Final Report:
Task Order #09-001

Pooled Fund Study TPF-5(039)
Falling Weight Deflectometer Calibration Center and Operational Improvements

April 2011

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

This is the final progress report for pooled fund study TPF-5 (039). It covers work done under Task Order #09-001 during the period September 2009 through November 2010. The report will be of interest to technicians who calibrate falling weight deflectometers (FWDs) and engineers who perform structural evaluation of pavements.

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16. Abstract

The objective of pooled fund study TPF-5(039) is to upgrade the existing falling weight deflectometer (FWD) calibration system to make calibration sustainable for the next decade without a loss of quality while ensuring any new procedures are compatible with all brands of FWDs sold in the United States. This involves upgrading the hardware and software used in calibration to take advantage of improvements in technology.

Task Order #09-001 involved eight subtasks providing technical support to the FWD calibration centers and facilitating the transition of responsibility for Quality Assurance visits to the AASHTO Materials Reference Laboratory (AMRL).

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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)

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CHAPTER 1. INTRODUCTION

Pooled Fund Study TPF-5 (039) was created to update and advance the science of falling weight deflectometer (FWD) calibration. The pooled fund study began operations in September 2004 and ended in November 2010. Much was accomplished during that period. This report focuses on the activities under Task Order #09-001.

The hardware, software and calibration protocol that were developed in 1990-92 by the Strategic Highway Research Program served well for ten years. However, by the end of the 90's technological advances in computers, operating systems, and programming languages had rendered the DOS-based software and the data acquisition hardware completely out of date. If nothing was done, FWD calibration would have become impossible to perform.

Going into the 21st Century, growth in the usage of FWDs by state highway agencies and the private sector gave urgency to the need to update the calibration process. In August 2001 the American Association of Highway and Transportation Officials (AASHTO) Subcommittee on Materials put forth a resolution encouraging the Federal Highway Administration (FHWA) to address the problem.[(1)] With the support of 17 state DOTs the FHWA created a pooled fund study to find a solution.

The pooled fund study goals were to modernize the hardware and adapt the software to Windows-based computers. Corollary objectives were to preserve the accuracy of the calibration procedure and to modify the calibration protocol to expedite it.

Comprehensive documentation of the research activities leading to the redesign of the calibration protocol and upgrading of the software and hardware are contained in Report No. FHWA-HRT-07-040.[(2)]

CHAPTER 2. TASK ORDER #09-001

TASKS AND ACCOMPLISHMENTS UNDER T.O. #09-001

Task Order DTFH61-04-C-00041-T-09001 covered the period August 28, 2009 through November 30, 2010. It had six tasks, plus two optional tasks. The two optional tasks were authorized, so there was a total of eight tasks.

- Task 1. FWD calibration center quality assurance and technical assistance services.
- Task 2. Transfer of long-term calibration center support stewardship.
- Task 3. Software updates and upgrades.
- Task 4. Communication and coordination.
- Task 5. Task order #2 report.
- Task 6. Quarterly progress reports.
- Optional Task 7. Calibration system improvements.
- Optional Task 8. Calibration center operators meeting – travel support.

Accomplishments made under each task are reported in the following sections.

TASK 1. FWD CALIBRATION CENTER QUALITY ASSURANCE AND TECHNICAL ASSISTANCE SERVICES

Cornell provided technical support to the existing six (6) Regional LTPP FWD Calibration Centers (Texas, Colorado, Pennsylvania, California, Montana and Minnesota). In addition, we provided assistance to the Indiana DOT Calibration Center. No new FWD Calibration Centers were established during the reporting period.

Between January and July 2010 we calibrated the reference load cells for each of the centers listed above. No problem calibrations occurred (that would require replacement of strain gages, reconditioning, etc.). Several calibrations were done on a rush order basis as the center's QA visit was imminent. Courier shipment was used for all load cells.

The Colorado and Minnesota centers required training for new operators. This involved a three-day program of instruction and hands-on practice, culminating in operator QA certification. Checklists were used to assure the uniformity and objectivity of the QA procedure.

On site QA visits were conducted at all seven of the publically-administered FWD Calibration Centers (table 1). With the exception of the visit to the Colorado center, in all of the other visits we were accompanied by one or more of the AASHTO Materials Reference Laboratory (AMRL) personnel. In addition to the publically-administered calibration centers, QA visits were also conducted at Foundation Mechanics (JILS), Dynatest, and Half-Space Engineering, and AMRL also participated at the latter visits, but that was not considered part of the pooled fund study.

Table 1. QA visits in 2010

Center	QA Visit Date
Colorado DOT*	3-Mar-10
Indiana DOT	25-May-10
Minnesota DOT*	19-May-10
Montana DOT	27-May-10
Pennsylvania DOT	6-Apr-10
TAMU/TTI - Texas DOT	23-Apr-10
UC Davis - CalTrans	11-May-10

* Operator training 3-day course given

Calibration center support was continuous throughout the reporting period, including software support, telephone support, e-mail communications, and troubleshooting. This was done mainly via email and telephone. On the average about seven calls or emails were answered each month, with issues ranging from software bugs to problems with calibrating an FWD. The QA visits also provided a good opportunity for face-to-face technical support.

One of our most extensive technical assistance activities was for the Minnesota DOT calibration center. For many years they had been experiencing intermittent problems with electrical noise (figure 1). To avoid the problem they usually scheduled their calibrations in the evening hours. This posed difficult problems and unhappiness for all concerned.

After many telephone calls and emails without much success, we scheduled an on site visit at the MinnDOT facility to personally investigate the problem. During the first visit no electrical noise was observed, so we set up some equipment so MinnDOT could gather long-term data. From their reports we determined the noise began soon after sunrise and ended just before sunset. The MinnDOT facility is located close to a clear-channel AM radio station, and we realized the RFI noise was coming from there. At night, FCC rules required a reduction in broadcasting power. We also discovered they used a directional antenna system at night which directed the signal away form the MinnDOT facility.

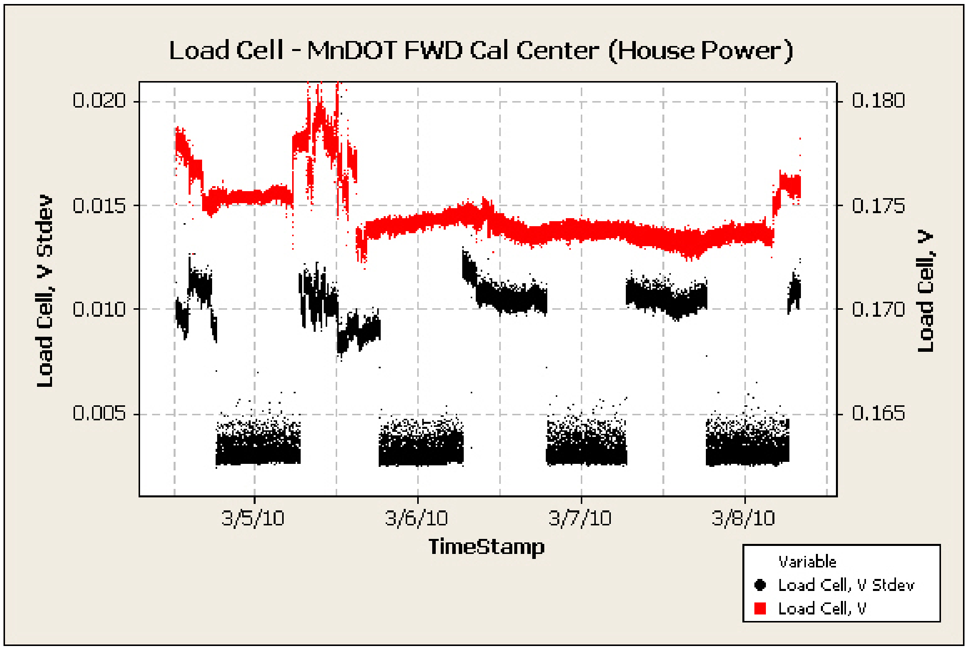

Figure 1. Data collected in the MinnDOT calibration center over a Friday – Monday period.

A second site visit at MinnDOT was made in an effort to find ways to overcome the problem. We discovered that the grounding of circuits in the part of the building housing the FWD Calibration Center were ineffectual, while the office area was well grounded. Several alternative ways of powering the calibration equipment were explored, resulting in a recommendation that they buy a DC powered motor generator and avoid using the house electrical lines. As an interim measure we loaned MinnDOT our motor generator equipment to try out for few months to verify that it would solve the problem. They recently returned our equipment, having bought some of their own. The noise problem has been solved.

TASK 2. TRANSFER OF LONG-TERM CALIBRATION CENTER SUPPORT STEWARDSHIP

We devoted considerable time and effort to training and working with AMRL personnel to build their confidence with taking over responsibility for the QA visits. The primary people from AMRL included Maria Knacke, Geremy Jablonski and Danny Stegmaier.

As noted under Task 1, two and often all three AMRL people participated in each of the site visits listed in table 1. The single exception was the site visit and operator training session at Colorado DOT which was arranged with very little advance notice.

A systematic program leading to transfer of responsibility began with the first visit in April to Pennsylvania DOT, and concluded with the visit to Dynatest in late June. Initially the AMRL people mainly observed, while at the end they had primary responsibility to conduct the site visit. During the series of site visits they developed their own QA checklist, with accompanying policies for administering the certification process.

At the request of Bob Lutz, AMRL, a special three-day training session on load cell calibration was held at Cornell for Bob, Geremy Jablonski and Danny Stegmaier on November 10-12, 2009. The agenda for the two-day meeting covered all aspects of implementing AASHTO R33.(7) It also included refresher training on FWD calibration procedures using AASHTO R32.(6)

We also arranged for AMRL to have program time during the fall 2009 and 2010 FWD Users Group meetings and the associated Calibration Center Operators Meetings. In 2010 AMRL took primary responsibility for leading the Operators Meeting.

Based on a discussion with AMRL in January 2011, the Cornell Local Roads Program has committed to support them by offering reference load cell calibration services in the future, using AASHTO R33, until they decide they would like to make other arrangements. We will also continue to provide technical back-up for the AMRL staff on an as-needed basis.

We recently learned that Danny Stegmaier has taken a new job, and he is no longer available to do the QA visits. That is an unfortunate loss after investing so much time in his training.

TASK 3. SOFTWARE UPDATES AND UPGRADES

Software upgrades to *WinFWDCal* and *PDDXconvert* were made throughout the reporting period. Suggestions and requests for changes came mainly through feedback from the Calibration Center Operators. The on site QA visits were a particularly good way to solicit operator input. On the average, revisions were sent out every couple of months.

Before each revision of the software was released, extensive testing to catch "bugs" was made in the Cornell Lab. A particularly large push was made before the two webinar training sessions.

During the reporting period two webinars were held to train people in the use of Version 2 of the *WinFWDCal* software. The two-hour webinars were arranged through NHI and held on Dec. 17, 2009 and October 6, 2010.

A new software package, *RefLCCal*, was created to support calibration of reference load cells according to the AASHTO R33 procedure.(7) One problem with reference load cell calibration is there is no reliable way to know if a load cell has been calibrated incorrectly. Thus an extensive number of data checks were built into the *RefLCCal* software to help reduce the chance of an incorrect calibration.

Programming and refining *RefLCCal* was much more time consuming than was originally expected. An opportunity presented itself in late February 2011 to try out the new software at an independent laboratory in Denmark that calibrated the reference load cell for the Carl Bro FWD manufacturing company. The result was the software performed quite well, and only a small number of modifications were needed to complete the release.

An extensively illustrated *Users Manual* has been written to accompany the software.(5) This software should be particularly useful in the future to calibration centers outside the USA, as well as to AMRL.

TASK 4. COMMUNICATION AND COORDINATION

In accordance with this task, Cornell organized the Calibration Center Operators meeting in fall 2009 and 2010. We also made presentations on the status of the project at the FWD Users Group meetings in 2009 and 2010.

While the possibility of holding a web conference with the Technical Advisory Committee was envisioned, the conference was not held. This choice was at the discretion of the COTR.

TASK 5. TASK ORDER #09-001 REPORT

This document is the Task Order #09-001 accomplishments report. It is the final progress report for the pooled fund study.

In addition to the Task Order #2 report, three additional reports have been submitted.

- Software Users Manual: *WinFWDCal.*(3)
- Software Users Manual: *PDDXconvert.*(4)
- Software Users Manual: *RefLCCal.*(5)

For each software package, the documentation included the software source code, an install module, MS Word and PDF version of the manual, a set of TIFF figure files, and a set of Section 508 figure captions. These materials were provided electronically on separate CDs.

A comprehensive, 266-page project report, edited and updated to include all aspects of the pooled fund study including Task Order 08-001 and 09-001, was submitted on November 17, 2010.(2)

Draft copies of two revised AASHTO standards, R32 and R33, were submitted and approved by AASHTO.(6,7)

TASK 6. QUARTERLY PROGRESS REPORTS

A progress report was submitted on March 10, 2010 covering the period from September 1, 2009 through February 28, 2010. According to the revised TOPR proposal submitted on July 2, 2009, two progress reports were scheduled to be submitted in October 2009 and January 2010. However, due to an extension of T.O. 08-001 to August 28, 2009, along with delays at Cornell signing the T.O. 09-001 agreement, it was agreed in February 2010 to combine the two reports into one.

OPTIONAL TASK 7. CALIBRATION SYSTEM IMPROVEMENTS

Four projects were pursued under this task.

- Update and submit the AASHTO R33 standard for reference load cell calibration.

- Write software based on the revised R33 to support the process of load cell calibration.
- Update and submit the AASHTO R32 standard for FWD calibration.
- Develop a high-capacity reference load cell.
- Develop a protective box for the data acquisition board.

Notice to proceed on the high-capacity load cell was received on March 25, 2010. Development of the protective box for the DAQ came about due to problems experienced during the reporting period. While it was a calibration system improvement (Task 7), it was also a technical support activity (Task 1). Accomplishments of each project are detailed below.

Update and submit AASHTO R33

Leading up to the pooled fund study the available version of AASHTO Recommended Practice R33 for reference load cell calibration was predicated on the March 1992 version of the Strategic Highway Research Program (SHRP) FWD Calibration Protocol. By 2009 a substantial number of changes in the protocol for calibrating reference load cells had been made, along with changes in the equipment, computer operating system, and data analysis methods. This necessitated an extensive update in the AASHTO R33 procedure.

On May 24, 2010 the revised copy for R33 was submitted to the supervising subcommittee at AASHTO. The final ballot on the revisions was concluded in January 2011, and the updated version of R33-11 will be published by AASHTO this spring.(7)

Write software to support R33

Throughout the years from 1992 until the present the Cornell Local Roads Program has served as the sole agent for calibrating reference load cells. The software that was used for this purpose was relatively simple, since it was only used in-house. Initially DOS software was used. In 2004 we upgraded from a 12-bit DAQ board to a 16-bit board, and the software was rewritten in LabView.

The task of writing a Windows based program to support R33 turned out to be substantially more than we originally envisioned. This was primarily due to the need to make sure it was self-contained. The software must be used with all types of universal testing machines, in both metric and U.S. customary units. As reported under Task 3, we had an opportunity to use the *RefLCCal* program at a consulting testing laboratory in Denmark in late February 2011. The software worked very well, and it has been released to FHWA for distribution.

Update and submit AASHTO R32

AASHTO Recommended Practice R32 for FWD calibration was completely rewritten and submitted for approval in June 2008. It was approved by AASHTO and published as R32-09.

Additional refinements were made to the procedure in 2009 and 2010, based on our experiences and on feedback from the calibration centers. The changes were mainly in the acceptance criteria for both reference and relative calibration.

On a request from FHWA we reviewed and updated the R32-09 standard to reflect the recent changes. On June 22, 2010 the revised copy for R32 was submitted to the supervising subcommittee at AASHTO. The final ballot on the revisions was concluded in January 2011, and the updated version of R32-11 will be published by AASHTO this spring.(6)

Develop a high-capacity load cell

Based on the standard usage of FWDs during the SHRP study, FWD calibration is typically done at load levels of 27, 40, 53, and 71 kN (6000, 9000, 12,000 and 16,000 lb.). While the procedure under AASHTO R32 allows nearly any set of load levels, most FWD owner agencies still use the SHRP load levels. The 106 kN (24,000 lb) capacity reference load cell is used for this purpose.

That procedure meets the needs of FWD owners, but some concern has been expressed by HWD owners whose equipment is capable of loads up to 300 kN (68,000 lb) or so. They would prefer that their load cell was calibrated over a wider range of loads to assure the accuracy of the calibration.

Thus under the pooled fund study we set about to design a high-capacity load cell, capable of accurately measuring loads up to 300 kN or more. A proposed design had been developed during earlier years of the study (figure 2). One goal for the design was to use commercially produced load cells in order to reduce the cost of the final product. Aluminum was used for the upper and lower plates to minimize the weight.


Figure 2. High-capacity load cell.

Three points define a plane, so three commercial load cells were used in the design. Each element had a capacity of 30 kN, giving a total capacity of 90 kN.

Even though the three load cells were purchase at the same time, and they bore sequential serial numbers, they each had a slightly different sensitivity (i.e., volts output / volt excitation / kN). This did not pose a major problem for the static calibration of the load cell (using the R33 procedure). However, a directional sensitivity was found when the system was used to measure the dynamic loads of the FWD.

For instance, if a reference line was drawn on the load cell, when it was aligned with the tongue of the FWD trailer as 0 degrees one gain factor was obtained. If the load cell was rotated to a 90 degree position, a different gain factor was obtained. Different gain factors were also obtained at 180 and 270 degrees. These gain factors differed by one percent or more, which was beyond the 0.3 percent limit obtained with the current equipment.

An effort was made to balance the different load cell sensitivities using a balancing network purchased from the load cell manufacturer, but that did not eliminate the directionality in dynamic loading.

In the final analysis the project was abandoned for several reasons.

- The cost of the three load cells plus a balancing network caused the overall cost to be comparable to the custom load cell that is currently used. Thus the cost saving goal was not achieved.
- It did not appear that dynamic directional effects could be eliminated. This is not a problem with the current custom reference load cell design because the sensitivities of the load links can be adjusted to be identical.
- Due to the very rigorous linearity requirement in the AASHTO R33 procedure (standard error of 0.0020 or less) the FWD load calibration assures that the gain factor for HWD machines is valid to a high load level.
- The current R33 procedure yields a load gain factor that exceeds the accuracy needs for backcalculation.
- There is a minor concern that if an HWD is calibrated at the higher load range the concrete test pad may experience fatigue damage and cracking.

Develop a protective box for the DAQ

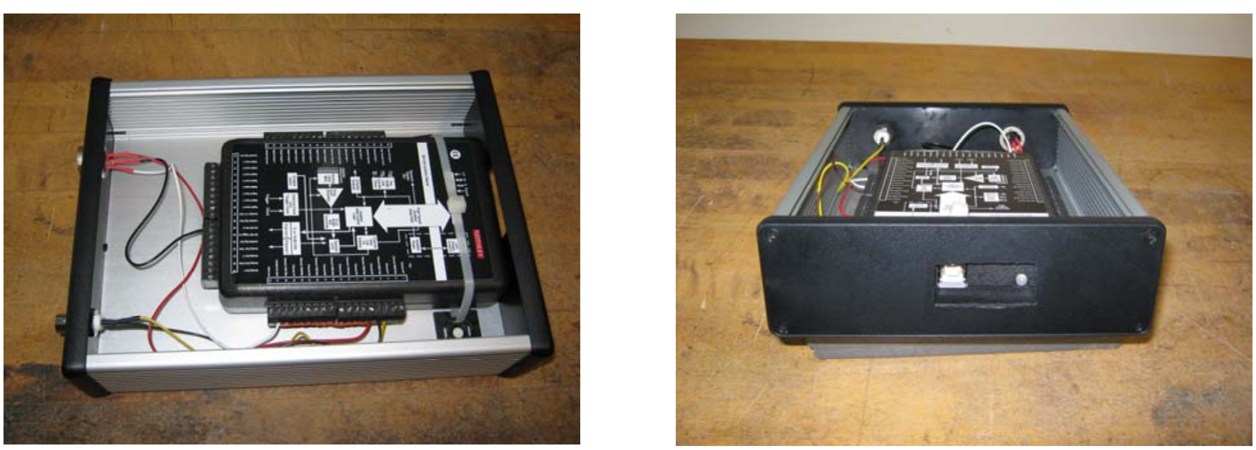

Figure 3. Protective box for DAQ board (cover removed).

After a period of use of the new hardware for AASHTO R32 feedback from users caused us to become aware that the wires leading to the screw terminals on the DAQ board were vulnerable to becoming loose.

We selected an inexpensive metal box in which we put the data acquisition board, held in place by a strip of Velcro (figure 3). This removed all stress on the screw terminal wiring, and had the added benefit of providing quick disconnect cables for the inputs and output.

As reference load cells come to us for calibration we are installing the DAQ board in the protective box. We expect to have completed the upgrade for all calibration centers by the end of the summer 2011.

OPTIONAL TASK 8. CALIBRATION CENTER OPERATORS MEETING – TRAVEL SUPPORT

Travel support to attend the Calibration Center Operators Meetings in fall 2009 and fall 2010 were sent to all seven FHWA-supported centers. Due to a delay in getting T.O. 09-001 in place and fully operational, the notification in the fall 2009 was late in getting out, and the response was unenthusiastic.

A similar situation occurred in fall 2010, although the response was substantially better than in 2009. T.O. 09-001 was originally scheduled to expire on August 25, 2010. A no cost time extension through October 2010 was requested in early August specifically to allow offering travel support, and approval was received on August 17. Five operators attended due to this support.

Travel support to attend the two Operators Meetings was also extended to AMRL personnel. They attended both meetings.

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