POLITECNICO DI TORINO

AUTOMOTIVE ENGINEERING

(Vehicle System Development)

Master's Degree Thesis

Improve Quality, Reduce Cost and Increase Efficiency with Model Based Definition

A.Y 2020/2021

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Abstract

Advancements in the products of the automotive industry resulted in ever more complex designs, which rooted from the increasing demands from customers as well as regulations. Complex designs though, are a challenge to manage as with the traditional mode of product development, they are expensive and require a wide array of processes to perform. To answer for such challenges, Model Based Definition is seen to be able to create data structures as well as streamlining the product development process through setting a standardized data library that encompasses many essential data across users with greater ease than the traditional design methods through drawings and 2D models. By linking MBD's potentials with concepts within product life cycle management, it was found that MBD provides a wide-array of possibilities to improve design quality, cost effectiveness, as well as effectivity in the automotive industry.

This thesis was conducted at Astra Daihatsu Motor in Jakarta, Indonesia, in order to examine the impacts of implementing MBD in an automotive manufacturing company. Numerous interviews were conducted with all the related department in ADM via video call due to the current situation with the pandemic. The results were compiled and analyzed with a hypothetical framework, covering the interconnected disciplines of MBD.

Keywords: Model Based Definition, Automotive Industry, Product Life Cycle

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Nomenclature

ADM	Astra Daihatsu Motor
DMC	Daihatsu Motor Company
MBD	Model Based Definition - A method referring to the use of the 3D model as the main and only source of information.
MBE	Model Based Enterprise
EC	Engineering changes
PLM	Product Lifecycle Management
vPLM	Virtual Product Lifecycle Management
PDM	Product Data Management
3D Master	The usage of the 3D model as legal document
CAD	Computer Aided Design, the creation of digital 3D models
Catia v5	CAD - system
FT&A	Functional Tolerancing and Annotations, module in CATIA V5
GD&T	Geometric Dimensioning and Tolerancing
Package	Term used in ADM for rough boundaries file taken from DMC
TDP	Technical Data Package
STEP	Standard for the exchange of product model data
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
Downstream	Departments performing tasks later in the development process
PO	Purchase Order

RFQ	Request for Quote
RFP	Request for Proposal
ECO	Engineering Change Order
ExpertCAD	2D CAD-system
NC	Numerical Control
ISO	International Organization Standardization
QA	Quality Assurance
KPI	Key Performance Indicator
QIS	Quality Inspection Standard
VIS	Vehicle Inspection Standard
SSC	“Simple, Slim and Compact” concept used in ADM
3DPMI	Volvo’s version of MBD
OEM	Original Equipment Manufacturer
PMI	Purchasing Managers Index
B2B	Business to Business
CMF	Color Material Finishing
UX/UI	User Experience Design for Vehicle
CMM	Coordinate Measuring Machine
CAM	Computer Aided Machine

Chapter 1: Introduction

1.1 General Area of Concern

In nature traditional design process is more sequential. It consists of three modules in the traditional engineering process: CAD modelling, followed by design optimization and then developing final working drawings. CAD software available these days only focused on one or two modules causing the modules to get separated from each other in the industry practice, meaning different tasks are conducted at different times using different software in different departments.

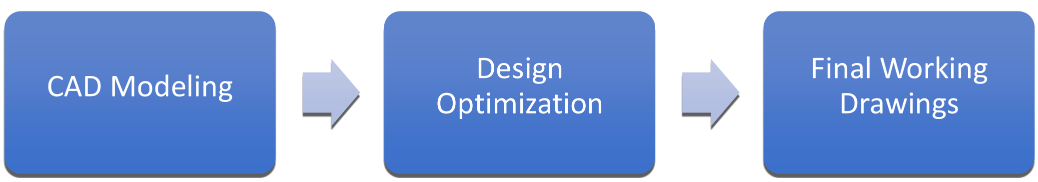

Figure 1: Engineering Design Sub-process

The issue with this approach is that it creates lots of separate CAD files starting from the early design steps up to the design optimizations. It also consumes too much time to generate and operate files at different workstations, since transferring files between workstations could be a non-value adding, and time-consuming work. Most importantly the format incompatibility between workstations that could lead to an issue.

Given this background, importance of model-based development (MBD) has increased and, in recent years, complex systems have been implemented through computer assisted applications to meet these needs. In Asia and other part of the world, the entrenchment of the technology has been fairly slow and limited to industries that are “traditionally” utilizes it, such as aircraft, satellites, and rockets. This, in addition to problems such as high investments, software limitations, proprietary formats, interoperability to legacy data, security, implementation, and cultural changes, slows down the implementation of 3D models and elimination for the need of conventional 2D drawing in wider automotive industry (Zhu, Durupt, Remy, & Li, 2016).

1.2 Company Background

PT Astra Daihatsu Motor (also called ADM) is an automobile manufacturing company based in Jakarta, Indonesia. It is a joint venture company between Daihatsu, Astra International and Toyota Tsusho. Astra Daihatsu Motor is the largest car manufacturer in Indonesia by production output and installed capacity, and the second best-selling car brand behind Toyota. ADM also supplied most Toyota-branded models sold in Indonesia. ADM aims to produce car at top quality. To achieve this, the advancement needs to be on edge, both in technology and innovative forms. The increased use of a digitalized way of working has been proofed to be more effective and iterative. MBD is a term used to describe a methodology where 3D model is used as the main source of information. It is created as a methodology in which 2D drawings are rendered redundant, MBD does include the 3D model being the legal source of documentation.

Figure 2: ADM Company Logo

The main source of information used in ADM are still 2D drawings as 3D cannot fully convey all the information regarding the item itself. Compared to other large companies within the manufacturing industries ADM is considered to be more orthodox regarding this matter as they still haven’t fully utilized MBD in all of their manufacturing departments. Research and Development department are one in a few that has analyzed the adoption and benefit of MBD as it is claimed to have one source of information, the 3D model and allow the stakeholders to obtain the relevant information from the source in an effective manner.

1.3 Purpose

This thesis seeks to explain how MBD is able to be implemented in a way that it contributes positively to product lifecycle management (PLM). This research first compiles the data on the latest research and application of MDB in the automobile industry to describe how MDB is implemented. By analyzing how MBD is used in such applications, this thesis exposes the main areas in which MDB is useful, such as to create data structures as well as streamlining processes. By analyzing the current use of MDB, in ADM then analyzed the challenges that hamper the use of MDB within the automotive industry, as well as its possible future use to contribute to product lifecycle management.

To summed up the goal was to provide an objective assessment regarding the change to MBD at ADM.

1.4 Scope

As mentioned in the background section these MBD 'essential elements' are needed to be worked upon for full realization in MBD-oriented enterprises. It is needed to have a comprehensive knowledge of information flow as there is still lack of common understanding on which information is essentially needed in moving from 2D to 3D model for each workflow in the product lifecycle. Though standards have started to be set, there is still a long way to go in developing model-based product definition until complete maturity to fully replace two-dimensional drawings. After all, as Goher put it, MBD is not based on a single solution; rather it is a result of many applications integrated together for a common goal. The 'interoperability' issues of all these applications are a big obstacle in the realization of model-based enterprises (GOHER, SHEHAB, & AL-ASHAAB, 2019).

Noticing the challenges faced by the automotive industry, as well as the opportunities provided by MBD, this thesis seeks to explore the research and possible applications of MBD at ADM to answer such challenges.

1.5 Delimitation

The thesis was constrained to analyze the method and process in the product development. More intensive examinations around the tools and modules needed for MBD were taken out of the scope of the project.

The numbers regarding to the cost of license and educations for the MBD software were left out as this is disclosed between Astra Daihatsu Motor.

The investigation was done towards the department at ADM that are likely to be affected by MBD. This included Research and Development, Production and Logistic, Procuring and Purchase.

1.6 Organization of the thesis

The structure of the thesis is as the following:

Firstly, after the explanation of the introduction in this chapter, the method used to obtain the information are followed in Chapter 2. Where it would explain each step done to construct this thesis.

It is followed by Chapter 3, consisting the literature review and theoretical focused. It starts with the description of MBD as well as its beneficial purposes. However, the theoretical focus is conducted only the one that has a strong relation to the problem being discussed in this thesis.

The empirical research conducted at Astra Daihatsu Motor is covered in Chapter 4. That includes interviews and observations.

The main results obtained from the discussion, including all quantifiable results found regarding the use of an MBD approach are presented in Chapter 5.

Finally, Chapter 6 summarizing the conclusion and future recommendation is written in the ultimate chapter. It is the followed by the list of references and the appendix.

Chapter 2: Methods

Several methods were used to analyze the current situation at Astra Daihatsu Motor. First, interviews were conducted at different departments of ADM to investigate how far they have been implementing MBD. These interviews were done continuously during the entire thesis. The interviewees were chosen at different managerial level and key personnel within the projects that closely related to MBD in order to receive a wide spectrum of information.

Observation was then done to ensure the information collected in the interviews was correct and also to identify additional problems that did not emerge during the interview.

All interviews conducted was semi structured as they follow a certain template but were customized depending on each roles of the department. The first interview was used as the reference to the rest of the interview.

2.1 Literature search

In this project, chain sampling strategy was utilized. The chain sampling strategy is conducted by starting a basic search state that is likely to yield results within the range of interest. The chain sampling gives expansions of the project by investigating references from the articles found.

2.2 Interview

The interviews were done using snowball method where existing subjects recruit future subjects from among their acquaintances. As the sample builds up, enough data are gathered for the research. Snowball method is similar to chain sampling method but it is more focused on people rather than articles. Firstly, a contact network was initiated at ADM through the Human Resources division, from there directions and suggestions were made based on the needs of the project proposal. This caused an expansion in the contact network inside the company proofing that the snowball method is an appropriate way to find participants from a relatively inaccessible population (Berg. 2004) which due to the size and its restricted access at ADM was the most fitting.

The interviews were carried out in different departments in ADM with varying background in order to get a picture on how the company has been using MBD in their practice. Similar interviews were also conducted at other companies similar to ADM in the same aspect to investigate the impacts that already occurred.

Due to the current situation with the Covid-19 all the interviews, meetings and several presentations were done via internet, where information about MBD was discussed or presented.

2.3 Survey

Surveys were conducted in R&D and Production and Logistic department in order to understand more in detail on how far MBD has been implemented in ADM and also to know the point of view of the key personnel that are working on site. Each respondent was asked to answer a google doc questionnaire where several questions and answers regarding to MBD are presented.

2.3 Observation

Observations were proven useful as it gave a new perspective which resulted in the discoveries that might be left out from the interviews. It was then done to ensure the information collected in the interviews was correct. The aim was to obtain a realistic view on the topic for example how much time was spent using 2D drawings.

2.4 Information Extraction

The information obtained from the interview was mostly used to map out the situation at ADM, but also to aid in the search for quantifiable example the of costs associated with drawing. The results were to provide more concrete basis to justify how much resources could be saved using MBD.

In order to analyze the findings from the information gained during the data collection phase was divides into different sections matching with the benefit, challenges, need for change and quantifiable data. The next step was to compare the responses from each participant and evaluate the result from each department in order to conclude the implementation.

Chapter 3 Literature Review

3.1 Model Based Definition to Support Data Structure and Design Process

By definition, MDB is a method that makes the 3D solid model the only basis in the PLM. This is since MBD integrates the drawing of annotations, which then eliminates the need to create engineering drawings (Lundqvist & Phillips, 2016). Early applications of MDB include the design process of B-777 airplane by Boeing in the aircraft industry which attained 100% digital definition. In their application, Boeing integrated the process design platform, which ensured uniformity of data within their systems – enabling engineers to work seamlessly through data.

As both a method and a technology, MBD is based on the manipulation of three-dimension models of an object, that are able to be constructed to great details and include its smallest parts. As such, MBD allows the visualization of a scalable design that is composed of various attributes and is able to be manipulated. To do so, the MBD employs data that are composed of three main entities, which are the design models, 3D annotations, and attributes (Zhu, et al., 2016). These three entities are the building blocks that allows for real-time model manipulation. The MBD framework at its core works by transforming simple geometrical data to comprehensive sources of information for a whole product life cycle. It prevents data from being scattered in different forms in the PLM database. Simply put, MBD is a database management and information exchange to support product lifecycle management.

Modern and highly accurate 3D computer assisted design (CAD) software provide for detailed designs. For example, the use of CATIA V5 Standard Scale within CAD means product size can be designed to 1km, and an accuracy of up to 1μm (Alemanni, Destefanis, & Vezetti, 2011). MBD encompasses databases such as parts and parameters library, which can later be linked together, creating a linkage between part structure, process structure, and machine-tool structure. This means that design data would not be scattered in different forms throughout the project design management database. The MBD data would be the only reference document for future processes of engineering and manufacturing (Alemanni, Destefanis, & Vezetti, 2011). Based from such linkages, the systems could then be used to aid in the workflow of process planning and implementation. As such, it would help in manufacturing process and technology, ranging from process planning, process validation, and process execution (Zhu, et al., 2016).

On a more practical basis, MBD has a wide-array of values aside from providing a data structure. Struss and Price noted that first, MBD is useful in early design phases, where only a partial specification of components and parameters are available. This condition requires what they call qualitative models to better visualize, understand, and solve the issues, since quantitative values alone could not provide sufficient background as well as solution. Second, tasks such as FMEA or the creation of diagnostic manuals are designed to address statements about classes of behavior and symptoms rather than a specific quantitative value that directs to an instance. Third, faults are qualitative deviations from what ought to be functioning normally, instead of arbitrary deviations of quantitative values in respect to precise values. Therefore, faults need to be displayed through qualitative values. Fourth, precise quantitative values are difficult to attain since it is near impossible to portray the myriad of quantitative values in the operating environment. Fifth, qualitative models are seen to be able to provide sufficient level of abstraction to model complex systems where mathematical models often have difficulties in defining. Lastly, qualitative understanding provides an intuitive representation and presentation of knowledge to the users (Struss & Price, 2003).

MBD models require the support of a product data management system that integrates all the departments of product data and information, as well as organizes design activities according to a specified workflow (Eynard, Gallet, Nowak, & Roucoules, 2004). This is so the data is effectively spread across all users. For example, engineering staffs can obtain the MBD design model from the design department effectively, and then proceed to combine the obtained information with their situation within the product department to allocate the necessary resources and plan their manufacturing process. The data would then be organized and managed throughout the process structure, and that each machining operations would then be defined by using MBD design model as well as the process planning information. As MBD provides a library of data structure as well as streamlines the design process, by effect it reduces design costs and shortens product development life cycle, as well as reduces the time to market new products (Struss & Price, 2003).

3.2 Practices of MBD-assisted Product Lifecycle Across Industries

There has been various research and applications utilizing MBD, which included studies on product information integration within design models that are aimed to support information needs of a full lifecycle with the Core Product Model (CPM) (Rachuri, Bouras, Fenves, Foufou, & Sriram, 2008). Some other research also found the positive effects of MBD technology in the manufacturing process. The use of MBD was positive to the product lifecycle management implementation on a spacecraft, thanks to its versality in simplifying the minding the complex nature of a product (aeronautics, mostly). Such utilization allowed for the streamline transfer of product information, from design and all the way to the end of the lifecycle, opening a wide-array of possibilities in design (Vezetti, 2009).

The use of MBD has also been predominantly limited to the aeronautics industry, as can be seen by the number of research and application that are mostly listed for such industry. A particular research highlighted the use of MBD in Chinese aeronautics industry, and found that whilst Chinese aeronautical industry only utilized MBD after their American and European counterparts, MBD and PLM have proven to be a core technology for supporting future product development in Chinese aeronautical industry. The use of MBD is seen as to be bring significant advancement in the management and efficiency of product development and manufacturing for Chinese aeronautical companies. They also asserted that the implementation of full 3D models for product design and process engineering based on MBD methods is a required step to improve the competitiveness of a company (Zhu, et al., 2016).

A growing research and application of MBD is on its relation to product lifecycle in the automotive industry, that is always in need of improvements in the field of quality, effectiveness, and cost efficiency. First, it was seen to be effective in reducing paper-based design drawings, and in-turn, saving time in design process, a more flexible project development, and consistent data that is easily accessible. An interconnected infrastructure of MBD can also help with disseminating data to various departments, thus aiding the various processes involved in the product lifecycle. More importantly, the MBD is seen to be able to automate tasks, as well as managing product data from requirements to retirement (Alemanni, Destefanis, & Vezetti, 2011).

An interesting research on MBD argued that there needs to be an understanding as to what and how much information is needed of the product lifecycle in defining MBD to maximize the efficiency of the method. This was done through an industrial survey to record the present state of MBD adoption, that includes the present information that are mainly used in the workflows, the model's capacity of carrying such information, as well as the challenges to adoption. This was then evaluated in terms of advantages and disadvantages of the practical use MBD (Miller, 2017).

The automotive industries face challenges in fault analysis as well as diagnosis during the life cycle of their products. This is especially true in the context of increasing complexity and sophistication of vehicle systems. To answer this, MBD creates libraries and streamlines processes. Yet, it is a method that requires its users to set definitions, standards, as well as common practices, in order to create a common working language for data management. This is translated to standards, which insofar have been established for Functional Tolerancing and Annotations: ASME Y14.5 209, and ISO 1101:2004 (Alemanni, Destefanis, & Vezetti, 2011).

MBD can be applied to testing integrated systems such as an ECM (engine control module). It was based on an existing approach to unit testing, using mutations of operators or statements in the description of a unit (Dynov, 2017). From such, this method was then extended to the testing of unit integration. In order to do so, two aspects are considered: 1. Data Flow Integration and 2. Control Flow integration. Data flow integration focuses on data flow relationships between the different units, and control flow integration focuses on the execution order of the units. This process of testing is then aimed at revealing errors in those two types of integrations. This work is grounded on the objective to define abstract methods for detecting mutants within automotive systems by generating a set of test data that help uncover these errors (Dynov, 2017).

Other automotive company such as Volvo reported the use of 3DPMI to be fully implemented by 2017. This is since that it not only alters the way designing is done (switching from 2D to 3D), but it affects the information flow between departments, and reduces the lead time between different departments. As such, Volvo found that they had a 10-20% increase of efficiency due to the use of MBD, which translates to 2-4 weeks of a 20 weeks sprint time. Other benefits which might be obscured is from the cost savings in case of project changes, as well as the cost of paper. This may seem miniscule, yet it has to be put in perspective that automotive industry requires a lot of administrative work that is able to be streamlined by MBD (Lundqvist & Phillips, 2016).

A standardized data structure provided by the use of MBD provides the benefits of time and cost reduction for engineering processes. This is since MBD allows for data centralization and the reduction of number of formats that are used in various phases of design process. In turn, this leads to easier tool integration, the simplification of workflow rules, as well as a more flexible management of design documents (Alemanni, Destefanis, & Vezetti, 2011).

3.3 Challenges in the Practical Use of Model Based Definition

Implementation of an effective MBD have faced various problems. Being a relatively new innovation in the industry, it requires that professional engineer employed for MBD is sufficiently trained on the method. The use of MBD requires a comprehensive knowledge of information flow, which sometimes is lacking due to the previous experience that are mainly limited to 2D models with differing workflows within the product lifecycle (GOHER, SHEHAB, & AL-ASHAAB, 2019).

This type of challenge be seen in MBD experiences in which major OEMs and other Tier 1 companies experienced gaps between the expertise, mindset and way of communication of function developers and testing experts. There is still no standardized approach to documenting models which can be understood equally well by both parties. This leads to communication challenges and having to go back and forth trying to understand the models and integrate them into the test environment.

An effective education program is required for engineers who are without sufficient experience in development using MBD. Wakitani et. al explore such practice and evaluation of model-based development education in practices implemented by Hiroshima University and Mazda Motor Corporation, an automobile manufacturer, and the consequent educational effects. The education are implemented for 159 people for 4 months, and they found that even under constrain of undertaking the learning program in parallel with performing their work, many the MBD method is recognized internally to some extent even when the learners were in charge of operations other than those relating to said method and that recognition to the effect that simulation models were necessary for MBD has been gained to some extent, what limit the success of the experiment is despite the fact that the relevant learners had knowledge of MBD, they were not able to understand the entire picture of how MBD is performed because they have not had any experience in development in line with the V-type process, or even when they are in charge of some operations in the V-process, they do not recognize so (V-type process is following operations for which computer simulations play an important role: (i) model in the loop simulation and (ii) hardware in the loop simulation, and is part of MBD implementation). Consequently, as they had little operational experience (or successful experience) with V-type processes, it can be assumed that their self-efficacy in being capable of carrying out MBD operations is low (Wakitani, Yamamoto, Morishige, & Adachi, 2019).

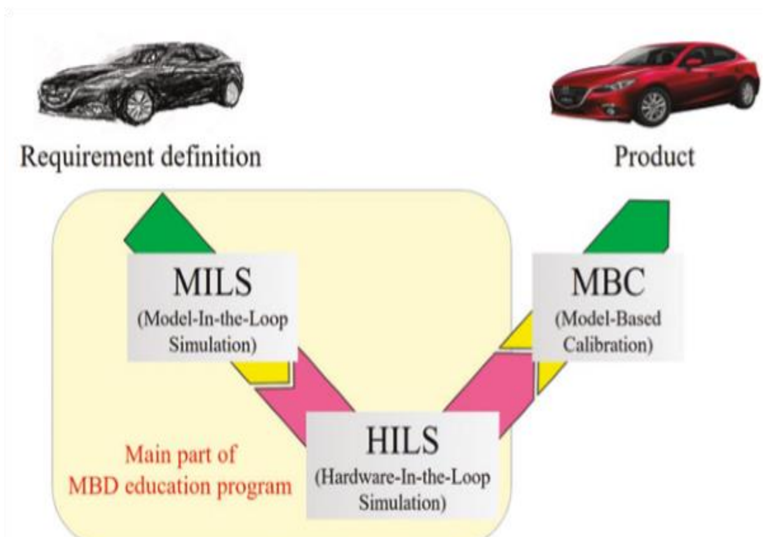

Figure 3: V-type development process and their relation to MBD

With these results, Wakitani et. al. has come to believe that successful experience in practical training led to improvement of self-efficacy for the future operational performance, even if MBD itself is not completely understood.

While that’s perhaps is the necessary evil and required bridge considering the situation prior to the training, it remains ineffectual. There’s also other problem to implement MBD that’s not limited to the particular company that started its shift to 3D environment: some supplier will not be ready for MBD, and the end users has to be trained to generate model with PMI too.

But even with this downsides, MBD-oriented enterprises have significantly better lead against their competitor. On its most basic level, MBD is stated to allow for 20-25% time reduction during the design phase, allows any replacement or repeat work to be started very quickly and ensures the exact same manufacturing strategy will be used to create identical parts, reduces the number of rejects and less interruption in planning by rejects. The model-based design contributes to faster releases, enhanced design and better reliability of automotive embedded systems. It demonstrates outstanding benefits and naturally will becomes more commonplace in the automotive industry (Doorakkers, 2019).

One way that this conundrum might to be solved is by establishing a *Common Information Model*. Common Information Model represents details that are relevant in different versions of models including design, manufacturing, and quality models. Within these models used in different workflows are domain specific elements. The Common Information Model will contain the information that is common amongst these different domain specific elements.

To reach a Common Information Model, several sets of information will need to be understood. In an MBD environment, the model is the main knowledge artifact for product definition – what information a MBD needs to provide must be known. Also, in certain circumstances, different disciplines in industry will use the same model, but require different perspectives or contexts of the model. Breaking the data up across different platforms can be a challenge, but beneficial to the users (Ruemler, Zimmerman, Hartman, & Thomas Hedberg, 2016).

3.4 2D to 3D transition

Before attempting to establish a Common Information Model, it is important to understand what information needs to be in the 3D-CAD model to be able to communicate the same amount of information as a 2D drawing, which are:

- GD&T Information.

For models to convey all the information contained in drawings, they will need to contain a wide variety of data. MBD should consist of one central knowledge artifact containing 3D geometry with GD&T and functional tolerances and annotations (FT&A). GD&T and FT&A refer to the products dimensions, tolerances, and any other annotations that the model must contain to be correctly interpreted.

- Basic Characteristics.

MBD files must contain basic characteristics of the product. These characteristics that must be contained within the model are notes, base-coordinate systems, dimensions, tolerances, flag notes, technical comments regarding material, surface smoothness, weight and other general notes.

- Information Assurance.

Information assurance is critical within each step of a models process through PLM, and issues include protecting sensitive information; enabling collaborative supply chains and security framework for collaborative CAD and role-based-view generation is a necessity

- Security.

  Each process of PLM security is extremely important for any company. Certain technologies exist managing digital rights. Organizations such as NIST's Information Technology Laboratory and the World Intellectual Property Organization (WIPO) are creating standards within this area.

- Standardization.

  Standardizing product meta-data is crucial for company collaboration and efficiency in production. Product meta-data includes information such as part number, bill-of-material, product-assembly structure, author, approver, supplies, version, and change history. Having this information standardized throughout engineering systems reaches out to other information systems.

- Singular Data File.

  A critical part within each process of a Common Information Model is keeping it a singular data file for downstream consumers, in which case can be easily distributed within other areas of other departments such as design, manufacturing and inspection.

- Transformation of Information.

  Aside from what information needs to go into the Common Information Model, another issue that must be addressed is if the model needs to be used in a different software package or if the model will ever need to be translated using a neutral file format. If this is the case, it is important to know what information needs to come out of the model after being translated as opposed to what information actually does come out in the resulting file. It is also important to know and understand what information gets lost in this translation.

  This is good time to remind ourselves that MBD is still a relatively new technology yet again, because as for now, it is difficult to conclude what information is common amongst different models. Based on the results of Ruemler et.al survey, a proposed Common Information Model would need to be workflow specific because of the varying degrees of information in the different workflows. A general Common Information Model would lack enough information to be beneficial to a company's processes (Ruemler, Zimmerman, Hartman, & Thomas Hedberg, 2016). To establish a Common Information Model, more specific information regarding the workflows is needed, and perhaps it is what's necessary to ensure further use of the model-based definition in the automotive industry.

In technical terms, challenges typically come from the essential elements that are needed to be worked upon for the full realization in MBD. As though there were standards as stated before, the wide use of MBD still requires further efforts to create a common language for MBD to fully replace the traditional 2D drawings. Insofar, it was found that manufacturing and inspection related information is supported by MDB, but technological improvements are still needed to support the realization of a full lifecycle data with MDB. Moreover, detailed solutions such as lighter size formats, or accessibility for downstream use by vendors other than established corporations will significantly improve automotive industry as a whole.

3.5 Example of MBD Dimensioning in Automotive Industry

MBD is more efficient and reliable to produce the PMI annotations on the CAD model, it also provide clear visual that makes it easier to understand. When reading blue prints, engineers will have to go back to reading various section and detail views which often scattered on multi-sheet drawings. With the implementation of MBD far fewer section or detail views are needed, making it easier to understand and read in a dynamic of 3D model. The section detail can be echoed on and off for additional clarification.

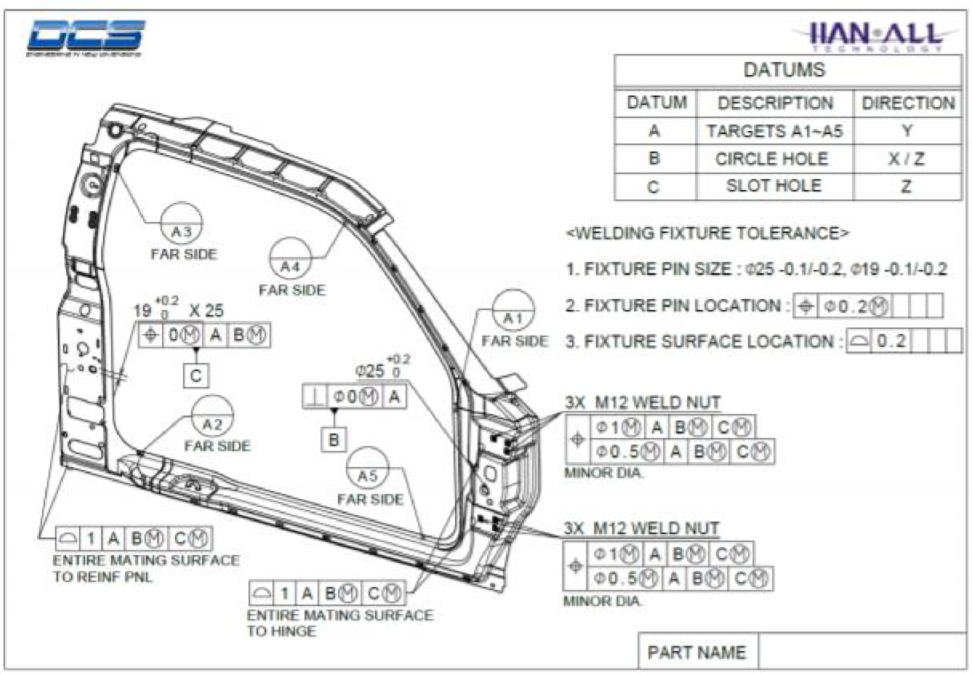

Figure 4: Example of MBD dimensioning on door frame

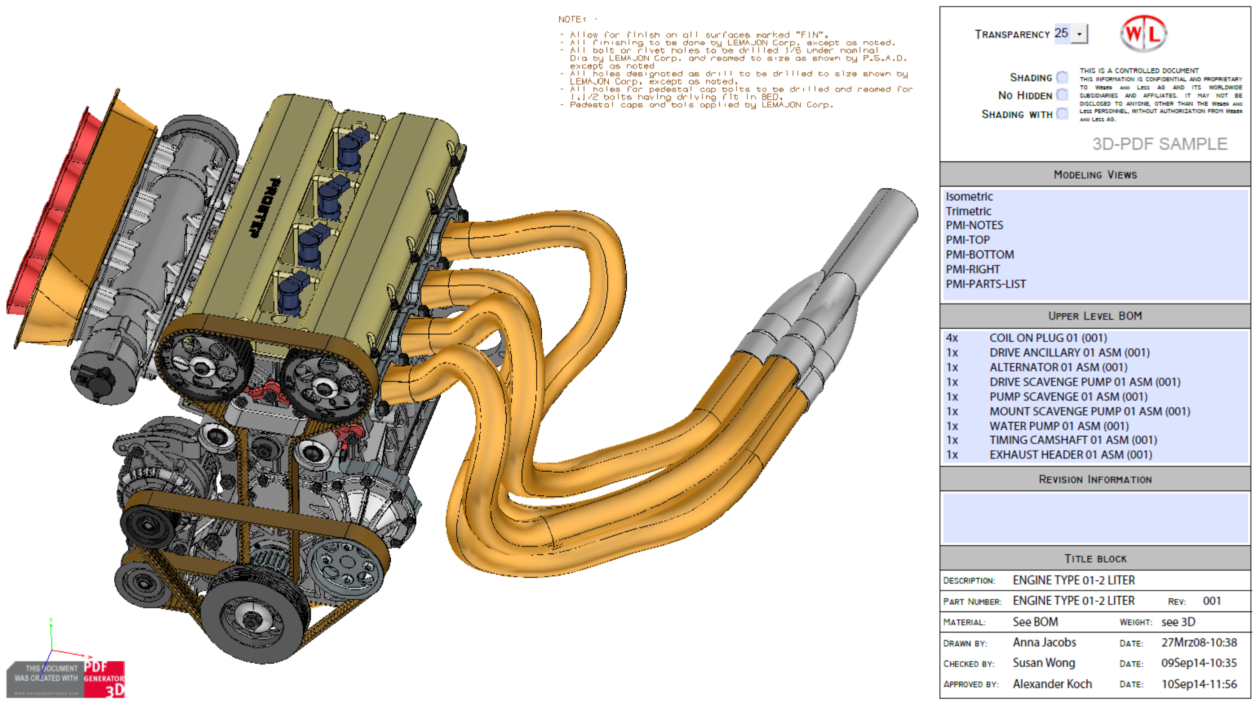

Figure 5: TDP of a 2-liter engine

The Technical Data Package is conveyed with a framework containing all the engineering, design data and descriptive documentation required to support the system throughout its lifecycle. TDP gives the premise for adjusting the framework and supports competitive re-procurement of system components. TDP consists of models, drawings, associated lists, specifications, standards, quality assurance, performance and operational requirements. TDP is often communicated in the form of PDF.

POLITECNICO DI TORINO

SOLIDWORKS LET'S GO DESIGN

Date: 1/26/2021
Revision:
Designed By: aurel
Part Number: Base Plate modified

APPROVALS		
TITLE	NAME	DATE
DRAWN	aurel	11 November,
CHECKED		
APPROVED		

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
MODEL IS REQUIRED TO COMPLETE PRODUCT DEFINITION
FOR ALL NON-DIMENSIONED FEATURES IN THIS DOCUMENT
ALL DIMENSIONS OBTAINED FROM THE MODEL ARE BASIC
UNLESS OTHERWISE SPECIFIED
THE GENERAL TOLERANCE FOR ALL UNTOLERANCED SURFACES = 0.2MM
INTERPRET DRAWING IN ACCORDANCE WITH ASME Y14.5-
2009, AND ASME Y14.100-2013

File name: Base Plate modified
Sheet: 1 of 2

Figure 6: Example of MBD dimensioning in PDF form on base plate

Chapter 4 Empirical Study

4.1 Astra Daihatsu Motor

In Indonesia, Astra Daihatsu Motor (ADM) utilizes a production system that incorporates a version of the Japanese SSC concept which has been optimally adapted to the local market. By expanding the SSC concept overseas, Daihatsu has been able to develop the approach that underpins high-quality Japanese manufacturing to suit the local environment. More specifically, ADM has adopted Quality Gate—a system which, instead of sending defective products downstream, stops the line and fixes the defect there and then—and has established a bright, quiet and comfortable working environment that includes measures to combat the heat.

Including consigned production, Daihatsu produced about 500,000 vehicles in FY2019, and is the largest automobile manufacturer in Indonesia. In order to promote local development, they have also established an R&D Center at the Karawang Assembly Plant, which commenced operations in October 2012. The center is equipped with the first automobile test course in Indonesia.

As mentioned in the Scope, three main departments at ADM were investigated; Research and Development, Production and Logistics and Procurement and Purchase which are all divided up into more sub-departments. The study focused on examining the current way of information flows at ADM and how each department are prepared for the transmission and implementation of MBD.

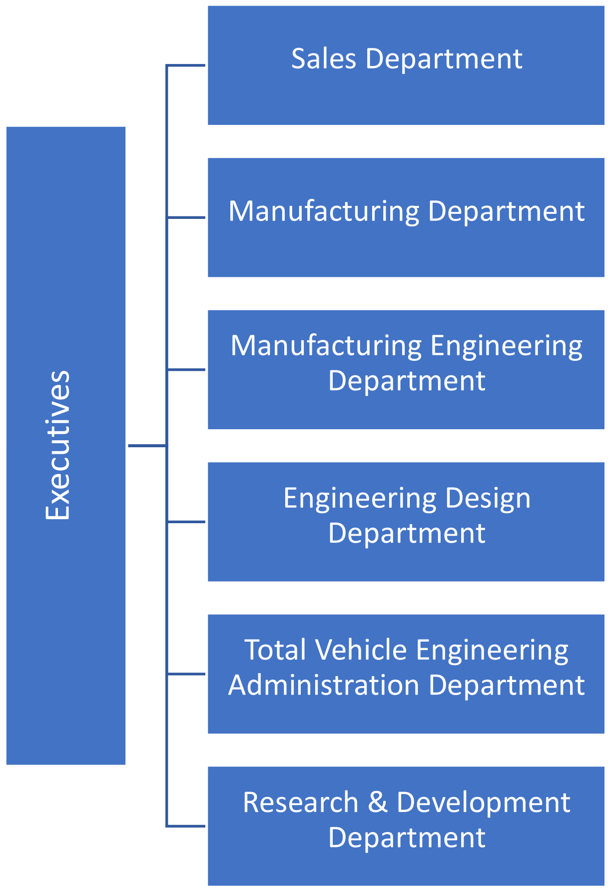

Figure 7: Decision making chart in ADM

4.2 Systems in Astra Daihatsu Motor

To fully understand the information flow at ADM, it is important know how the systems work and what programs are used to forward information. These programs and systems are ought to be modified in order to fully accommodate the implementation of Model Based Design.

The systems in ADM are designed to be customer focused with all the tasks that create value for the customer being prioritized. In order to assure a certain standard and quality, all the departments in ADM are following ADM Product Development Process along with the guidelines that has been established by Daihatsu Motor Company Japan as their mother company. These guidelines are not rigid as it has to be modified accordingly to fit the need and regulation of Indonesian market.

This leaves room for improvement when collaborating between departments. One of the main goals in ADM's Research and Development department is to make a creative technical drawing which could be processed for production with minimal number of problems.

ADM is using modularization system where instead of creating new vehicle's frame every year, each vehicle is using ''package'' obtained from DMC Japan where it contains rough boundaries of how the vehicle is going to look like. This package is given to the styling designer for them to exploit and improve it to the customer need but they can't go far off the boundaries.

The cost of the software and the man power that would be available to utilize the software are two important points upon deciding which software to use. Currently ADM is using CATIA as their main CAD software as it is more reliable for surfacing compliance with Toyota and Daihatsu group. By using this software ADM is also able to utilize platform in Toyota where there are several designs that has been standardized, such as; bolt, nut, clip, lock, handle, etc. Besides CATIA they also use Alias Autodesk, based on the interview with the designer Alias has a better user interface. It can produce the same quality surface with less steps therefore it is more efficient timewise but it is more expensive than CATIA.

Another critical portion is the modules for the systems in the implementation of MBD. MBD should consist of one central knowledge artifact containing 3D geometry with GD&T and functional tolerances and annotations (FT&A). GD&T and FT&A refer to the products dimensions, tolerances and any other annotations that the model must contain to be correctly interpreted.

4.3 Implementation of MBD

4.3.1 Research and Development

Astra Daihatsu Motor has multiple sub departments in Research and Development. The main focus in this chapter has been on styling department and design engineer as they are the one who is closely applying the implementation of MBD in their daily project. Both styling designer and design engineers can be divided into several division depending on which part of vehicle they are focusing on. Styling designer and design engineer are working in parallel by using CATIA the design engineer creates a 3D model and creates 2D drawing based on the model where here it contains the tolerances and other kind of information such as type of material used since 3D model can only convey nominal value ex: dimension. As they are satisfied with the technical drawing, it is then transferred for validation test in order to check if the vehicle is up to the standard of the company before then sent to the production team.

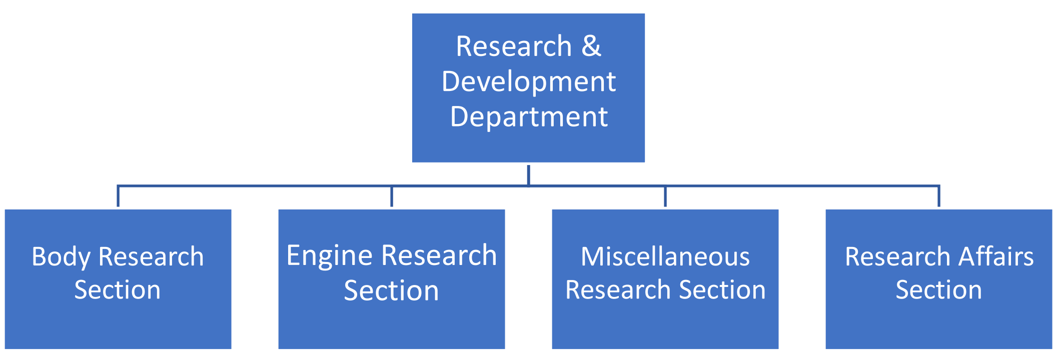

Figure 8: Research & Development Sub-division

According to one of the interviewees from the Geometry and Assurance department in R&D, the operation of Fasteners and Material Data can be disregarded if 3D is used as legal document. This brings to a total of roughly 15% saved time in a cross-functionality perspective.

A small survey was conducted in the Research and Development department where each participant was asked how they receive customer order information and how the communicate between each division in the department. The following options were given: drawings only, primarily drawings (with supplemental models), primary 3D-CAD models (with supplemental drawings), and 3D CAD models only.

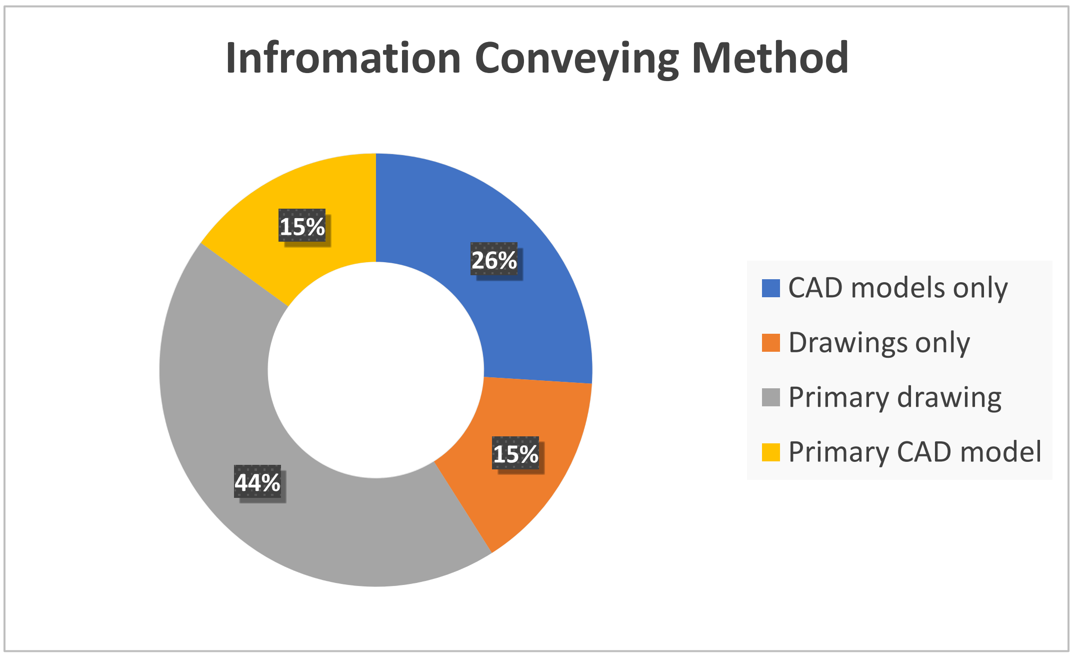

Figure 9: Survey Chart of R&D

Amongst the 30 respondents, 44% of them chose Primary drawing with supplementary 3D model as their preferred method in conveying information inside the department. This shows that drawings still play a crucial role in ADM.

4.3.2 Styling Designer

Hosted in the R&D department, styling designers are in charge to make styling proposal that is derived from the map concept obtained from the marketing division to create a new or update the vehicle style based on the market demand while simultaneously work with the design engineer for the technical issue. ADM modularization structure enables different variations that suits different tasks and purposes which makes the majority of their vehicle unique. Styling designer is divided into exterior, interior, CMF, UX/UI.

Even though the global OEM mostly goes for digital as their form of idea expansion, ADM is still orthodox in a sense that the base idea has to be done manually before then be converted into digital 3D. The advantages by going digital 3D are that it is easier for the designer to evaluate the surface quality and also the proportion of the vehicle in all angle. In the CMF division, paint workshops would have to stop production to test while with a 3D model they would be able to work simultaneously. By going 3D, it is also found to cost significantly less compared to clay model, but in ADM itself clay modeling is still much preferred as it is more convincing to the older designer than using fully digital 3D.

There are 2 types of changes that could be done; Minor Changes and Major Changes. With Minor Changes by using a template, only external body accessories such as bumper is improved. Meanwhile with Major Changes up to 80% of changes are done. These changes are done along the way depending on the lifecycle of the vehicle. The engineers would want best material to be used in the production and the designers would like the car to look new. To balance out the needs from both departments, the management department would have to make a priority list. Car in the middle life cycle can make some minor refreshment since they want the cost of the refreshment to be far less than making a new car. These days ADM are only focusing in doing Minor Changes.

For example, Daihatsu cars have a 15 years lifespan. Along this lifecycle it will undergoes 3 minor changes to upgrade. The goal in every change is facelift as it is done to make the car look brand new to attract customer interest.

Another advantage of going digital in this case is that it is easier for the styling designer to modify as a single content, allowing others to see the early design and adjust their design as well as giving early feedbacks.

4.3.3 Design Engineer

The job desk of a design engineer is to build a cab structure from the body shell package coming from the styling designer. Due to the outline of the design, Cab structure could be fully described in 3D but in ADM the 2D drawings are still used to communicate the design as it is the master document. With the utilization of MBD there are fewer changes made late compared to when using 2D material, this leads in better quality in shorter time. In the engineering section they have boundaries that is related to the process and capability for manufacturing the vehicle.

Design engineer is also conducting simulations and calculations where they run digital tests on everything from strength to fluid dynamics for the components and designs. Here only 3D geometries are used.

Design engineer also have to take into consideration the estimated cost, weight and performance of the vehicle as they build their model. In ADM the weight of the vehicle is estimated from the existing vehicle and also the size from the drawing. Both drawings and models are needed in order to fully describe their designs to the other departments. The 2D drawings contains all the information, the 3D is used to describe the designs geometry. This creates extra material that needs to be maintained and updated as changes are made. It would lead to waste that could occurs when the details are wrongly produced due to the ambiguous information between 2D and 3D. With MBD, chain of tolerances would already exist digitally instead of manually placing it from the 2D material.

The largest difference with the implementation of MBD were the tasks and time spent on each objective. According to the interview at ADM the design engineer is working closely with validation test department for functionality test using CAE for early prediction where they would run simulation on a model that has been made that is as close as possible to the real condition in real life. CAE offers a great help in trial in the actual CAD, where they could obtain the wanted result by just running the simulation while discarding testing. This allowed 100% of MBD implementation and the sole use of 3D models making it faster and easier to share as the designs were released earlier and no drawings have to be made.

Challenges that can be found in the usage of MBD is the fact that welding couldn’t be simulated and it required a uniform way of working. Another challenge that could be confronted is that not everything could be handled by 3D, for example only about thirty percent could handle 3D material. It would also need extensive effort to obtain a positive result in the areas such as ergonomics.

A typical design scenario requires engineers to produce different documents as they make changes based on information gained during the design process. When the documents reach the manufacturing stage, they are often the cause of delays, inefficiency and waste because they are subject to misinterpretation by manufacturing workers who must take time to determine the designers' intent. A large percentage of scrap and rework in the manufacturing process is due to inaccuracies in the documents, misinterpretations or inefficient collaboration between design and manufacturing. MBE minimizes such problems by adding information required by downstream consumers of the 3D model, who can include manufacturing, suppliers and subcontractors, quality, procurement, maintenance and repair entities. Reusing this single set of engineering data in the model can reduce costs.

In order to test the interference, it is the task for design engineer to add the colliding parts into the 3D. It is relatively common that they send the wrong version of 3D as there are different versions. The most critical error is when the product has different or wrong article number as it could delay the testing process.

In 3D it doesn't cover the target performance therefore at ADM they are following Daihatsu technical standard number in their technical drawing. The mechanics also prefer sticking to the 2D drawings than to handle 3D as it is more straightforward without having to learn how to operate the software itself.

Besides styling, design engineer also works together with the supplier regarding the capability that exists outside ADM. Often the 2D material doesn't contain enough information.

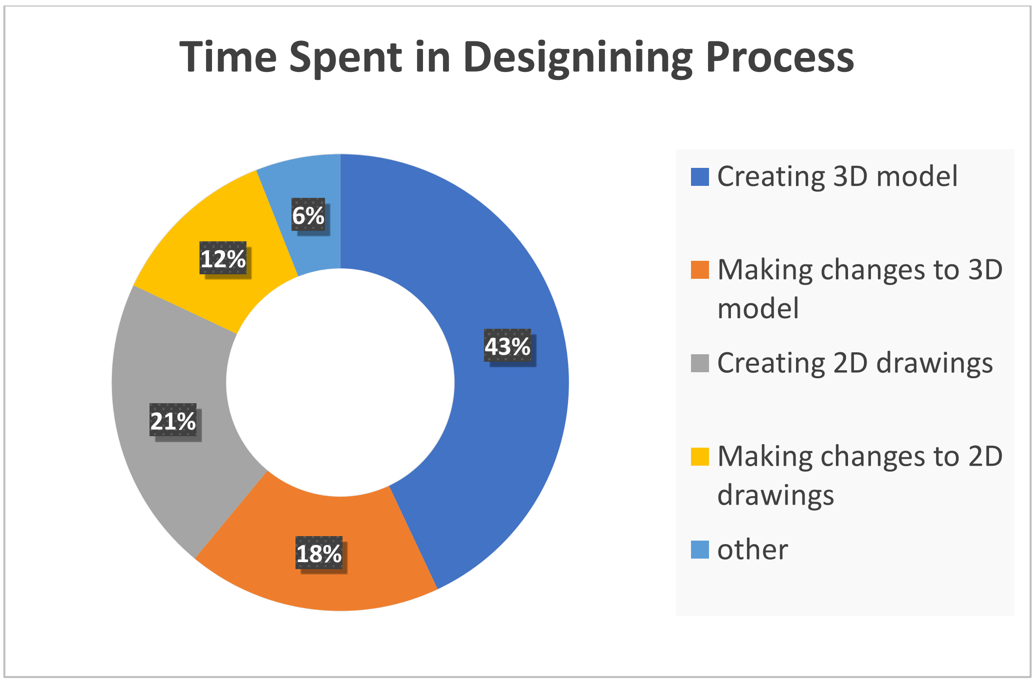

Figure 10: Design Chart

4.3.4 Quality Team

Quality Inspection Standard QIS or Vehicle Inspection Standard VIS is responsible to assure the quality of the vehicle. This department is the bridge between design engineer and purchasing department. With the implementation of MBD it could increase the efficiency to interpret drawing, for instance the drawing could be too big to display making it difficult to interpret. By using 3D models such problem wouldn't happen.

It also could happen that during communication between the supplier and production department that the 3D file is missing. With only the availability of 2D material for manufacturing, often the information attached to it is not enough and it could cause error for future manufacturing, therefore this error should be fixed prior to manufacturing and it would cause additional hours in worktime. With MBD this situation could have been prevented.

In reality ADM cannot fully rely on 3D models as they are not always synchronized with the 2D. Often found that in the 3D models it doesn't correspond to the correct article number. This can cause issues in SOP and series of production. Based on the interview, it is actually easier for the person in charge to make a quality standard based on its actual picture. Therefore, when a product has been made, they would take pictures of it and compare it with the drawing.

PMI is non-geometric attributes such as dimensions, tolerances, datums, etc. This data can be found on the 2D drawings. However, in MBD, PMI is related to 3D CAD model. 3D CAD model ought to incorporate product characteristic designator called PMII which is just another type of PMI.

PMII is really important for the quality and inspection of product, hence it is created on the inspection floor. The critical characteristics are identified and set up in the early planning stage with the implementation of MBD. This information would be driven downstream and allowing closed loop quality feedback to be provided earlier in the product development process.

Quality is determined by PMI therefore; PMI should be as smart as it can be. MBD data that includes product characteristics and designations helps uniquely identify and unambiguously verify the product.

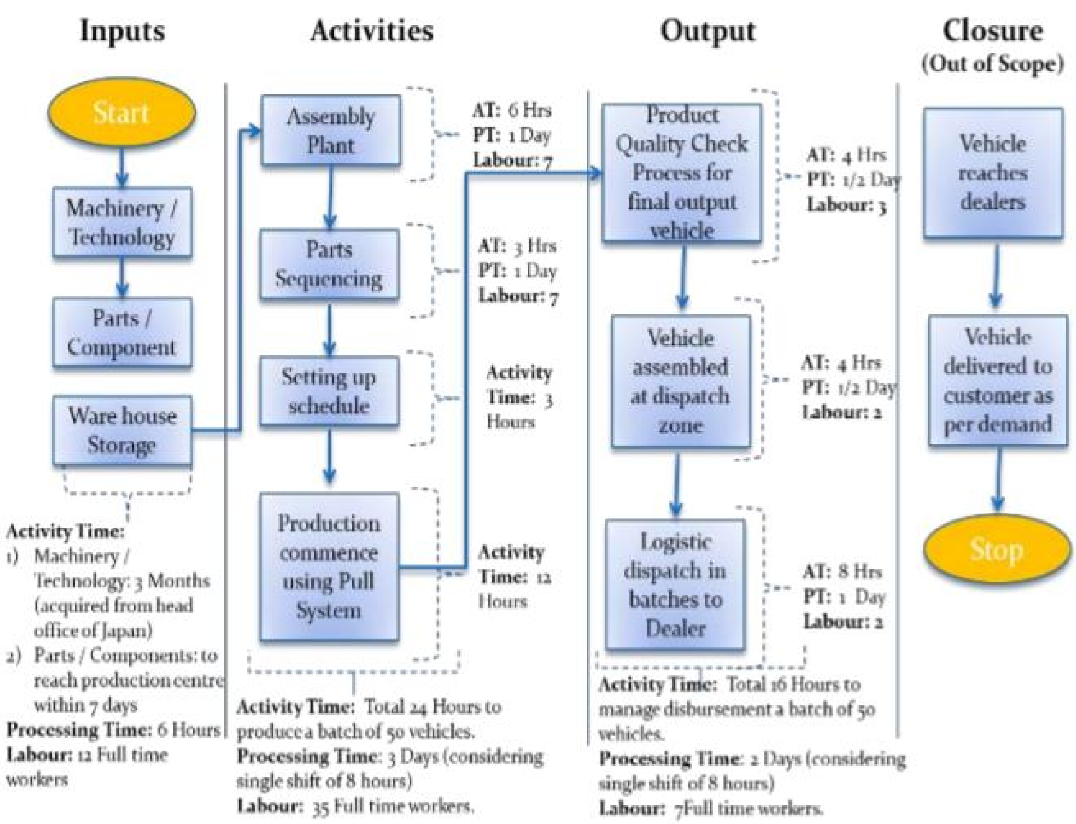

Figure 11: Production Process Flow Chart

4.3.5 Production and Logistics

Production consists of the assembly line as well as inspection line where vehicle would be checked and tested. In ADM production line consists of 4 main plants: (i) Stamping (ii) Welding (iii) Painting (iv) Assembling line (v) Inspection line. Up until today drawings are still mainly utilized as not everyone have an access of CAD data. The drawings are used for quality standard and inspection standard but for assembling they relies on 3D.

For instance, in middle class car there are minimum 3000 components in 3D digital data. If one of the components is send to the supplier only with a single file, it could confuse the assembling team as it could be unclear where this specific part should be positioned, what the section looks like and how the touching is suppose be since they only have an access to a single part in 3D. In the 2D master, the connection section would be visible.

MBD could be assessed on a part-level containing all the information within a 3D model affect and development for the direct use in NC machines. It could also be assessed a larger perspective, for example on how the parts are assembled.

Product initiation should start as soon as possible in order to have all parts to be finalized on time. Designs have to be published early to allow the opportunity to give feedback. At times design engineers would only release their design in the last week, this could lead to parts not finishing in time and higher cost if adjustments have to made since they are in the later stage. The earlier the changes it would reduce the cost as they lack the resources to create the vehicle.

Feedback from each department related to the designs are important to be made as it would create an opportunity for design improvements. MBD allows the publications of designs and changes as soon as they are made.

ECO is really important in the development and production line. ECO is a document that is used to bring about authorized changes in components and assemblies. They may also be used for changes in documents such as drawings, processes, work instructions and specifications. It can also be used for "a modification that will have an effect on a manufactured product or manufacturing process." Often the personal at product initiation are not aware of which part is to be submitted as they do not read the ECO, as the result it could leads into problem such as attachments couldn't be assembled according to standard.

In current working method the 3D articles made by R&D couldn't be reused since it is made in nominal measure, making it unusable to a large extent for the recipient. Therefore, it is believed that MBD would reduce a lot of waste in terms of drawings of process parts since here one drawing must be made for each step of the process of manufacturing an article, this could be nulled with MBD. In ADM parts articles are obtained from the mother company DMC.

A similar survey done in Research and Development department was also done in Production and Logistic department where the respondents were asked whether or not they would be able to produce a part according to specification if only a 3D-CAD model was given without any drawing.

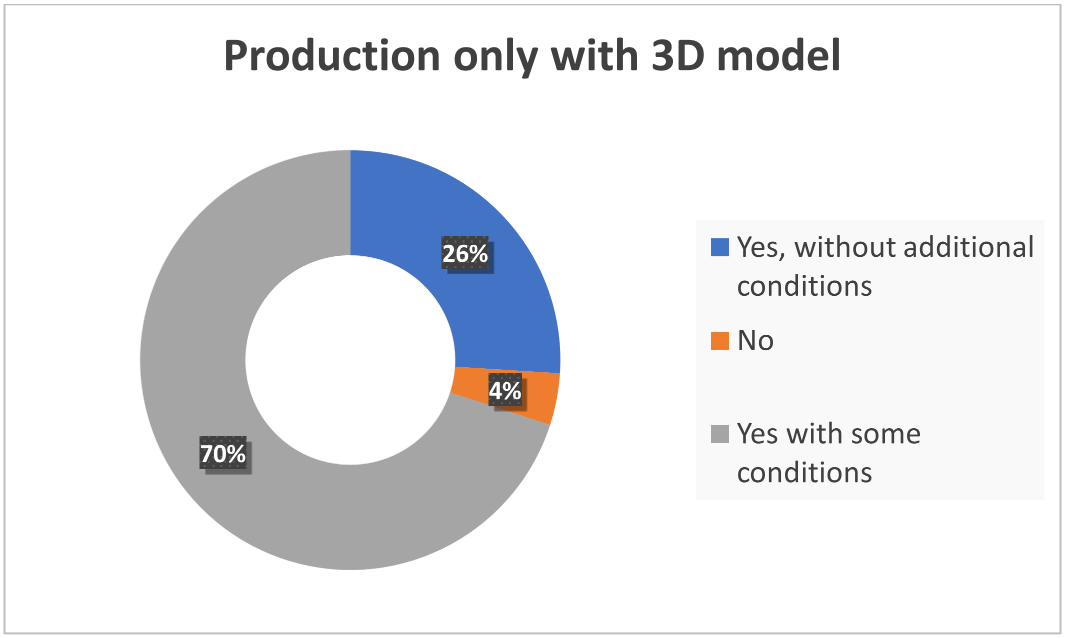

Figure 12: Survey Chart of Production and Logistic Department

The majority of respondent in the Production and Logistic department could produce the part with only 3D CAD as their source of information under some conditions. They would communicate with the design engineer in order to consult and gather more detailed information before manufacturing the part as 3D CAD couldn't cover all of the information regarding to the part.

An MBD workflow (or model-centric approach) employed a 3D model with PMI is machine-readable and has all necessary manufacturing information implanted within the 3D model. MBD guarantees the design plan and final product will be aligned throughout its product development cycle: one authority source, one single truth that everyone can depend on. This leads to automation, resolves human error, provides cost-savings and speeds up the entire manufacturing process and modification.

Programing a CMM would effectively take twenty hours depending on the complexity of the portion. Manufacturing engineers will have to sit side by side with the 2D drawing(s) on a screen or indeed printed sheets of paper. They waver back and forward between the 2D drawing and CMM/CAM to read and study the tolerance and surface finishes before then approving all the data while manually entering it within the necessities into their software.

Global methods for production are leaning towards a more digitalized way of working. In order to accommodate the advancement of technology all the production personal in ADM have to join a company's learning center called DOJO where they would learn about the basic and fundamental of production line both through videos and on site in the training line for 1-2 weeks assisted by a senior.

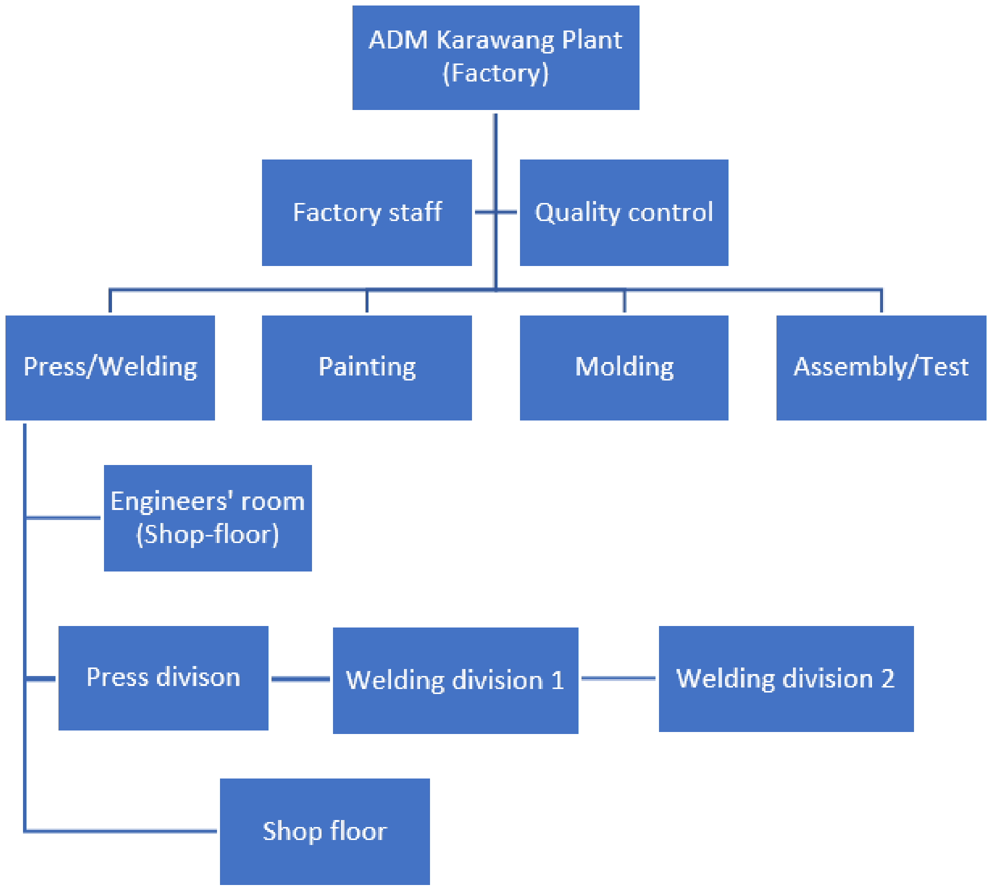

Figure 13: ADM Factory House

4.3.6 Procurement and Purchasing

When design engineers are satisfied with their designs, they would send the 3D models and 2D drawings called TDP to the Procurement division where here they would identify the needs and requirement of the project, source and evaluate suppliers, negotiate terms and condition with the supplier as well as performing cost analysis for profit margin analysis.

The TDP in these processes is crucial. A complete and clear set of technical data gives surety for the supplier because clear technical data reduces the risk for that supplier. This will result in a more aggressive bid which resulting in lower cost of their product. TDP can use 2D drawings however this leads to its own challenges. In order to interpret 2D drawings they required specialized knowledge, experience and skill to interpret and often 3D model and 2D drawing can actually be different from one another.

On the other hand, TDPs can incorporate MBD within the frame of commented 3D models. Compared to 2D drawings, MBD require less specialized knowledge experience and expertise for interpretation. Furthermore, with MBD there would be no drawing that can separate from the drawing.

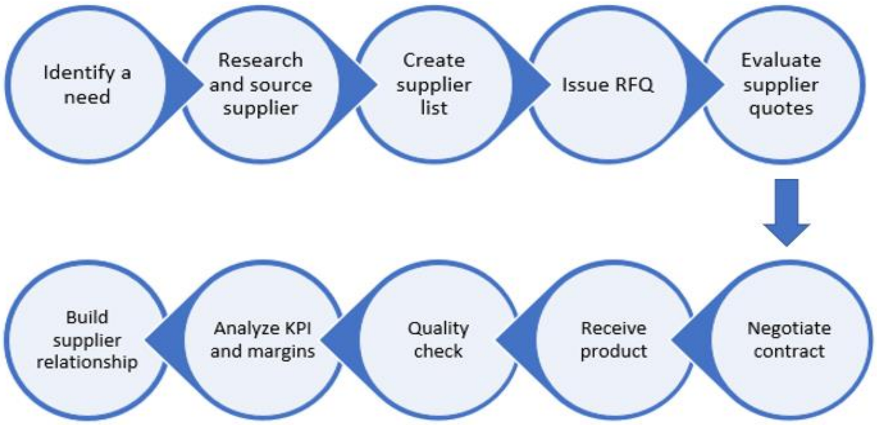

Figure 14: Procurement Work Flow

The purchasing process is a sub-process of procurement that centers on the value-based stage, related to buying items and it's administrations. All the activities that involve in purchase from creating the purchase order until arranging the payment. The main focus of purchasing department is to be able to realize short term objectives that incorporate quantity, timing and cost.

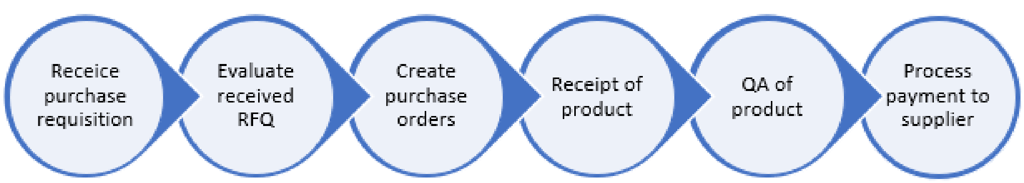

Figure 15: Purchase Work Flow

When ordering material, tools are included in the order. With the implementation of MBD only one material needs to be downloaded without having to determine whether it matches or not since in ADM there is no special division that is assigned to check whether the 3D models are matched with the 2D drawings. By just using a single content with master information the suppliers would be able to see the requirements for the product.

Used in the RFP or RFQ process, MBD offers more confidence in bidding suppliers about the technical constraints of item delivery. It also creates a more accurate 3D models at an earlier phase of the project which would lead to a greater number of simulations for better quality to be produced.

As per today ADM is still using 2D master in their purchasing division as this division is the bridge between the company and the suppliers. Stated by the head of purchase division in the interview complications would emerge mainly from the supplier side with the implementation of MBD as often the suppliers are using different systems

Chapter 5 Results

5.1 Benefits

With the progression of innovation and technology, the competition between company in the market are getting fiercer, as the result some engineers are beginning to realize the focal points of MBD and begins to utilize it as the premise for their business. With MBD the engineers are able to keep all of their model designs and annotation in one place and also realize the full value of their 3D assets.

By using MBD, industry leaders are starting to increase efficiency, utilization and improve their information sharing, revolving their business around the model itself and hence becoming Model-Based Enterprises. Yet many engineers in ADM are still skeptical as to the real value of MBD.

INCREASE EFFICIENCY AND REDUCE PRODUCTION COST

By having one record file with all of the annotations and comments attached passed around all of the departments, would increase the efficiency as no time will have to be wasted to update multiple files or check the files whether they contain the same information or not. As stated in the interview ADM doesn't have a special division that is in charge to check the synchronization between files. Therefore, the implementation of MBD would likely offer a huge benefit.

Having a 3D annotated model also makes the information easier to understand for downstream consumers than it would be with a 2D drawing. This easy to access and understand information will reduce the probability that models will have to be rejected or revamped due to miscommunication that leads to defects products.

This limits the probability of data being misplaced or confused in the communications. It also implies that any unnecessary information is scrapped quickly, allowing departments to do their job without having to dive through unnecessary data. Therefore, any mistakes could be detected in early stage that would naturally reduce the cost as it wouldn't have reached the production stage.

REDUCE DELIVERY TIMES

MBD permits engineers to incorporate all of their annotations and comments onto the 3D model resulting in less time spend on recreating annotation from 2D CAD drawings. Moreover, having this information implies that time is also spared during communication with the manufacturers. With all of this time saved it leads to a faster delivery time and product will reach the market a lot faster.

IMPROVE PRODUCT QUALITY

This ease of communication moreover implies that none of the information needed for manufacture is lost or misinterpreted. This means that less mistakes/error or non-conformances will take place during the manufacturing stage. Also, most 3D software permits engineers to simulate and demonstrate their model precisely, so having this information on the model will prove that it is of a high quality.

5.2 Challenges

SOFTWARE LIMITATIONS FOR SUPPLIER COLLABORATION

Implementation of an effective MBD have faced various problems. Being a relatively new innovation in the industry, it requires that professional engineer employed for MBD is sufficiently trained on the method. The use of MBD requires a comprehensive knowledge of information flow, which sometimes is lacking due to the previous experience that are mainly limited to 2D models with differing workflows within the product lifecycle (GOHER, SHEHAB, & AL-ASHAAB, 2019).

This type of challenge be seen in MBD experiences in which major OEMs and other Tier 1 companies experienced gaps between the expertise, mindset and way of communication of function developers and testing experts. There is still no standardized approach to documenting models which can be understood equally well by both parties. This leads to communication challenges and having to go back and forth trying to understand the models and integrate them into the test environment.

Within a product design and manufacturing enterprise, designers and engineers have access to specialized training and software for 3D modeling. Individuals with access to specific workstations or viewers can easily view the information. However, without specific software or hardware, suppliers can’t access the MBD. During the interviews, it was apparent that procurement and purchasing was the main opponent to the change. Similar to many departments, the main concern that was raised was that it was uncertain how the department would be able to extract the data necessary. In addition to this, it is also predicted that an indefinite number of suppliers to ADM is unable to manage the 3D models that MBD would entail. By this issue alone, MBD is instantly dismissed according to one interviewee at Purchasing.

EXTENSIVE UP-FRONT COST

The greatest challenge of implementing MBD at ADM is the high number of capital investment. The transition of older original data from drawings into a 3D model is really costly and time consuming. It takes training time and cost to educate employees on a new process it is found in ADM that even under constrain of undertaking the learning program in parallel with performing their work, many the MBD method is recognized internally to some extent even when the learners were in charge of operations other than those relating to said method and that recognition to the effect that simulation models were necessary for MBD has been gained to some extent

CULTURAL CHALLENGES

Challenges typically come from the essential elements that are needed to be worked upon for the full realization in MBD. As though there were standards as stated before, the wide use of MBD still requires further efforts to create a common language for MBD to fully replace the traditional 2D drawings. Especially coming from a long establish company such as ADM, it is relatively troublesome for them to fully convert to MBD.

Chapter 6 Conclusion and Discussion

The needs for automotive products that are diverse and complex have in turn yielded a need for automotive companies to respond to such demands in a competitive manner. One of the ways to be competitive in the field in which intricate systems are combined and interrelated with adjustable parameters require innovation not only in the end product, but also on the methods of design. As such, it is crucial for the automotive industry to find means that enable them to effectively design their products as well as producing a product with a sustained product life cycle in mind.

Research on the operations of ADM analyzed the use of MBD in contrast with 2D drawing. The study encompassed the main departments within ADM corporate structure that includes: Research and Development, Production and Logistics, Procurement and Purchasing, and focused on examining the information flows within ADM, and how different departments are ready for the implementation of MBD. A compelling list of benefits can be seen from the experience of the design engineers within the R&D department, who found the MBD to be more user friendly and easier to modify. From the perspective of Product Inspector, MBD was found to be beneficial since changes can be made on the spot in 3D format, unlike in the traditional method where they have to send back a drawing for a re-design from the beginning when a design did not pass inspection. For design testing, MBD Is beneficial in providing a 3D environment in which engineers are able to add colliding parts into the 3D model, cutting time in tests. Furthermore, within the scope of simulation and calculations, MBD has been able to troubleshoot simulations in a timelier manner without having to refer to 2D drawings. When moving towards the bodybuilding phase, MBD is beneficial since it contains more construction information than 2D materials. In the next phase, the Q-team was able to use MBD since it does not contain issues from 2D drawings such as the need to provide room space for the drawing, or the overly complex overview of the drawing (Lundqvist & Phillips, 2016).

Testing phase with MBD is itself an interesting application, as testing at the model and code level is important to validate vehicle systems against defects that may be present in the user environment. As with MBD, Model based testing (MBT) gears the automotive industry towards automation and digitalization of testing. Through this method, testing would then be a computationally generated task. Yet, despite so, are only there in support of testing experts who are able to develop more effective tests or at least test fragments than any tool (Dynov, 2017).

The solution offered by MBD conceives a product data management system that integrates all the departments of product data and information, as well as organizes design activities according to a specified workflow. This enables quick and intuitive data access that is simplified from the traditional mode of product design. Automotive industry could shift from a design process that require engineers to jump between 2D and 3D models that are cumbersome in both quantity as well as method, as well as keeping better track of all aspects of a design in a compact 3D data form that is able to be manipulated in a standardized way that is common. This then led to the establishment of a library of data design structure, as well as a streamlining of the design process. Ultimately, this serves to reduce design costs and shortens product development life cycle, as well as the time to market new products.

The challenges for the Implementation of MBD comes from the fact that professional engineer employed for MBD needs to be sufficiently trained on the method. As such, an effective education program is required for engineers for them to be able to effectively utilize MBD as a method. Based on previous experience in several industries, it was found that providing engineers with such education helped to yield significantly better lead against competitors. MBD was found to have contributed to 20-25% time reduction during the design phase, as well as allowing replacement or repeat work to be started promptly, and ensures the exact same manufacturing strategy will be used to create identical parts. This then correlates with about 10-20% increase in design efficiency due to the use of MBD which were reported by several analyzed companies, which translates to 2-4 weeks of a 20 weeks sprint time. MBD also helped in often overlooked costs of administration such as paper, especially in automotive industry that has large needs of design and other types of administration. Furthermore, it was found that MBD was able to reduce the number of rejects and less interruption in planning by rejects. The model-based design contributed to faster releases, enhanced design and better reliability of automotive embedded systems.

A more delicate issue is since 3D models contain vital information, especially in B2B situations such as communicating with suppliers that manufacture parts. Since it is in the interest of a company to keep their trade secrets, they may not risk leak by concealing as much information as possible from the 3D models sent to the suppliers. This is problematic since there are many information that is edging the term trade secret, and that there is large amount of data sets within the 3D models that can be considered as trade secrets. As such, it is important for companies to find ways to include and extract only the relevant information so as to reduce the risk of leak. (Lundqvist & Phillips, 2016)

Model-based development in the automotive industry is being widely adopted by various companies in the automotive industry, and thus are going to be dominant practice. The advantages have insofar outweighed the challenges, since traditional document-based techniques are difficult to cope with the rising complexities of automotive products. Since MBD is still a relatively new technology, there needs to be further research that expand on the successes made by MBD in the automotive industry. A way ahead is to focus on how MBD is able to support a Common Information Model, as well as data standardization within the automotive industry.

Within the future, the use of 3D models as comprehensive production process would speed up the simulation tasks and make them more controlled. With the help of computer-aided technologies it can provide a more comprehensive set of data, allowing better integration and task automation.

References

Alemanni, M., Destefanis, F., & Vezetti, E. (2011). Model Based Definition Design in the Product Lifecycle Management Scenario. *International Journal of Advanced Manufacturing Technology*, 1-14.

Doorakkers, R. (2019). *Model Based Definition:Nice-to-have or must-have for an automated,flawless industry 4.0 production environment?* Eindhoven: IGS GeboJagema.

E., V., Destefanis, F., & Alemanni, M. (2011). Model-based definition design in the product lifecycle management scenarion. *Advanced Manufacturing Technology*, 1-14.

Eynard, B., Gallet, T., Nowak, P., & Roucoules, L. (2004). UML based Specifications of PDM Product Structure and Workflow. *Computes in Industry*, 301-316.

GOHER, K., SHEHAB, E., & AL-ASHAAB, A. (2019). Challenges of Model-Based Definition for High-Value Manufacturing. Astana: IOS press.

Lundqvist, T., & Phillips, F. (2016). *Thesis. The Main Effects of Implementing Model Based Definition in an Automotive Manufacturing Industry.* Stockholm: KTH Industrial Engineering and Management.

Mahesh, M., Ong, S. K., Nee, A. Y., Fuh, J. Y., & Zhang, Y. F. (2007). Towards a generic distributed and collaborative digital manufacturing. *Robotics and Computer-Integrated Manufacturing*, 267-275.

Simon F., Paul H., Mark C. (2011). *Model Based Enterprise Technical Data Package Requirements.*

Prostep company resources https://prostep.us/home/resources/3d-pdf-samples-and-examples/

Miller, A. M. (2017). Towards Identifying the Elements of a Minimum Information Model for use in a Mode-Based Definition. *12th International Manufacturing Science and Engineering Conference.* Los Angeles.

Rachuri, S. E., Bouras, A., Fenves, S., Foufou, S., & Sriram, R. (2008). Information sharing and exchange in the context of product lifecycle management: role of standards. *Computer-Aided Design*, 789-800.

Rachuri, S., Fenves, S., & Sriram, R. D. (2005). A product information modeling framework for product lifecycle management. *Computer-Aided Design*, 1399-1411.

Ruemler, S. P., Zimmerman, K. E., Hartman, N. W., & Thomas Hedberg, J. (2016). PROMOTING MODEL-BASED DEFINITION TO ESTABLISH A COMPLETE PRODUCT DEFINITION. Virginia: ASME.

Struss, P., & Price, C. (2003). Model-Based Systems in the Automotive Industry. *AI Magazine*, 17-33.

Vezetti, E. (2009). Product lifecycle data sharing and visualization: Web-based approaches. *International Journal of Advanced Manufacturing Technology*, 613-630.

Wakitani, Yamamoto, Morishige, & Adachi. (2019). Practice and Evaluation of Model Based Development (MBD) Education. *IFAC, 52*(9), 206-211.

Zhu, W., Bricogne, M., Durupt, A., Remy, S., Li, B., & Eyna, B. (2016). Implementations of Model Based Definition and Product Lifecycle Management Technologies: a Case Study in Chinese Aeronautical Industry. *ScienceDirect*, 485-490.

Zhu, W., Durupt, A., Remy, S., & Li, B. (2016). Implementations of Model Based Definition and Product Lifecycle Management Technologies: A case study in Chinese aeronautical industry. *IFAC, 49*(12), 485-490.

Iyer A, Seshadri S, Vasher R (2013) Toyota Supply Chain Management, 74-83.

González, Ulises F. A DISCUSSION ON MODERN DESIGN OPTIMIZATION TOOLS: FULL ASSOCIATIVITY OF CAD, FEA AND EVENT SIMULATORS at http://www.algor.com/news_pub/tech_white_papers/design_optimization/

Reitz, W. (2000). A review of: "optimization concepts and applications in engineering" A.D.Belegundu and T.R. Chandrupatla. Materials and Manufacturing Processes, 15(2), 315–315.