The Current State of Model Based Definition

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Abstract. A new methodology for communicating engineering information called Model Based Definition is gaining popularity. In this article a comparison will be made of the so-called "traditional" way that engineers communicate their ideas using engineering drawings, where the drawing is the authority, and this new Model Based Definition methodology, where the 3D model is the authority.

The pros and cons of implementing Model Based Definition are critically analysed. The conclusions drawn from this analysis indicate where further development is needed if Model Based Definition is to become more widely accepted.

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1 INTRODUCTION

Historically information has been communicated by the product designer to other stakeholders in the production chain such as manufacturing and quality inspection by means of 2D drawings[34]. These drawings contain orthogonal projection views annotated with dimensions, geometric dimensioning and tolerancing, material specifications and other data. With the advent of a new methodology called Model Based Definition (MBD) this 2D drawing approach is often referred to as the "traditional way". Proponents of this new methodology claim applying MBD will lead to immense (time) benefits and greater accuracy when compared with the "traditional way"[27] not only because of the way data are handled within a CAD system but also because of the implications for PDM and PLM systems[5].

This article should not be seen as supporting or rejecting the widespread adoption of MBD. It has been written from a none biased perspective based on many years of experience of practically applying CAD/CAM systems in real engineering situations and an in depth study of the current state of the art for MBD. As such this article presents the advantages and disadvantages for both the traditional and MBD philosophies presenting the reader with discussion points as they consider the adoption of the MBD philosophy within their own environment.

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2 What exactly is the "traditional way"?

3D CAD systems have been widely adopted by engineers for many years. The first commercial 3D CAD packages came on the market in the early 70's and by the early 80's were widely available though still expensive restricting their use to large industries such as aerospace and automotive[10]. Neutral exchange formats like IGES (first version published in 1981)[12] and its successor STEP (first version published in 1994)[24] were also available since the beginning of the general availability of 3D CAD systems. So the real "traditional" way of working where the only way to get something manufactured was by passing a 2D drawing on paper created by a designer to the manufacturer and where the latter was forced to recreate the 3D model within his CNC programming system has been outdated for over 20 years. A literature study shows a distinction is made between "really traditional", "less traditional" and "least traditional", which leads to four different steps for the transition to MBD based on the degree of dependency on the 2D drawing[28]. These four steps are

1. 2D drawings only (really traditional)
2. Primarily 2D drawings (with supplemental 3D models) (less traditional) (used the most)
3. Primarily 3D models (with supplemental 2D drawings) (least traditional)
4. Full adoption of 3D models dispensing entirely with 2D drawings (MBD).

This places many of the advantages as claimed by the MBD proponents in another, less black and white, perspective as will be discussed in the remainder of this article.

3 Claims of MBD

MBD is supposed to lead to immense time benefits and related cost savings compared with the "traditional way". There are four claims related to interpretation by humans that seem to back-up this assumption[17]

1. it is much easier to interpret a MBD model compared with a 2D drawing,
2. it is much faster to create a MBD model as less dimensions need to be created,
3. the 2D drawing is ambiguous where the MBD model is not,
4. as the 3D annotations are placed directly onto the 3D model, the MBD model is always up-to-date whereas with 2D drawings one is never sure whether this is the latest version or not.

3.1 MBD model is easier to interpret

The claim that 2D drawings are more difficult to read than a 3D model can be considered true (see Figure 1a), however it is common practice to place a 3D view onto the drawing or to provide the 3D model in an exchange format like e.g. STEP together with the drawing (less traditional methodology). This makes reading the drawings easier and less ambiguous. The ability to correctly interpret 2D projection views correctly is a dieing art amongst young engineers[23] which makes MBD more attractive.

Creating and using MBD models does not necessarily mean the model is easier to read. When no attention is paid to the creation of appropriate "saved views" which can be considered as the MBD 3D counterpart of the traditional projection view this can lead to so-called spaghetti PMI[8]. PMI stands for Product Manufacturing Information. It is the collective name for all kinds of 3D annotations such as dimensional tolerances and GD&T. An example of so-called spaghetti PMI can be seen in Figure 1b.

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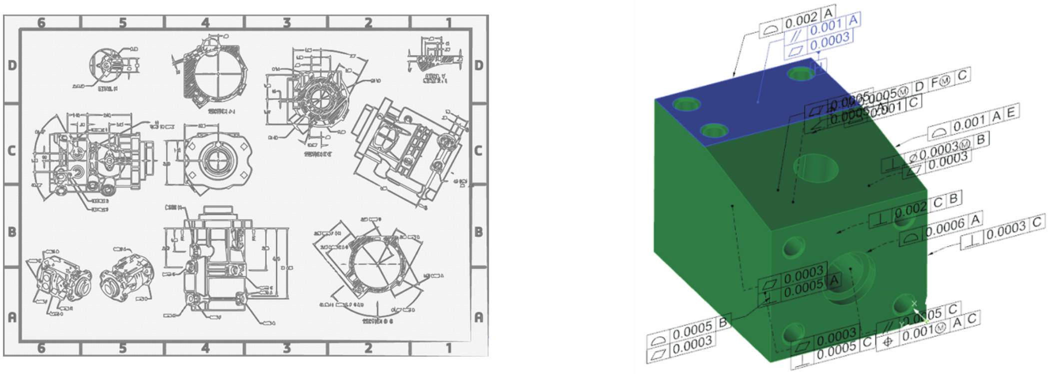

(a) Example of a traditional 2D drawing[36]

(b) Spaghetti PMI[8]

Figure 1: 2D drawing and MBD model difficult to read.

3.2 MBD model is easier to create

The assumption that it takes longer to create a 2D drawing than a MBD model only makes sense when a drawing is not derived from a 3D model and is created from scratch.

All modern CAD systems let the user create 2D drawings based on projection views that are derived directly from the 3D model and maintain a direct link with it, i.e. a change in the 3D model is immediately reflected in a change in the drawing[35]. They also provide tools that make it very easy to place annotations (dimensions, tolerances, notes, . . .) on these drawings[25, 30, 32]. So creating multiple projection views in a drawing is not more time-consuming than creating saved views which contain different orientations of the 3D model within the MBD philosophy.

The most labour-intensive activity is the detailing of the drawing. Detailing is more than just placing some dimensions and tolerances on the drawing. It is an experience-based decision making process which covers placing the correct dimensional tolerances and the correct form tolerances (geometric dimensioning and tolerancing annotations or GD&T for short). Without assigning proper tolerances there is no guarantee that after manufacturing the parts will function as expected[22]. CAD models are always created based on nominal dimension values. Very few packages allow the user to perform a tolerance analysis to verify the impact (functionality and cost of the part) of the applied dimensions and tolerances[26, 31, 33]. Even if they do this is not something that can be done quickly and correctly without proper training and a lot of experience. So it is safe to conclude that applying proper dimensions and tolerances takes an equal amount of time for both the 2D drawing and the MBD model.

3.3 MBD model is not ambiguous

It is always possible to create an unambiguous 2D drawing by correct use of views, section views and hidden detail (see Figure 2b). However, 2D drawings can be ambiguous when there are not enough projection views to correctly interpret the drawing (see Figure 2a).

3.4 MBD is always up-to-date

"Up-to-date" can refer to three things, namely geometry, dimensioning (including tolerances and GD&T) and availability. Availability means the latest version of the data is provided when the data is retrieved.

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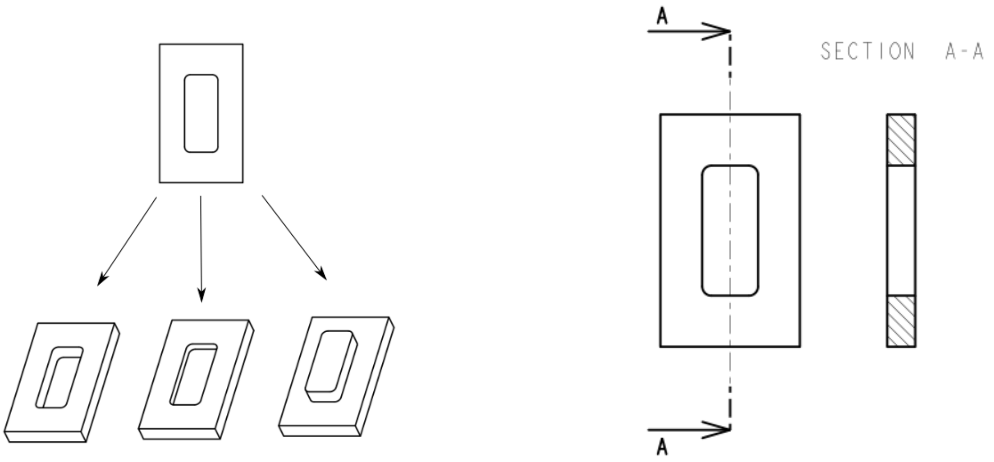

(a) Possible interpretations with one view

(b) Only one interpretation with a sufficient number of views

Figure 2: Ambiguity of 2D drawings.

3.4.1 Geometry

As there is a direct link between the projection views on the drawing and the referenced 3D model where every change to the 3D model is reflected directly in a corresponding change of the projection views there can be no inconsistency between the state of the 3D model and the projection views on the drawing. As the drawing is an additional file next to the 3D model that can be distributed separately there can be a problem whether the latest version is available or not when no precautions are taken when distributing it irrespective of whether a PDM/PLM system is used. As will be discussed later on in this article this can be easily solved. So regarding geometry being up-to-date the traditional way and MBD are on par.

3.4.2 Dimensioning

Dimensional and form tolerances have to be added on top of the model geometry as part of the documenting procedure. This applies to both the traditional and the MBD way of working. As such the danger of having a delivery (2D drawing or MBD model) not being adequately dimensioned exists in both.

3.4.3 Availability

In the case of MBD the delivery is always the latest version as the default CAD model and the documented model are one and the same. This also implies a PDM/PLM system needs only to track the 3D CAD model[5]. Regarding the traditional way this is a bit more complicated. The pure traditional way has one delivery, the 2D drawing. The less and least variants of the traditional way have two deliveries, the 2D drawing and the 3D model. As already mentioned previously the 2D drawing is a separate file that can be distributed independently from the 3D model so there is an uncertainty whether this really is the latest version[11]. Also the PDM/PLM system needs to track both the 3D model and the 2D drawing[5]. As the 3D model is the originating model every drawing is derived from, the problem whether this is the latest version does not seem to exist for the 3D model. However, the 3D model is not always the native CAD model. When stakeholders (e.g. suppliers) do not have access to the CAD system used to create the 3D model, the model has to be exported to an

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appropriate exchange format such as STEP AP242. This same issue also applies to MBD. What makes a format "appropriate" will be discussed in subsubsection 4.1.2. If an export is needed this can also cause an uncertainty whether this is the latest version.

All this can be solved by accessing the 3D model and the drawing through a PDM/PLM system which automatically generates the correct technical data package (TDP for short), e.g. a STEP file, a PDF file or both, which holds the latest version. There is one caveat however i.e. care must be taken to define how a model must be build within a particular CAD system and to determine which configuration parameters must be used in the respective exporting and importing CAD system in order to ensure the best possible transfer[18].

4 Consequences of MBD

A correct application of MBD implies the use of semantic PMI annotations. What these are and what the implications are will be discussed in the following subsections.

4.1 PMI semantics

4.1.1 What are semantics?

There is a difference between the creation of annotations as PMI presentation or as PMI representation[9]. When the annotations are created as presentation data this means there is only a graphical presentation (e.g. a GD&T symbol visualised with polylines) and human interpretation is necessary to determine what parts of the model the annotations are referring to[6]. When they are created as representation data (also called character-based) this means the annotation contains all the necessary information (type, values, references) without the need for a graphical presentation and human interpretation is no longer necessary. The information about the parts of the model the annotations are referring to is stored within the annotations and can be queried by software packages[14]. This is called semantic PMI[9].

4.1.2 What are semantics used for?

When 3D annotations exist as PMI presentation only a limited use is possible. The model can be transferred to the different stakeholders while retaining the PMI data but human interpretation is required in order to make use of them.

When 3D annotations exist as PMI representation this enables the MBD philosophy of reusing the CAD data to the full extent. Use of PMI representation makes it perfectly clear what exact model geometry (surfaces, edges or axes) the annotation is referring to and makes this, together with the dimension and tolerance values, retrievable for software packages and as such promotes reuse of the CAD data. For example a perpendicularity tolerance may be needed between two faces and with fully implemented MBD this tolerance can be attached directly to the required surfaces removing any ambiguity. This allows further automation. A first example of this are software packages that use the data provided by semantic PMI to generate a list of the dimensions (tolerances, GD&T) that need to be checked such as the AS9102 First Article Inspection document[2]. A second example are software packages that use semantic PMI to create measuring programs for coordinate measuring machines (CMMs)[13] which can lead to significant time gains[15].

All this automation is possible because it is sufficient to have access to the data as is. All stakeholders who do not need to change the 3D model and who only need to be able to extract the necessary data can benefit from the MBD philosophy. It means existing data (geometry and PMI annotations) can be reused and do not need to be recreated again[13].

A distinction must be made between the use of the native CAD model and of an appropriate neutral exchange file format like STEP AP242, QIF or 3D PDF (using PRC[1]). An appropriate neutral file format is a format that retains the PMI data the same way they are defined within the originating CAD system. Both

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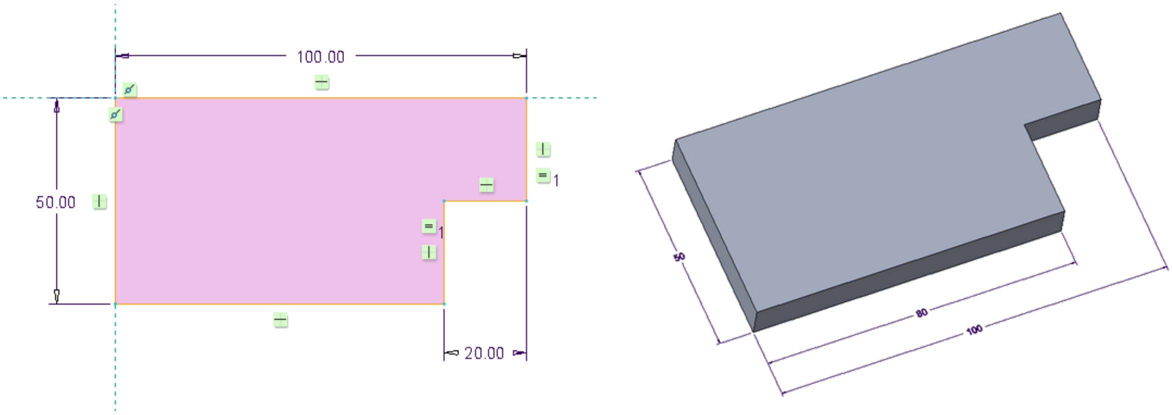
the native CAD model and an appropriate neutral exchange file format allow full use of MBD as it is currently defined.

At this moment stakeholders, such as CAM users, who do need to change the model based on the PMI annotations present do not benefit so much from the MBD philosophy[16] compared with quality inspection who only has to interrogate the model. An example of a situation where it is necessary to change the model is the milling of a workpiece with an asymmetric dimensional tolerance. A workpiece with a width of $50^{+0.2}_{\ 0}$ may not be milled to the nominal value 50 but to 50.1 which equals the nominal value plus half the tolerance width. In almost every CAD/CAM system this needs to be handled manually. The few packages that are capable of doing this (semi-)automatically only work with native CAD files[4].

The use of native CAD files makes it harder to make the necessary changes to the model when the dimension scheme applied in the features used to create the model does not match the one that is specified by the 3D annotations. It is harder because it is more difficult to apply the changes as there is not always a feature available that corresponds to the dimension that needs to be changed and because of the fact that different dimension schemes result in different tolerances (see Figure 3 en Table ??).



(a) Sketcher dimensions (b) MBD dimensions

Figure 3: MBD dimensioning scheme differs from sketcher.

	Resulting tolerances	
	Sketcher dimensioning scheme	*MBD dimensioning scheme*
20	19.8 - 20.2	19.4 -20.6
80	79.5 - 80.5	79.7 - 80.3
100	99.7 - 100.3	99.7 - 100.3

Table 1: Difference in resulting tolerances

As is the case with a 2D drawing the MBD model as a deliverable is considered a contract of one stakeholder (designer) with another (manufacturer)[27]. As the requirement to have correctly applied semantics removes any need for human interpretation this increases the responsibility of the designer. In the past there used to be draftspersons whose job it was to create detailed 2D drawings and as such were responsible for applying the required dimensions, tolerances and GD&T. This is now an additional responsibility of the designer[21].

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4.2 The CAD model is the authority

With the advent of the MBD philosophy there is no longer any need for 2D drawings either on paper or in a digital format. The CAD model itself is the authority, i.e. the master file that holds all the information[20]. This is both an advantage and a disadvantage. The advantage is that only one file needs to be maintained. The disadvantage is a possible vendor lock-in. The most important requirement in order to have a successful MBD implementation is a CAD system that supports 3D annotations with semantic PMI. The different stakeholders are completely dependent on the 3D model. The danger exists that once a particular CAD system is chosen the dependency on this system will lock every stakeholder in to the ecosystem of the CAD vendor. As a consequence this results in one other disadvantage, namely the uncertainty about the lifespan of the proprietary file format used by the CAD system. This has an impact on the data retention policy of a company. A firm must be confident the design data will remain available for a long time. In the automotive industry this is for a period of 25 years and in the aircraft industry this is even for 40 years[7]. CAD vendors can not guarantee this. It is even uncertain whether the CAD company still exists after 40 years. Therefore, the solution must be found elsewhere. This can be using a standardised neutral exchange format for the CAD data which supports semantic PMI like STEP AP242 (which covers the whole product life cycle), QIF (which covers quality systems)[19] or 3D-PDF with the embedded PRC format[3]. There are two downsides to using a neutral exchange format. The first one is that a CAD model saved in a neutral exchange format is a derivative. It has to be regenerated each time the CAD model is modified. This can be accomplished by specifying it as a technical data package (TDP for short) within a PDM/PLM system. The second one is the loss of the history of the features that were used to build the CAD model. This makes it more difficult for stakeholders other than the original designer to make changes to the model[7] and as a result can complicate change management. Stakeholders who need to make modifications that need to be enrolled back to the original model can do this only by modifying the original native CAD file and are hence forced to use the same CAD system as the designers. Stakeholders such as manufacturers who need to make modifications to the CAD model that do not need to be enrolled back into the original model can make use of techniques like direct modelling which allows modifications to models that contain no features. An example of such a modification is the change of a nominal value to reflect the mid of an asymmetric tolerance in order to have the correct value to mill or turn.

4.3 Use on the shop-floor

People on the shop-floor have always used 2D drawings to do their job even with the availability of 3D models[5]. It has always been very hard to get information from the manufacturing process back into the design. This information can be the requirement of a change of the drawing or can be engineering information that needs to be maintained. When 3D models are the source from which drawings are derived, the originating 3D models have to be modified by the designer and the drawings regenerated[5]. Concerning the engineering info it is unclear where exactly this info needs to be stored. This can be on the drawing, in a separate document or in another way. This can lead to a shattering of the information[5].

These difficulties can be overcome by applying the MBD philosophy and using the 3D model as the only authority but this seems to create another set of difficulties. As MBD is very heavily software driven[20] the people on the shop-floor need to have the proper software tools at their disposal and need to be trained to use it. This leads to an increase of responsibility which can overstrain the users[29]. Variability on the shop-floor such as a certain CNC machine not being available and therefore a switch to another machine and possible another operator makes it necessary to have standards to enter additional engineering information in to the system. Up till now MBD relies heavily on traditional standards such as ASME Y14.5 and although new standards such as ASME Y14.41 are emerging this is still not sufficient[20].

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5 Conclusion

In today's discussion about why MBD should be used instead of the so-called traditional way the emphasis is too much on arguments that were valid more than 20 years ago but are no longer valid today with the general availability of advanced 3D CAD systems. The emphasis should be on the two most important advantages MBD has to offer, namely creating one authority that can be shared across all stakeholders and acting as an enabler for further automation. A growing number of CAD systems support the use of semantic PMI and saved views which makes it possible to use the 3D model itself as the authority and eliminates the need for traditional drawings. Because semantic PMI not only contains numerical values but also the references these values relate to, this allows automatic generation of First Article Inspection documents and automatic creation of CMM measuring programs. This is called reuse of the CAD data. However, this is limited to applications, often related to quality inspection, who only need to query the model. Only very few software packages can use the MBD model to automatically modify the model when needed. They can only do this within a specific CAD system on a model build within that system, not on models stored in a neutral exchange format. The ability to modify the model is needed in applications such as CAM packages where the nominal value of a dimension with an asymmetric tolerance has to be changed to generate a suitable tool path. Besides this there are other problems that need to be overcome in order for MBD to succeed. The fact that the CAD model is the one and only authority has an impact on the design chain. Where in the past there was a designer who created the model and a draftsperson who created drawings annotated with the proper dimensions, dimensional tolerances and GD&T, the designer is now responsible for everything. Because everyone, not only the designers but also manufacturers and suppliers - have to use the same CAD model there is the danger of a possible vendor lock-in. It also means that they have to embrace a new technology and have to be trained for this which can overstrain the users and lead to an additional labour cost.

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