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Exploring the Feasibility of Supply-chain Data Reuse through Standards-based Interoperability for MBD

An ITI technical brief outlining NIST project findings which demonstrate the use of 3D MBD model data in downstream processes via ISO standards

Abstract

Moving to model based definition (MBD) 3D technical data packages (TDPs) provides opportunities to improve quality and reduce costs in manufacturing. MBD models need to contain all of the necessary product manufacturing information (PMI) and enable machining and inspection programming to be done without manually re-entering data. Many software applications used in manufacturing and inspection rely on neutral data formats to read 3D MBD models.

Contractors are usually required to deliver TDPs that are compliant with industry standards and customer specifications. 3D models often need to be provided as part of the TDP in neutral formats such as STEP (ISO10303) format, 3D PDF (ISO 14739) or JT (ISO 14306). Simply producing a correct file type may meet contractual requirements, but how do you know that the data contained in TDPs both meets ISO standards and is usable downstream?

Careful planning and adjustment of recommended practices to be more MBD focused are necessary to produce data that both meets required ISO standards – and – is complete and sufficient for downstream use. When neutral files are unusable downstream, significant cost and quality risks are introduced as users re-create data manually to carry out their tasks.

ITI has participated in a National Institute for Standards and Technology (NIST) project that demonstrated the feasibility of using an ISO standards based approach to moving MBD downstream and identified areas where there is the most significant opportunity to use that MBD data downstream while saving time. Downstream process maturity was analyzed and benefits were assessed. It was demonstrated that currently the most significant opportunity to save time is in the areas of coordinate measuring machine (CMM) and first article inspection (FAI) programming. This technical brief explores the NIST project and its findings.

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Standards and Compliance

When government programs fund design activities, contractors must deliver engineering data in a technical data package (TDP) compliant with MIL-STD-31000A. This standard allows for 3D model data deliverables (Type 3D), commonly referred to as Model Based Definition (MBD) models. These models typically have no associated 2D drawing (although in some cases 2D drawings may be still be used), and have the potential to be used in both human-interpreted (graphical) and machine-interpreted (semantic) processes downstream.

For TDPs defined as Type 3D, 3D models must be provided in STEP (ISO10303) format, or a native format capable of producing STEP. A contract may require additional ISO standard formats, such as 3D PDF (ISO 14739) or JT (ISO 14306). Simply producing a correct file type may meet contractual requirements, but is that data usable for downstream applications?

Careful planning is necessary to produce data that both meets required ISO standards – and – is complete and sufficient for downstream use. When neutral files are unusable, significant cost and quality risks are introduced as users re-create data manually to carry out their tasks. A correctly defined MBD schema and appropriate validation checks are important steps in achieving MIL-STD-31000A compliance.

ITI has participated in a number of related National Institute for Standards and Technology (NIST) projects that are helping to accelerate the development of practical exchange of MBD data in supply chain contexts. In earlier projects1,2,3, the focus was on ensuring that CAD models, defined with MBD and downstream reuse in mind, were verified to conform to MBD standards, and could be translated into ISO standard formats, and that those translated data files could be analyzed 1) for compliance to the MBD aspects of the standards, and 2) could be validated to correctly and completely represent the original MBD data. ITI's consultants, using ITI's CADIQ validation product, perform these critical verification and validation analyses.

Results of those projects showed that work was needed in the standards, in the CAD systems, and in translators, to better capture MBD data and transform it into forms that could be used downstream with confidence. Work to further improve the quality and robustness of MBD data continues. Ongoing efforts by organizations like the CAx Implementor Forum (co-sponsored by PDES, Inc. and ProSTEP), the JT Implementor Forum (co-sponsored by the JT Open Consortium and ProSTEP) and the 3D PDF Implementor Forum (sponsored by the 3D PDF Consortium), in conjunction with ITI's verification and validation expertise, continue make progress on this critical requirement.

[1] NIST GCR 15-977, Measuring the PMI Modeling Capability in CAD Systems: Report 1 - Combined Test Case Verification, October 2015

[2] NIST GCR 15-998, Measuring the PMI Modeling Capability in CAD Systems: Report 2 - Combined Test Case Validation, October 2015

[3] NIST GCR 15-999, Measuring the PMI Modeling Capability in CAD Systems: Report 3 - Fully-Toleranced Test Case Verification, October 2015

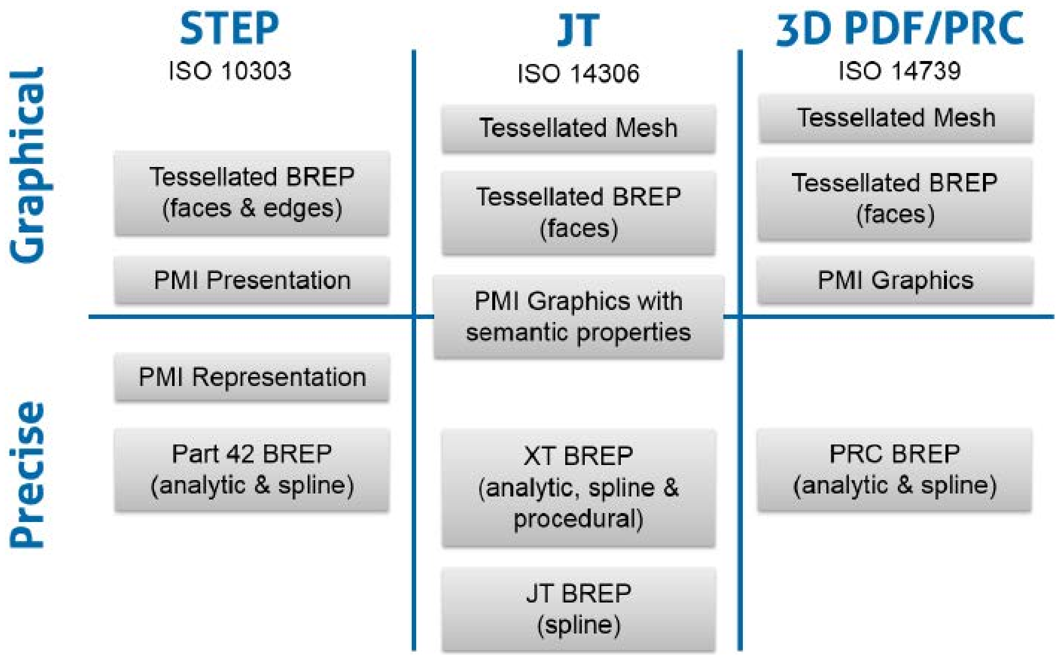


Figure 1 - Neutral format geometry and PMI options

Achieving cost savings through direct consumption of MBD models in manufacturing (CNC) and inspection (CMM/FAI)

It has been assumed that moving to MBD based (3D) TDPs would provide opportunities to improve quality in the supply chain and reduce costs in manufacturing and inspection. If PMI representation (semantic) data in ISO standard formats (See Figure 1 above) could be sent downstream and ingested directly by CAM and CMM planning applications, it was expected to enable machining and inspection programming to be done quickly. The data was also not expected to require manual re-entry, thus reducing the cost of transcribing the data and also eliminating the potential for costly rework in the event of transcription error.

The subject of this technical brief is the most recent NIST project4 that is a follow-on the work described above, in which researchers sought to focus on actually demonstrating the ability to use one of these standards, ISO 10303 (STEP AP242) to move MBD data downstream. In the course of the project, downstream process maturity was to be analyzed and benefits were to be assessed. The team members in this project included ITI, Rockwell Collins, Core Technologie, CNC Software, Mitutoyo, and Geater Machining and Manufacturing. Their roles in this supply chain MBD exchange process are shown in Figure 2.

[4] NIST GCR 15-1009, Investigating the Impact of Standards-Based Interoperability for Design to Manufacturing and Quality in the Supply Chain, December 2016

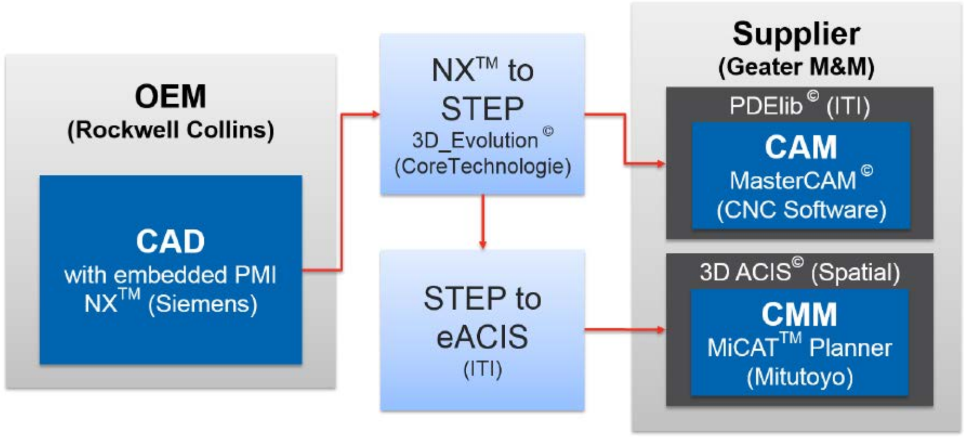
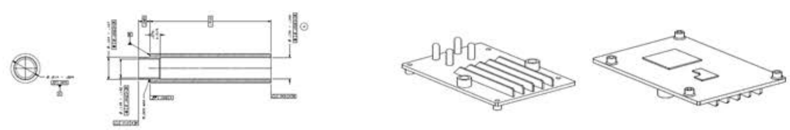


Figure 2 – Supply-Chain MBD Data Exchange Process

Two production parts were used, one turned part (Spacer) and one milled part (Heat Sink). In order to understand the potential benefits of MBD, three different model creation and information transfer processes were explored for each of the two parts. The three methods were intended to compare and contrast conventional data creation and delivery with an MBD focused data creation and delivery process.

In the fully realized MBD approach, the design model was exchanged via STEP AP242 containing all PMI as structured representation (semantic) data. A 2D drawing was included only as a visual reference. In the conventional approach, a design model was exchanged via STEP containing only a boundary representation (b-rep) geometry model and a regular, fully dimensioned 2D drawing was used for exchange of PMI data. In a third approach, the design model was exchanged via a STEP AP242 file containing only the b-rep geometry model and only key PMI data was exchanged via a regular, partially-dimensioned 2D drawing.

The following tables describe the metrics captured during the team's analysis of the process. The three methods above are shown in each table and for each of the two models. Models -903 and -904 are for the fully realized MBD model approach. Models -905 and -906 are for the conventional undimensioned model and the fully-dimensioned 2D drawing approach. Models -907 and -908 are for the conventional undimensioned model and partially-dimensioned 2D drawing approach.



CAD Metrics	Spacer, Shouldered			Heat Sink, Top		
827-9999	-903	-905	-907	-904	-906	-908
Number of PMI entities	23 (24*)	---	---	78 (90*)	---	---
3D model	with embedded PMI	with no embedded PMI	with no embedded PMI	with embedded PMI	with no embedded PMI	with no embedded PMI
2D PDF drawing	for reference visual only	full dimension and 2D PMI annotation	key 2D PMI annotation only (PDD)	for reference visual only	full dimension and 2D PMI annotation	key 2D PMI annotation only (PDD)
CAD model creation (modified existing part)	0.5 hours	0.5 hours	0.5 hours	0.5 hours	0.5 hours	0.5 hours
Model-embedded PMI	3.0 hours	---	---	6.0 hours	---	---
2D PDF drawing creation	0.5 hours	1.0 hours	0.7 hours	0.5 hours	2.4 hours	1.3 hours
CAD tool issue resolution and designer education	9.0 hours	0.5 hours	0.1 hours	4.9 hours	0.5 hours	0.1 hours
CAD model resolution to address CAI issues	2.3 hours + 4.5 hours to figure out NX	---	---	3.0 hours + 1.3 hours to figure out NX	---	---

* Original PMI entity count based on objects found under *PMI* in the NX Part Navigator – eventually reduced count through issue resolution

Figure 3 – CAD modeling metrics for MBD vs. conventional drawing vs. partially-dimensioned drawing

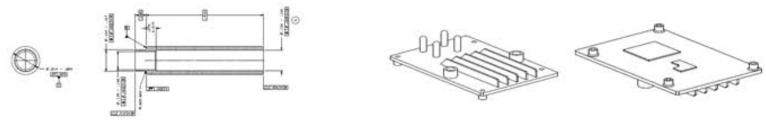
The first table (Figure 3, above) shows the metrics for each method of CAD model creation. The research indicated that there was a significant “learning curve” among the designers observed in this study for MBD creation (none had experience with MBD-based design modeling before the study). The designers indicated, however, that they felt much more comfortable with the new MBD process at the end of the study and suggested that designer education and issues with use of the CAD tool for MBD would diminish over time. It was also observed that drawing creation, if needed, for the MBD approach was significantly faster than annotation of conventional 2D Drawings. Another observation was that the designer had to take care to apply PMI to the 3D model accurately to ensure that downstream tools could use the embedded PMI data in the MBD model. For example, designers had to be sure to associate appropriate model surfaces to each piece of PMI during creation in the CAD tool.

The second table (Figure 4, next page) shows the metrics for CAM processes. Surprisingly, the metrics showed no significant change in time required for any of the three process methods: MBD-based, conventional drawing-based, or partially-dimensioned drawing-based. Possible reasons why the team had such a result for the CAM process are discussed in the conclusion of this brief.

The final table (Figure 5, next page) shows the metrics for CMM processes. The choice of the first model, the Spacer, was problematic for the team. Unfortunately, the CMM machine made available to the team for this study did not have a CMM probe that was small enough to measure the very small features of the Spacer part. As such, no metrics for automated inspection data for that part could be collected. The team performed inspection of the Spacer by hand for completeness. On the other hand, the metrics for automated inspection of the Heat Sink part were significant. Automatic capture of PMI data embedded in the STEP AP242 definition by the CMM planning software significantly reduced the time to prepare, program, and verify the CMM. In addition, no manual transcription was required, so no rework was required to trace back errors that might have resulted from such transcription errors.

CAM Metrics	Spacer, Shouldered			Heat Sink, Top		
827-9999	-903	-905	-907	-904	-906	-908
CAM process preparation a) Gather information b) Analyze job c) Determine approach	**3.25 hours** a) .25 hours b) .50 hours c) 2.5 hours	**3.25 hours** a) .25 hours b) .50 hours c) 2.5 hours	**3.25 hours** a) .25 hours b) .50 hours c) 2.5 hours	**3.83 hours** a) .33 hours b) .50 hours c) 3.0 hours	**3.83 hours** a) .33 hours b) .50 hours c) 3.0 hours	**3.83 hours** a) .33 hours b) .50 hours c) 3.0 hours
CAM setup a) Model preparation (PFIX) b) Setup (Pre-Programming Setup)	**.45 hours** a) .0 hours b) .45 hours	**.45 hours** a) .0 hours b) .45 hours	**.45 hours** a) .0 hours b) .45 hours	**.68 hours** a) .45 hours b) .23 hours	**.39 hours** a) .27 hours b) .12 hours	**.40 Hours** a) .28 hours b) .12 hours
CAM programming a) Part programming b) Tooling preparation	**1. hour** a) .5 hours b) .5 hours	**1. hour** a) .5 hours b) .5 hours	**1. hour** a) .5 hours b) .5 hours	**3.23 hours** a) 3.01 hours b) .22 hours	**3.13 hours** a) 2.75 hours b) .38 hours	**2.3 hours** a) 2.08 hours b) .22 hours
CAM verification a) Create work instruction (Setup Sheets) b) Review process (Run Vericut)	**.15 hours** a) .1 hours b) .05 hours	**.15 hours** a) .1 hours b) .05 hours	**.15 hours** a) .1 hours b) .05 hours	**.42 hours** a) .32 hours b) .1 hours	**.5 hours** a) .35 hours b) .15 hours	**.53 hours** a) .35 hours b) .18 hours
Totals	**4.85 hours**	**4.85 hours**	**4.85 hours**	**8.16 hours**	**7.85 hours**	**7.06 hours**

Figure 4 – CAM process metrics for MBD vs. conventional drawing vs. partially-dimensioned drawing



CMM Metrics	Spacer, Shouldered			Heat Sink, Top		
827-9999	-903	-905	-907	-904	-906	-908
CMM process preparation				**.1 hours**	**.5 hours**	**.75 hours**
CMM setup				**.1 hours**	**.75 hours**	**1 hour**
CMM programming				**.5 hours**	**4.76 hours**	**4.75 hours**
CMM verification a) Verify information b) Verify for collisions				**.3 hours** a) .15 hours b) .15 hours	**1 hour** a) .5 hours b) .5 hours	**1 hour** a) .5 hours b) .5 hours
a) CMM inspection run b) Manual inspection	**.5 hours** a) 0. hours b) .5 hours	**.25 hours** a) 0. hours b) .25 hours	**.25 hours** a) 0. hours b) .25 hours	**.7 hours** a) .2 hours b) .5 hours	**.4 hours** a) .2 hours b) .2 hours	**.4 hours** a) .2 hours b) .2 hours
CMM data analysis				**.5 Hours**	**.5 hours**	**.5 hours**
Totals	**.5 hours**	**.25 hours**	**.25 hours**	**2.2 hours**	**7.91 hours**	**8.4 hours**

Figure 5 – CMM process metrics for MBD vs. conventional drawing vs. partially-dimensioned drawing

Conclusion

This project demonstrated that currently the most significant opportunity to save time is in the areas of coordinate measuring machine (CMM) and first article inspection (FAI) programming. Inspection processes for CMM and FAI were accomplished in **72% less time when consuming the PMI data directly from the STEP AP242 model than via previous methods using transcribed 2D drawing information.**

Though the CAM planning system was also able to consume the PMI data from the STEP, the CAM planning software was not yet able to make use of the imported PMI data and, as such, CNC programming for CAM still required manual data entry, therefore not showing the efficiency gains as demonstrated here for CMM. However, the team was confident that future generations of CAM software will begin to see improvement in process time and quality in a similar way.

MBD is not expected to save a lot of time in the CAD design phase, but designer education and continuing improvements in CAD systems' MBD capability will be key to delivering quality design data for MBD purposes and, in turn, is critical to achieving downstream impact.

Looking ahead, many software applications used in manufacturing and inspection will begin to rely on direct consumption of neutral data formats containing 3D MBD models because of the savings in time and reduction of errors requiring rework. Although using ISO standards allows the supply chain to manage software costs more effectively and provide this new approach to rapid exchange of data, directly between systems and without human verification, it makes it that much more important to validate these derivative exchange formats against their original data source.

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Contact us today to learn more!

www.iti-global.com
info@iti-global.com
1-800-783-9199

5303 DuPont Circle
Milford, OH 45150, USA