superpave Software - Ease of Use
- **Evaluation Category**: PDA Hardware - Reliability
- **Evaluation Category**: PDA Hardware - Service & Support
- **Evaluation Category**: PDA Hardware - Stylus - Comfort
- **Evaluation Category**: PDA Hardware - Touchpad - Reliability
- **Evaluation Category**: PDA Hardware - Touchpad - Ease of Use
- **Evaluation Category**: PDA Hardware - Touchpad - Comfort
- **Evaluation Category**: PDA Hardware - Touchpad - Durability
- **Evaluation Category**: PDA Hardware - Touchpad - Sensitivity
- **Evaluation Category**: PDA Hardware - Screen - Size
- **Evaluation Category**: PDA Hardware - Screen - Visibility

**Evaluation Scale**: Poor <= Average => Good
APPENDIX G. PDA Inspector Questionnaire – Feature Requests Graph

- Integrated keyboard: 38%
- Field entry of Job Mix Formula (JMF) data: 88%
- Smaller unit: 0%
- Email/wireless synchronization: 50%
- Jump between screens: 75%
- Bigger screen: 50%
APPENDIX H. Sample Formula Calculations Performed

Mass

- Mass Loss = Mixture Mass - Aggregate Mass
  
  \[ \text{Mass Loss} = \frac{\text{Mixture Mass} - \text{Aggregate Mass}}{\text{Mixture Mass}} \times 100 \]

- \( \text{Pb}= \frac{\text{P} \sin g}{\text{Mixture Mass}} \times 100\% \)

- \( \%\text{Ind}= \frac{\text{P} \sin g}{\text{Total (P} \sin g \text{Mass})} \times 100\% \)

- \( \%\text{Acc}= \frac{\text{SubTotal (P} \sin g \text{)} \times 100\%}{\text{Total (P} \sin g \text{Mass})} \)

Gmm Bowl Method:

- \( \text{A} = \text{Mass of HMA plus bowl in air} \)
- \( \text{B} = \text{Mass of bowl in air} \)
- \( \text{X} = \text{A} - \text{B} \)
- \( \text{C} = \text{Mass of HMA plus bowl in water} \)
- \( \text{D} = \text{Mass of bowl in water} \quad \) (1 decimal place)
- \( \text{Y} = \text{C} - \text{D} \quad \) (1 decimal place)
- \( \text{Z} = \text{X} - \text{Y} \quad \) (1 decimal place)

\[ \text{Gmm} = \frac{X}{Z} = \frac{\text{Mass of HMA plus bowl in air} - \text{Mass of bowl in air}}{(\text{Mass of HMA plus bowl in air} - \text{Mass of bowl in air}) - (\text{Mass of HMA plus bowl in water} - \text{Mass of bowl in water})} \]
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

\[ Gmm = \frac{A}{\text{VolumeOfMix}} = \frac{A}{A + B - C} \]

\[ Gmb@ N \ max = \frac{\text{MoldMassInAir}}{\text{SaturatedMoldMass} - \text{MassOfMoldInWater}} \]

\[ D1 = \text{CorrectionFactor } @ \text{Nd} = \frac{Hgt@ N \ max}{Hgt@ N\ des} \]

\[ D2 = \text{CorrectionFactor } @ \text{Ni} = \frac{Hgt@ N \ max}{Hgt@ N\ ini} \]

\[ D3 = \text{PercentStone}(Ps) = 100 - Pb \]

\[ Gse = \frac{100 - Pb}{(100 / Gmm) - (Pb / Gb)} = \frac{D3}{(100 / Gmm) - (Pb / Gb)} \]

\[ Gmb@ Nd = Gmb@ N \ max * \frac{Hgt@ N \ max}{Hgt@ N\ des} = Gmb@ N \ max * D1 \]

\[ Gmb@ Ni = Gmb@ N \ max * \frac{Hgt@ N \ max}{Hgt@ N\ ini} = Gmb@ N \ max * D2 \]

\[ Pba = \frac{(100 * Gb)(Gse - Gsb)}{Gsb * Gse} \]

\[ Pbe = Pb - \left( \frac{Pba * (100 - Pb)}{100} \right) = Pb - \left( \frac{Pba * D3}{100} \right) \]

\[ VA@ N\ des = \frac{Gmm - Gmb* D1}{Gmm} * 100 \]

\[ VMA@ N\ des = 100 - \left( \frac{Gmb * D1 * D3}{Gsb} \right) \]
\[
VFA@Ndes = \left( \frac{VMA@Ndes - Va@Ndes}{VMA@Ndes} \right) \times 100
\]

\[
DENSITY@N_{max} = \frac{Gmb@N_{max}}{Gmm} \times 100
\]

\[
DENSITY@N_{des} = \frac{Gmb@N_{des}}{Gmm} \times 100 = \frac{Gmb@N_{max} \times D1}{Gmm} \times 100
\]

\[
DENSITY@N_{ini} = \frac{Gmb@N_{ini}}{Gmm} \times 100 = \frac{Gmb@N_{max} \times D2}{Gmm} \times 100
\]

\[
\#200/Pb = \frac{\#200\%Acc}{Pbe}
\]
APPENDIX I. PDA TCO Comparison – Acquisition & Annualized Costs

**Acquisition Costs**

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

**Annualized Costs**

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