Implementation of Model-Based Definition-Case of Manufacturing Industry in Finland

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Abstract. Model-Based Definition (MBD) supplies benefits in digital product process, especially in communication between engineering and downstream processes. This is possible due to a semantic machine-readable 3D model, which is gaining popularity in modern CAD/CAM systems. Particularly aerospace and automotive industries have utilized MBD in their processes. However, MBD is less used in Small and Mid-Size Enterprises (SME), where manufacturing series are typically small, but products can be highly configured. This inspired us to make a survey for Finnish Mechanical Engineering companies which typically are SME companies with highly specialized products. We wanted to find out, how familiar MBD is to them, how they transfer Product and Manufacturing Information (PMI) from design to manufacturing, what are their objectives in MBD, and what barriers need to be overcome before introducing MBD in companies. Most of the informants in our survey are familiar with the MBD, but less than half of them is either using or introducing the MBD in their companies and suppliers. Despite developed digital design and manufacturing tools in the Mechanical Engineering Industry, lack of skills in using MBD both among companies and their suppliers was the main reason for not utilizing MBD.

Keywords: semantic MBD, PMI, Ideal Digital Product Process

Nomenclature

AL(i)	Awareness Level in level i
CAD	Computer Aided Design
CAI	Computer Aided Inspection
CAM	Computer Aided Manufacturing
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
DCD	Drawing-Centric Definition
ECC	Engineering Change Control
ERP	Enterprise Resource Planning
IDPP	Ideal Digital Product Process
MBD	Model-Based Definition

MCD	Model-Centric Definition
MES	Manufacturing Execution System
OEM	Own Equipment Manufacturing
RAL	Relative Awareness Level
SME	Small and Mid-Size Enterprises
STEP	Standard for Exchange of Product model data

1 Introduction

A Model-Based Definition (MBD) supplies benefits in perceiving the blueprints by visualizing the 3D model. Furthermore, a machine-readable semantic MBD dataset transmits the Product and Manufacturing Information (PMI) between various information systems of the manufacturing process. Such process we call as an Ideal Digital Product Process (IDPP) (Fig. 1). It exploits the Digital Thread, which is a common path for information exchange between different systems.

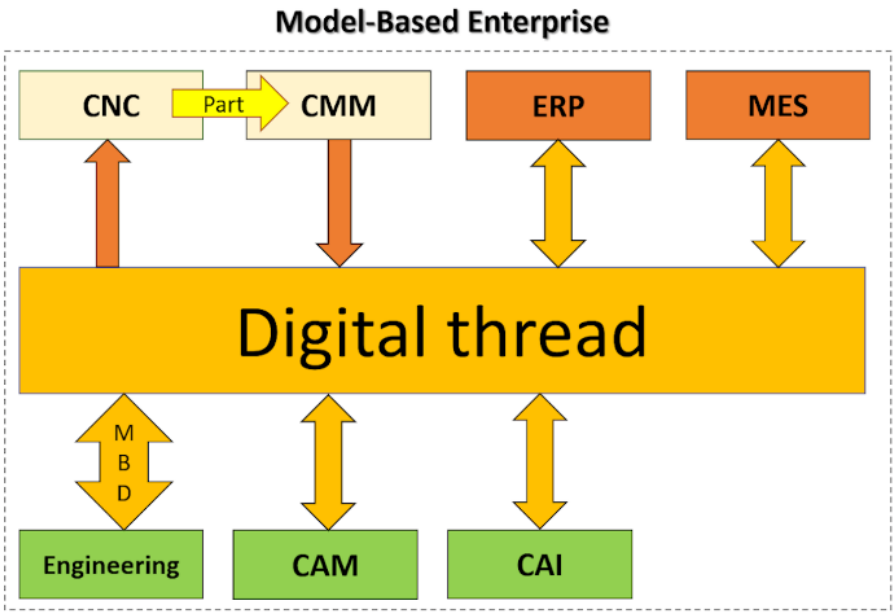

Fig. 1. Ideal Digital Product Process.

A semantic MBD model in database supplies engineering information for downstream process. The model can be transmitted as a native CAD (Computer Aided Design) format or as a neutral transmission format such as STEP AP242. Manufacturing process in another department or in a company uses this file and produces CAM

(Computer Aided Manufacturing) programs for CNC (Computer Numerical Control) machine. The CAM programming can be fully or partly automated due to semantic MBD model. The machined physical part is delivered to the inspection for measuring the part with a Coordinate Measuring Machine (CMM). Before the inspection process, CAI code (Computer Aided Inspection) was generated either automatically or human-assisted with the semantic MBD model. If the inspection phase of the physical part detects deviations compared to the MBD model, feedback of this manufacturing issue will be sent to the upstream for a corresponding person. The approved part is delivered to the next phase of process such as surface treatment, which receives relevant information from same source as machining, programming, and inspection. The semantic MBD model includes information of materials, surface quality as well as tolerances that are necessary data in the product life cycle. These data sets are available since the designer has uploaded the semantic MBD model into product data system. Sourcing and production can start preparing for material purchase and assembling process phases because all necessary information is available in the single-source of truth where the Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) can access. Despite developed digital data systems and manufacturing technologies, product process is rarely as fluent as introduced in the IDPP. This inspired us to make the survey for find out how the Finnish Mechanical Engineering Industry delivers a Product and Manufacturing Information to production and what are the reasons why MBD is rarely used in Finland. Typically, production series are small, and products are highly customized in Finland. However, many product assemblies include simple components which are sourced from low-cost companies. This research focuses on the Finnish Mechanical Engineering Industry.

2 Literature review

Traditional way to define the product has for decades based on 2D documents such as drawings even though 3D modelling has taken place in engineering [1]. Bijnens and Cheshire [1] named four steps moving from traditional way to Model-Based Definition [1]. In our earlier research [2], we recognized three essential levels of product definition methods that are:

- DCD, Drawing-Centric Definition, where manufacturing is executed according to drawings only.
- MCD, Model-Centric Definition, where native or neutral 3D model is master, and drawings are as a supporting information.
- MBD, Model-Based Definition, where drawings are not used.

Standard SFS-ISO 16792:2021 in Annex B[1] [3] introduces five classification codes that define what data are included within the drawing, 3D data set or both (Table 1).

[1] Excerpts from standards are included with the permission of the Finnish Standards Association.

Table 1. Classification codes definitions adapted from the standard SFS-ISO 16792:2021.

	Classification code				
	1	2	3	4	5
A	No	Yes	Yes	Yes	Yes
B	No	No	No or partial	Complete	Complete
C	Complete	Complete	Simplified	Complete	No
D	No	No	Yes	Yes	Yes
E	Drawing	Drawing	Drawing and 3D model	Drawing or 3D model	3D model

Legends in Table 1: A= 3D model, B=3D annotation, C= Drawing, D= Related data, and E= Master.

Significant challenge in adopting MBD for main product definition method is to fulfill all legal and operational requirements [4]. Furthermore, in manufacturing ecosystem we noticed as a challenge the nature of communication relating tools in both sides of the communication [5]. This means, if manufacturing company can open drawings only, supplying 3D models from engineering causes confuse among downstream users. Modern CAM software can use features that are included in 3D model files and this method in tool path programming has gain in popularity [6]. Zhou et al. [7] compared the annotated 3D models to traditional drawings and found that the value is not in faster human-readability, but machine-readability [7]. This supports our observations of efficient programming that was more fluent with the help of machine-readable semantic 3D models. Zhou et al. [8] found benefits in MBD to record and exchange the collaborative definition information between members of life-cycle product team [8].

Exact and high-quality product definition is based on standards that are mandatory for traditional way. Standards have been developed also on MBD point of view and nowadays they are several [3] [9]. However, it depends on version of 3D CAD software, how comprehensive set of new standards they use.

Kirpes et al. [10] made a research survey for using 3D product model in assembling process planning [10]. Their survey resulted that utilizing 3D product models in agricultural equipment and automotive assembling production caused significant savings. Furthermore, they found that companies are moving away from drawings and paper-based work instructions to applications based on 3D models. [10].

Our survey focuses on Finnish Mechanical Engineering Industry that manufactures mainly small but highly configurable product series. Research of MBD in this context has been done less.

3 Research methodology

Our research is based on literature review and Web-based survey application called LimeSurvey. This tool was used for realizing versatile anonymous surveys, and it eases monitoring of answering activity. In addition, it prevents to answer several times in the same survey, unlike some other tools we evaluated. We selected the survey as a research methodology because during the pandemic, we were able to collect responses of large group of informants. We structured the survey's questions so that an informant cannot answer irrelevant questions if s/he selects a specific answer. For example, if the informant is unfamiliar with MBD, the following MBD-related questions are skipped.

4 Research

We made the survey during Q2/2021 for 160 persons in 66 Finnish mechanical industry companies. As a result, we received answers from 69 respondents representing 44 companies. Through the survey, we wanted to get answers to following research questions:

- How familiar MBD is to you?
  - Furthermore, if MBD is familiar to you, what plans do you have concerning MBD?
- How is the Product and Manufacturing Information delivered to production in your company?
- What are your objectives of utilizing MBD?
- What are barriers to overcome to adopt MBD in your company?
- What functionalities in your company could utilize MBD or is being used now?

Furthermore, we wanted to find out, what industries and what sizes of companies are more mature to adopt MBD.

Companies stand for wide range of industries in Finland (Table 2). Size of the personnel is presented in Table 4. One company can stand for a few industries because companies consist different departments such as automation and steel structure engineering. This explains the variations in number of informants and companies.

Table 2. Type of industry that informants stand for.

Products or services	Companies[pcs]	Companies [%]
Electronic devices (Low voltage)	11	16.0
Steel structures	10	14.5
Electric devices (High voltage)	8	11.6
Motor vehicles	8	11.6
Other products	8	11.6
Sheet metal products	7	10.1
Machined parts	7	10.1
Plastic products	6	8.70
Die casting parts	2	2.90
Furniture	1	1.45
Consulting	1	1.45
	69	100

Other products in Table 2 are according to informants among other things such as cabin assemblies, mobile machineries, device assembling, and large process plant steel structures. Number of companies 69 (Table 2) means that one company can stand for many industries. However, the total number of the different companies is 44 (Table 3).

Table 3. Roles in a value chain and number of companies.

Category	Role	Companies [pcs]
A	Own products only	18
B	Own products and subcontractor	22
C	Subcontractor	3
D	Consultant	1
		44

Category B in Table 3 stands for widely company types because that category also contains system suppliers. The system supplier may produce product assemblies with Own Equipment Manufacturing brand (OEM) and deliver them to customers' larger product systems. For example, cabin of mobile machinery stands for system supplier's product. Furthermore, the category B has subcontracting companies that may produce own products beside OEM business.

Table 4. Size of companies according to personnel.

Personnel	Informants [pcs]
XS: 1-10	3
S: 11-50	7
M: 51-250	19
L: 251-500	11
XL: 501-1000	13
XXL: 1001+	16
	69

The largest group of companies in Table 4 is M-sized companies. This as well as XS- and S-size companies are common in Finland.

Table 5. Size and role of the companies where informants are working. One company can represent many roles.

Size	A [pcs]	B [pcs]	C [pcs]	D [pcs]	Sum
XS	1	1	0	0	2
S	4	2	1	0	7
M	7	6	6	0	19
L	5	5	2	0	12
XL	2	4	6	1	13
XXL	9	4	3	0	16
	28	22	18	1	69

Table 5 represents categories of companies according to the informants.

5 Results

We classified the results of the survey to five themes which describe status of MBD in companies. The themes are Awareness Levels of the term MBD, type of used PMI definition, objectives of utilizing MBD, barriers to adopting MBD, and suitability for MBD in companies' functions.

5.1 Awareness Levels of the term MBD

We classified informant's answers according to the following table (Table 6).

Table 6. Awareness Levels of the term MBD (i =1…6).

i	AL(i)	Informant [pcs]	Informants [%]
1	MBD is not familiar	20	29.0
2	Familiar, but not will be used	25	36.2
3	Will be in use after 1-3 years	14	20.3
4	Is currently being introduced	6	8.70
5	Is currently in use	3	4.35
6	We and suppliers are using MBD	1	1.45
		69	100

Answers to the question of how well MBD is known in companies show that even 29.0% of informants did not know the term MBD (Table 6). However, 34.8% of the informants answered their' companies are either already using or introducing this technology in near future.

5.2 Type of used PMI definition

Documentation which is delivered from design to production varies and we have classified them according to the standard SFS-ISO 16792:2021 (Table 7). The Classification Code 5 in the standard defines that the annotated 3D data set do not include drawings.

Table 7. PMI from engineering to production. Classification Codes of the Maturity adapted from the standard SFS-ISO 16792:2021.

Maturity Class	Type of PMI definition	Informants [pcs]	Informants [%]
0	Mixing drawings and assisting documents	8	11.6
1	Manufacturing according to drawings only	12	17.4
2	Drawing is mandatory with a neutral 3D model (STEP, IGS etc.)	28	40.6
3	Drawing is mandatory with a native 3D model	6	8.70
4	Drawing or 3D model is mandatory, semantic annotated 3D model, and view-only 3D model as a dataset	12	17.4

5	3D is mandatory, drawings when needed, semantic annotated 3D model and view-only 3D model as a dataset	3	4.35
		69	100

Our survey indicates that the most popular (40.6%) is to use drawings as a mandatory with a neutral 3D model (Maturity Class 2). Furthermore, manufacturing according to drawings only (Maturity Class 1) is still commonly used method. However, same share of informants (17.4%) answered they use semantic annotated 3D models. Thus, these companies belong to Maturity Class 4. Maturity Class 0 stands for basically drawings only or drawings with assisting documents such as flame cutting drawings and bill of materials.

We define a term Relative Awareness Level (RAL) (Equation 1) for studying informant's Relative Awareness Level in companies according to companies' role in a value chain. RAL number is analyzed for each category of company role (A…D) in Table 8.

$$RAL = \frac{\sum_{i=1}^{6} i \times AL(i)}{\sum_{i=1}^{6} n(i)} \quad (1)$$

where,

RAL = Relative Awareness Level,
i = Index of Awareness Level (Table 6),
AL(i) = Order of Informants in Awareness Level i,
n(i) = Number of informants in level i.

Table 8. Informants' Relative Awareness Level (RAL) on MBD according to companies' role.

	A[pcs]	B[pcs]	C[pcs]	D[pcs]	Sum
AL(1)	9	6	4		19
AL(2)	9	12	4		25
AL(3)	6	3	5		14
AL(4)	3	2	1	1	7
AL(5)		2	1		3
AL(6)			1		1
	27	25	16	1	69
RAL	2.11	2.28	2.63	4.00	

Table 8 indicates that Category D (Consultant) is highly aware of MBD, but due to a single informant, it is a single case as well. Category C (subcontractor) covers all Awareness Levels. Significant notice is that Categories A (Own products only) and B (system suppliers and OEM) are least aware of MBD.

Respectively, informant's Relative Awareness Level according to size of the companies is presented in Table 9.

Table 9. Informants' Relative Awareness Level on MBD according to company sizes.

	Size						
	XS[pcs]	S[pcs]	M[pcs]	L[pcs]	XL[pcs]	XXL[pcs]	Sum
AL(1)	1	4	8	1	4	2	20
AL(2)	1	3	8	7	3	3	25
AL(3)			2	2	4	6	14
AL(4)					2	4	6
AL(5)	1		1			1	3
AL(6)				1			1
	3	7	19	11	13	16	69
RAL	2.67	1.43	2.05	2.45	2.31	2.94	

Table 9 indicates that large companies (L…XXL) are more aware of MBD than smaller companies (S…M). However, very small companies (XS) are more aware on it.

5.3 Objectives of utilizing MBD

Table 10 presents informants' goals for utilizing MBD in their company. Most of the informants (28.9%) considers increasing the product and operations quality as a main goal for utilizing MBD. Furthermore, 23.1% of informants considered increasing the competitiveness as main goal. Other reasons got share of 11.5% and they related to better visuality of Engineering Change Control (ECC), minimizing mistakes, general effectiveness due to single dataset instead of many, increasing flexibility in managing and planning product structures, accelerating product development due to faster iterations, and shorter lead time.

Table 10. Informants' objectives for MBD.

Objective	Informants [pcs]	Informants [%]
Increasing the product and operations quality	15	28.9
Increasing the competitiveness	12	23.1
Decreasing the production costs	7	13.5
Shorten the delivery time	6	11.5
Fulfilling the customer requirements	6	11.5
Other reasons	6	11.5
	52	100

5.4 Barriers to adopting MBD

Reasons for a informants' low interest in MBD are presented in Table 11. Suppliers limited skills were the highest barrier (29.5%) to adopting MBD in companies. In addition, own personnel in informants' companies needed more training in MBD (25%). Unlike Ruemler et al. [11] noticed, responders did not recognize lack of business pull as a barrier for adopting MBD. Only 5% of informants considered that customers do not need MBD. Ruemler et al. [11] found there was 22% of informants who found lack of business pull. [11]. According to them, customers found MBD useless due to big drawing-based legacy data. Transforming this to MBD was evaluated to be too large work. Too high investments were ranked in third place with 13.6%. However, other reasons got also share of 13.6%. This answer holds mainly same reasons mentioned in suppliers' and own personnels' limited skills in MBD, but also big legacy data was seen an obstacle to adopt new digital methods. Similar reason Ruemler et al. [11] found as well. What is worth noticing, lack of standards was mentioned in other reasons to be a barrier to adopt MBD. This is not true today [3].

Table 11. Barriers to adopting MBD. Informants were allowed to choose more than one alternative.

Barrier	Informants [pcs]	Informants [%]
Lack of skills in suppliers	26	29.5
Lack of skills in our personnel	22	25.0
Too high investments	12	13.6
Other reasons	12	13.6
MBD adds no value to our business	9	10.3
Customers do not need MBD	5	5.70
We do not trust on MBD	2	2.30
	88	100

5.5 Suitability for MBD in companies' functions

Informants' conceptions on the most potential functionality of MBD in their companies is presented in Table 12. Consequently, the most potential functionality was engineering (24.4%), production was the number two (22.1%), and measuring was the number three (17.4%). More than one function was allowed to choose in the survey.

Table 12. Suitable functions for MBD.

Function	Informants [pcs]	Informants [%]
Engineering	21	24.4

Production	19	22.1
Measuring	15	17.4
Product structures	12	14.0
Work instruction planning	11	12.8
Production control	7	8.10
Other functions	1	1.20
	86	100

6 Conclusions

Our survey indicates that MBD is commonly known among Finnish mechanical industrial companies. More than 71% of respondents recognizes the term MBD. Furthermore, over 34% of informants are going to utilize or already are utilizing MBD. The most common method to deliver Product and Manufacturing Information from Engineering to Production is Maturity class 2 (Table 7). It means drawing is mandatory with a neutral 3D model. Pure MBD method is not utilized in any company, but MBD with assisting drawings as well as view-only 3D model is in use some companies.

The most interesting objective for introducing MBD technology are increasing the Product and Operations Quality (25%). In addition, more than 80% of informants informed that better quality as well as lower production and product costs are their main objectives for utilizing MBD.

As other researchers have noticed, the limited skills of suppliers, as well as customers' own personnel's limited skills, may set barriers to adopting MBD. Challenges may become with high investments to software, systems, and training the personnel.

Our survey indicates that large companies are aware of MBD, and they are adopting it. Smaller companies are either less aware of or skeptical adopting MBD. Large companies have great resources to invest in new development. However, the suppliers of these companies have little adopted MBD.

According to the informants, MBD suits the best for Engineering, but also to Production and Measuring.

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