Manufacturing Strategies and Processes for ICE, HEV, and BEV Vehicles

Amey Phatale

Process Engineer, Magna International
Belvidere, IL, USA

Abstract
The process of building a car in the automotive industry involves several critical stages, including planning, designing, and production, each essential to ensuring product quality and market success. This paper explores the comprehensive approach adopted in car manufacturing, beginning with market analysis and forecasting to understand consumer needs and trends. The design phase leverages advanced software tools to develop components and assembly processes. Production integrates lean manufacturing, Just-in-Time (JIT) methodologies, and automation, focusing on chassis assembly, engine integration, body construction, painting, and final assembly. Different vehicle types, including Internal Combustion Engine (ICE) vehicles, Hybrid Electric Vehicles (HEVs), and Battery Electric Vehicles (BEVs), are discussed, emphasizing their unique production requirements. The paper further details quality control measures to ensure product reliability and compliance with industry standards.

Keywords: Automotive Manufacturing, Car Design, Chassis Assembly, Toyota Production System (TPS), Lean Manufacturing, Just-in-Time (JIT) Production, Internal Combustion Engine (ICE), Hybrid Electric Vehicle (HEV), Battery Electric Vehicle (BEV), Vehicle Assembly Process, Automation in Manufacturing, Quality Control in Automotive Industry.

1. Introduction

Before a car is manufactured, several steps are undertaken. The process begins with meticulous planning, which includes conducting a market survey or market study. Following this, the car's design and production phases are initiated.

The automotive manufacturing industry is one of the largest businesses in the contemporary era, necessitating thorough market studies to mitigate business risks. These studies are conducted based on market trends, historical customer feedback, competitor products, and other relevant factors. This comprehensive analysis provides a foundational understanding for planning any product, in this case, a car. Typically, the development of a car model from inception to assembly takes approximately 4-5 years. This timeline requires significant forecasting of market needs and trends for the future. To gauge public reaction and gather feedback, companies often create concept cars that showcase futuristic designs and features intended for future production models.

Fig 1. Modern Body Assembly Line| Source [1]

Once the objectives are defined, various parameters for execution are considered in the planning process. These parameters include the supply chain, car specifications, feature lists, price range, and segment identification. Planning also encompasses the design factors.

The designing process then commences, undertaken by various engineers. This will be discussed in more detail later. Various tools and software are employed to design each part, using different materials according to their applications.

Additionally, this process includes designing the assembly process for the car, which is known as the production phase. See Fig.1 above for an example of an automated assembly line.

2. PRODUCTION

A. Components

The production process consists of an assembly line involving thousands of parts. These parts, or components, are supplied by Original Equipment Manufacturers (OEMs) or other suppliers. Typically, they are transported to the plant using trucks or rail systems, depending on the type of car body. Once at the plant, these components are stored in the inventory.

B. Chassis

1. Internal Combustion Engine (ICE)

Automobiles are typically constructed from the ground up and inside out. Historically, the chassis served as the foundational base upon which all components were attached during assembly. The chassis includes the frame, wheels, suspension, powertrain, and engine. In contemporary manufacturing, the roll cage or body frame is used as the base for attaching components. The engine is assembled on a separate part of the chassis and later attached to the main frame during the assembly process. This type of chassis is known as a monocoque chassis. The frame is then moved along the conveyor or assembly line. Additionally, as illustrated in the figure below (Fig 2.), modern manufacturing processes use robots to fabricate (through bolting, welding, etc.) the frame, a task that was previously performed manually by workers.

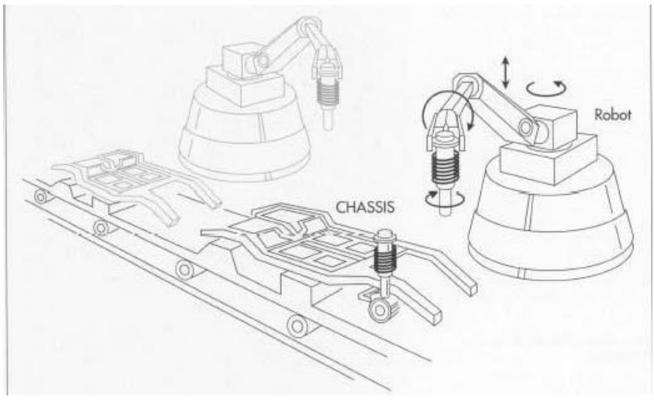

Fig 2. Chassis of an ICE Vehicle| Source [2]

2. Hybrid Electric Vehicle (HEV)

Hybrid Electric Vehicle operates on a combination of rechargeable batteries and internal combustion engine. There are two type of hybrid vehicles – Plugin Hybrid Electric Vehicle (PHEV) & Hybrid Electric Vehicle (HEV). The chassis of a HEV is capable of accommodating both an internal combustion engine and electric powertrain. Below is an image of hybrid vehicle module and Battery Pack (Fig 3)

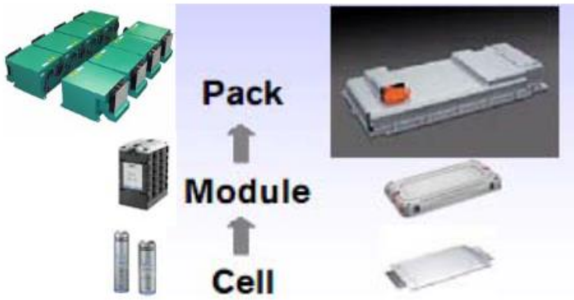

Fig 3. Cell Module & Pack| Source [21]

3. Battery Electric Vehicle (BEV)

Battery Electric Vehicle are gaining popularity in last few years. BEV runs entirely on rechargeable batteries and produces zero emissions. The chassis of a BEV is designed to accommodate and support the electric drivetrain, battery packs and other components. The battery pack is the main part and is placed on the bottom of the chassis. Below image shows an example of a Battery Electric Vehicle's Chassis (see Fig. 4).

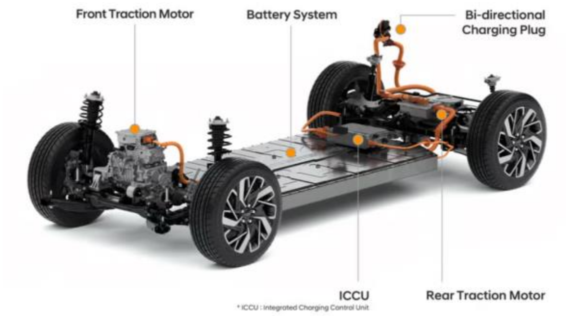

Fig 4. Hyundai's Battery Electric Vehicle Chassis| Source [22]

C. Body Shop

The main body of the vehicle is constructed in the body shop. The front hood, rear boot, doors, and side panels are either stamped through dies or supplied by external vendors, then attached to the frame through bolting and welding. To achieve precision and consistent accuracy, jigs and fixtures are employed during this process. The body assembly follows a separate line from the chassis assembly. Most of the welding on various panels is performed by robots, although manual labor is required for bolting the parts together. Once the frame assembly is complete, it is transferred to an overhead conveyor for the subsequent process, typically painting. The painting process involves multiple steps: inspection, cleaning, electrostatically applied undercoating, dipping, drying, topcoat spraying, and baking (see Fig 5)

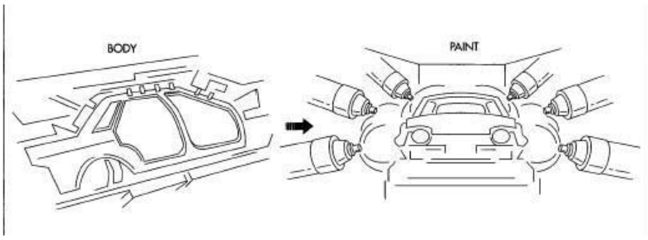

Fig 5. Body & Paint Process | Source [3]

D. Paint Shop

The body must undergo a thorough inspection process, known as the body-in-white operation, before painting. The vehicle shell is transported through a brightly lit room, typically with white walls, where it is meticulously wiped down by visual inspectors using cloths soaked in highlighting oil. Under bright lights, inspectors identify any defects in the sheet metal body panels. Dings, dents, and other imperfections are repaired and corrected on the line by skilled repair personnel. After the shell has been fully inspected and repaired, it passes through a cleaning area where it is immersed and cleansed of all residual oil, dirt, and contaminants.

As the shell exits the cleaning area, it passes through a drying booth before undergoing an undercoat dip. This process involves an electrostatically charged bath of undercoat paint, or Ecoat, which coats every nook and cranny of the body shell, both inside and out, with primer. This coating serves as a substrate surface for the topcoat of finish paint to adhere to.

Following the undercoat paint bath, the shell is dried in a booth before proceeding to the final paint operation. In modern manufacturing, vehicle bodies are spray-painted by robots that are pre-programmed to apply precise amounts of paint to specific areas for the optimal duration. Research departments have extensively studied robotic painting to ensure a high-quality finished product. Today's robotic painters have significantly advanced from the days of Ford's first Model Ts, which were manually painted with brushes. After the shell is fully covered with a base coat of finished paint and a clear topcoat, it is cured in baking ovens at temperatures exceeding 275 degrees Fahrenheit (135 degrees Celsius). Once the paint process is complete, the shell is sent to the main assembly line, also referred to as the trim chassis fitment in some companies

E. Trip Chassis Fitment

This process includes three major segments: Interior Assembly, Mating, and Quality Testing

1. Interior Assembly

The painted shell moves through the interior assembly area where workers install all instrumentation and wiring systems, dash panels, interior lights, seats, door and trim panels, headliners, radios, speakers, all glass, the steering column and wheel, body weather-strips, vinyl tops, brake and gas pedals, carpeting, and front and rear bumper fascia. This process may involve multiple sub-assemblies for different parts such as doors, console panels, and seats. Robots assist workers by picking up seats and trim panels and transporting them to the vehicle, enhancing the ease and efficiency of the assembly process.

2. Mate

At this stage, the chassis assembly conveyor and the body shell conveyor converge. In modern manufacturing, the chassis is divided into two parts: the body chassis and the engine chassis. This is also known as a monocoque chassis, as illustrated in the figure below (Fig 6.).As the chassis moves along the body conveyor, the shell is robotically lifted from its conveyor fixtures and placed onto the car frame. In the case of a monocoque chassis, only the engine is lifted and mounted onto the chassis suspended on the conveyor. Assembly workers, some positioned at ground level and others in work pits beneath the conveyor, carry out the mounting process. Once the mating is complete, the car moves down the line for the installation of final trim components, the battery, tires, anti-freeze, and gasoline. At this point, the car is ready to be started.

Fig 6. Monocoque Chassis |Source[4]

3. Quality Testing

After assembly, the car is driven off the line, where its engine is audited, its lights and horn are checked, tire balancing and dynamic alignment are performed, and its charging system is examined. If any issues are identified at this stage, the car is sent to a central repair area, typically located near the end of the line. A skilled crew of troubleshooters analyzes and repairs all problems. The car also undergoes a water test to ensure the proper fit of door panels, glass, and weather-stripping. After passing the final audit, the vehicle is subjected to dynamic testing and is driven on a test track to identify any further issues. It is then sent to a staging lot, where it awaits shipment to its destination.

CONCLUSION

The process of building a car in today's automotive industry is a complex and multifaceted endeavor that incorporates advanced design principles, lean manufacturing techniques, and automation to enhance efficiency, quality, and production capacity. While traditional manufacturing practices like chassis construction and engine assembly remain integral, the growing demand for hybrid and electric vehicles has introduced new challenges. These challenges include integrating complex battery systems, managing supply chains for critical components, and ensuring compliance with evolving environmental regulations.

Despite significant advancements, the industry faces several ongoing challenges, such as adapting production lines for greater flexibility to accommodate different vehicle types, managing costs while implementing automation, and addressing the environmental impact of manufacturing processes. The transition towards sustainable mobility will necessitate further innovations in production, including the increased use of renewable materials, energy-efficient processes, and the implementation of Industry 4.0 technologies like the Internet of Things (IoT), artificial intelligence (AI), and robotics.

Future efforts in automotive manufacturing should focus on optimizing production lines for greater efficiency, reducing waste through advanced recycling processes, and adopting new materials that enhance vehicle performance while reducing emissions. Moreover, closer collaboration between automotive companies, technology developers, and regulatory bodies will be essential to drive the next wave of innovation in sustainable car manufacturing.

References

1. K. Sanchez, “Mexico Could be Home to Next North American BMW Factory,” MotorTrend, Jun. 26, 2014. [Online]. Available:
2. https://www.motortrend.com/news/mexico-could-be-home-to-next-north-american-bmw-factory/ (accessed Jul. 21, 2015).
3. “Auto-assembly plant layout and ohs cathywalker-2011.5.28 2003 power point,” SlideShare, May 28, 2011. [Online]. Available: https://www.slideshare.net/slideshow/autoassemblyplantlayout-and-ohs-cathywalker2011528-2003-power-point/8134774 (accessed Jul 2015).
4. “How automobile is made - production process, manufacture, making, used, parts, components, product,” www.madehow.com. [Online]. Available:
5. https://www.madehow.com/Volume-1/Automobile.html (accessed Jun 2015).
6. A. Diwan, “What is a Chassis and what are its types?,” CarBikeTech, Oct. 17, 2014. [Online]. Available: https://carbiketech.com/chassis/
7. “Design for Assembly (DFA),” SlideShare, Feb. 10, 2015. [Online]. Available: https://www.slideshare.net/slideshow/design-for-assembly-dfa/44493715 (accessed Jul 2015).
8. A. Sarmento, E. Marana, G. Batalha, R.L. Stoeterau, "Design for Assembly Study Case: Automotive Fuel Intake Cover", Research Gate, Oct. 2011, DOI: 10.4271/2011-36-0046. [Online]. Available:
9. https://www.researchgate.net/publication/297582386_Design_for_Assembly_Study_Case_Automotive_Fuel_Intake_Cover
10. J. D. Stroud, “Understanding the Purpose and Use of Benchmarking,” isixsigma.com, Feb. 26, 2010. [Online]. Available: https://www.isixsigma.com/benchmarking/understanding-purpose-and-use-benchmarking/ (accessed Jun 2015).
11. A. Alrabghi, "Benchmarking experience and potentiality in Saudi public services", Research Gate, Oct. 2010. [Online]. Available: https://www.researchgate.net/publication/294871909_Benchmarking_experience_and_potentiality_in_Saudi_public_services
12. D. Demuro, “Concept Cars: Why Do Automakers Build Them?,” www.autotrader.com, Oct. 2013. [Online]. Available:
13. https://www.autotrader.com/car-shopping/concept-cars-why-do-automakers-build-them-215703 (accessed Jun 2015).

14. H. Boeriu, “BMW building new auto body shop in Spartanburg,” BMW BLOG, Aug. 07, 2015. [Online]. Available: https://www.bmwblog.com/2015/08/07/bmw-building-new-auto-body-shop-in-spartanburg/ (accessed Aug 2015).
15. AutoConceptionTV, “What Goes into Designing a Concept Car?,” YouTube, Jun. 19, 2015. [Online]. Available:
16. https://www.youtube.com/watch?v=AbvtRgiedKE (accessed Jul. 2015).
17. H.J. Warnecke, R. Bäßler, "Design for Assembly — Part of the Design Process", ScienceDirect, Jan. 2008, DOI: https://doi.org/10.1016/S0007-8506(07)61572-8. [Online]. Available:
18. https://www.sciencedirect.com/science/article/abs/pii/S0007850607615728
19. G. Michalos, S. Makris, N. Papakostas, D. Mourtzis, G. Chryssolouris, "Automotive assembly technologies review: challenges and outlook for a flexible and adaptive approach", ScienceDirect, Jan. 2010, DOI: https://doi.org/10.1016/j.cirpj.2009.12.001. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S1755581709000467
20. K.L Edwards, "Towards more strategic product design for manufacture and assembly: priorities for concurrent engineering", ScienceDirect, Nov. 2002, DOI: https://doi.org/10.1016/S0261-3069(02)00050-X. [Online]. Available:
21. https://www.sciencedirect.com/science/article/abs/pii/S026130690200050X
22. G. Boothroyd, P. Dewhurst, and W. A. Knight, Product Design for Manufacture and Assembly, Second Edition, Revised and Expanded. CRC Press, 2002. Accessed: Jul 2015. [Online]. Available:
23. https://books.google.com/books?hl=en&lr=&id=ZcyaWeick-YC&oi=fnd&pg=PP1&dq=How+does+the+design+affect+the+vehicle+assembly+requirements%3F&ots=71NPayyR5N&sig=Ya_KFMhWGAj3ki1F5f2io1_W0sc#v=onepage&q&f=false
24. E. Molloy, H. Yang, J. Browne, B.J. Davies, "Design for Assembly within Concurrent Engineering", ScienceDirect, Jan. 2008, DOI: https://doi.org/10.1016/S0007-8506(07)61945-3. [Online]. Available:
25. https://www.sciencedirect.com/science/article/abs/pii/S0007850607619453
26. C.P. Kartha, "A comparison of ISO 9000:2000 quality system standards, QS9000, ISO/TS 16949 and Baldrige criteria", Research Gate, Oct. 2004, DOI: 10.1108/09544780410551269. [Online]. Available:
27. https://www.researchgate.net/publication/235294968_A_comparison_of_ISO_90002000_quality_system_standards_QS9000_ISOTS_16949_and_Baldrige_criteria
28. J. Manzella, “The Impact of Globalization and New Technologies on Manufacturing,” The Manzella Report | The Premier Source For Global Business And Economic News. Jul. 2001. [Online]. Available:
29. http://www.manzellareport.com/index.php/manufacturing/180-the-impact-of-globalization-and-new-technologies-on-manufacturing (accessed Jul. 2015).
30. G. Mintchell, “The Assembly Plant of the Future,” Automation World, Jan. 10, 2011. [Online]. Available:
31. https://www.automationworld.com/home/article/13297613/the-assembly-plant-of-the-future (accessed Jul. 2015).
32. G. Watson, “Benchmarking for success: Evaluate your company against others, not yourself.,” Manufacturers’ Monthly, Oct. 17, 2013. [Online]. Available:
33. https://www.manmonthly.com.au/benchmarking-for-success-evaluate-your-company-against-others-not-yourself/ (accessed Jul. 2015).
34. Nrel, A. A. Pesaran, G.-H. Kim, and M. Keyser, “Integration Issues of Cells into Battery Packs for Plug-In and Hybrid Electric Vehicles,” Apr. 01, 2009. [Online]. Available:

35. https://www.researchgate.net/publication/228540067_Integration_Issues_of_Cells_into_Battery_Packs_for_Plug-In_and_Hybrid_Electric_Vehicles (accessed Jun. 15, 2015)
36. M. Vaughn, "Hyundai's Powerful Electric Future Will Ride on This All-New Platform," Autoweek, Dec. 02, 2020. [Online]. Available:
37. https://www.autoweek.com/news/green-cars/a34842331/hyundai-e-gmp-platform/ (accessed Jul. 2015)