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A Comparison of Model-Based Design and Traditional 2D Engineering Drawings in Manufacturing Using Flowchart Analysis

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A Comparison of Model-Based Design and Traditional 2D Engineering Drawings in Manufacturing Using Flowchart Analysis

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1. Introduction

Productivity improvement is a focus for most manufacturing companies. Productivity is a measure of the ratio of outputs such as goods and services divided by the inputs such as labor and capital (Heizer, Render, 2006). Being able to increase production with fewer resources reduces cost and drives profitability. Model-based definition (MBD) is a way of creating engineering documents for use in a manufacturing setting, which seeks to increase a company's productivity and reduce cost. Model-based-enterprise.org (2014) defined MBD is an annotated 3D Computer Aided Design (CAD) model which contains all the necessary information needed to define a product. Full implementation of MBD results in the elimination of traditional engineering drawings. All product manufacturing information (PMI) is contained within the model. PMI communicates non-geometric characteristics in 3D CAD systems necessary for producing product components or subsystems, for example, Geometric Dimensions & Tolerances (GD&T), dimensions, surface finish, and material specifications (MBE Living Dictionary, 2003).

This study's goal is to determine whether the use of MBD is more productive than traditional engineering drawings in a manufacturing facility. There are two sides to this argument with many variables to consider, which has provided motivation for this research. The intent of this research is to examine prior literature as well as leveraging knowledge and experience on the subject to investigate the different aspects of using MBD versus traditional 2D drawings. The information conveyed in this study will investigate the advantages and disadvantages of MBD, so the reader can make an informed decision about their own needs for implementation.

Currently MBD is commonly found in the aerospace, defense, and automotive industries. The reasons for the move to MBD are because 2D drawings are inefficient, duplicate information, and can be out of date with the CAD model. The most common benefit for MBD is in the product life cycle. When the product is designed upfront using CAD models and MBD as opposed to a 2D drawing, a 25-50% reduction in time and changes is spent on design (Schimmoller, 2016)

Although positive results have been seen by the large aerospace and automotive industries, there are criticisms regarding MBD. This criticism largely lies in the ease of information retrieval from 2D drawings. When there is no 2D drawing to use for communication purposes, the model is the lone source for PMI. If there is an issue on the shop floor it is more difficult to communicate the problem using a model than it is to mark-up a 2D drawing to explain the area of concern. Models and drawings alike are used to communicate information from the engineering team to other departments and firms. The tools used for transferring drawings are well developed and readily available. The tools and methods used for transferring 3D models with all the PMI contained have more complex processes. Not all neutral file formats will transfer the PMI with the CAD model; leaving off tolerances and feature control frames. If a firm does not have the correct tools, it will add cost to implement MBD.

The next section of this paper is the review of prior literature. This presents a further background of MBD and how it is used; as well as advantages and disadvantages. This is followed by implementation considerations. This will discuss the hurdles to implementing MBD and provides available solutions. Case studies were reviewed to examine issues and benefits companies actively using MBD have experienced in the fourth section. In the fifth section of the paper, process flow charts are discussed, created, and analyzed for traditional drawings and MBD in different departments for a manufacturing setting. The main focus of the flow charts is comparing the number of steps in each process. The final section concludes the research.

2. Literature Review

MBD uses 3D models as complete sources of information for design, production, distribution, technical documentation, services, and overall product lifecycle (Alemanni, Destefanis, & Vezzetti, 2012). This is a departure from the way geometric design has been handled since the beginning of manufacturing. Until recently, the PMI documentation has resided on a 2D engineering drawing. Traditional engineering drawings are a two dimensional technical document used to fully and clearly define requirements for a product (Farlex, 2003). 3D modeling programs were not available until the late 70's and became more popular in the 1980's. The drafting processes could be partially automated, expedited, and paired with computer aided machining (CAM) programs to increase productivity, but the cost of the programs were too expensive for most engineers to use (Atwell, 2013). Once the models are created with Pro/ENGINEER, or the dozens of other software available, the model geometry was used to create the 2D engineering drawing. This saved time because instead of having to recreate the geometry in every view, as well as creating section and detail views, it could all be done with a few clicks of a button. Once the views were in place, all of the dimensions, feature control frames, notes, and other PMI were added to the drawing.

MBD allows a person creating 3D models to add dimensions, feature control frames and other PMI onto the 3D model directly. This saves time because the dimensions were traditionally being added as part of 3D model creation, and then duplicated onto the 2D drawing. The 3D model becomes the master document for engineering, manufacturing, purchasing, and quality departments. Data remains consistent because it is stored in a single form (Cohn, 2014). Opportunity for error is reduced due to the elimination of manually creating and adding another document to the process.

Suppliers and other stakeholders may not have access to CAD software due to cost, because CAD software licenses are expensive. The annotated 3D model, originally created in a CAD system, must be converted to a non-CAD file format to allow non-CAD users to access and review it, so a tool utilized by MBD is 3D PDFs or edrawings (Quintana, Rivest, Pellerin, & Kheddouci, 2012). In these 3D PDFs and edrawings, the 3D information is published into a 2D format using predefined views of the model for use by operators or suppliers who prefer 2D documentation. The model can be fully rotated, and when a dimension is selected, the features associated with the dimension are highlighted. 3D PDF eases the transition from traditional 2D drawings to MBD, as it is more intuitive, easy to print, and can be opened in various programs that will read PDFs. MBD has the capability to publish a highly-interactive 3D PDF which incorporates 3D content for operators or suppliers to zoom, rotate, and measure the 3D model with a PDF reader, (Cao, 2016). For stakeholders who can work with CAD files, but do not have the same native CAD software, neutral file formats can be used to convert the 3D geometry and annotations.

The main benefits seen by use of MBD are time and cost reduction for the engineering department (Alemanni et.al, 2011). Time and cost reductions are realized by only creating and maintaining one CAD file instead of two, through the product life cycle. Other benefits within the engineering department can be seen in the simplification of workflow, format and drafting standards. There are many rules for creating drawings based on a set of standards. The drawing standards will no longer be needed or maintained, and will be replaced by standards used for creating a 3D model with PMI which are much shorter and simpler.

The MBD concept is changing the approach for inspecting products developed using the 3D model. Traditionally, the inspection process has been carried out using 2D engineering drawings derived from the 3D model, because there was no GD&T information attached to the solid model (Quintana et al., 2010). Companies are updating quality assurance processes to work with MBD because many of aerospace's key manufacturers are demanding it (Knoche, 2006). These companies have realized significant improvements in their operations that prove adopting portable Coordinate measuring machines (CMM) and 3D inspection practices is worthwhile (Danford,2010). CMMs are being used with model-based inspection software, and have changed first-article inspections into a five minute process rather than the hours or even days often experienced using more traditional methods (Knoche, 2006). According to Knoche MBD also allows operators of CMM devices to set up automated inspection routines, ensuring parts can be inspected in the same way, in the same places, and with the correct tolerances every time.

One criticism of MBD is what to do with legacy data. According to the article "The Argument Against Model-Based Definition" (2016), operators and companies using the same patterns and processes are more likely to continue working in the same patterns; making it difficult to implement MBD. Some companies still sell product that were designed using hand drawn 2D drawings. For products that have already been designed using 2D drawings, it would take a large amount of work to remodel using MBD. Training and equipment costs for companies implementing MBD are significant and are a negative aspect of MBD.

3. Implementation Considerations

Implementing MBD is a complex process, and there are many variables that need to be considered. After reviewing literature, it became obvious that implementation of MBD would take a well thought out plan. This section is not intended to be the roadmap for implementing

MBD, but rather an organization of thoughts and concerns companies should consider before implementing MBD.

As stated in the literature review there are many stake holders that do not have access to CAD and will require a viewer that will allow the downstream users to view a 3D model and the specific information they are interested in. This is particularly important during the price quoting process. When implementing MBD, open conversations and meetings with suppliers will need to take place to understand how they will consume the PMI. Currently 3D PDFs and STEP files support conversion and transportation on MBD models, however STEP files still require a CAD program to access a model. A company implementing MBD will need to develop a workflow for how information from the native CAD files to all the stakeholders is processed.

For manufacturing and inspection purposes there are many programs available that will use the annotated 3D model for the use of programming CNC machines or the programming of CMMs as discussed above. Using 3D models is not a new concept for manufacturing, but is rather new for quality assurance and inspection departments. 3D scanners have been developed which will scan entire parts in minutes and compare the scan data to the annotated 3D model. Based on the GD&T in the model, inspection software can analyze the scan data and prepare a full inspection report without the use of a traditional 2D drawing. The cost for this software and equipment is substantial and will have to be analyzed against the cost and time savings to ensure return on investment.

Training is also needed for any person who currently interacts with 2D drawings. Depending on the CAD package, training courses are offered for CAD users to learn how to use the design tools for MBD and annotate a 3D model to reflect all the PMI. This training may include transferring data to neutral file formats for the downstream users. The training for other departments in the facility will be the responsibility of the company. Other departmental users will need to know how to access the information they traditionally receive from the 2D drawing and apply it. It is advised the CAD users be trained first, and they will function as the main resource for training other departments. Training is a cost and time commitment for the company and will be a vital part of any implementation plan.

Currently, companies use specific drafting standard such as ASME Y14.1 and ASME Y14.5. These standards are the guidelines for constructing 2D drawings. MBD has been documented in the 2003 ASME Standard Y14.41-2003 Digital Product Definition Data Practices, which sets requirements for CAD software developers to follow tolerances, dimensional data, and other digital design annotations on 3-D solid models (Thilmany, 2010). It will be the responsibility of individual companies to create policies for the CAD users creating MBD models. This will ensure the information will be as consistent and unambiguous as it was on 2D drawings.

A statement of propriety can be found on most drawings used in manufacturing. This allows the company to take legal action if another party steals the proprietary information from the drawing. How a statement of propriety will be communicated using MBD should be considered. Currently companies use drawings as contracts. These drawings can be signed with an approval signature and stored for legal purposes. With the full implementation of MBD, everything is electronic and will add complexity to this process. Many companies that have implemented MBD still use general arrangement and approval drawings to get customer and third party regulation approvals. Currently electronic signatures are being used on many documents as an alternative to handwritten signatures. There is software available to ensure electronic signatures are secure and cannot be duplicated unlawfully. Electronic signatures are a reliable alternative to handwritten signatures, but will add cost to secure and implement.

2D drawings are used as controlling documentation and no downstream operation can be executed without the 2D drawing. The drawings function as the tool to release the design intent, validate it, or halt production if changes are needed. A product data management (PDM) or product lifecycle management system can manage the state of a drawing from creation to release; however a trigger will need to be put in place to halt production if needed. The drawing will no longer be controlling the steps of the product lifecycle and will need to be addressed during implementation of MBD. This will be addressed when reviewing the engineering change management process. Changes usually indicated on a marked up 2D drawing will now need to take place in a 3D environment. 3D PDFs have the capability of creating mark ups electronically, but will be a more complex process than manually using a pen and paper.

2D drawings have been the common way for companies to safely and securely maintain the PMI of a product or part. The proper storage of 2D drawings is important because of its use for product liability and historical reference. When considering how to implement long term storage for MBD the two most important aspects are the integrity and sustainability of the data. The solution chosen should be readily available, not compromise the information from the original 3D model, and require the minimum amount of storage capacity so the maximum amount of material can be stored.

4. Case Study Review

Price (1998), in the late 1990's, reviewed a process Boeing worked to develop which allowed for paperless product development. Boeing used this process known as "Design, Manufacturing, and Producibility Simulation," on the redesign of the T-45 horizontal stabilator. The process of paperless product development or Virtual Product Development (VPD) is defined as the entire product design, tooling and manufacturing processes, before fabricating parts or tools, is verified virtually, so there was no need to generate MIL-STD-100 2D drawings. Price found Boeing achieved a 62% reduction in product development time, a 42% reduction in development costs, 61% reduction in engineering work, 45% reduction in manufacturing labor hours and 84% increased product quality through reduction of part nonconformance through the application of this approach.

Quintana et al. (2010) evaluated a study of two aerospace companies. In this study eleven sample drawings ranging from low, medium and high complexity based on the number of views and annotations on the drawing were examined. The 2D drawings were converted using CATIA and SolidWorks to 3D models with the PMI included. The dimensions, tolerances, and general notes were incorporated into the 3D model. The revision block and title block information were not included in the 3D model. On average 96% of the information on the drawing could be incorporated into the 3D model. Limitations of the software or reduction in standards no longer necessary were the reason for not being able to convert 100% of the information. The MBD model yielded a file size reduction of 25–30% compared to a 2D drawing plus a non-annotated 3D model. The study observed no time reduction achieved by adding annotations to the 3D model versus adding annotations to a 2D drawing because 3D annotation tools are very similar to those used for annotating 2D drawings.

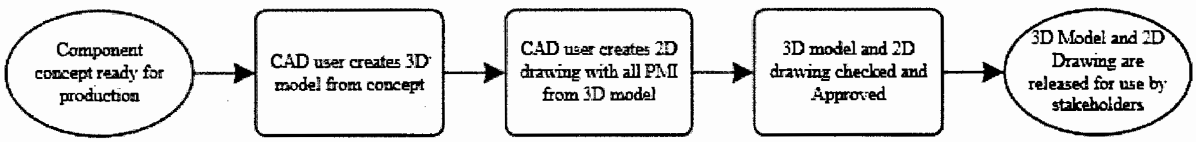
In the first case study, Boeing is able to reduce cost and time for product development of T-45 horizontal stabilator. MBD is shown to reduce cost and time in the early stages of product lifecycle. In the product development phase the design concept is quick to the downstream departments and they are able to use the 3D model more efficiently than a 2D drawing. Many of the questions still surrounding MBD are in regards to maintenance and long term reliability. Although time and cost savings are seen during product development, it is argued in the second case study that there is no time savings because the amount of time to create a 2D drawing and an annotated model are equal. The biggest observed savings in the second case study is the reduction of the number and size of files.

5. Flow Chart Analysis

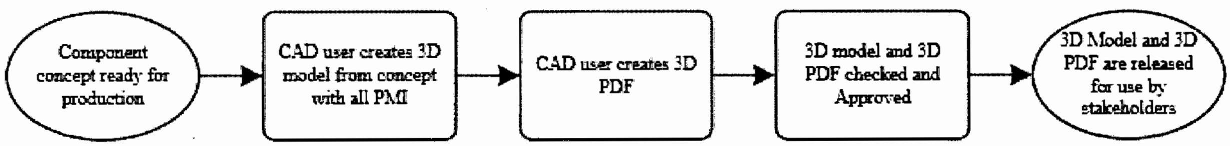
A process flow chart is a diagram which uses graphic symbols to depict the nature and flow of the steps in a process (Holloway, 2013). This method was used to compare the application of CAD data for this research. The flow charts created for this research compare the use of 2D engineering drawings, a 3D annotated model paired with a 3D PDF, and a process that uses only the 3D annotated model. The flow charts represent the process of a component from the creation of the CAD data, through purchasing, to manufacturing, and finally inspection.

Process flowcharts were created and analyzed for number of steps in the process and ease of communication of PMI. It was assumed that these are valid variables to indicate productivity differences between MBD and traditional engineering drawings. It was assumed that the fewer number of steps in the process flowchart will indicate a time savings. The examination of the flow charts compares the number of steps in the process each department took to use traditional drawings vs. MBD. Also the total number of steps from drawing creation through inspection, and the ease of PMI communication through traditional drawings vs. MBD was also examined.

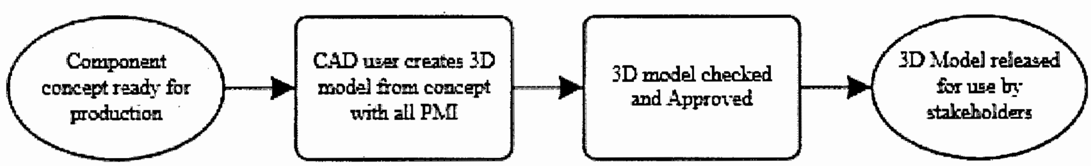
Flow charts were completed for the creation of traditional 2D engineering drawings made from a 3D model, the use of an annotated 3D model along with a 3D PDF and an annotated 3D model only to determine which scenario would result in the most efficient process.



2D drawing made from 3D model



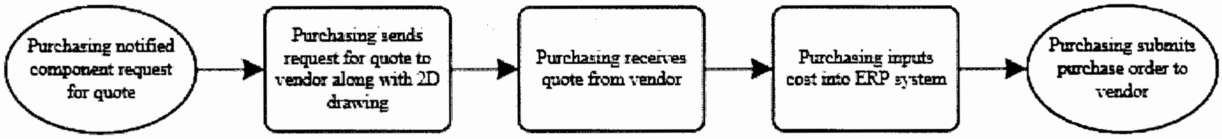
3D annotated model and 3D PDF



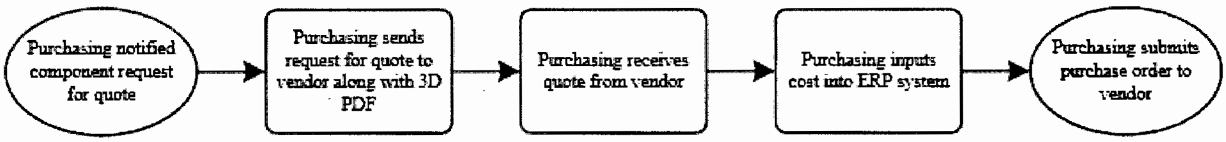
3D annotated model only

Figure 1.Flow Chart - CAD Document Creation

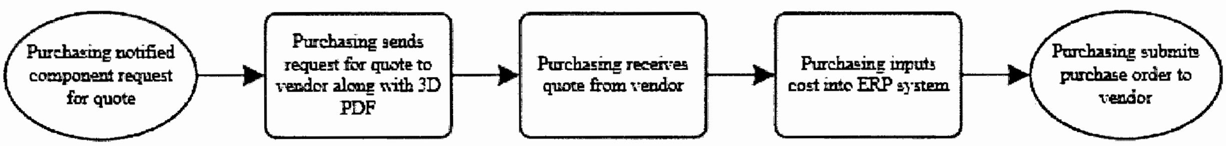
Figure 1 shows the flow charts for CAD document creation. It was observed that the creation of only a 3D annotated model took one less step than the other processes. As stated above in the case study of the two aerospace companies, creating an annotated 3D model versus a 3D model and a 2D drawing on average took the same amount of time. In the scenario of creating an annotated 3D model and a 3D PDF, the expectation is this process would take the longest, if the evidence presented in this case is accepted. However, creating an annotated 3D model and a 3D PDF was the best for ease of communication, because there was a fully annotated model paired with an intuitive 3D PDF. This option contains the maximum amount of information and document transfer options.



2D drawing made from 3D model



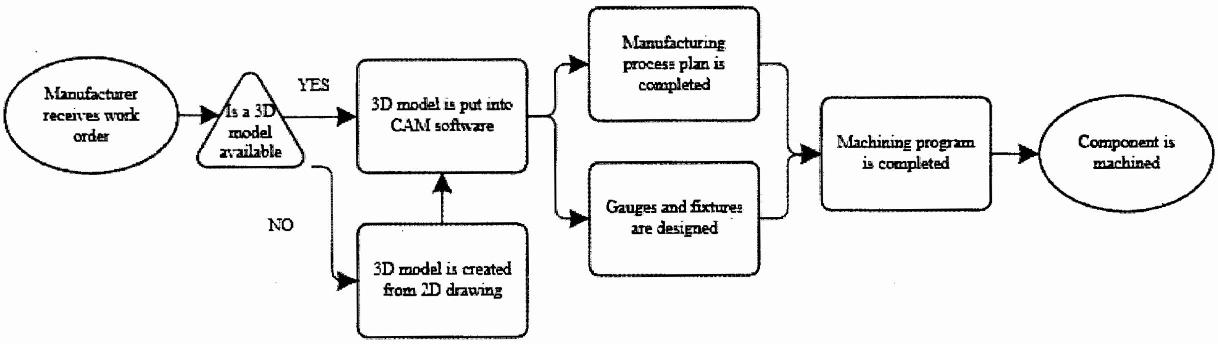
3D annotated model and 3D PDF



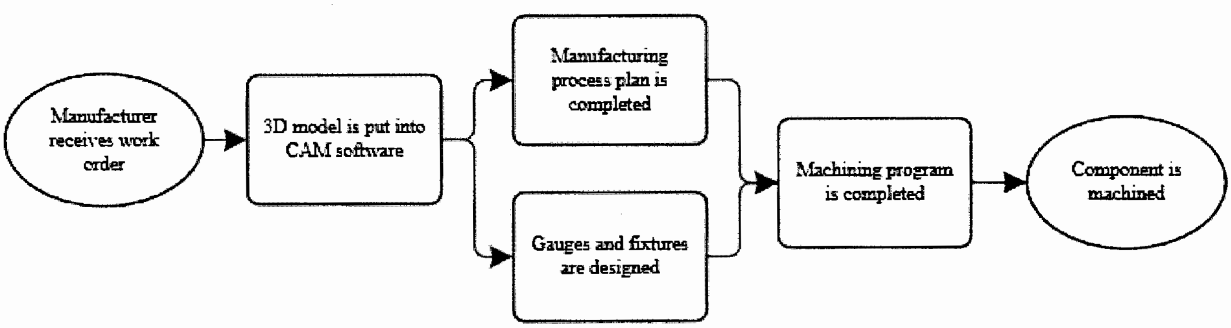
3D annotated model only

Figure 2.Flow Chart – Purchasing Department Quoting Process

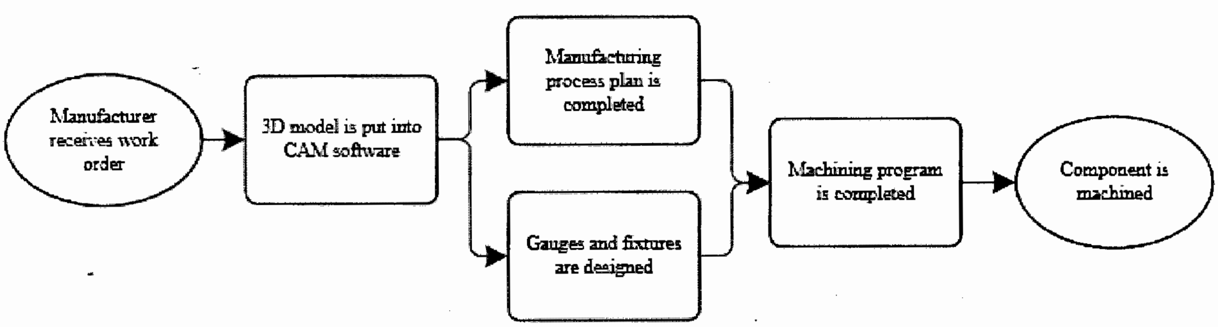
Figure 2 shows the process flow charts for the purchasing department's use of CAD documents in the price quoting process. It was observed the purchasing department was neither more nor less efficient in any of the three scenarios. The purchasing department acts as a middle step between engineering and the suppliers. Since all of the files needed were already created, the purchasing employees experienced no change in number of steps in their quoting process. The purchasing team is paramount when implementing MBD for the communication with suppliers and what their capabilities are. The ease of communication is based on what the supplier is able to accept.



2D drawing made from 3D model



3D annotated model and 3D PDF



3D annotated model only

Figure 3.Flow Chart – Manufacturing Department Programming Process

Computer aided manufacturing (CAM) software available today prevents many manufacturing departments from dealing with 2D drawings for programming; and if they do it is to generate a 3D model to use in the software. Figure 3 shows the manufacturing department's programming process is not affected by MBD. As long as there is a model to use, their process remains the same. An MBD model will add some extra information to the CAM software, but the process plan cannot be fully automated. It is still a manual process completed by a manufacturing engineer. The ease of communication is the same for all three scenarios with the assumption that a 3D model is available for use.

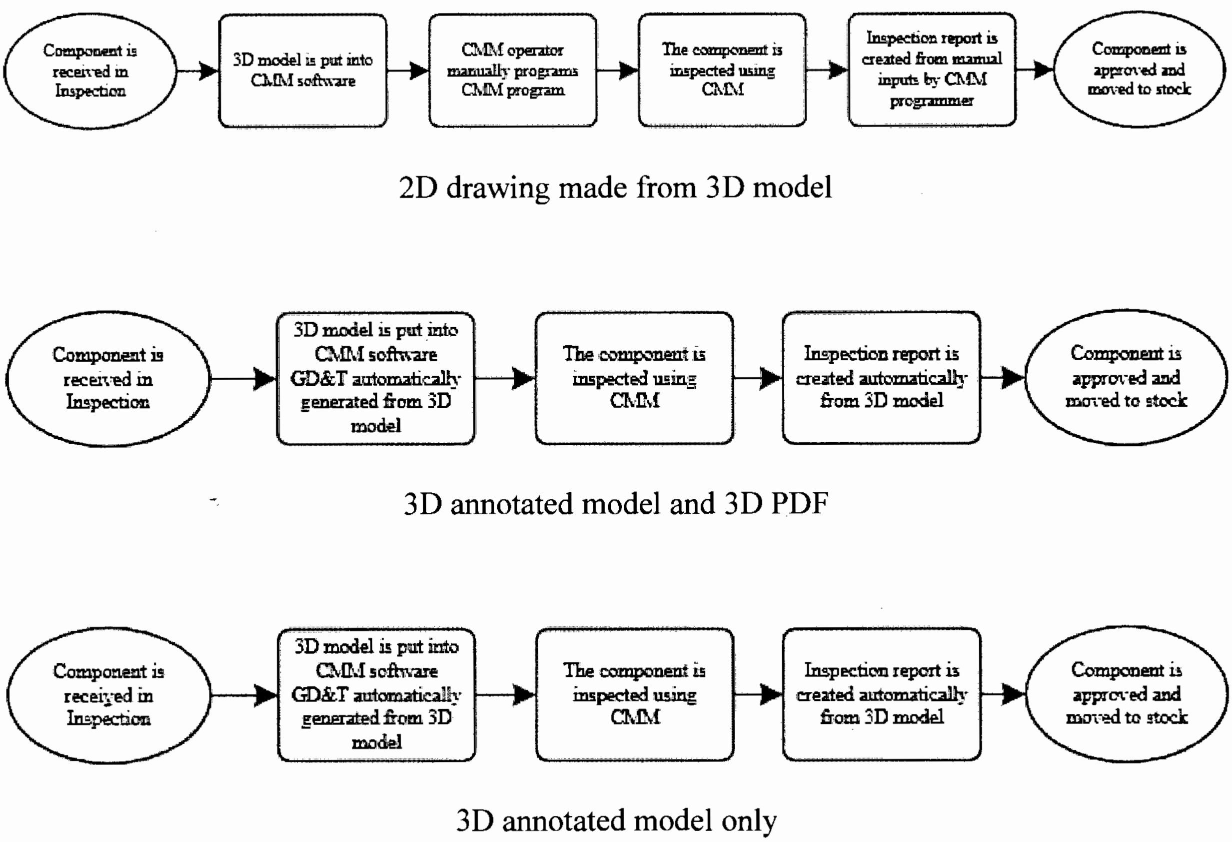


Figure 4.Flow Chart – CMM Programming Process

Inspection of products has the largest potential for increased productivity. Currently, many software programs are developed for use with MBD. As observed in the two scenarios with annotated 3D models, the 3D model automatically generated the CMM program and the inspection report. The automatically generated program is a time savings compared to the scenario without an annotated 3D model. The CMM operator must manually generate the CMM program with the GD&T from a 2D drawing if MBD is not used. Inspection is most often the largest bottleneck for manufacturing production speed. The primary reason for the bottleneck is not limitations of the CMMs or limitations of the programmers, but is the direct result of the limitations of the software tools the programmers use (Haftl, 2009). MBD is directly addressing and resolving this issue.

6. Conclusion

Overall, from the flow chart exercise above, using a 2D drawing made from a 3D model yielded 22 steps with the assumption a 3D model is available for manufacturing. Using a 3D annotated model along with a 3D PDF yielded 20 steps and an annotated 3D model only yielded 19. The results of the flow chart analysis indicate that using an MBD model only is the best scenario for time efficiency. Using a 2D model made from a 3D model is the least time efficient. When examining ease of communication the annotated model paired with a 3D PDF contained the maximum amount of information and document transfer options. The results indicate MBD made component production from CAD data creation through inspection more time efficient than a 2D model made from a 3D model, but there are concerns and costs which must be considered.

Through the investigation of what companies today are experiencing, the obstacles in the way of implementation of MBD, and analyzing process flow charts, an examination of the uncertainty and opportunity of MBD was accomplished. It is important to learn from the experiences of innovative companies and individuals to understand how to proceed with our own challenges. MBD will not be the answer for increased time efficiency and productivity for every company. In fact, it will have the opposite effect if there is a significant amount of active components with only 2D drawing documentation. The solution for a company that meets this description is to put together an implementation plan, initiate the culture change, and start to use MBD as a part of new product development strategy.

Companies that are relatively new and on the cutting edge of technology, implementation of MBD will be less of an uphill climb and more of an evolution of business operations. MBD appears to have opportunity for increased time efficiency and productivity if the correct tools are in place, and the right culture of employees is excited about the possibilities.

To enhance the knowledge of MBD and its possibilities, the reader must get hands-on experience with the software and downstream tools. MBD opens the door for many design and inspection tools; from tolerance stack up software to automatically generated inspection reports. Every company has unique needs and capabilities which are important to understand. There are a lot of different products and many sources of information available. Consider all options and challenges before rushing into the next big thing.

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