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A METHOD FOR TRANSFORMATION OF EBOM TO MBOM WITH MULTI-CAD ENVIRONMENT IN AUTOMOTIVE BIW MANUFACTURING

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Abstract— **In modular platform, product designer releases BIW modules in CAD & PLM as per functional requirement and these are flat structure and don't have manufacturing sequence information. Then manufacturing planner prepares manufacturing stage assemblies based on the manufacturing facility and provide make or buy decision. To prepare stage assembly planner need to work in multi CAD environment like CATIA, DELMIA and PLM systems. Manufacturing planner generates stage assemblies from design modules by ensuring exact positions of designed components and distributes weld spot, arc weld, studs as per manufacturing stages. To distribute weld spot, arc weld and studs, manufacturing planner need to launch these modules in DELMIA, however the conversion of CATIA fastener information into DELMIA environment is a complex activity. This paper presents detailed process flow, tools & techniques with one use case to create manufacturing stage assemblies of a complex assembly - underbody rear floor with minimum planner's manual effort with no gap between design BOM and manufacturing BOM.**

Keywords— **EBOM, MBOM, Stage Assembly, Automotive, BIW Manufacturing, Modular BOM, CAD Restructuring, Joinery, Fasteners, DELMIA V5**

I. INTRODUCTION

With the increasing demand on natural resources, infrastructure and digital life style is shaping the economics and societies to a next level. Because of smart living style, customer centric products and services is dominating over mass production, is required in shortest possible time without compromising the quality of the product. To support the customer product, OEMs need to improve Concurrent Engineering Methods by involving Product Design to Manufacturing. OEMs also need to validate Manufacturing Processes, Production Systems, and facility resources through digital validation prior to physical implementation. Due to Product modularity OEMs need to improve their collaboration with Suppliers by providing early access to Design, Production Process, and Resource information. This whole process will ensure the benefits of Modularity and help in to deliver the customer centric product in shorter delivery lead times. This requires OEMs to adopt information technology (IT) based mechanical process over manual processes. PLM system & Digital Manufacturing play vital role in new product launch to the market with shortest possible time using flexible manufacturing process. PLM System & Digital manufacturing enable flexible manufacturing system (FMS). FMS is a method for producing product that is readily adaptable to changes in the product being manufactured, both in type and quantity. Hence PLM system is required to create & manage wide range of products.

Digital manufacturing is an established area within PLM that supports collaboration across several phases of the product, which has been now evolved from manufacturing initiatives such as design for assembly, design manufacturability, computer integrated manufacturing, flexible manufacturing, lean manufacturing etc. (Jovanovic & Hartman, 2013).

Modularizing the bill of material involves the breaking down of products into "options" or "Modules", which in various combinations, determine the final products. Each module consists of stand-alone sub-assemblies, or of kits of parts that cannot be put together until final assembly. There are two somewhat different objectives in modularizing the bill (Hegge et al. 1991):

1. To disentangle combinations of optional product features, and
2. To segregate common from unique parts.

BOM (bill of materials) management and configuration are critical to any small-medium-big size OEMs, whether BOM consists of ten parts or ten thousand parts. Now a days OEM always need to develop more innovative products in order to remain competitive and hence managing accurate product definitions, including bills of materials, becomes very complex. All OEMs need to coordinate the upfront planning of available options and features to meet their customer demands, as well as to connect with a their partners and suppliers who also need to be interconnected with manufacturing, service and support. For manufacturing product schedule, product structure provides the basis for process planning. OEMs can be largely classified as make-to stock (MTS), assemble-to-order (ATO), make-to-order (MTO) or engineer-to-order (ETO). Based on the market segment and product alignment many OEMs follow one or more approaches to reach the end customer, e.g. MTS can co-exist with MTO or MTS can co-exist with ATO. In Automotive many OEM uses different terminology for MTS such OCV (OEM configured vehicle) and MTO as CCV (Customer Configured Vehicle). Both OCV and CCV are derived from Super BOM or 150% BOM.

II. LITERATURE REVIEW

During the studies we have gone through multiple technical papers on PLM, CAD, Digital Manufacturing mainly based on EBOM, MBOM, BOP , Flexible manufacturing , simulation, BIW manufacturing, details of which are mentioned below:

Jiaming et al. [2014] has explained importance of bill of material (BOM) in auto manufacturing industry and then the mechanism to prove modular BOM in multi-variants enterprise to achieve accuracy and zero inventory of materials. And explained how Manufacturing bill of material (MBOM) was implemented and applied in ERP system in Huzhou Anda Automobile Parts Co., Ltd. Phani Paritala et al. [2017] has presented a review on applications digital manufacturing different industry and how it is helpful for mass customization over mass production, to achieve production target time. It is also explained how to manage manufacturing processes and facility and validate it in digital environment to anticipate production problems at early stage of product design. It is also explained that how different enterprise level system like PLM, CAD, digital manufacturing, ERP are integrated to transform manufacturing to smart manufacturing.

Vivekanand S. Gogi et al. [2016] has explained the driving forces behind the flexible manufacturing (FMS) and hence it is a basic need for any manufacturing industry. It has explained about important tools and technologies which are used to achieve automatic guided vehicles, (AGV), production batch scheduling, neural network and simulation modeling. Also explained on advantages and disadvantages of flexible manufacturing. FMS helps to reduce inventory and improves machine utilization.Debra A. Elkins et al. [2008] has discussed on how agile manufacturing has help to achieve flexibility to manufacture unpredictable and continuous change in customer demand. Here, it is presented two simple decision models that provided initial understanding and business need for investment in agile manufacturing systems. These are hypothetical models which helps to take decision on investment. The models are applied for engine and transmission parts machining which is a first step toward developing practical business case tools that help industry to assess the value of agile manufacturing systems. Sadasivam Narayanan et al. [2018] In this paper, a flexible spot welding cell - which is flexible both at fixture and work cell level is developed to handle multiple Body-In-White (BIW) part varieties. The work-cell is a human-robot cooperative cell where the operator loads/unloads the parts on one side, whereas the robot concurrently performs welding operation on other side. The fixture is made modular and is reconfigured for change in part varieties. The flexibility of proposed work cell and fixture are investigated and validated by considering two different BIW spot weld assemblies. The performance of robot, cycle time estimation for the process, checking of fixtures, collision detection between weld gun and fixtures are evaluated in virtual environment. The flexible weld cell is proved to be compatible for both the BIW assemblies considered for study. The proposed concept shorten the design & fabrication time of fixture - squeezing the investment cost, assembly cost and floor space; besides reducing the cycle time and improving the robot utilization by 30% - 40% when compared to the conventional method. A. De Toni et al. [2010] in this paper, and review is made to differentiate the huge content regarding manufacturing flexibility. The literature on manufacturing flexibility is review based on six different aspects: (i) definition of flexibility, (ii) request for flexibility, (iii) classifications of flexibility, (iv) measurement of flexibility, (v) choices of flexibility and (vi) interpretation of flexibility.

Young K. Ro. et al. [2007] In this paper, it is explained how modular BOM helps to achieve communization in outsourcing of parts and hence able to achieve cost reduction. This study helps to understand the significant of modularity in sourcing, product development, and supply chain. This study is mainly based on interviews conducted with automakers and suppliers from 2000–2003. Lampón, Jesús F et al. [2017] in this paper, it has explained the impact of adopting modular platform and modular architecture helps to achieve collaboration by increasing manufacturing mobility. It also helps to adapt the manufacturing processes and facilities to increase for mass manufacturing. A. Al-Zaher et al. [2013] This paper has explained the modular approach to get flexibility in manufacturing. By adopting the modularity during the design of open-gate framing system which enable variability within a family of product. As a results reducing at least 30% of the gate weight. Bo XIE et al. [2012] This paper explains the significance of BOM modularization and how it benefits the production management. It also explain the implementation challenges and the way out to support the enterprise on making the BOM modularization come true. J.Pandremenos et al. [2012] This paper reviewed the evolution of modularity in automotive industry. It also highlights the challenges of current trend of “unibody” which support high production volume and low flexibility over the modular architecture which can support middle to mass production and manufacturing flexibility.

Ilker Erdem et al. [2015] In this paper, it is explained how modularity helps to develop cost effective tooling in automotive BIW manufacturing. Also it helps to accommodate new product or variant with minimum changes in tooling. Sadasivam Narayanan et al. [2018] In this paper, it has explained the significance of modularity in achieving the shorten design & fabrication time of fixture - squeezing the investment cost, assembly cost and floor space; besides reducing the cycle time and improving the robot utilization by 30% - 40% when compared to the conventional method.S. H.

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Minhas et al. [2011] in this paper, it is explained the significance of reconfigurable strategies to achieve customer demands, faster time to market and shorter innovation cycles. This can be achieved by following, reconfigurable joining cell design, Strategy for precise machining applications and Fast calibration of monitoring system used in commissioning and maintenance.H.C. Xu et al. [2007] in this paper, EBOM to MBOM conversion is explained which could solve the perennial problem of integration between design and manufacturing systems. It has also explained the algorithm for transforming EBOM into MBOM conversion based on the bill of process (BOP).Min Liu et al. [2013] This paper elaborated on solving the transformational problem of Bill of Material from EBOM to maintenance BOM for Maintenance, Repair and Overhaul (MRO). A model is designed which uses different components specific to maintenance BOM and a transformational process through feature recognition methods and rules. Yongqian Zheng et al. [2006] This paper discussed about the BIW and importance of BOM, both design and Manufacturing BIW. Due to data volume the planning work of the manufacturing process of BIW is very complex which plays a critical role in BOP. It has devised different BOM views and methods to manipulate these views which supports to handle huge variety of data.

It is observed that, there is no specific study available on establishing process and methodology for conversion of Design BOM to MBOM for BIW.

III. METHODS & METHODOLOGY

A. What is BIW and its manufacturing process?

In automotive industry BIW is the backbone of the structure of the vehicle. BIW is one of the stage in the automotive manufacturing where a vehicle body's components have been assemble together, using different joining techniques like spot welding, arc welding, sealant laser brazing, riveting, etc. Figure 1 illustrate the exploded view of BIW without closure of a passenger vehicle.

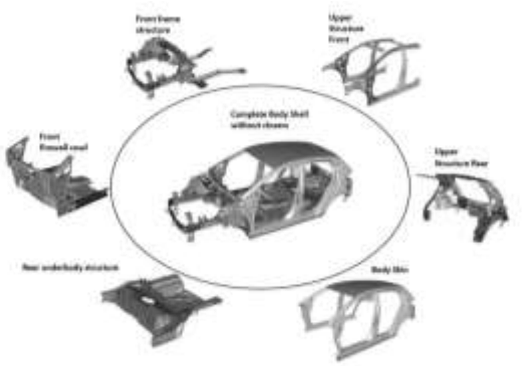

Fig. 1. Schematic diagram of BIW structure of Vehicle

Complete BIW is manufactured before painting and before the engine, chassis sub-assemblies, or trim (glass, door locks/handles, seats, upholstery, electronics, etc.) have been assembled in the Trim-Chassis-Fitment (TCF) line. Generally it consist of ~1000 steel based components for any passenger vehicle and around ~1500 steel based components for any commercial vehicle. These components are assembled with Weld spots, arc weld, sealant and studs which are around 6000, 9000 mm, 8000 inch, 200 respectively. To manufacturing this there are ~100 of stations required depending upon the OEM’s outsourcing strategy which make it more complex and cumbersome process to produce BIW in assembly line. In a BIW manufacturing station consist of mainly welding fixture, gripper, and material handling equipment, weld gun and robot, as illustrated in Figure 2.

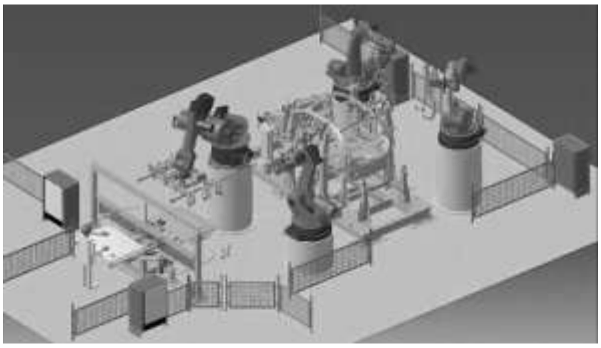

Fig. 2. Schematic diagram of BIW structure of Vehicle

To manufacture the complete BIW it goes through many different stages (around 5-10 depending on the facility) in assembly line which can be broadly classified into under body, upper body and closure with mechanism. Number of different stages varies mainly due to the outsourcing decision and available or upcoming manufacturing facility which are different from one OEM to others.

In modular platform concept EBOM does not contain manufacturing staging sequence and mainly it is having the Design view of the BOM. In a passenger car, the complete BIW module consist of around 30 modules in EBOM which mostly remains in flat structure (around 2-3 levels) within any one module. So the manufacturing planning team is having the responsibility to convert this EBOM flat structure into Staging-based structure which consist of around 5~10 levels and more than 100 stage assemblies. This stage-based BOM represents the Manufacturing Bill of Material or MBOM. Figure 3 illustrate one example of BIW staging for underbody assembly.

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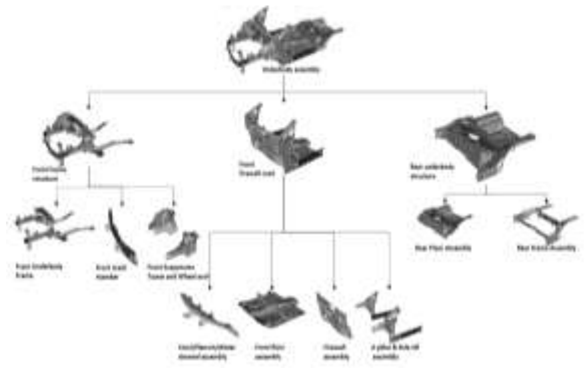

Fig. 3. High level Build Sequence of underbody assembly

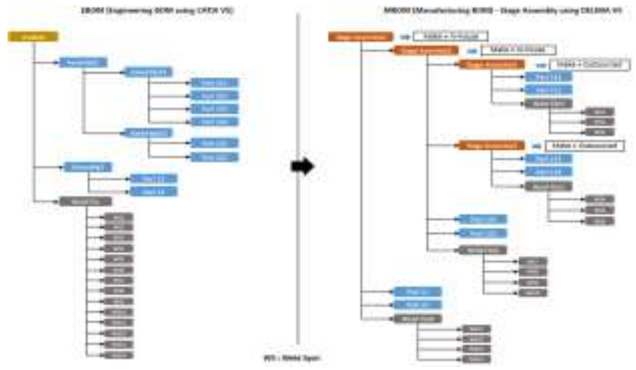

Fig. 4. Example of EBOM to MBOM conversion

B. What is flexible manufacturing in BIW context?

Due to mass customization OEMs need to manage new product variant in existing line. To accommodate these variant in not so flexible line always results into modification in existing manufacturing facility and processes. Whereas if a line is flexible then there is no need to have additional investments with respect to facility like fixture, robot, weld gun, grippers etc., which are typically used in BIW manufacturing line and manufacturing processes, It also gives OEM to reduce the “Time To Market” cycle. However it works well when there is communization of maximum manufacturing process and facility for different BIW variants. This could be possible through BIW product design based on modular platform which ensure maximum communization across variants.

Challenges in MBOM BIW conversion process

During EBOM to MBOM conversion (illustrated in Figure 4) for BIW which could varies from skill-set based to technologies based. Followings are the few key challenges highlighted which any OEM can face:

- Manufacturing planner’s job is to create painted BIW from engineering modules without changing design definition of part & sub-assemblies.
- MBOM staging and re-structuring which could varies across platforms and programs. Since manufacturing planner usually doesn’t have much skill in CAD environment like product designer, so manufacturing planner should be able to create MBOM very easily, quickly and accurately.
- Mechanism for work content distribution like Weld spot, Arc weld, Sealant, Stud etc.
- Poka yoke related to MBOM re-structuring and work content distribution is required to ensure CAD BOM assignment with proper position matrices (including CAD instances), BOM count between EBOM & MBOM accuracy to avoid BOM mismatch.
- Change management of EBOM to MBOM to conversion in staging along with work content distribution.

C. Solution Architecture

The following process flow as presented in Figure 5 ,explains the typical customer need which routes through marketing and sale team to Product designer and realization of the product in manufacturing line:

1. In any business scenario, customer gives their requirement to sales and marketing team who are the interface between customer and OEMs.
2. Marketing & Sales team convert customer need into existing product portfolio or demand new features and functionalities in existing product or a totally a new product.
3. As per their need and requirement it goes through the Product designer to check the feasibility of customer request.
4. Product designer also identify the required changes to be done in the existing variant or a new variant is to be designed to fulfill the customer need.
5. Product designer then start their design activity on the existing module(s) or design new modules to support the vehicle variant.
6. Post design activity it goes through the manufacturing process and planning team for converting design modules into stage assembly or changes in existing stage assemblies.
7. These stage assemblies are to be shared with Line builder and sourcing team for required development and manufacturing.

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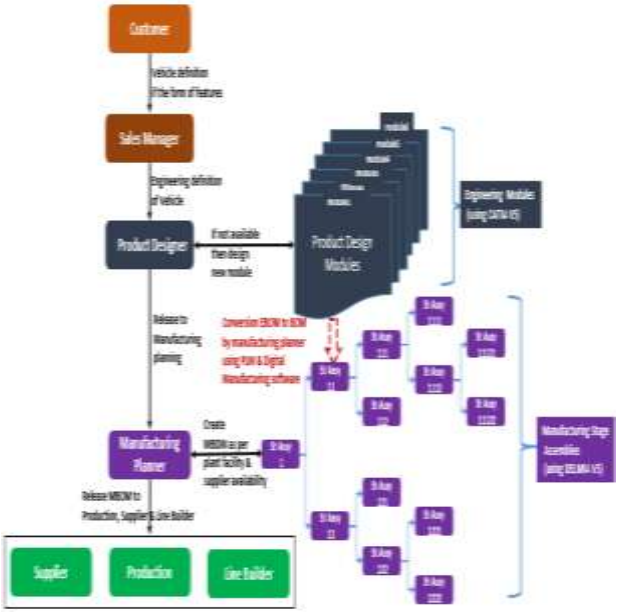

Fig. 5. Workflow diagram of Customer need to Manufacturing

As mentioned in point 6, which requires conversion of design modules into manufacturing stage assemblies in CAD environment need lots of deliberation to handle design and process complexity, which is explained in a separate section.

D. Stepwise MBOM Process flow

In the below figure 6, complete MBOM process flow is explained which is majorly divided into two parts:

1. Creation of Stage Assembly in Native CAD environment along with work content distribution of Spot, Sealant, Arc, Studs etc.
2. Activities related to Manufacturing change management in PLM – check-in/check-out, Revise of CAD and subsequent BOM generation of Stage Assemblies.

Fig. 6. MBOM Process flow

From Figure 7 till Figure 16 explain the sequence of creation of Stage Assembly in Native CAD environment along with work content distribution of Spot, Sealant, Arc, Studs etc.

E. Example – Stage Assembly Creation process of Underbody Rear Floor:

Here, one complex module called underbody rear floor is taken for stage assembly creation process. Rear underbody floor is consist of approximately 160 components and 640 weld spots. Manufacturing planner need to create 5 different stage assembly and distribute the weld spots respectively accurately, easily and quickly without much knowledge on CAD.

Designer create the CAD model in native CAD environment and release it through PLM change management process which is usually workflow based release process. Post Design release engineering change gets flow to manufacturing planning team for their study and subsequent creation of Stage assemblies along with work content distribution. Figure 7 is one of such example which is released by Designer in CAD and PLM environment.

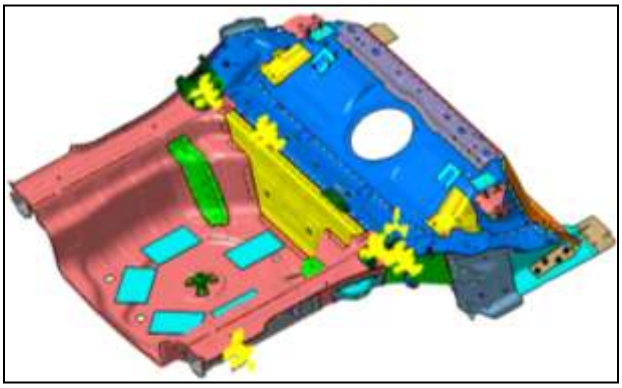

Fig. 7. Underbody rear Sub Assembly in EBOM (Native CAD format Courtesy: CATIAV5)

Manufacturing planner open the engineering design module in CAD environment to study the structure and work content released by designer. In the Figure 8, planner has opened the CAD module to study the weld joint assembly for required staging, which requires the transformation from Native CAD environment to Digital Manufacturing environment. For this transformation, an interface process & program is developed to convert design fasteners into manufacturing fastener. It has been introduced in MBOM process flow to facilitate and differentiate design faster and manufacturing fastener so that manufacturing planner can recognize unassigned manufacturing fasteners very easily.

Fig. 1. Digital conversion of EBOM weld Joint in cylindrical shape to spherical representation in MBOM (Courtesy: DELMIA V5)

Figure 9 explains about the build sequence of stage assembly, as per make or buy decision by manufacturing planner and this is pre-requisite for re-structuring and fastener distribution. The output of this activity is a PPR for a Stage assembly.

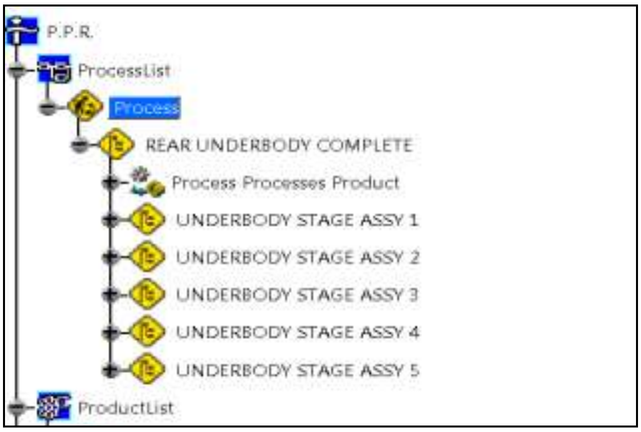

Fig. 9. Five stage assemblies with parent child relationship with is created inside PPR under process view (Courtesy: DELMIA V5)

Figure 10, 11, 12 and 13 explain about the steps of assigning EBOM parts & fasteners to MBOM stage assembly as mentioned in step above.

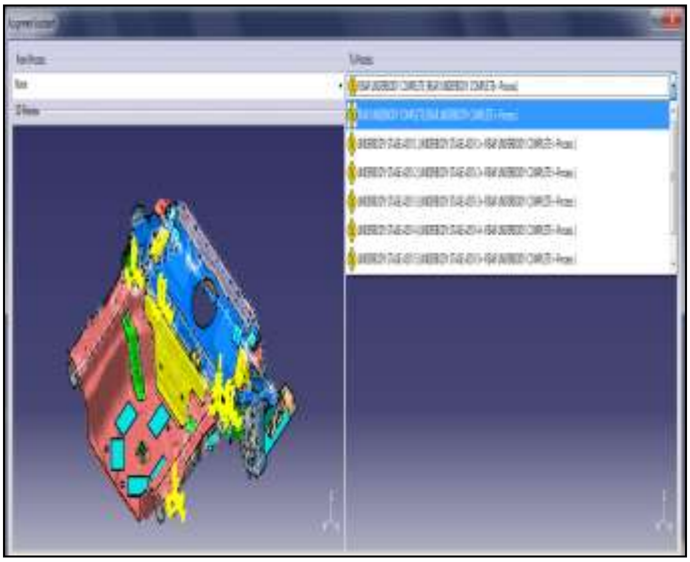

Fig. 2. Assignment of EBOM parts & fasteners to MBOM stage assembly (Courtesy: DELMIA V5)

In above figure left window indicates EBOM parts to be assigned to stage assembly and right window indicates Stage assembly appearing for assignment.

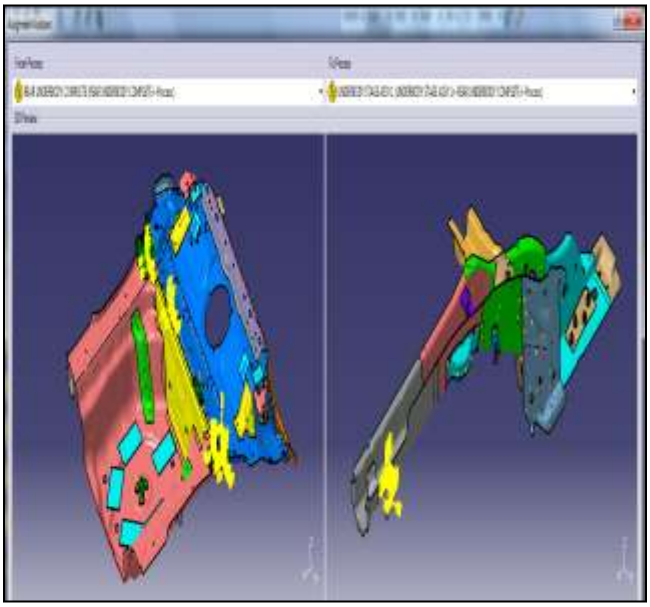

Fig. 11. Parts & fasteners assigned to "Stage Assembly 1 – Longitudinal Rear LH" (Courtesy: DELMIA V5)

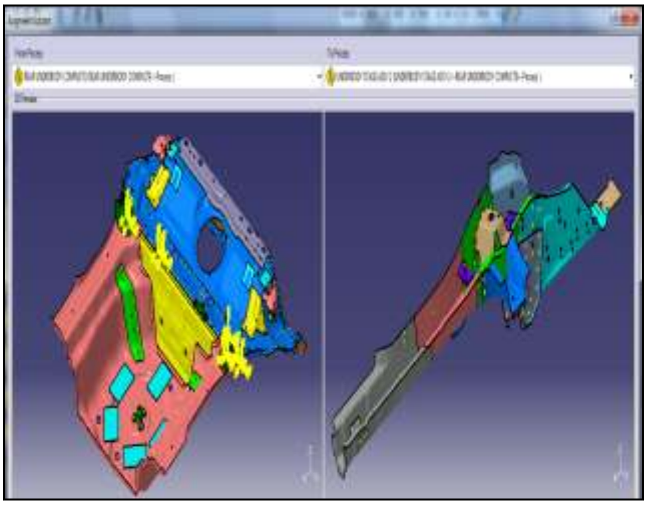

Fig. 12. Parts & fasteners assigned to "Stage Assembly 1 – Longitudinal Rear RH "(Courtesy: DELMIA V5)

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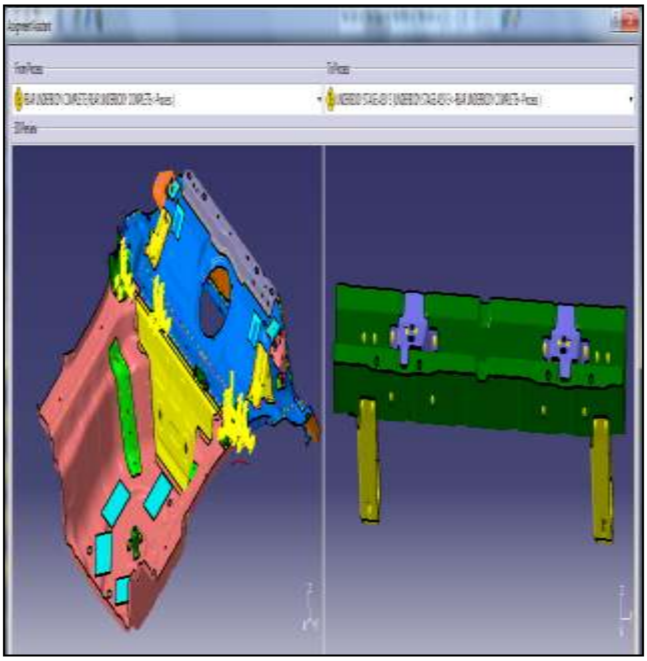

Fig. 13. Parts & fasteners assigned to “Stage Assembly 3 – Cross Member Rear Floor“(Courtesy: DELMIA V5)

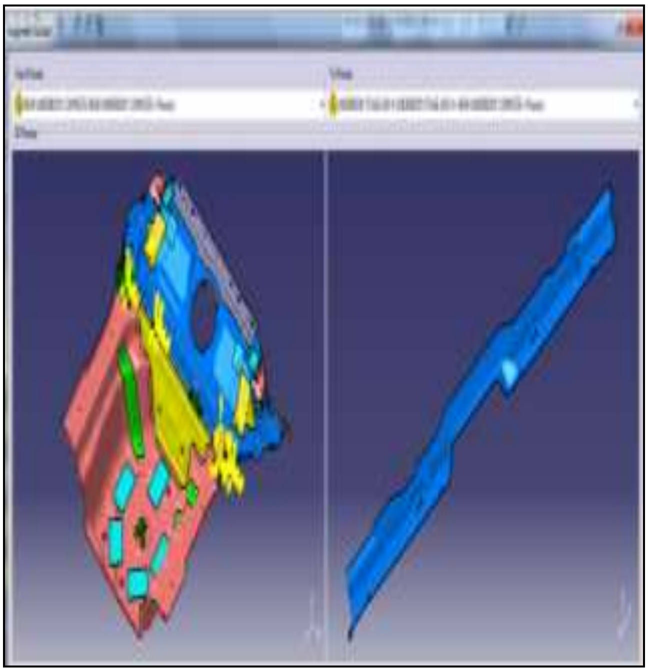

Fig. 14. Parts & fasteners assigned to “Stage Assembly4 – HeelBoard Cross Member Rear Floor“(Courtesy: DELMIA 5)

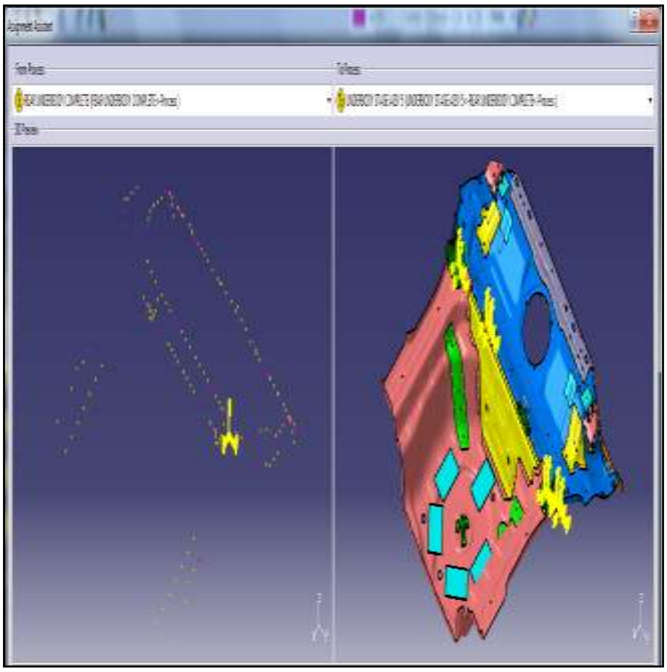

Fig. 15. Parts & fasteners assigned to “Stage Assembly5 – Rear Floor Panel Assy “(Courtesy: DELMIA 5)

Figure 16 represents parts which are stored under relationship node “Process First Processes Products” and Fasteners are under relationship node “Process Processes Products” in Digital Manufacturing software.

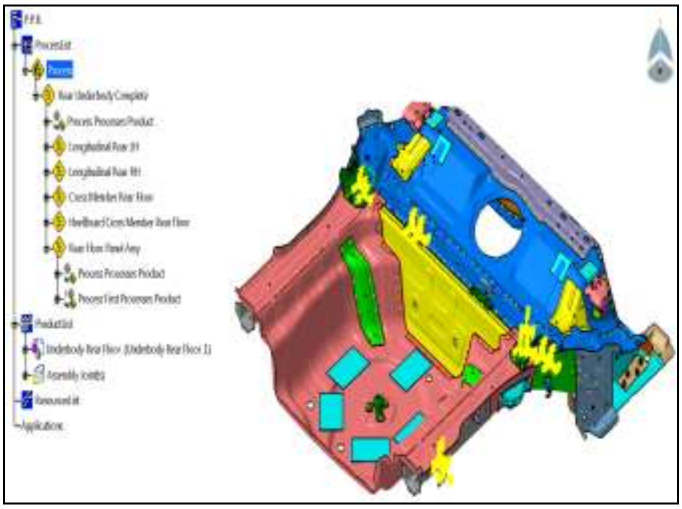

Fig. 16. It indicates how parts and fasteners are segregated under different groups (Courtesy: DELMIA V5)

Respective stage assemblies as explained above (stage 1, stage 2, stage 3, stage4 & stage5) resides in PPR files so these PPR need to be process to convert individual Stage assembly in native CAD format and then product manufacturing information (PMI) in the form of annotations are added

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manually by the manufacturing planner. Since it is tedious, time consuming and complex process so many industry develop export tool which is very easy and flexible to export the simple stage assembly and if required it can also export the top level stage assembly which all the child stage assemblies along with required details already explained above. This also shorten the conversion cycle time.

These stage assemblies are then checked-in into PLM system for BOM release and implementation. Many OEMs put lots of checks and control so that correct BOM can get checked-in to PLM system. These checks are mainly related to capture BOM, Fastener quantity related issues which can affect downstream agencies while sourcing and manufacturing the stage assembly. This is also required to ensure design product definition after MBOM creation through synchronization process.

Once Stage Assembly is build then it goes through the PLM workflow for release so that sourcing and BOM adoption can happen. To keep the check and control on work content distribution many OEMs put lots of effort through manual inspection or automation to capture mismatch of Weld count, Arc Count, Arc length, Sealant length and Stud count between EBOM and MBOM , if any. These validations are very vital and critical for vendor development and also for in-house manufacturing and any erroneous could results into faulty product and lead to financials losses along with the compromised product quantity.

All these steps and process are also applicable for change management implementation.

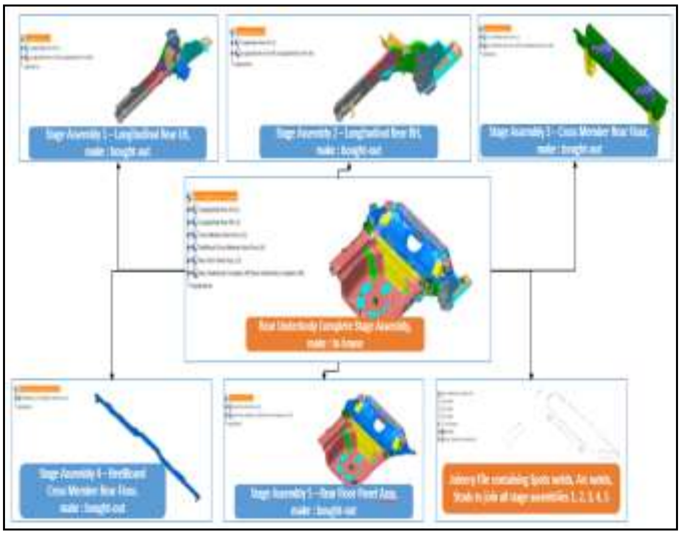

Fig. 17. Example on different staging (Courtesy: CATIA V5)

IV. RESULT AND DISCUSSION

	Assembly Name	No. of Components	No. of Weld Spots
Input Module	Underbody Rear Floor Assy	159	639
Output Stage Assemblies	Longitudinal Rear LH	37	115
	Longitudinal Rear RH	41	125
	Cross member Rear Floor	15	38
	Heelboard Cross member Rear Floor	3	0
	Rear Floor Panel Assy	63	201
Joinery file containing all weld spots to join above 5 stage assembly in-house			160
Total Components & Weld Spots		159	639

Fig. 18. Table containing components & weld spots comparison between input design module and output stage assemblies

With the above process and methodology, manufacturing planner is able to restructure the input design module and distributed the weld spots accordingly without any position change and mismatch between design module and output stage assemblies.

V. CONCLUSION

BIW MBOM system & conversion process – The Benefits

- Manufacturing planner can easily create painted BIW from engineering modules without changing design definition of part & sub-assemblies.
- Manufacturing planner can able to create MBOM easily, quickly and accurately without much skillset in CAD environment like product designer.
- This process and automation ensure correct work content distribution like Weld spot, Arc weld, Sealant, Stud etc. with required Poka yoke related to MBOM re-structuring and work content distribution is required to ensure CAD BOM assignment with proper position matrices (including CAD instances), BOM count between EBOM & MBOM accuracy to avoid BOM mismatch.
- Change management of EBOM to MBOM for conversion in staging along with work content distribution becomes simple and easy.
- Seamless data flow for digital manufacturing & simulation with same output PPR file being used for MBOM creation.

Above mentioned benefits which is under the scope of current article can support or lead into following broad level benefits for any OEM:

- Product early validation & shorter time-to-market in the context of manufacturing.
- Capitalize, standardize and optimize manufacturing processes & manufacturing facility to achieve the highest productivity with production quality from one car program to another.
- Achieve plant flexibility for the increasing number of variants that come with more car programs in same platform.
- Collaboration between design and manufacturing.
- Reduce Cost and Development Time for manufacturing process.
- It helps to faster ramp up for Production system.
- Anticipating Manufacturability by digital simulation of Manufacturing Operations before production.
- Increase Quality by Validating Production Process Design.
- Reduce and eliminate physical trails with digital simulations.

Future scope

- This process could be extended for multi-plant MBOM creation which could support different manufacturing set up/facility distributed in different geographical locations and also local vendor based decisions without affecting the design definition.
- The same concept could be extended for station wise BOM creation and its management which is more detailed and complex in nature. This station wise BOM can be shared in a systematic manner with shop floor for digital display at station to achieve Industry 4.0 drive across OEMs.

Abbreviation

- CAD: Computer Added Design
- PLM: Product Life Cycle Management
- BIW: Body-In-white
- EBOM: Engineering Bill of Material
- MBOM: Manufacturing Bill of Material
- PPR: Product Process & Resource
- BOM: Bill of Material
- OEM: Original Equipment Manufacturer
- BOP: Bill of Process

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