PROGRESS REPORT

Working Meeting One

October 28, 2015

EXECUTIVE SUMMARY

This was the first working meeting of the consortium, which is funded through the AMTech program of the Advanced Manufacturing Office of NIST (an earlier kick-off meeting in July had generated interest in the large-scale manufacturing community). The initial proposal referred to this meeting as the"*Planning and Visioning Council.*" The majority of the meeting was spent gathering information from the participants in a series of different brainstorming formats. These data will be used in guiding the planning for the **Needs Assessment and Gap Analysis Workshop** in February 2016. The final portion of the meeting was spent on administrative activities, including choosing a name for the consortium, electing an interim board of directors, soliciting names and companies for future participation in the consortium, and narrowing dates for the next workshop to be held in Charlotte, NC. The data collected from the participants are summarized in the remainder of this report.

The administrative actions are shown in the following table:

Item	Result
Consortium name	PrecisionPath Consortium for Large-scale Manufacturing
Interim Board	Ron Hicks, Ed Morse, Glen Cork, Patrick Welch, Gary Confalone
Next Meeting	February 24-25 (proposed) in Charlotte, NC

INITIAL BROAD DISCUSSIONS

(Agenda Item III)

In order to stimulate discussion, participants were asked to verbally respond to two questions; 1. *"In making large products to precision tolerances, what is driving change in your industry?"*, and 2. *"What are two or three critical challenges you face in meeting this change?"* The responses are summarized below.

1. Drivers of Change

There were 19 total responses to this question, with many responses covering a wide range of topics. Several themes emerged:

> **Software, data management and analytics:** Eight comments were related to challenges around creating, communicating, and acting on the "digital thread" data. New instruments and tools make it increasingly fast and easy to collect large volumes of measurement data, often using relatively low-skilled operators; but making sense of the data often requires highly trained individuals and lots of analysis time. Automated analysis and decision making in near real time is desired. It is important for digitization to connect everything. We

are good at digitization in fabrication and design but could improve in assembly digitization and data management. Common user interfaces and data structures across multiple measurement instruments and platforms is highly desired.

Workforce, automation, and supply base issues: A total of 13 comments were related to challenges with workforce, including skills certification, finding and training workforce, and the need to automate metrology processes to address the need for shorter cycle times. Several people observed that it is particularly difficult for the supply base to adopt new portable measurement technologies due to lack of capital funds and in-house knowledge to operate the instruments. Automation of both instruments and analysis was seen as a potential way to address some workforce issues. Need to certify robot performance was also mentioned as being important.

Alignment and assembly: A total of five comments were related to increased use of portable metrology equipment for alignment and assembly of large components, systems, and machines. A drive towards determinate assembly and reduced cycle time are important drivers.

Accuracy: A total of seven comments were related to issues of accuracy and traceability of instruments. Several responders noted challenges related to managing thermal and gravitational distortions as demand for accuracy increases. Changes from metal to composite construction in some industries is creating challenges in achieving desired tolerances. Incorrect or poorly thought out GD&T specifications from designers are a source of frustration. Better methods to more completely understand and characterize the measurement accuracy of various instruments is needed.

Cost, cycle time and throughput: Almost all respondents agreed that they are facing significant pressure to reduce time required for measurement activities in order to meet production schedules. In some cases, cost is increasingly becoming a limiting factor. Reliability of measuring equipment is more critical as it becomes more integrated into the manufacturing process.

2. Critical Challenges

For this part of the discussion, participants were asked to list several critical challenges they face in meeting change in their industry. They were then asked to rate the "criticality" of the entire list of issues on a scale that ranged from near-term (i.e. less than five years) to long-term (i.e. more than ten years). The five issues rated most critical were: *reliability, accuracy, data management, common user interface, and automation and integration of metrology instruments into production processes*. Issues ranking low on criticality included: *parallelization of metrology with other work, development of new methods, gravitational and thermal distortions, and cost justification*.

TECHNOLOGY FAMILIES AND ATTRIBUTES

(Agenda Item IV)

In this portion of the agenda, participants were first asked to list the types of instruments used. The question was posed as: *What are the primary metrology technology families (e.g. laser trackers) that you (or your customers) use?*

The responses were categorized into the following groups:

Laser Trackers , Scanners, Metrology Software, Manual Measurement, Fixed CMM , Profilometers, Laser Radar, Theodolites & Total Stations, Photogrammetry, Articulated Arm CMMs, IGPS (Indoor GPS), Structured light, and "Other Technologies" (*Laser Projectors, NDI – composites, NDI – Paint, Targeting, Google Glass*)

Participants then listed instrument attributes that are important to these technologies. The text of the question was: *What attributes (e.g. accuracy, speed, or portability) of these technologies are of importance?*

A very large number of responses were consolidated into the following attribute list:

Accuracy, Cost Effectiveness, Speed, Measurement Range, Environmental Sensitivity, Required Training, Environmental Requirements, Data Characteristics, Software Interface, Safety / Reputation, Portability / Versatility, and Non - Contract Measurement

Following the grouping described above, the relative importance of the attributes were voted on for each technology family. The rating ranged from critical (5) to not important (1). These data were averaged for all of the meeting participants.

Table 1: Example of Data Collected (averages shown)

		Attributes				
		Accuracy	Speed	etc …	etc …	etc …
Instrument Families	Laser Trackers	4.84	3.76	---	---	
	Structured Light	4.36	4.18	---	---	
	etc ….	---	---	---	---	

The full data collected are shown on the next page. The 'average importance' scores are also shown for each row and column. One task for the next meeting will be to utilize these data to develop the status of current technology capability, and where we should be in, for example, the next 10 years.

Table 2: Summary of Data Collected (averages shown)

Attributes / Technology Families	Accuracy	Cost Effectiveness	Speed	Measurement Range	Env. Sensitivity	Required Training	Environmental Requirements	Data Characteristics	Software Interface	Safety / Reputation	Portability / Versatility	Non - Contract Measurement		
Other Technologies	3.00	3.83	3.67	2.83	4.00	4.50	2.27	2.00	3.30	3.30	4.10	3.44		3.35
Laser Trackers	4.85	4.15	3.77	4.46	4.38	5.00	3.75	3.58	4.33	4.00	4.75	2.58		4.13
Scanners	4.08	3.85	4.00	4.08	4.23	4.46	3.73	4.82	4.09	3.73	4.91	5.00		4.25
Metrology Software	4.54	3.46	3.85	2.55	4.85	4.75	1.67	4.00	4.92	4.00	2.67	2.27		3.63
Manual Measurement	3.92	3.33	2.92	1.70	3.92	3.92	2.67	1.75	1.17	2.92	3.92	1.83		2.83
Fixed CMM	4.91	3.18	3.36	2.55	3.45	4.09	4.00	3.80	4.30	4.30	2.00	3.20		3.60
Profilometers	3.56	2.89	2.78	2.13	3.56	4.22	3.00	2.89	2.44	3.11	3.56	2.33		3.04
Laser Radar	4.82	4.00	4.82	4.55	4.18	4.73	3.73	4.18	4.36	4.00	4.36	5.00		4.39
Theodolites & Total Stations	3.91	3.00	3.09	3.91	3.82	4.36	3.09	2.55	3.27	3.36	4.36	3.82		3.55
Photogrammetry	4.55	3.64	4.09	4.27	4.09	4.55	2.91	3.91	4.36	3.73	4.82	4.18		4.09
Articulated Arm CMMs	4.73	3.64	3.36	1.73	4.45	4.73	2.92	3.50	4.08	3.67	4.50	3.25		3.71
IGPS (Indoor GPS)	3.67	3.58	3.75	4.50	3.83	4.33	3.18	3.09	4.09	3.36	3.73	3.18		3.69
Structured light	4.36	3.91	4.18	3.09	3.91	4.40	3.73	4.64	4.36	3.64	4.09	5.00		4.11
	4.22	3.57	3.66	3.26	4.05	4.46	3.13	3.44	3.78	3.62	3.98	3.47		

USAGE SCENARIOS

(Agenda Item VI)

The final technical area of discussion asked participants to respond to the question, *"How is portable metrology used for supporting large scale manufacturing in your (or your customer's) business?"*. A total of 75 responses were received. The responses have been grouped into categories, with the number of responses in each category and sub-category noted in parentheses.

1. Alignment and registration of components during assembly (11 responses)
    a. Component alignment (7 responses)
    b. Virtual Assembly (4 responses)
2. Alignment and registration of components and fixtures to manufacturing machinery (7 responses)
3. Post-process evaluation of design dimensions and geometry for components and assemblies (15 responses)
4. In-process evaluation of component and assembly dimensions and geometry (12 responses)
    a. Dimensional and geometry checking (5 responses)
    b. Process feedback and control (6 responses)
    c. Verifying supplier quality (2 responses)

5. Calibration, accuracy evaluation, and control of manufacturing equipment (14 responses)
    a. Machine accuracy evaluation, calibration (5 responses)
    b. Verify accuracy of tooling, fixtures, transfer standards (6 responses)
    c. Feedback control of machines (3 responses)
6. Reverse engineering of existing or as/built facilities, components and systems (8 responses)
    a. Facility condition and utilization (3 responses)
    b. Reverse engineering of legacy components and systems (1 response)
    c. Facilitate repairs (2 responses)
    d. Digital model of "as-built" system (2 responses)
7. Other (8 responses)
    a. Training
    b. Documentation
    c. Comparison to other measurements
    d. Data for analysis models
    e. Coupon testing
    f. Additive manufacturing
    g. Strain and compression measurements
    h. Part selection

As is true for the technology and attributes data, this information will be valuable in supporting the activities in the Needs Assessment and Gap Analysis Workshop to be held in Charlotte, NC in February 2016.

We hope to see you there!
The PrecisionPath Team