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Process Design and System Layout for an Automobile Manufacturing and Assembly Plant

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Abstract: ***The Automobile is the most complex product, and the development of a vehicle will take years of Research and Development (R&D) starting from designing, analyzing the product structure from sub-levels, building prototypes, testing the prototypes, finalizing the vehicle to manufacture. It is also essential to find the correct suppliers to manufacture the components, parts for the vehicle, assembly of all these to the vehicle, and go through examination and analysis of various stages of the processes in building the vehicle, and it is a herculean task. With the increase in competitiveness in the Automobile industry, the Original Equipment Manufacturers (OEM's) want to reduce their investments in manufacturing, keeping core competencies of R&D within the industry, and outsourcing remaining functionaries to Tire companies. The main goal of this paper is to illustrate the step by a step manufacturing process that is needed to produce an Automobile. And explaining each step that takes the Automobile from sheet metal to complete product, this helps to understand the process chain, logistical and distribution network that an Automobile follows throughout its Product Life Cycle (PLC).***

Keywords**:** ***Manufacturing, System, Automotive, Stamping, BIW, Painting, Final Assembly***

I. INTRODUCTION

Automobile Industry is one of the most complex and most dynamic industries in the engineering division, and it is the engineering marvel created by humankind. In recent years there is an increase in demand in the industry due to fierce competition, product life cycle change, and an increase in customer demand [1]. With faster growth in the sector, Automobile industry's major issues concerned with customers' need for variety, variants, design stylings, safety, comfort, and within the industry's internal problems related to Elimination of Waste in processes, Process Efficiency, Manufacturing Efficiency and improvement in Overall Equipment Effectiveness (OEE).

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Due to these global concerns, most of the Original Equipment Manufacturers (OEM's) are shifting the manufacturing scenario where they concentrate only on core components of the Automobile in-house and outsourcing most of the Automobile components to the reliable vendors and suppliers depending on their availability [3].

These OEM are concentrating mostly on R&D functions and manufacturing critical, value-added, technologically advanced operations of high capital investments in-house and leave the rest to vendors and suppliers [3].

In the Automobile industry, there is a lot of manufacturing processes that happen to start from the selection of different materials for the requirement of the Automobile [5]. People in the Automobile industry will have a lot of research going on the range and designing of a single component [4]. The present-day industry does not compromise on the aspect of the quality of its products [4] by maintaining a benchmark standard to sustain in the market [5].

In case of selection of material for the chassis, the R&D department of any Automobile industry will carry on different kinds of analysis for the chassis by considering different materials into considerations [5]. One of the fewer weight materials available in the market is aluminium [5]. They will be the diverse composition of aluminium is possible; the behaviours of these materials will vary [4]. So, the suitable material will be taken into the consideration of design by Research and Development engineers [5]. Aluminium is used only for high speed and sports vehicles due to its cost factor. But by using aluminium, it reduces the weight of the Automobile, and thereby it reduces the load on the prime mover. It will directly impact the overall Efficiency of the Automobile [5].

And after the selection process is over, we will again make the prototype of the BIW or Chassis, and we will still do the analysis for the prototype and will observe the results[7]. In our Automobile, we also involve FMS systems for the mobility of the components or raw materials of the industry. Will reduce a lot of random times in the industry and thereby increasing the overall Efficiency of the Automobile industry [6]. Even in the welding process, which is a significant part of the joining Process in the Automobile industry will be undergoing different tests to know the strength of the weld and which type of welding process will have a better life [8].

II. STEP-BY-STEP AUTOMOTIVE MANUFACTURING PROCESS:

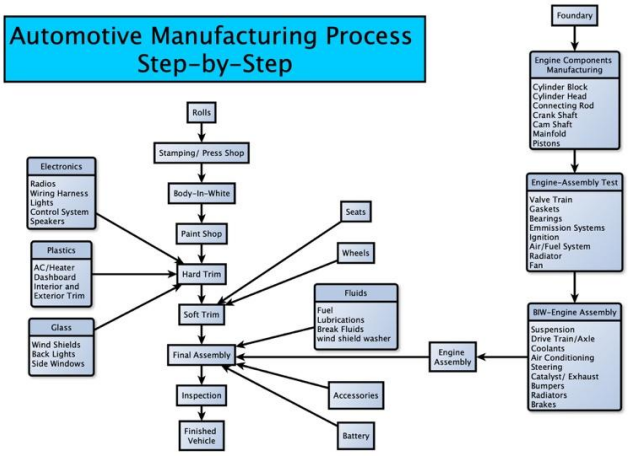

Figure 1: Major Departments and workflow for Automotive Plant (2)

Major departments that involve in Automotive Manufacturing are Stamping Department, Body-In-White Department, and/or Chassis Department, Foundry Department, Painting Department, Manifold Department, Final Assembly Department [2].

III. LIMITATIONS

In this paper, the discussion is about the entire outline of the plant layout for the Automobile industry and divided into two-part, one is the main process flow from stamping to the final assembly, and the second part is foundry. The foundry treated as the secondary part of the Automobile industry, and again, it is brought back into the main process flow in the assembly operation. So, for the simplified analysis, this paper is excluding the foundry part and mainly concentrating on the main process flow of the Automobile industry.

The Assumptions and/or Limitations that considered in the deriving process flow of the Automobile industry are

1. The chassis that discussed in this paper for the analysis is a monocoque chassis.
2. The most parts and/or components of an Automobile manufactured with in the industry itself.
3. The analysis was done by neglecting small parts of the Automobile.
4. This paper is through the outline of the Automobile industry.
5. This paper does not follow any single Automobile industry or model of vehicle.
6. This process flow and specifics of the production process may vary from one industry to another.
7. This paper only reflected the main process flow and had excluded the foundry part of the industry.

IV. DEPARTMENT WISE PROCESSES:

A. Stamping Department

The press shop/stamping is a department in the automotive industry and is the foremost Process in the manufacturing of an Automobile production and use dies and punches to cut the sheet metal into required shapes [9], [10]. The stamping department is responsible for the production of a complete vehicle body [9]. Stamping It involves a metal cutting process where the coils of metal cut into uniform dimensions into smaller sheets, and particular shape formed with the help of different presses for different components for an Automobile Body [9]. It is a forming process in which extreme pressure is applied on the sheet metal blank within its plasticity limit to obtain the desired shape. The main reason for the stamping process is to produce parts of any dimension and shape out of sheet metal. [10]

The stamping department is responsible for making Automobile Body parts like the bonnet, hood, doors, roof, etc. It consists of various sheet metal operations like blanking, coining, hemming, flanging, embossing, etc. Every part may not undergo every process in stamping, as it depends on the complexity of the piece. Stamping operations performed in various stamping stations that use a die and a Mechanical press of a specific part for forming the desired shape [11].

A Stamping department produces the car's complete external shape. An Automobile requires around 40 to 50 significant panels, and most of them are produced in house and don't want to outsource because of the defined geometry and quality of the Automobile [12], [13]. Most of the smaller sheet metal components manufactured by Tire Companies [12], [13]. To produce these panels, it will take 100- 200 dies and change-over of these dies, depending on the variant of the vehicle, which is the most essential and crucial Process in stamping [12], [13].

Stamping Process is divided into two parts 1) Material Production Process and 2) Panel Production Process. The Material Production Process starts from the wounded coil till the blanking press where the coil transferred from de-coiler, feeder, strip-wash, and lubrication and cuts into panels by dies in Blanking Processes. In Panel Production Process, Press Machines are used to produce the designed panel components of required shapes and sizes [12], [13].

The flowchart describes the flow of different operations sequentially in the stamping process. The flowchart is drawn, keeping in view of every all the parts of a car body. So every operation may not be performed on the sheet metal blank.

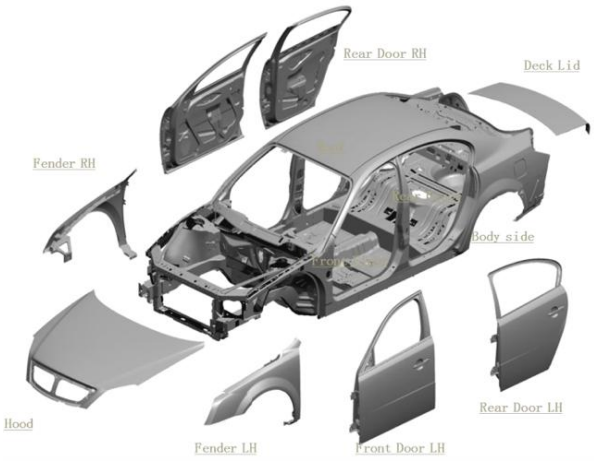

Figure 2: Sheet Metal Panels for Car Body ()

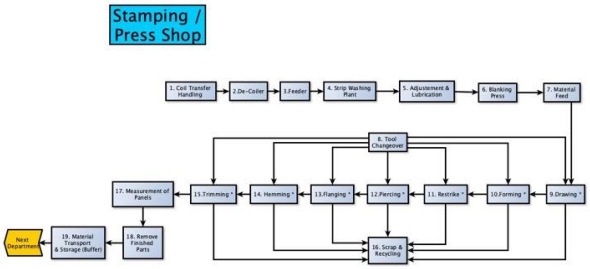

Figure 3: Stamping Department (3), (4)
* Processes depend on the type of body parts.

The processes involved in the Stamping Department are

1. Coil Transfer Handling
2. De-Coiler
3. Feeder
4. Strip Washing
5. Adjustments and Lubrication
6. Blanking Press
7. Material Feed
8. Tool Change-over (or) Tool Set-up
9. Drawing
10. Forming
11. Re-Strike
12. Piercing
13. Flanging
14. Hemming
15. Trimming
16. Scrap and Recycling
17. Panel Measurements according to dimensions
18. Finished part removal
19. Material Transport and Storage

- Firstly, the sheet metal coil fed through a de-coiler to the strip washing plant. After washing, necessary adjustments and lubrication did.
- Depending on the size of the body panel, the blanking of the strip done to the required dimensions.
- The blanked sheets fed to the stamping press, and the punching done with the appropriate die.
- Other operations like hemming, flanging, piercing, restrike are done if the required product has a complex shape. Trimming is done to remove the excess material is present in it.
- It is to ensure the precision of the part that had produced, inspection will be done on it, and the approved parts sent to the inventory storage.
- The scrap produced during this stamping process recycled for reusing the material.
- Every part will not require all operations. So, changing of tool or die will be done for the required parts.

An Automobile body may contain more than 1500 stampings, and nearly 60-70% of metal parts of an Automobile made by plastic forming [12], [13].
Hydroforming is a newly constituted technology in the automotive industry as it offers distinguished advantages compared to conventional manufacturing processes. In this Process, fluid pressure is applied to the metallic blanks to form desired component shapes. The amount of scrap material observed for the conventional stamping process is 20-30%, whereas, for hydroforming, it reduced to 0-10%. Hydroforming has many applications like automotive engine cradle, camshafts, exhaust pipes [14].

B. Body-In-White Department

BIW standards for Body-In-White. BIW is a stage in Automobile manufacturing. Here the complete body shell of the Automobile is welded and structure from all the sheet metals formed into sub-assemblies
The assemblies of all the Frames and Panels of both Structural Components,
as well as the exterior parts of an Automobile combined with homogeneous materials, form car body structure. BIW does not include doors, engines, and other moving parts.

Components of BIW are

1) A-Pillar
2) B-Pillar
3) C-Pillar
4) D-Pillar (Depends on Car Variant)
5) Roof Frame/ Roof Structure / Roof Panel
6) Floor and other Panels
7) Front and Rear Longitudinal Beam
8) Rocker/ Side Sill
9) Dashboard Mounting Panel
10) Hood (Frame and Panel)
11) Front Fenders (Right and Left)
12) Rear Fenders (Right and Left)
13) Decklid/ Trunk lid/ Tailgate (Frame and Panel)
14) Doors (Frame and Panel)
15) Dashboard Mounting Panel
16) Cross Member
17) Fire Wall
18) Floor, Seat and Boot Pan

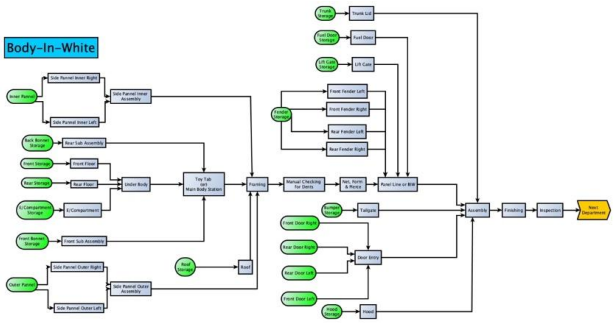

Figure 4: B-I-W Department (3), ()

BIW consists of a different kind of joining Processes like welding, soldering, brazing, adhesive bonding and mechanical joints we use all this joining Process according to the need of the components that we join [15]. In BIW, one can come across different types of components with different shapes. And there is a material property of each material vary that from the other, and the metallurgical processes might also need to join dissimilar metals that are used to join different components together and derive the desired shape [15].

In BIW, the most commonly used material for the manufacturing of the components is steel, and there will be different compositions of steels that we use in the Automobiles according to usage and the loads that applied to the members [16].

In BIW, the hot-stamped steel is used up to 30% of the total material that we use in BIW [16]. The main reason for the usage of hot-stamped steel is that it has relatively low weight when compared to most of the steels, and it also has more crash resistance and high strength at a very low cost [16]. The HSS (High-Speed Steel) is the major material used in the structural components of the BIW [17]. The weight of any material and its strength plays an important role in the selection of the material. Most of the panels and components in the BIW will be coming from the Stamping process, where we will convert the sheet metal rolls into different panels and components. At an average, the BIW will have 2206 weld spots involved, the majority part of this welding process is to join the pillar parts of the Automobile chassis [17]. The maximum part of the welding operations done by robots [17].

The BIW in our will be mainly having five major assembly stations. They are listed below

1. Under Body
2. Side panel assembly (exterior & interior)
3. Toy tab
4. Framing
5. Panel line
6. Assembly [15].

In the Automobile industry, we will maintain storage for every component to reduce the entire manufacturing time in the industry [16]. So, in our design of BIW, consideration of storage for every component that is coming out from the Stamping shop and directly takes out components that need to assemble from the storage only [17].

In the BIW process plan that we have adopted, we can clearly say that the Process in Underbody and side panel assembly (exterior & interior) are independent Processes and can be done simultaneously with any interference. In contrast, the toy tab is dependent on the Underbody and the sub-assemblies of the front and rear. So, by this, we can say that BIW consists of both independent and dependent process flow [18], [19].

Under Body: - Under Body assembly, majorly consists of 3 parts that are the front floor, rear floor and engine compartment this will make a platform for the entire BIW and each component is assembled on the Underbody [18], [19]. And the type chassis that we are taking into the consideration for the entire layout is a monocoque chassis, where we will not find and ladder structure to assemble the BIW [18], [19]. So, in our analysis of monocoque chassis, the Underbody will act as a basic structural frame to assemble the components [18], [19].

Side Panel Assembly: - This side panel assembly consists of both outer and inner panels like in Underbody. They will also come from the stamping process. They will be taken from the store directly. This inner panels will also be housing the guideways for the electrical lining. In contrast, the outer panels will be like smooth finished work without any penetrations on them [18], [19]. This panel assembly will mainly have the pillars of the Automobile like A pillar, B pillar, and C pillar according to the design of the Automobile this pillar may vary [18], [19]. This side panel assembly will be directly going to the framing process, and this assembly might have some buffer time to it because the framing is dependent on the toy tab [18], [19].

Toy Tab: - Toy Tab can also be called as main body station because the Underbody and the sub-assemblies of front and rear are taken together and joined here [18], [19]. The toy tab is a dependent process because it mainly depends on the underbody assembly and sub-assemblies [18], [19]. The further step of the toy tab is the framing Process. The toy tab prominently uses welding operation and some hemming operation. All these operations are carried out by robots [18], [19].

Framing: - In framing, we will get an almost integrated outlook of the chassis. The parts that assembled in this framing process are the toy tab and side panel assemblies and the roof of the Automobile [18], [19]. All the parts of the framing process assembled on the toy tab [18], [19]. On the toy tab, the assembly will be on the side panels of the Automobile, and then after the roof of the Automobile is assembled on the panels [18], [19]. This process is the most important step in the BIW to get an integrated chassis or body [18], [19]. And this body after framing will be sent for a manual inspection for the checking of the dents in the body and this framed body is sent to the piercing of any required holes on the frame for further processing [18], [19].

Panel line: - This is the final stage of the BIW, where we assemble the fenders, liftgate, and fuel door. So, this panel assembly will have all the entire part of BIW except the doors of the Automobile [18], [19].

Assembly: - This final assembly in BIW will mainly have the assembly of the doors, hood, and tailgate, trunk lid [18],[19]. By this assembly, the entire Process of BIW completed, and this complete assembly is taken out for the finishing process. Then there will be a final inspection for each assembly, and then the certified body will only be allowed to the next department, i.e., Paint shop [18], [19].

C. Painting Department

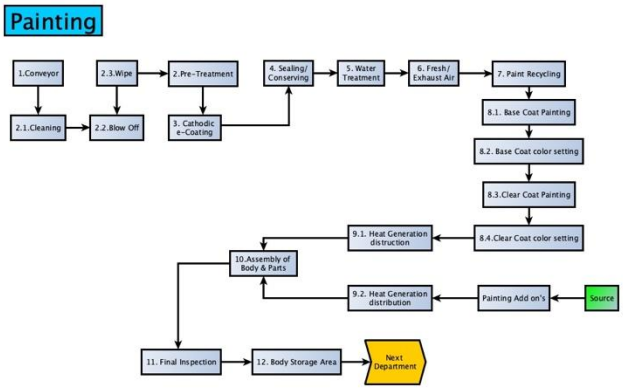

Figure 5: Painting Department (3), (14)

Paint application is the most required process for vehicle production, and it is not exclusively done for covering but also for the safety of body surface,

it also increases the visual interest by adding the shades as well as the shine and imperative offering focus [20], [21]. Car paint will be paint used on cars for both embellishment and security reasons [20], [21]. The mostly used water-based acrylic polyurethane lacquer paint is presently utilized paint for the painting process is done after the body of the vehicle is assembled [20], [21]. The painting process is done to give more attraction to the vehicle, good appearance, and to provide a protective layer against the corrosion as well as the weathering. There are main four major process involved in the paint shop [20], [21]. They are 1. Pre-treatment, and Electrodeposition or E-Coating, 2. PVC sealing, 3. Primer coat painting, 4. Topcoat painting [20], [21].

Pre-Treatment:

After completion of B-I-W, it is important to clean the body surface to get rid of all the deposits obtained during different operations, and this cleaning process is done through three dipping processes, 1. Degreasing, 2. Conditioning, 3. Phosphating. After cleaning, the Pre-Treatment process done where it acts as a primer to bond onto the metal [20], [21].

Electrodeposition or E-Coating:

The next Process is Electrodeposition or E-Coating, where this Process is done to prevent the metal body from corrosion, this Process is done and depends upon various types of sheets that are used for car body materials [20], [21].

Rust Proof Materials: PVC Sealing:

PVC is Polyvinyl Chloride Sealing and applied to doors, trunk, hood, dashboard, and all the exterior and interior joints. And also used mostly for Underbody to achieve noise-proof platform and to reduce the vibrations that occur in B-I-W, this also helps the Underbody from rust and corrosion and chipping protection [20], [21].

Primer:

After PVC Sealing the next step is applying primer to the body, and it is of three types 1) Powder Type, 2) Water-borne, 3) Solvent-borne, Primer helps as an adhesive between the E-Coating and Topcoat providing the corrosion protection and appearance of the vehicle [20], [21].

Topcoat:

The next step in this process is topcoat, and it has two steps a) Basecoat and b) Clearcoat

a) Basecoat: The Basecoat is usually for the primary coloring pigment for the vehicle [20], [21].

b) Clearcoat: The Clearcoat is usually for the protection of UV light, environmental effects, and provide a smooth finish for the vehicle [20], [21].

Spray Coating:

The last and final process is Spray Coating, where tiny droplets of paint are absorbed in a continuous gaseous phase that applies to the parts and complete body. This Process gives the fine finish of the paint, and the appearance furnished with the quality look. After this process, the heat generation process is done for sticking the paint to the body, while this Process continuous other small parts form the storage is also in Process of the above coatings and join in another line. They both get assembled, and the painting process is completed [20], [21].

Inspection and Storage:

After the last spray coating operation, the final steps are to inspect the quality of the painting operation, a thorough check for every part of the body done, and this Process is done either manually or in automated testing condition. Only after thorough and rigorous inspection, the vehicle sent to assembly. Otherwise, the vehicle has the repeat all the processes again till the final quality standards are met, and the car body is sent to Storage / Assembly department [20], [21].

D. Final Assembly

Assembly line usually consists of many numbers of workstations, and it is important where all the components of the B-I-W and Mostly, the Powertrain of the Automobile are assembled sequentially in a fixed pattern [22].

In this assembly process and/or department, most of the work carried out manually, and the workers move along with the conveyor to complete the task at that station. They will scale back to the initial position to work on the next Automobile in the line [22].

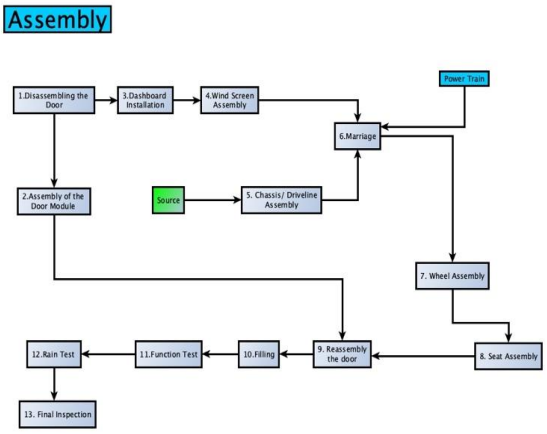

Figure 6: Final Assembly

After the painting process completed, the B-I-W will move to the final assembly department. In the first station, the primary operation is to dis-assemble the doors from the rest of the body, dashboard, and other instrumentation panels are fixed. This process is completed manually by the workers. The next station is the most important, and it is the assembly of B-I-W to Powertrain, which is termed as marriage station, here the body and powertrain meet together. A lot of many assembly works are carried out, and this station the Automobile gets its complete structure and final appearance, in the next station's wheels, seats. Finally, the doors installed to the Automobile, which previously removed for assembly process to the Automobile and all the necessary tests for the engine, chassis did, and a thorough final inspection is conducted to the vehicle and stored in the warehouse for distribution around the world [22].

V. RESULT AND DISCUSSION

In this paper, the complete manufacturing of the main automobile line had discussed,

and step by step production processes had explained according to their departments in each section, respectively [23]. As the Technological advancements in the Automobile Industry is growing day by day globally, and with increase in customers demand for variety of variants in Automobile it is important to understand the flow and complexity of Automobile in order to reduce the lead time for faster production, better use of equipment and an increase in Overall Equipment Effectiveness (OEE), and its near to impossible to change the system [23].

VI. CONCLUSION

To apply Discrete Event Simulation (DES) for an Automotive OEM and increase the OEE with a reduction in Bottlenecks. It is important and necessary to recognize the complexities involved in manufacturing of Automobile and to understand the Process and/or Product flow to identify the bottlenecks, improve the equipment efficiency and overall improve the plant productivity, This work helps to identify the complete processes that are operating in Automobile industry and will help to study and implement DES for overall improvement in OEE [23].

VII. FUTURE SCOPE

The next step for this work is to use the layout described in this paper with the help of DES to create a simulation environment using the methodology proposed by law and Andres Skoogh [24] and try to remove the bottlenecks and improve performance and Efficiency this layout and check the overall improvement in the plant layout. One of the biggest challenges that the Automobile OEMs will face in the future is to realize change and the need to adapt to the electric vehicle's technology. This paper can be useful to simulation experts to observe the process changes that happen in different departments and can act accordingly how well the plant is performing during these changes [23], [24].

ACKNOWLEDGMENT

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