2013

Cost-effective Design of Automotive Framing Systems Using Flexibility and Reconfigurability Principles

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Cost-effective Design of Automotive Framing Systems Using Flexibility and Reconfigurability Principles

By

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A Dissertation
Submitted to the Faculty of Graduate Studies
through Industrial and Manufacturing Systems Engineering
in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy at the
University of Windsor

Windsor, Ontario, Canada

2012

Cost-effective Design of Automotive Framing Systems Using Flexibility and Reconfigurability Principles

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This dissertation includes 5 original papers that have been previously published / submitted for publication in international conferences, as follows:

Thesis Chapter	Publication title/full citation	Publication status
Ch. 1	Al-Zaher, A., ElMaraghy, W., Pasek, Z. J., 2010, "*Robust and Cost-effective Design of Automotive Framing Systems Using Reconfigurability Principles*", The 2nd Canadian Quality Congress, Toronto, ON. Canada.	Published
Ch. 1	Pasek, Z. J., Al-Zaher, A. 2010 "*Towards Reconfigurable Body Framing Systems for Automotive Manufacturing*, "15th IEEE International Conference on Emerging Technologies and Factory Automation, Bilbao, Spain.	Published
Ch. 3,4	Al-Zaher, A., ElMaraghy, W., Pasek, Z. J., 2011, *Enabling Car Body Customization through Automotive Framing Systems Design*, The 4th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2011), 2-5 October, 2011, Montreal, Canada	Published
Ch. 5	Al-Zaher, A., ElMaraghy, W., Pasek, Z. J., 2012, *Reconfigurable manufacturing systems design methodology for Automotive Framing Systems BIW*, (CIRP 2012), May 21 - 23, 2012 Ann Arbor, Michigan, USA	Published
Ch. 5, 6	Al-Zaher, A., ElMaraghy, W., Pasek, Z. J., 2012, *RMS design methodology for Automotive Framing Systems BIW,* Submitted for the Journal of Manufacturing Systems.	Submitted
Ch. 5, 6	Al-Zaher, A., ElMaraghy, W., Pasek, Z. J., ElMaraghy, H., 2012, *Design of Reconfigurable Automotive Framing Systems BIW,* the 23rd CIRP Design Conference 2013 march 11th - 13th, 2013 in Bochum, Germany.	Submitted

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Al-Zaher, A

Date: Oct 15/2012

Abstract

Manufacturing enterprises are entering an era of new challenges where manufacturing needs to compete in a global economy with open and unpredicted market changes. Manufacturing facilities need to possess a high degree of flexibility, enabling mass customization of production. Reconfigurable Manufacturing Systems (RMS) is a relatively new concept, which if adopted properly, will become a design foundation for the next generation of world-class production systems. They will help automotive companies achieve rapid response and cost-effective product delivery aligned with the current market demand.

This research introduces new systematic methods dealing with a *complete end-to-end design process* to production systems, where the uncertainty of product variety is mapped to product attributes and manufacturing processes, then mapped into a production line using product decomposition into systems, sub-systems, and modular assembly. Graph network (NW), change propagation index (CPI) and hybrid design structure matrix (HDSM) were introduced

Design structures matrix (DSM) and hybrid design structure matrix (HDSM) were used along with axiomatic design (AD) to ensure customer needs are translated into action. A hierarchal structure has been developed for a body-in-white (BIW) framing system. Implementation for best practice and coordination between processes in all design stages is a prerequisite for other function requirements. Knowing systems level interaction early in the product developments process is critical for design concept selection, and systems architectures decisions. However, existing methods that address the system’s interaction, such as the design structure matrix (DSM), are good to analyze the systems but cannot be used during conceptual synthesis when most important designs are made. Systems level knowledge is critical to the success of the design of large systems and needs to be captured at the early stage of the design.

Results of using the proposed methodology on a real case study shows that the proper implementation of flexibility and reconfigurability in the production system increase the capability and shows significant improvements in throughputs of production systems. Real production data was used to redesign the assembly line of production systems using digital manufacturing (DM) and production simulation. Simulation model of the state of practice was developed using DELMIA’s Digital Manufacturing solution (IGRIP).

Dedication

To my parents, my wife, my children Sarah, Sarya, Noor, Ayat, Faris, Rawan and Muhammad, my brothers and sisters, and all those who made this work possible.

Acknowledgements

It was a great challenge for me to make the decision to work on my PhD program. After so many years working in the automotive industries, transitioning from hands-on and everyday problems to the academia and research world took me a while. At the end, I believe I adjusted myself, and it has been a great privilege to spend a little more than three years in the Department of Industrial and Manufacturing Systems Engineering at University of Windsor; its members will always remain dear to me.

My first debt of gratitude must go to my advisors, Dr. Waguih ElMaraghy and Dr. Zbigniew Pasek. They patiently provided the vision, encouragement, and advice necessary for me to proceed through the doctorial program and complete my dissertation.

A special thanks goes to my PhD committee. I thank Dr. Hoda ElMaraghy who helped me in the streamline method and the tools I used. Without Dr. Hoda's direction, it may have taken me much longer to finalize my research. Also, I thank Dr. Jerry Sokoloski for his support, guidance, and helpful suggestions. Their guidance has served me well, and I owe them my heartfelt appreciation.

Next, I would like to thank the Intelligent Manufacturing Systems (IMS) Centre's Directors, researchers and staff. Special thanks to the directors Dr. Hoda ElMaraghy and Dr. Waguih ElMaraghy for providing the innovative environments, collaboration with industries, and the state of the art lab equipments. Thanks to administrative staff of the IMSE Ms. Angela Haskell, Qin, Ms. Sandra Mehenka. Thanks to all researchers at the IMSC, some of whom are Dr. S. Badrous, Dr. T. AlGeddawy, H. Tabti, A. Zaiout, K. Ramadan, A. Adawy, M. Hanafy, A. Qureshi, M. Kashkoush, A.R. Seleim, and many more. Thanks to Ramadan Barakat as well. A very special thanks goes to Zaina Batal and Sousan Khaled, who help in proof reading of my dissertation. Also, I have to include a special thanks to Saqib Syed and his advisor Dr. J. Urbanic.

I have to acknowledge the following people who have offered positive input and recognized my research in the early stage: Dr. Egon Müller, the External Examiner of Chemnitz University of Technology in Germany, Dr. Darek Ceglarek of the University of Warwick in the UK, Dr. Yoram Koren and Dr. Jack Hu from the University of Michigan in the USA.

Many thanks go to the systems designers, product developers, and CRW leaders at the GM Technical Center. Among them are Dr. H. Zghal, H. Mechlih, W. El-Cheikh, Mike Blanc, the Engineering Manager at Gonzales Designer Group, Todd Nowaczyk, the Senior Project Manager at PICO- COMAU in Michigan, and Igor Baseski, the Senior System Engineer at General Dynamics in Michigan, with whom I worked for almost 15 years.

Thanks to all my friends in Canada, the US, and especially in Syria. Thank you to my best friends, some of whom are Toufiq Yaser, Mohammad Al-Masalmeh, Eisa Hamad, Haitham Alarashi, and Yasin Al-Mahmoud. To all my friends in other parts of the world, you were great sources of joy and support.

I want to thank my parents, and my family, especially my brothers and sisters. Their love provided my inspiration and was my driving force. I owe them everything and I wish I could show them just how much I love and appreciate them. Thanks to my wife, Samia, whose love and encouragement allowed me to finish this journey. She already has my heart, so I will just give her a heartfelt thanks. I also want to thank my parents for their unconditional support.

Finally, I would like to dedicate this work to my lost sister, Eida Al-Zaher, who left us too soon. I hope this work would have made her proud.

Thank you all, again.
Al-Zaher, A.

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Nomenclature

Abbreviations

AD	Axiomatic Design
AHSS	Advanced High Strength Steel
BIW	Body in White
BSI	Body Side Inner
BSO	Body Side Outer
CD	A Clamping Location
CE	Concurrent engineering
CI	Coupling Index
CP	Common Positioning
CPI	Change Propagation Index
CPM	Change propagation Matrix
CT	Cycle Time
DC	Design Configuration
DM	Digital Manufacturing
DMM	Domain Mapping Matrix
DP	Design Parameter
DPA	Digital Pre-Assembly
DPP	Digital Process Planning
DPV	Digital Planning Validation
DSM	Design Structure Matrix
DT	Design Task
EOAT	End of Arm Tooling
FR	Functional Requirement
GBL	Toyota's Global Body Line
GSL	Graphical Simulation Language
GVI	Generational Variety Index
IBAS	Nissan's Intelligent Body Assembly System (IBAS)
IS & S	Innovative Solution and Support
KCC	Key Critical Control
KCE	Key Critical Elements
KCGs	Key Control Groups
HDSM	Hybrid DSM
HPV	Hour Per Vehicle
LC	Life Cycle
LH	Left Hand
MD	Manufacturing Design
MDM	Multiple-Domain Matrix
MID	Modularity in Design

MIP	Modularity in Production
MIU	Modularity in Use
MSE	Manufacturing Systems Execution
NC Block	A One Direction Part Locators
NW	Net-Work
NWG	Net-Work Graph
OEM	Original Equipment Manufacturer
OGS	Open Gate Systems
QFD	Quality Function Deployment
PD	Product Design
PLM	Product Life Management
PDM	Product Design Management
PPDS	Planning Processes Data Sheet
ROGFS:	Open Gate Reconfigurable Open Gate Framing Systems
RSM	Response Surface Model
RH	Right Hand
RMS	Reconfigurable manufacturing systems
SC	Surface Control
SOO	Sequence of Operation
TC	Teamcenter
TP	Top Positioning
UHSS	Ultra-High Strength Steel
VMALs	Virtual Manufacturing Assembly Lines
WH/RL	Wheelhouse Right Hand & Left Hand

Symbols

ΔE	Binary Number (0, 1) Indicating Element's Change
ΔX	Changes in Car Body Styling
CP	Common Positioning
Iv_i	Set of Inner Body Assembly (Within a Product Family)
Ov_i	Set of Otter Body Assembly (Within a Product Family)
Pi	Set of Product Variants
SC	Surface Controls
Si	Styling of Vehicle Family
T_{CT}	Total Cycle Time
T_{Gate}	Time Required (Gate: Work Position -to- Retract Position)
T_{Robt}	Time Required (Robot: Pounce to Weld to Clear)
TP	Top Positioning
T_{SK}	Time Required (Skid: Approach to Work Position)
UBv_i	Upper Body Variants

Chapter 1

1. Introduction

This chapter presents the automotive overview of product platform developments, research motivation discussed, main objectives and problem formulation, followed by a literature review and the research focus (gap goal and approach).

1.1: Automotive Overview

1.1.1: The Automotive Industry

In the 1950s, the market was dominated by the American Big Three (GM, Ford and Chrysler), capturing 95 percent of total U.S. market share. Three companies produced their vehicles on strategy based mass production assembly lines. This was evident since six models accounted for 80 percent of all cars sold in 1955 (Yakushiji, 1984). At that time, it was easy to defend their market share with a small number of vehicle models. In the 1980s, the U.S. automotive industry began losing market share to higher quality, affordable, fuel-efficient cars from Japanese automakers. In response to this market share loss, U.S. automakers began focusing on improving quality by adopting Just In Time (JIT) is a production strategy. The adoption of JIT and other philosophies helped improve the quality but did not fully bridge the gap between the quality of U.S. and Japanese cars. The gap remained because U.S. automakers tried applying JIT techniques without a full understanding of the whole Japanese manufacturing system, while Japanese automakers had decades to develop, refine and master their JIT approach.

Another significant paradigm of the 1980s was the global nature of vehicle manufacturing. Automakers started assembling vehicles around the world. This trend was accelerated in the 1990s with the construction of overseas facilities and mergers between multinational automakers. This global expansion gave automakers a greater capacity to quickly expand to new markets and at lower costs, and make data availability on the web accessible to consumers. Consumers wanted a vehicle that was “customized,” inexpensive, reliable, and quickly attainable. They also want vehicles that were less harmful to the environment, which led to the introduction of hybrid vehicles by Japanese automakers in the late 1990s.

1.1.2: The Automotive Industries in North America

Since then, the automotive market has evolved significantly. Customers started to demand variety in vehicle models and foreign competitors started to gain market share in the United States. Market segments started to become more fragmented, creating a need for more diverse vehicles. The traditional mass production strategy could not keep up with the market trend, since switch costs for changing to a new product was very high. To reduce this inefficiency in cost and to respond to the need of customers, automakers implemented *product platform strategy*. By sharing key elements among various products in the product family, manufacturers were able to develop new products quickly, and at reduced cost. One of the key concepts of product families is the distinction between common and unique elements, where common elements are used in all product variants while unique elements are specific to a single variant.

However, in recent years, potential drawbacks of the product platform strategy have become apparent. By sharing too many elements among different vehicles, variants were not sufficiently differentiated from each other, losing their unique brand identity. An example of this is the Chrysler K platform, which at one point, was the base platform for virtually every car the company developed (Eun Suk et al., 2007b). What was needed was a product platform strategy that was indeed an effective strategy to reduce development time and cost, while remaining flexible enough to support multiple vehicle variants from a single platform. At the same time, motor companies were under severe pressure to keep costs down to remain competitive in a highly competitive market, with a very low profit margin. As a result, companies are now trying to reduce the number of vehicle platforms, since each platform costs upwards of a billion dollars to create and sustain. New strategies trend implies that each vehicle platform must accommodate a greater number of vehicle variants, thus requiring a wider platform bandwidth in terms of product attributes and system-level design variable values.

As the industry moves toward adopting universal platforms, this hybrid strategy will be adopted by more Original Equipment Manufacturers (OEMs) . A major reason for this is the dimensional and functional flexibility offered by the platforms being developed and used today. These platforms not only support different brands but also different price segments as they are made up of basic components used in all types of vehicles. Fig. 1-1 shows GM starting to lose their market shares to imported, mainly Japanese, automakers.

Japanese automakers are better prepared to adapt quickly to market change and they are ahead of their counterparts in North America by 3-5 years in terms of product/process management. The key to the flexibility in their manufacturing systems is that the people who design the cars are working closely with the people who are building the cars; systems and car designers have offices in the body shop (Brown, 2004).

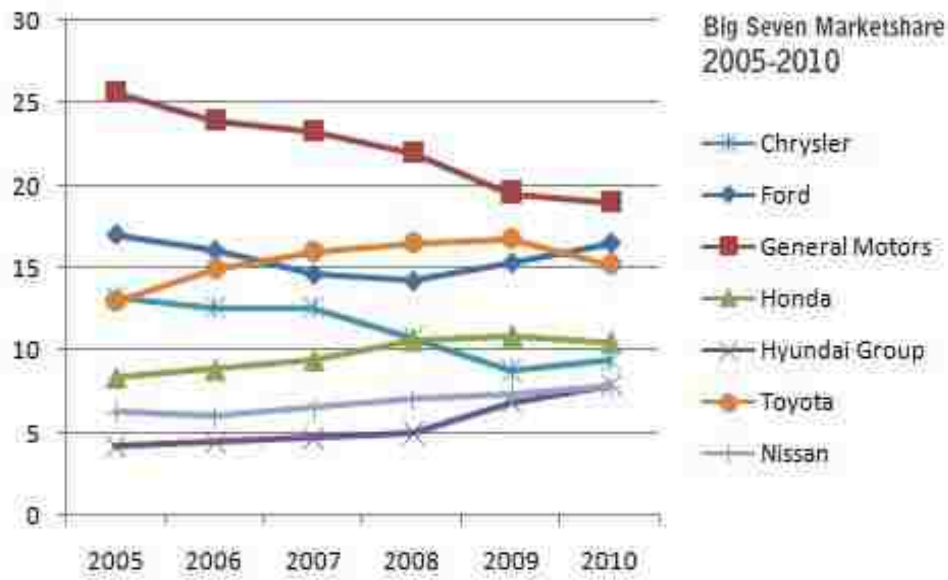


Fig. 1- 1: GM market share sources (sources: City-Data.com)

In today's global economy with open and unpredictable market changes, new enablers are needed in both product development and manufacturing systems (Wiendahl et al., 2007). Car makers, in particular those of North American origin, explore economies of scale and scope through globally shared features of their products, such as: (1) common vehicle development, (2) collaborative engineering processes, and (3) unified manufacturing processes. Manufacturing enterprises are forced to reassess their production paradigms, so that their products can be designed to maximize potential achievable variants, while the manufacturing systems that make them can be designed to operate efficiently by robustly accommodating future product changes, minimizing time to market, and providing reliable production base. Manufacturing facilities have to possess a high degree of flexibility enabling mass customization of production.

Mass customization is the capability of a firm to offer high product variety, high overall volume, and at the same time, low cost, and fast delivery. Modularity is one of the primary means of achieving market demand (ElMaraghy, 2011). Mass customization was brought in as a way of addressing the growing fragmentation of the automotive markets. It has, however, brought in almost unmanageable growth in a number of car models and corresponding car platforms. In 2008, for example, General Motors offered 70 models across eight brands, while at the same time Toyota had only two brands and about 30 models (Qiang et al., 2004). As a result of its bankruptcy and reorganization, GM sold off some of the brands and tightened the product lines. Leading car manufacturers realize that in volatile global markets, they have to adopt new production and assembly concepts of automotive framing systems that will improve their profitability. Multiple models can now be assembled on a single production line. This maximizes efficiency and allows companies to respond quickly to customer preferences through the use of reprogrammable tooling, such as robotics, with smart end-of-arm-tooling (EOAT) and reconfigurable gates (inner/outer assembly framing) in the body-in-white (BIW) shop, standardized equipment, and common build sequence in final assembly.

Typically, more than 80 percent of the tooling and equipment in a body shop are not specific to an individual model, but can be used for all models produced (Vlasic, 2008). It can be programmed to weld various models, such as sedans or SUVs. In a paint shop, all equipment is programmable to cover all styles efficiently and cost effectively. In the final assembly, all major automakers are building more models, derived from global platforms, on the production lines that can simultaneously handle multiple products allowing for efficient utilization of people and equipment.

The main processes are grouped into four stages as shown in Fig.1-2: Parts stamping and modular assembly, BIW framing, paint, and final assembly. The second stage is the final assembly process; (automotive framing process) as shown in Fig.1-3, consisting of a common under-body complete (BIW platform), followed by the inner/outer framing. Inner framing, creating the car body structure, together with the outer metal panels (skin) define the vehicle styling, which in turn are tied to vehicles' unique visual features.

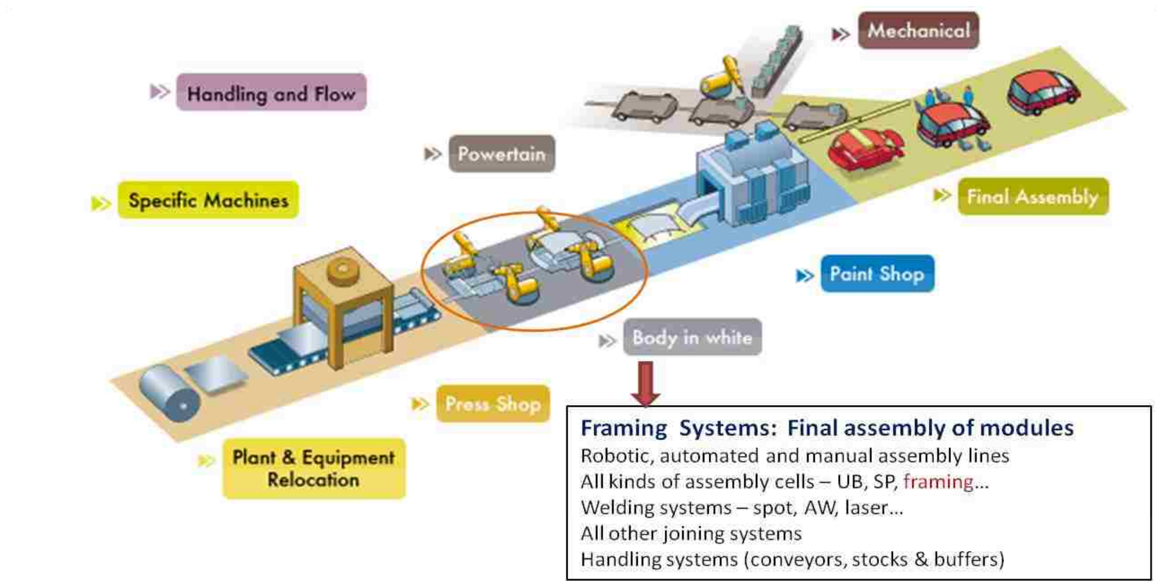


Fig. 1- 2: The Four main activities in factory complete process of vehicle production (Adapted from: Actemium.com, 2012)

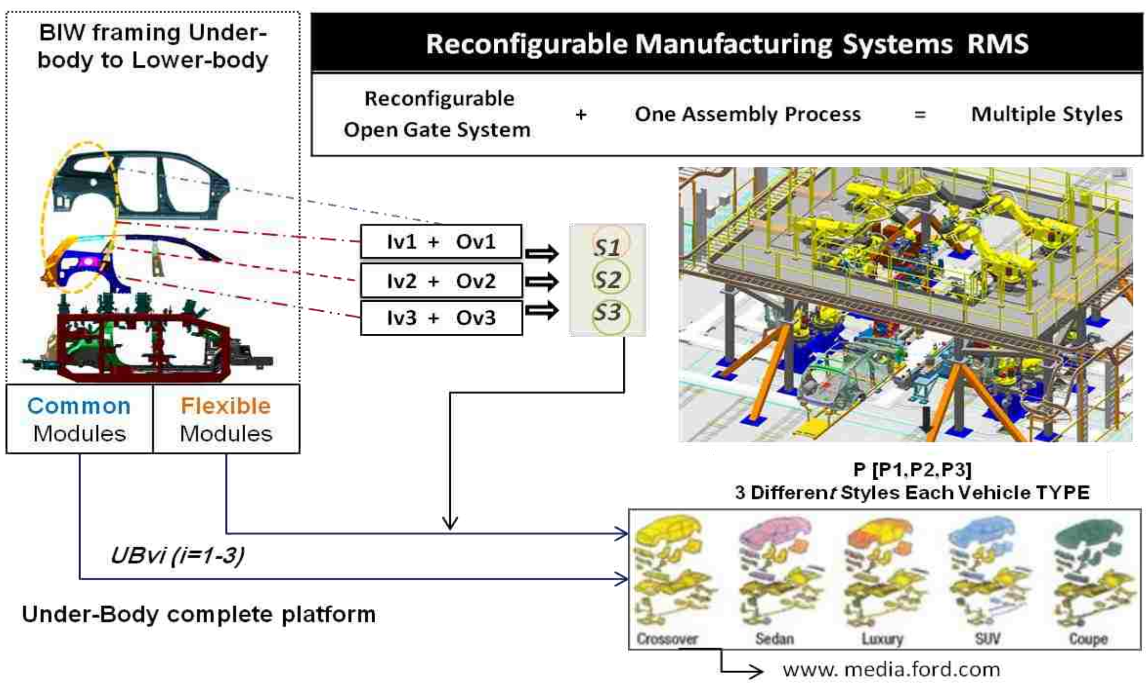


Fig. 1- 3: Under-Body BIW Platform and Vehicle Styling

1.1.3: Overview of Product and Production Developments

Platforms can be defined as common infrastructures that serve as a backbone for multiple product variants. This can include common components, processes, and interfaces that allow end products to achieve unique variety in their product attributes by adding unique elements to product platforms. Unique elements are only found in individual variants, but not in the common platform. Thus, the classical distinction is between unique parts, which are only found in one variant at a time, and common parts, which—taken as a whole—form the product platform.

Product platforms was redefined by Eun Suk et al (2007a) as follows: An infrastructure (system) that consists of common and flexible elements (components, processes and interfaces), which enables production of distinctive product variants and product families by adding unique elements, without changing common core elements.

The goal of the work in this dissertation will focus on the production systems to add flexibility to the key components of the production systems (main function) to allow a quick adjustment (or modification) to accommodate a pre-defined product family. Fig.1-4 shows the relationship between the product platform and product family. The product family variant is the combination of the product platform (common modules) with common elements and flexible elements. The lower-body is considered as common modules for each segment product family, i.e., an example of three styles of P1-segment are P1 (S1, S2, S3).

The upper body is a combination of common elements (CE) and flexible elements.
Common elements (CE), when combined with one of the unique elements (A, B, and C), becomes the upper-body (UB). When one variety of the upper-body (UB) is secured to a common lower-body (LB) to produce one style of product family, this process is called the framing systems of car body BIW. This process is performed by three functions; loading modules to the under-body platform, then using gate tooling to accurately position all modules according to pre-set defined positions.

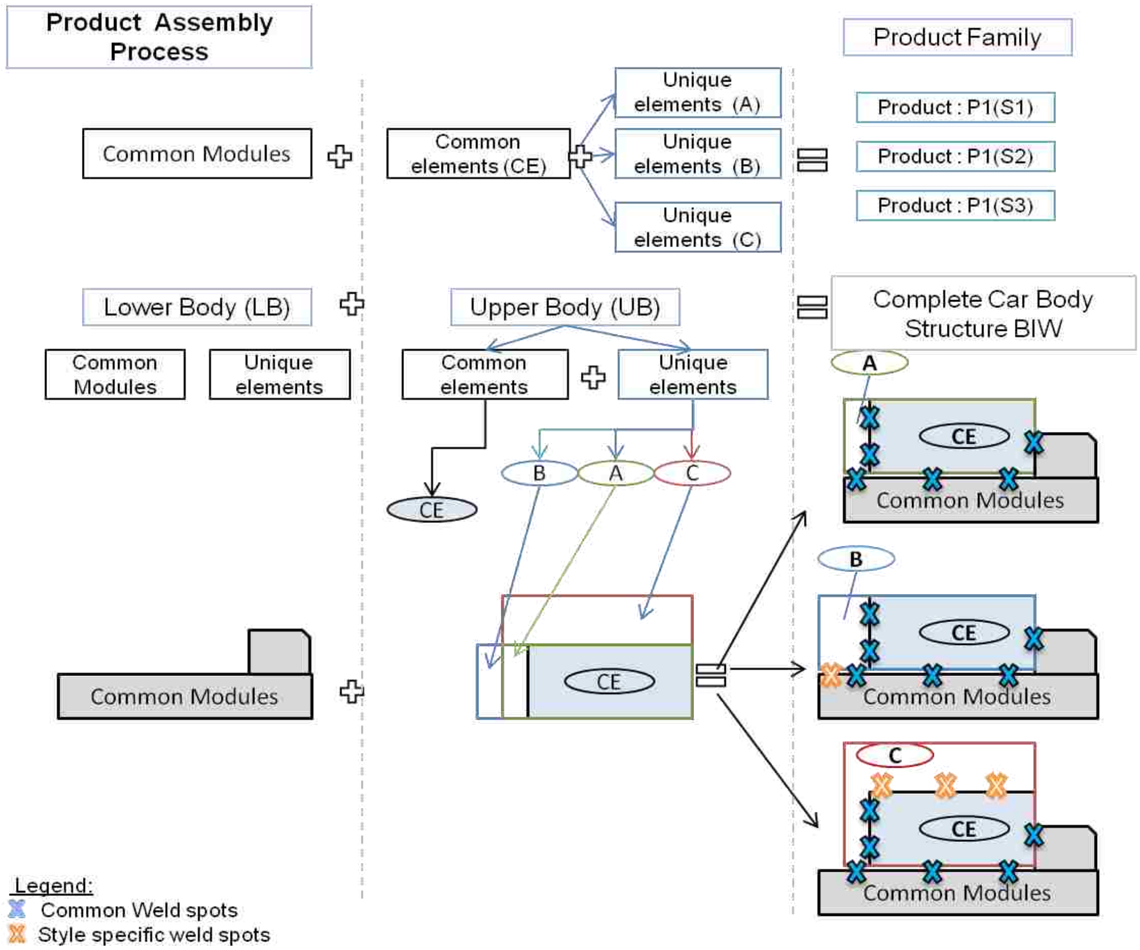


Fig. 1- 4: Under-body BIW platform and product family (vehicle styling)

The third function is the joining process (minimum weld to freeze the geometry of modules) as shown in Fig.1-6 a, b, c, and d. Each module was represented as an assembly of sub-modules or components interface (physical connection) between common modules and flexible modules of upper body to lower-body. The author of this work has established and categorized three groups of connecting elements (CP, SC, TP) between all modules (Al-Zaher et al., 2011). The modules are listed as follows:

- M1: common module (under-body),
- M2: BS (inner assembly contains two parts below the beltline (M2_c) and above the beltline (M2_f)
- M3: D-Ring modules
- M4: Roof R/F header

Modules are connected through flexible elements; the three connecting groups are as follows:

- CP: common positioning between the common elements (below the beltline) and the common modules (under-body platform) see Fig. 1-6, c
- TP: top positioning and connecting top modules to upper M2-F
- SC: surface controls used as flexile controlling points (programmable device; smart device) while securing connection.

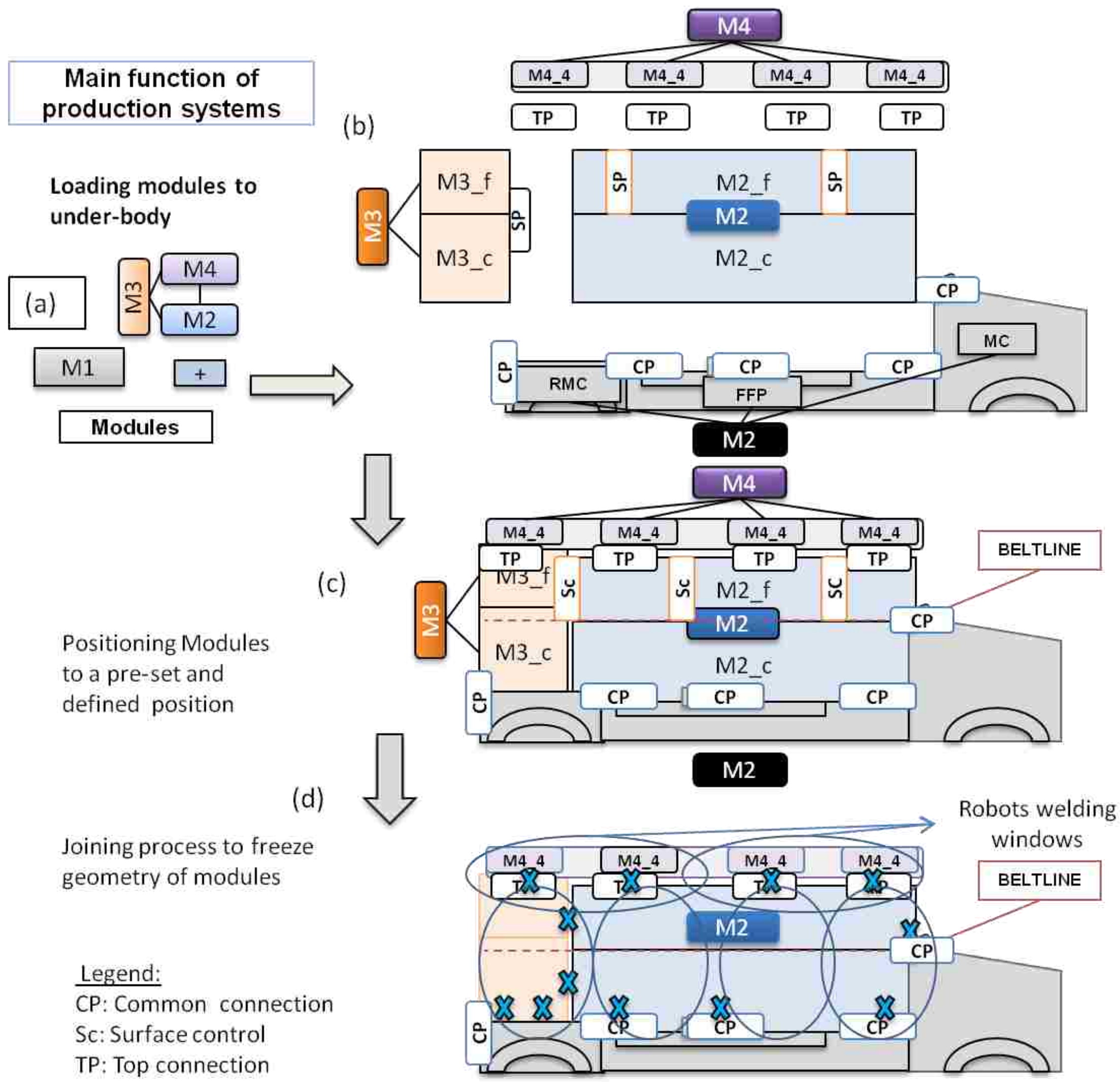


Fig. 1- 5: Assembly process of under-body BIW Platform and upper-body modules

Flexibility is embedded within these components within a top connection, and the lower has flexibility but needs to be common across a family product and as a function requirement in a multiple style to achieve commonality below the beltline.

The third function is the joining process; spot-welding with a servo-trans gun is assumed for inner framing. (Fig. 1-6 d) shows weld spot locations are common for all styles for the first style, but then there are changes in the second and third styles. The new welds are associated with unique elements.

Due to the high cost of producing the under-body platform, a new trend in the under-body development in the last few years included flexibility to create a new function to accommodate new product segmentation. On the other hand, production systems need to economically accommodate these changes, and the basic objective of this work is aimed that direction.

1.1.4: Requirements of Manufacturing in the Global Environments

The common theme in the requirements of future manufacturing systems, in particular, the automotive framing system, is to respond to changes as needed. Reconfigurable manufacturing systems are capable of altering their functional ability to satisfy system requirements more economically. An enterprise can survive only if this objective is achieved appropriately. The manufacturing environment has a great impact on the performance of a manufacturing system. Current environment has some critical requirements for a manufacturing system (Bi et al., 2008). These requirements are briefly summarized as follows:

(i) Short lead-time. Product lead-time affects the performance of a manufacturing system in different ways (Smith, Reinertsen, 1997). Early product introduction is an advantage over the competitors and increases peak sales. The earlier a product is made, the better its prospect is for obtaining and retaining a large share of the market and bringing a higher profit margin.
(ii) More variants. Products become versatile and customized. Versatility implies a product needs more components for additional functions and features. Customization means a product has options for individual tastes (Tseng, Piller, 2003). A manufacturing system is forced to produce more product variants to meet fragmented, sophisticated, and personalized needs (Simpson, 2003).

(iii) Low and fluctuating volumes. The required volumes of many products are falling since: 1) the limited market niches are shared by global competitors; 2) the life cycle of a new product becomes shorter and the durability of the product becomes longer; 3) different-generation products exist on the market at the same time; and 4) product customization has fragmented the entire market demands into small portions.

(iv) Low price. The product price is a primary feature to most of the customers. On the one hand, the globalized market offers customers with more windows to purchase low-price products with the same quality and service. On the other hand, the price is heavily time-dependent, and the price margin can reach its limit very soon after the product is introduced into the market.

Many other requirements, such as quality and durability, are not discussed here since the customers tend to regard them as essential features of a product.

1.1.5: Literature Review of Automotive Framing System

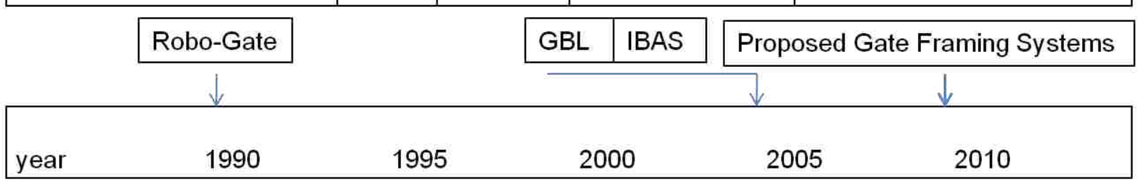
I) Gate systems used in framing systems

As production requirement increase, different systems evolve for the BIW structure. The focus of literature is on the Gate line (more details in Ch 3). Different concepts of framing have been developed with the objectives of high productivity, assured quality, and flexibility of framing becoming more demanding as requirements of the automotive. Framing systems development (Drishtikona.com, 2012) were is summarized in Fig. 1-6; shows the three types of framing gate systems and the number of styles can be run through the systems with switching Gate (y: need change over) or dedicated gate (N: no need for change over). The three types are: (1) Robo-Gate, (2) Open-Gate, and (3) Flexible and Reconfigurable Gate under R&D.

ROBO-GATE: Model Specific Framing Station; in prior automotive framing systems, a gantry position is above the assembly station at the midpoint of the conveyor line -Robo-Gate framing System (Ray, 1999). The gantry includes swing arms which move between a raised and lower position. In the raised position, which is the tooling positioned away from the body, it allows the body preassembly to transfer by skid and conveyer systems to the assembly station. The downward positioning, which is called the working position, involves blocks and clamps and are engaged with body reference (35- 50 CD and NC location) in predetermined positions of body components. At working position, robots weld through openings (60 - 120 WS) in the reference frame prior to re-spot. The issue with these types of framing is that it is very expensive to manufacture, and subject to wear after prolonged use, and is therefore costly to maintain accuracy. Some of these gates are still in use today.

OPEN-GATE: Recently, this new generation of framing systems has been developed to take advantage of the low cost and mass-produced robots. All these frames use dedicated gates using a mechanism to transfer gate positions between two positions, retract position and working position. The retract position allows vehicles to be transferred in and out of the assembly station. Gates are stored in storage systems, which allow changeover in a very reasonable time but cannot be used for production.

GATE TYPE	GATE	STYLES	CHANGE/OVER	Description
Robo-Gate	1	1	N /A	Model specific framing
Open Gate (5-8) new	1	3+	Y	Gate per/style/ storage mechanism needed
Toyota GBL (recent)	1	3+	Y	Gate per/style/ storage mechanism with special M/H
Nissan's (IBAS)	1	3+	Y	Gate per/style/ storage mechanism needed
Reconfigurable Gate	1	3 +	N	Reconfigurable Gate



Legend:
N/A: Not Applicable
Y: Storage Mechanism needed
N: Storage Systems not Needed

Fig. 1- 6: Vehicle framing historical development

Fig.1-8 shows the activities of the main functions of the vehicle framing systems. The three main functions which are considered for incorporation flexibility are:

1. Geometry (Positioning) function which includes all necessary means to ensure accurate positioning of parts in relation to each other;

2. Handling (Transferring) function which includes all equipment necessary to move parts, tooling, etc., and here, accuracy level is lower than required for geometry function;

3. Process (Tooling) function which includes all equipment adding value to the product being manufactured (welding guns).

<u>Most of the issues with these Gates</u> are in the geometry functions. All geometry stations are styles specifics, using storage mechanism to switch between styles. Some use units with a pivoting point to reach over to a reference block, increasing the complexity of the tooling, and increasing the weight, cycle time, changeover, gates storage systems, and overall cost. Lead-time for engineering and built time may take up to 6 to 10 months.

New trends in automotive gate systems are moving toward running more variants of the same family using the same tooling and the same process. The way to accomplish this is by moving to modular structure for the gate station, embedding flexibility and reconfigurable capability for the top and rear end of the gates

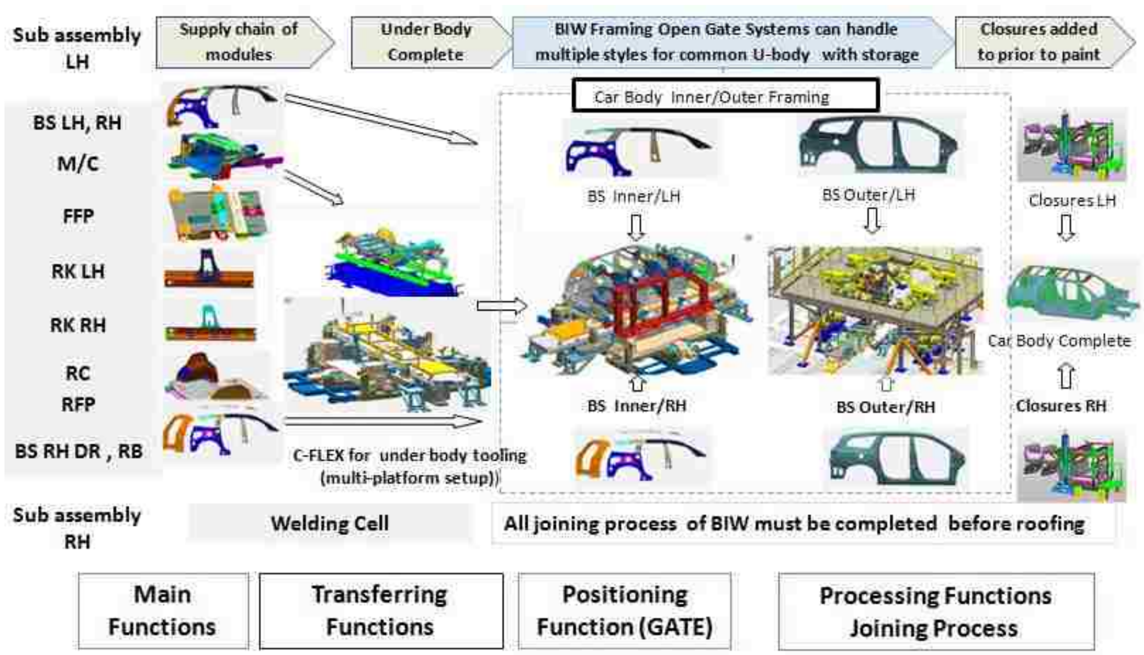


Fig. 1- 7**:** The main functions in framing systems

Toyota GBL uses different approaches. Japanese approaches cannot be applied to North American automotives (Brown, 2004). The modular concept allows the addition of standard tooling change equipment (front or rear magazine, lower magazine change) as phased investment. Loading of different parts as body sides, roof bows or reinforcements directly in the geometry station is not considered in the proposed approach to the Reconfigurable Open-Gate Framing Systems (Proposed Gate systems - ROGFS). It is important to acknowledge the work done by VW and BMW in the final assembly of vehicle framing systems on modules assemblies and under-body complete.

II) Previous methods

Fig. 1-8 shows a number of methods used in various stages of the life cycle of product and production systems developments. The first stage of the life cycle starts with the initial stage that defines *product functional requirement* to capture first customer needs and then translate them into the functional requirements of the product key characteristics (identify KPCs). A challenge in this stage is the difficulty to define the KPCs in a way that will address customer needs. In mature industries such as automotive industries (the focus of this dissertation) where 90 percent of the product developments are product upgrades, the CRs and FRs should be established clearly with more focus on generating the optimal sets of KCCs to be less sensitive to predefined functionality (FRs changes).

There are many sets of key characteristics controls that can be generated but the challenges in selection or the generation process can be listed as: (a) what selection processes are used to select, (b) how to add flexibility (DOF for KCCs), and (c) at what cost. The most widely used methods are the Axiomatic Design (AD) and Design for Manufacturing and Assembly (DFMA). The AD approach is based on the top-down design process. The design solutions are then evaluated and selected based on two design criteria defined as independence axiom and minimum information axiom.

However, AD does not emphasize on designing the detail configurations of KCCs to control KPC variations within specification targets. On the other hand, DFMA-based approaches focus on minimizing assembly cost by providing heuristic guidelines that can reduce a number of potentially unnecessary KPCs and KCCs. Steward, (1981) DSM proposed methods used to address these challenges by using a matrix to represent the interdependencies of design tasks as well as heuristic procedures to reduce the complexity caused by these interdependencies. Eppinger et al. (1994) and Browning (2001) presented the DSM hybrid model where the relations of activities and parameters are defined in the same matrix. In the CAD/CAM environment, the ability for adjustments of design configurations is still based on design experience.

However, the DSM approach depends on previous expertise which makes it more appropriate for automotive aerospace industries to capture the previous knowledge (Browning, 2001). DM, DSM, and DMM will be used in the dissertation. The proposed new framework is a concurrent approach for all the stages of the project life cycle. The goal of this approach is to establish a database for systems designers to depend less on experienced engineers.

The proposed methods (framework design) were added to Fig. 1-8 to show that the proposed framework presented as end-to-end process; from the product development, design for product, and production systems to production.

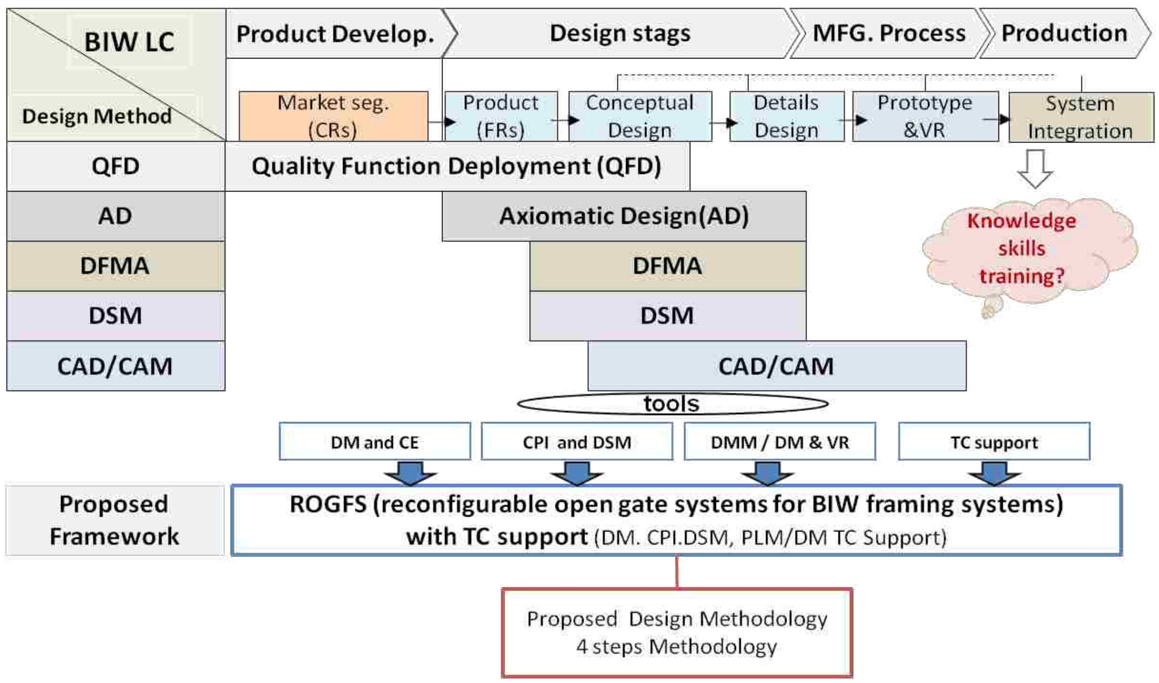


Fig. 1- 8: Previous related work - research gap (Adapted from Phoomboplab, Ceglarek, 2007)

1.1.6: New Trends & Challenges of Framing Systems for OEMs

Definition of automotive framing systems BIW; Framing system is a process and the related infrastructure for a precise positioning and securing car body components, such as, under-body platform with the upper body components (Baulier, 2010).

A number of recently developing trends have a significant impact on future designs and use of automotive framing systems. In car design, OEMs are moving toward smaller vehicle platforms, new electrical vehicles with flexible platform structure (due to fuel economy demands). Currently, no viable alternative to steel as car body material is considered. As a result, current solutions for car bodies (e.g., welded steel panels) will be around for at least another two decades, and so will be the systems to manufacture them. Interest in solutions aiming at reducing the body weight by using ultra high strength steels (UHSS) is growing. New part designs involving UHSS enable re-design of components, which until now remains integral, and brings in subcomponent modularization, possibly facilitating faster redesign cycles.

The challenge, however, is the integration of UHSS welding processes into the existing manufacturing systems. Other notable trends in automotive industries are: (i) increased use of the product life-cycle management (PLM) environment throughout the enterprises, and (ii) growing concern for the automotive industry, OEMs, and suppliers alike to sustain profitability and growth. The technological changes and operational economics have a big impact on the complexity of decision making. Decisions require a broader set of communities, both internal and external to the enterprise. OEMs and suppliers must ensure that they have the necessary information to make the right decisions on all levels.

1.1.7: The Main Issues with Current Framing Systems

The key issues with the current systems' layout systems shown in Fig. 1-9 (Al-Zaher et al., 2011) can be summarized as follows:

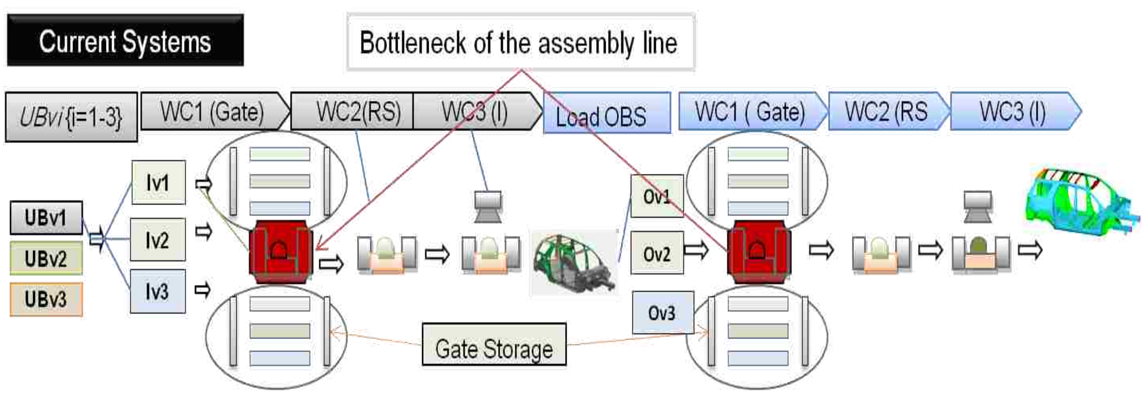


Fig. 1- 9: Current practice of automotive framing systems using Gates storage systems

- Currently, the gates structure are integral and strongly coupled design; (resulting in complex coordination of motion for some work units moving after the gate is in already in the working position; increased both mechanical complexity and overall weight).
- Changeover times have to be accommodated for in the production plan, as the line has to stop running.

- Gates storage systems require significant amount of floor space.
- Overall high cost, high lead-times for engineering and build time.
- Very expensive to manufacture and maintain.
- High cost of lost production due to downtime (breakdown or retooling).
- High risk in capital investment.

1.2: Research Motivation and Background

In today's open and global economy, customer demands are constantly changing to more variety of product, and better quality at a low price. This new shift in the market has increased the need for product variety, in which variety and customization replace standardized product (Siddique, Boddu, 2004). For manufacturing companies to stay profitable, they are forced to satisfy a wide range of customer needs while maintaining manufacturing costs as low as possible. The new proposed framing systems should address some of the issues with the current systems:

- To run multiple styles of the same family without changeover (switching gates)
- To improve throughput of the production systems
- To reduce time in launching a new product.

Manufacturing is forced to seek more efficient and flexible manufacturing, and assemblies for their product. In product development, the platform strategy attempts to save cost by sharing core elements among different products in the product family. There is significant research done in this field, but in the manufacturing and assembly systems, there are still many opportunities for research. The reason for that, as mentioned earlier, is that there is no collaboration between product development and manufacturing systems (production and operation). In this dissertation, the focus is on creating flexibility in the manufacturing processes, tooling, and equipments that are matching to the product developments. The flexibility and reconfigurability in the manufacturing systems is the property of manufacturing systems that is capable of adjusting to new change in product within reasonable time. The challenge here is to identify places in the production systems, tooling, equipment, and manufacturing process to embed flexibility, and finding how much flexibility is needed, and the cost associated with it.

1.3: Dissertation Problem Formulation

1.3.1: Axiomatic Design Principles (AD)

The axiomatic design methodology begins with the identification of customer needs and the conversion of these needs into a set of one or more high-level functional requirements. The goal is to develop the minimum set of independently achieved requirements that completely characterize the desired functions of the design (Suh, 1990). *The Axioms are formally stated as*:

Axiom 1: The independence axiom maintains the independence of the FRs.

Axiom 2: The information axiom minimizes the information content of the design.

The first axiom states that when multiple FRs exists, the design solution must be such that each FR can be satisfied without affecting the other FRs. When this objective is achieved, the design matrix will be diagonal, as each DP will affect only its associated FR with no coupling occurring in the off-diagonal elements. Such a design is said to be uncoupled. In cases where independence is not achieved, two possibilities arise: a) In one case, the design will be partially coupled, meaning that the rows and columns of the design matrix can be interchanged such that the matrix is upper or lower triangular; b) When off-diagonal elements exist and the matrix cannot be rearranged to a triangular state, the design is said to be coupled. Fig.1-10 shows the three different systems in FRDP (DM) forms.

An acceptable design is either uncoupled or partially coupled, a partially coupled design is said to be path dependent.

	DP_1	DP_2	DP_3
FR_1	X	O	O
FR_2	O	X	O
FR_3	O	O	X
Uncoupled System			

	DP_1	DP_2	DP_3
FR_1	X	O	O
FR_2	X	X	O
FR_3	X	X	X
Decoupled System			

	DP_1	DP_2	DP_3
FR_1	X	X	O
FR_2	O	X	O
FR_3	O	X	X
Coupled System			

Fig. 1- 10: Three different systems FR – DP form- AD matrices (Suh, 1990)

The design equations have the following forms: For the transition from

- FRs to DPs and DPs to PVs:
- [FRs] = [A] [DPs] (1.1)

- The elements of A are given by:

$$Aij = \frac{\partial FRi}{\partial\, DPj}$$

This equation is used to observe sensitivity for each FR with respect to the corresponding DPs which reveal which DPs can be more candidates for flexibility.

- [DPs]= [B][PVs]. (1.2)
- Where; [A] and [B] are called the design matrices
- [A], is the design matrix relating FRs to DPs and characterizes the product design.
- [B], is the design matrix that defines the characteristics of the process design.

Equations (1.1) and (1.2) are design equations for the design of a product. The information axiom provides a quantitative measure of the merits of a given design, and thus is useful in selecting the best among those designs that are acceptable. Any changes in the FRs in the future must incorporate flexibility in the system to be able to absorb the change. If flexibility is incorporated in DP1 for uncoupled and decoupled systems, other DPs and FRs will not be affected by change in FR1.

However, it is no longer the case with the coupled system. DP1 and DP3 are candidate DPs for the coupled system. For uncoupled system, DP1 and DP2 can be independently changed to accommodate future uncertainties in FRs. For the decoupled system, the flexibility can be incorporated into DP2 to accommodate changes in both FRs, or DP3 can be flexible as well. In the coupled system, it is not clear where to embed the flexibility. Most large complex engineering systems today (including product platforms) are coupled systems, where a single DP may affect several FRs. When a certain FRs trend becomes uncertain in the future, it is very difficult to change the system to meet the goal of that FR, largely due to such coupling and economic impact of making such changes.

- What is systems interaction?

Systems interaction can be defined as the interaction among key design variables in the systems of interest. In this dissertation, the systems are large and complex products, the design variables are either physical parts, or features of the design parameters of product and production systems.

- Why is it important to obtain systems interactions early?

When systems interactions are known, better management and decisions can be made for the product and process (Qi, 2002), and there is a window of opportunity for systems designers to implement flexibility at the conceptual stage of life cycle of the project. Manufacturing engineers and designers must concurrently consider life-cycle issues of products, and all options to re-use, re-manufacture, and recycle. The notion of re-use and recycle is not limited to products, but extends also to tooling, production equipments and processes.

1.3.2: Design Structure Matrix (DSM)

In the case of automotive industries, product development is much more mature in terms of product development, therefore the construction of DMs promote designers to reduce the interaction by a successful transformation of DM into DSM.
There are three steps to transfer DM to DSM(Dsmweb.org):

Step 1: DM construction (Axiomatic Design Matrix)

From Fig.1-10, in the coupled systems as represented below, there are three function requirements (FRs) and three design parameters (DPs) as shown. The "X" matrix represents relation DP affecting FR, and the "O" represents no relation.

	DP_1	DP_2	DP_3
FR1	X	O	X
FR2	X	X	O
FR3	O	X	X
Coupled System			

Each row of DM can be translated into:

$FR1= a_{11}*DP1+a_{13}*DP3$ (1.3)

$FR2=a_{21}*DP1+a_{22}*DP2$ (1.4)

$FR3=a_{32}*DP2+a_{33}*DP3$ (1.5)

Step 2*: Choose the output variables*

Where a_{ij} are coefficients of the design matrix solve for DP1, DP2 and DP3.

DP3= f (FR1, DP1)   from (1.3)   (1.6)

DP1= f (FR2, DP2) from (1.4)   (1.7)

DP2= f (FR3, DP3) from (1.5)   (1.8)

Step 3: DSM Construction

Now the relation among design parameters can be represented in the DSM, the dashed oval indicated the diagonal of the matrix.

	DP_1	DP_2	DP_3
DP_1	X	X	O
DP_2	O	X	X
DP_3	X	O	X
Coupled System			

The choice of output variables?

As shown in Step 2 is not a unique choice because of the coupling. Therefore, the choice of output is unique when the systems do not involve coupling, but rather sequential or uncoupled as shown below.

	DP_1	DP_2	DP_3	DP_4
FR1	X	O	O	O
FR_2	X	X	O	O
FR_3	X	X	X	X
FR_4	X	X	X	X
Decoupled System				

	DP_1	DP_2	DP_3	DP_4
DP1	X	O	O	O
DP_2	X	X	O	O
DP_3	X	X	X	X
DP_4	X	X	X	X
Decoupled System				

- What is the clustering of the DSM?

Clustering is used for grouping all elements that perform simultaneous action that can be grouped.

- What is the structure?

Structure is the most common word used in engineering terminology, and there seems to be very few definitions available. Commonly, the term *structure* is used in engineering for organizational structures and product structures. In mathematics (algebra and model theory), the term *structure* refers to a set of distinct entities, including the functions that transform these objects and the relations among the objects and functions (Oliver, et al. 1997).

The tasks that are presented in the diagram of Fig. 1-11 must work together to execute the overall process. The exchange of information can be presented in either form diagram or DSM.

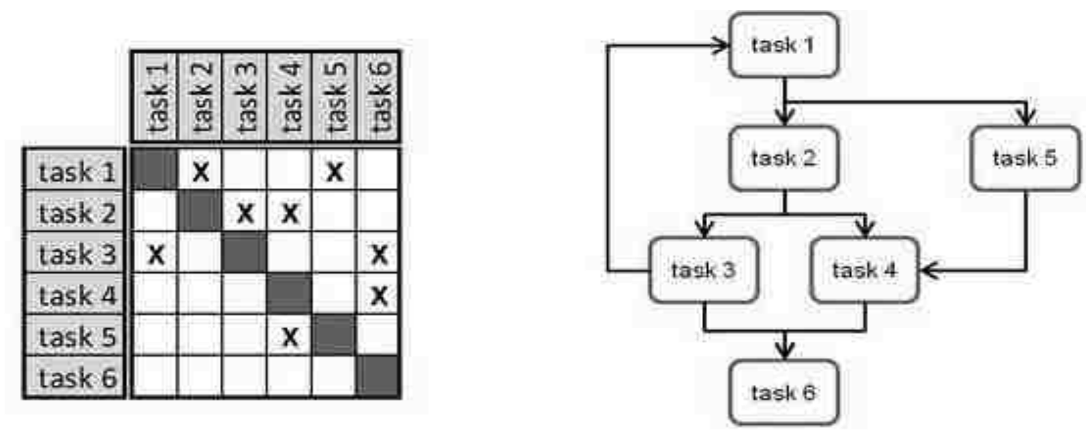


Fig. 1- 11: Binary design structure matrix of a simple process (Sources: Dsmweb.org)

Chapter 4 will introduce the Multi Domain Matrix (MDM), which allows a system's structure to be analyzed across multiple domains.

1.3.3: Axiomatic design approaches to re-design current automotive framing systems

Some of the issues with the current production systems were discussed in previous section, some of the issues becomes automakers requirements for the systems performances are summarized in Table 1-1, as a customer requirements CRs (Al-Zaher et al., 2010).

Table 1- 1: Customer requirements (CRs) in vehicle framing systems

Production Volume (2-3 styles)	**66* Jobs p/h (360.000 Units per/year)**
Maximize safety & reduce weight of vehicle	Use better material UHSS
Reduce cost 50- 80 % of tooling for the addition of new style, to reduce cost	Standardized units and use smart devices common tooling under tooling beltline
Design Reconfigurable gate to eliminate changeover time and storage mechanism	Modular structures to remove systems coupling.
Design constraints	Line Rate (CT) System Layout
o Takt time Cycle time)	55 sec. (Most assembly line rate)
o System layout restriction	JIT Supplies entries to the systems

Production volume per year based on the work-cell cycle time of framing systems, i.e. 66* Jobs p/h (54 sec CT)→ in 3 shift p/day = 22 H) 50 week p/year → production = 360.000 Units per/year.

The challenges in manufacturing system design are the translation from customer requirement to function requirement then to process design. In this section, a high level of FRs and DPs are to be aligned with proposed systems to perform as design. Fig. 1-12, shows the layout of the proposed systems as a solution to address some of the issues of current systems. In the new proposed methods, new tools were introduced to identify key elements (modules physical interface) in the product and production design at all levels at any stage of the design.

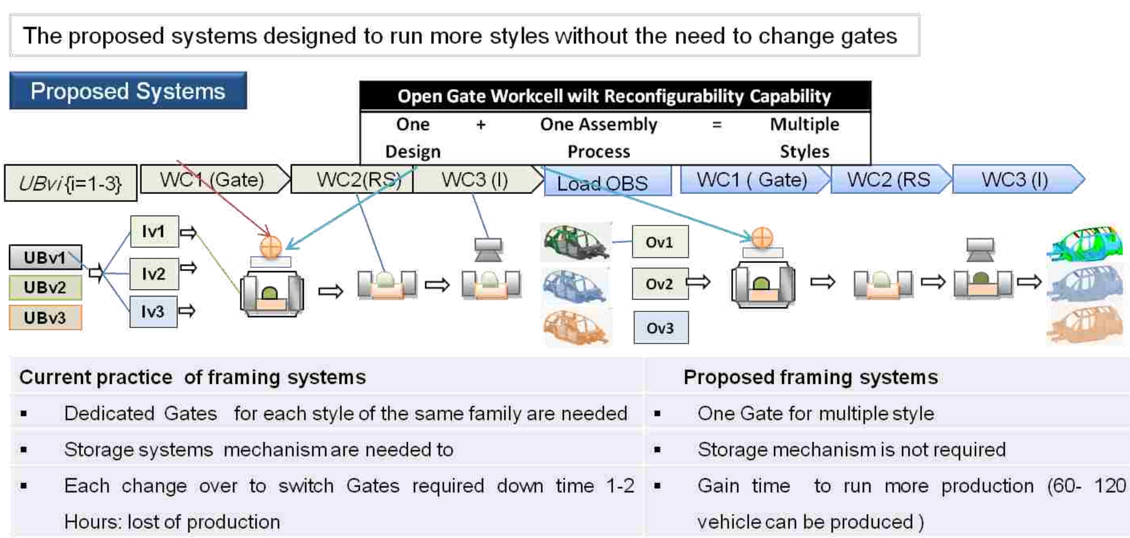


Fig. 1- 12: The proposed systems: to run more styles w/o changeover

In Fig.1-13 different styles of the same product family and commonality were estimated within 70-80% of the product and their production systems. The new proposed methods aimed to reduce this gap in the production systems by impending flexibility and reconfigurability at the early of life cycle of production systems.

The goals of the proposed methods of the framing systems are as follows:

- 1) To create a common understanding between product developer and systems design to process the engineering changes due to product upgrading (markets segmentation)
- 2) To use a common tool to evaluate changes in tooling and equipment.
- 3) To make available upfront the joining process assumption to plan flexibility at the early stage prior to final design of production line.
-

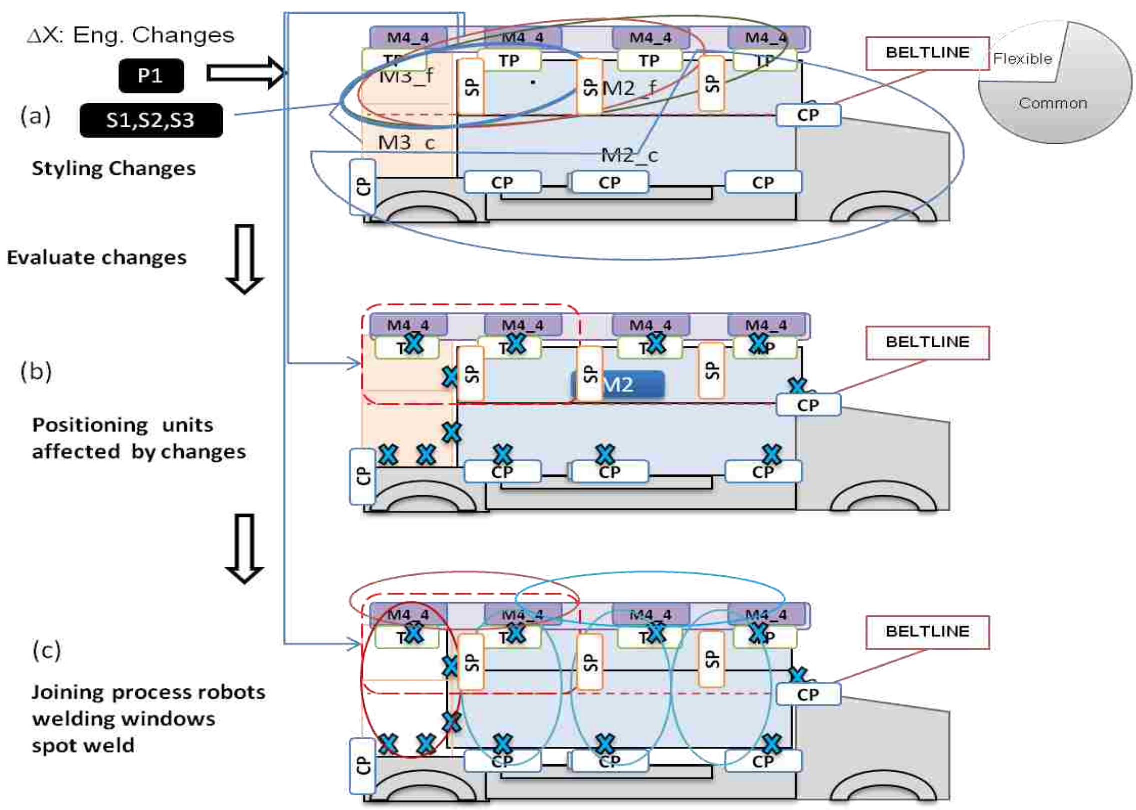


Fig. 1- 13: Commonality and flexibility of car body styles BIW

Fig. 1-14 shows the current proposed *Reconfigurable Open-Gate Framing Systems* (ROGFS); one design has the reconfigurability for the *top units and rear units* that correspond to geometry styling (engineering changes). Top units modules can be driven individually (robotics) or one base moved up and down with smart servo capability to each units, it cost more but the cost are justified by the significant increase in throughputs.

With the proposed framing systems, top units devices are programmable and the design constrain must be clear for the product designer to standardize product features such as pin diameter and orientation of tooling access to secure the assembly (assembly details: non-functional features).

These details were designed by manufacturing and assembly departments based on the selection of positioning and joining processes specification. The commonalities of these parameters are prerequisite to modularization the tooling for position and securing adjacent modular prior to joining process (welding execution).

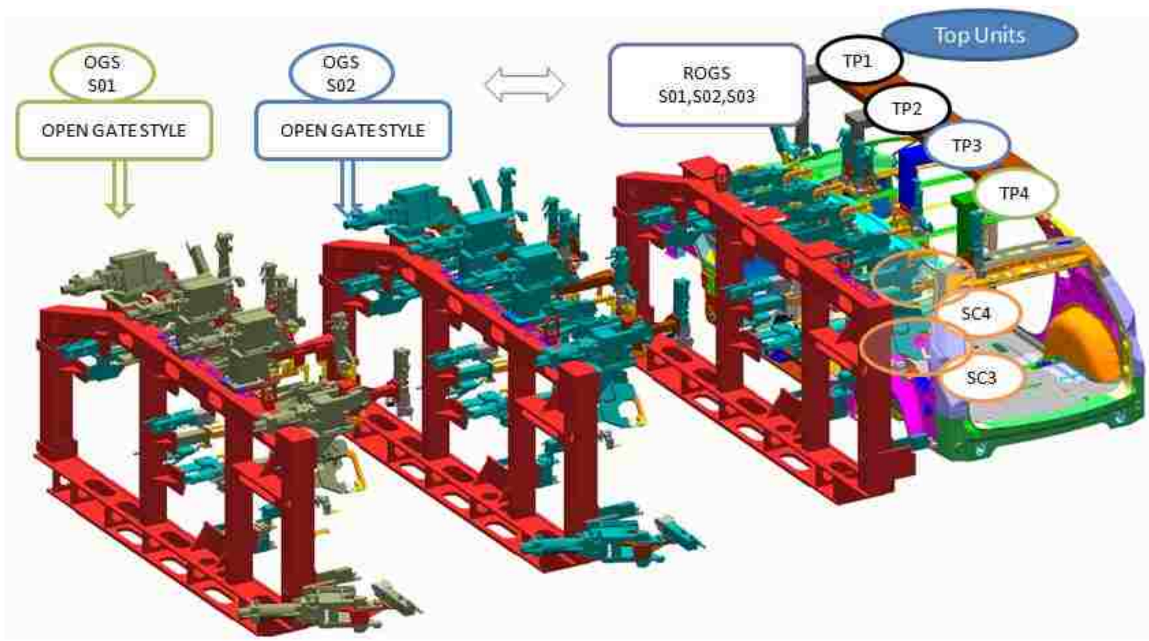


Fig. 1- 14: Proposed Reconfigurable *Open Gate Framing Systems* (ROGFS)

Fig. 1-15 shows the four domains of design. In the case of manufacturing system design, the decomposition takes place in the functional and physical domains. Axiomatic design was used as a tool for designing the strategy as well as the implementation process of the strategy. For this purpose, the terminology in Axiomatic design was renamed based on Nordlund (1996) as shown to be acceptable for the strategic planning using Axiomatic approach in framework design.

The current structure of the current gate systems are integrals and coupled, modular structure for the Open-Gate becomes pre-requisite (reconfigure gate with three modules) to improve line rate (to run different styles variants without extra time for changeover) by incorporating embedded flexibilities in the critical emends with the right degree of flexibility for each modular. System designers need to translate the customer requirement to engineering changes then define the function FRs and DPs at highest level. Mapping between domains must be clear to all managers and departments involved in design decisions.

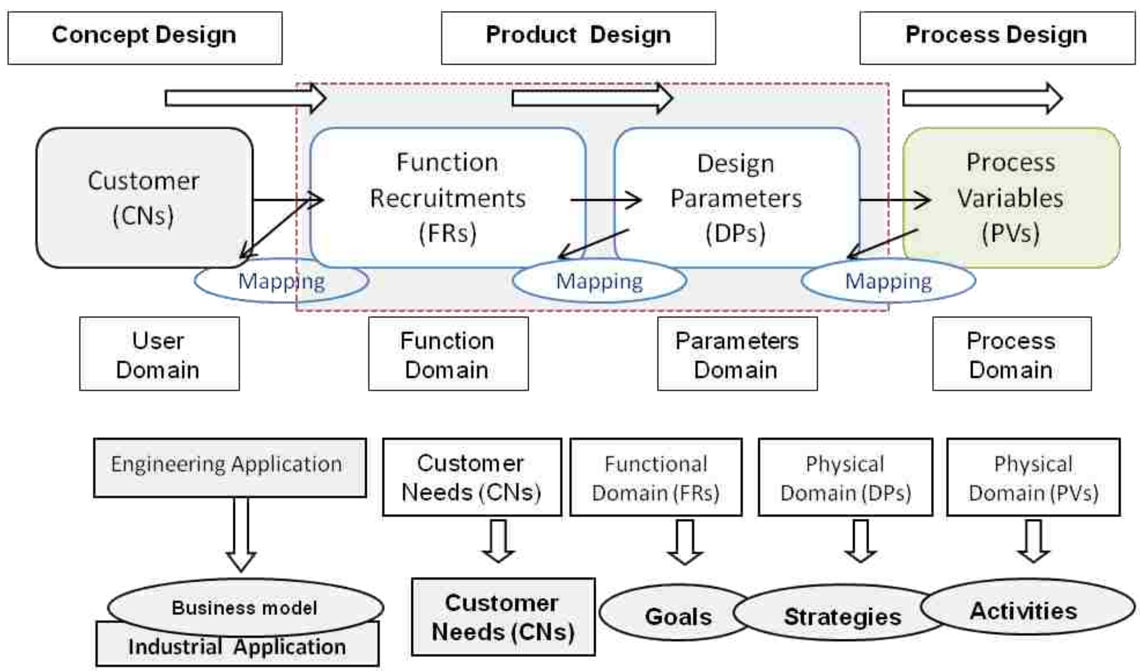


Fig. 1- 15: Axiomatic design applied to Manufacturing Systems strategies (adapted fromNordlund, 1996)

The highest level of FRs is chosen to maximize the long-term on investment by improving throughput of the systems. The relevant design parameter is to design toward mass production. The design matrix of first level is shown in Fig.1-16: as follows:

***Step* 1:** Mapping at the Highest Level FR → DP

FR= Maximize the long-term on investment, the level of FR are list as shown in Fig.1-16

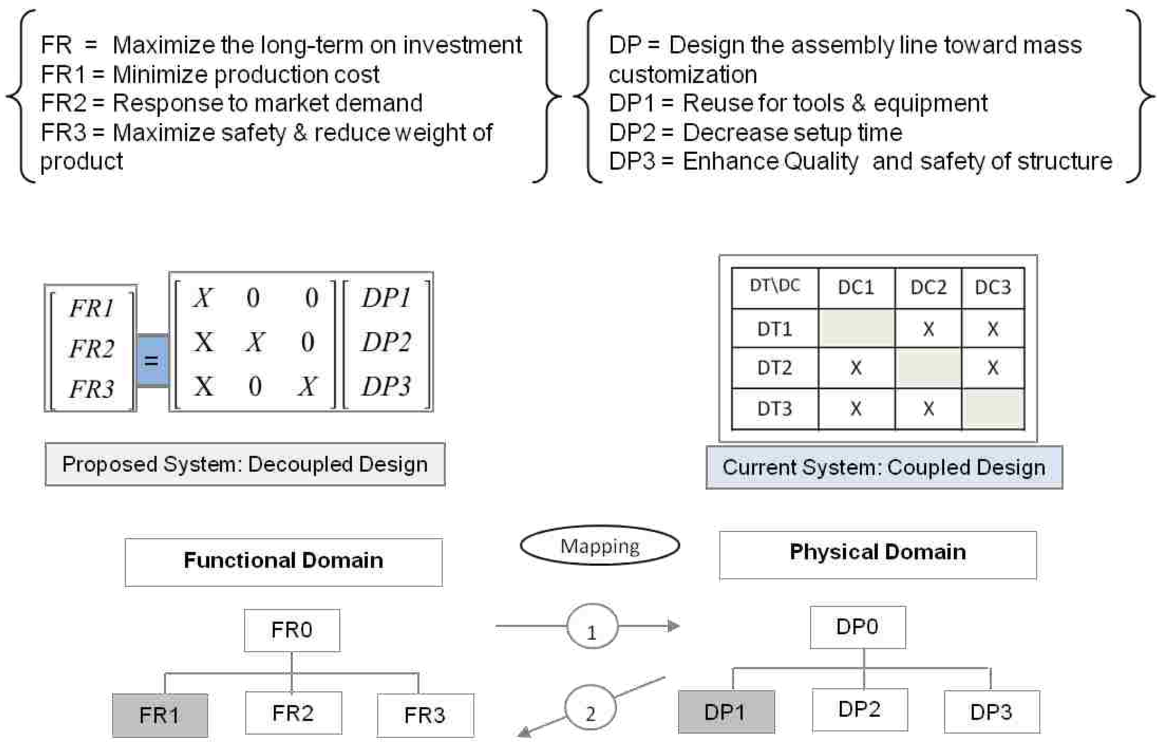


Fig. 1- 16: The first level of developed structure of vehicle framing systems

***Step* 2:** Decomposition by Zigzagging DP → FR

The second level of developing the structure is important to system designers to identify the source of coupling at the early stage then remove the coupling by applying modular structure as shown in Fig.1-17 and Fig.1-18.

Design parameter in the physical domain (DPs) to function domains (FRs), as shown in both in the integral structure and modular structures, are shown in Fig. 1-17. The intent here is to show using modular design of the gate is used to devolve the capability of Open Gate System.

Step 3: Second-Level Mapping FR → DP

The second levels of FRs with the corresponding DPs are shown in Fig. 1-17.

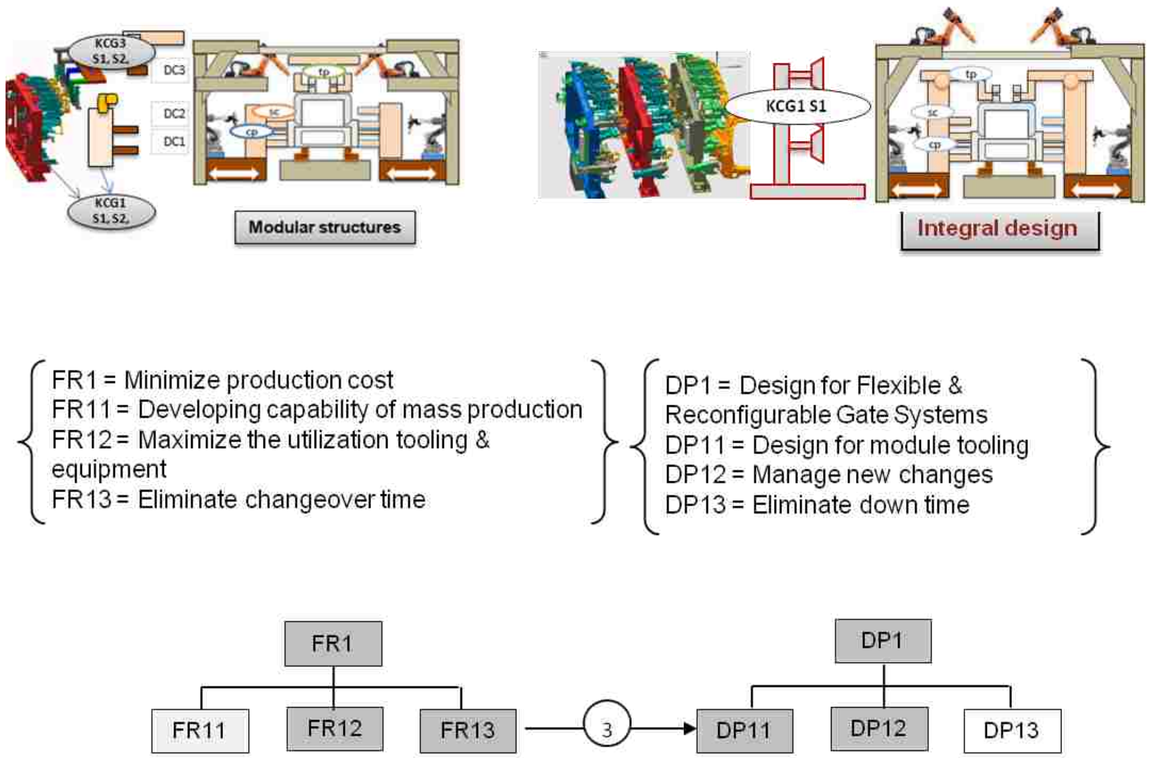


Fig. 1- 17: The second level of developed structure of vehicle framing systems

Because the DPs at the first level are not detailed enough to provide the desired output, these FRs must be decomposed. For the design defined by the selected set of DPs, FR1 may be decomposed into FR11 and Fr12 as

Step 4: Zigzagging Back to the Functional Domain DP $\longrightarrow$ FR

At the third level of decompositions, the designer must choose the parameter of positioning function and joining function to satisfy the design task as decoupled modules.

[DTs] = [A] [DCs] (1.9)

[DT1] = [CP_i] [DC1]+ [SC_i] [DC2] (1.10)

CP: represents the design matrix with constant variables (below the beltline)

[DT2] = [SC_i] {DC2] (1.11)

[DT3] = [TP_i] [DC3] (1.12)

DSM of 1.12 represents the top reconfigurable parts of the gate design.

Step 5: Third-Level Mapping FR → DP

Minimize production cost.

At the final level, designer can establish relation between multiple-layers of domain. Product requirement at the design stage (product features and characteristics) to achieve capability at the production level; modularity of tooling common tooling below beltline and flexibility and reconfigurability at the top and rear units see Fig. 1-18.

Now the decomposition process is complete because the highest level FRs can be controlled by the DPs selected. The lowest levels, FRs of each decomposition branch are leaves of the hierarchical tree. Relation of design parameters to design variables (design constrains) to accomplish the design objective: flexibility and reconfigurability of the Open Gate framing System.

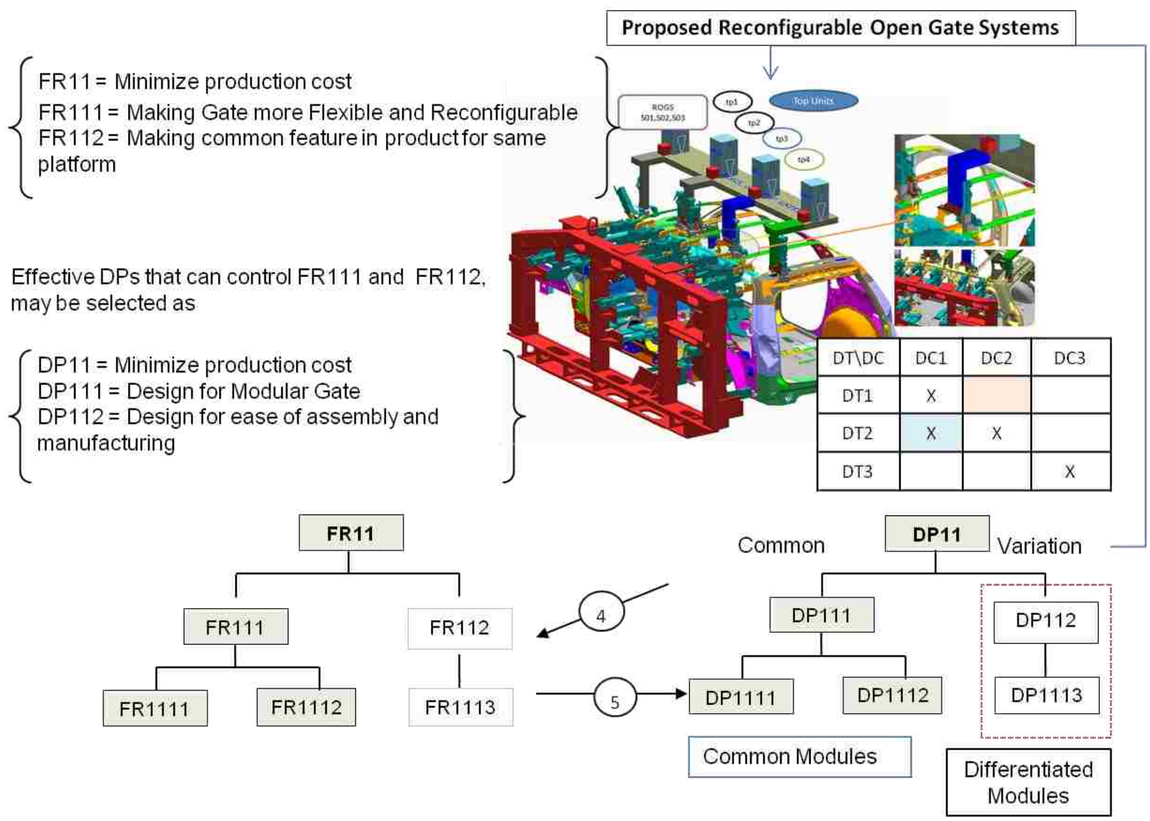


Fig. 1- 18: The third level of developed structure of vehicle framing systems

The application of Axiomatic design technology is used at high level to educate designers and systems engineers to recognize the coupling in the physical systems and how they are related to engineering changes (function requirement) by:

- formalizing the conceptual design process into a continuous and measurable activity driven by requirements,
- communicating the state of the design to all stakeholders,
- improving quality of design by analyzing and optimizing design architectures, and
- clearly documenting and communicating the logical "how and why" of a design.

1.3.4: Research Objective

The main objective is to develop a framework design process (*methodology*) for production systems of *automotive framing assembly* that is robust, cost effective, and quickly adapts to market change. RMS is the next generation of world class systems (Mehrabi et al., 2000, El Maraghy, 2005). The new proposed framing systems should address the issues with the current production systems and fulfill the needs of the market dynamics by:

- robustly accommodating the growing number of product variety within a family without the need to switch tooling (to improve throughput),
- utilizing standard components (platform) to reduce cost, improve maintainability and quality,
- extensively utilizing math-based engineering concepts (to validate the production process prior to physical implementation) and PDM/PLM/ Teamcenter to facilitate broad engineering collaboration,
- developing and enhancing new manufacturing strategies and operational tactics,
- resulting in significant throughputs increase.

The proposed design of the framework is considered a problem solving process approach which consists of the four main stages, with three transitional stages, and the fourth stage being the parallel stage as shown in Fig.1-19. The stages are (1) Manufacturing Systems analysis, (2) Manufacturing systems design, (3) Manufacturing Systems operation & maintenance, and (4) is the refine offline gate combined with support center (Teamcenter with platform capabilities). Reconfigurability of the systems is represented by the third stage or the extension of the life cycle of production systems, when new changes (product upgrade) within the pre-set boundaries of systems design variable, such as horsepower, wheelbase, track, and material properties to improve safety of vehicle body structures. Detailed formulation of the process is presented in Chapter 5.

The framework provides a guideline to support and to structure the different stages of the design methodology. The process starts with:

Stage 1: Manufacturing Systems Analysis; Diagnostics Stage

The manufacturing systems analysis is the first stage of the life cycle where the formulation and definition of the manufacturing system is performed to satisfy specific needs. The main constraints at this stage are the manufacturing strategy, the characteristics of the product, and the process.

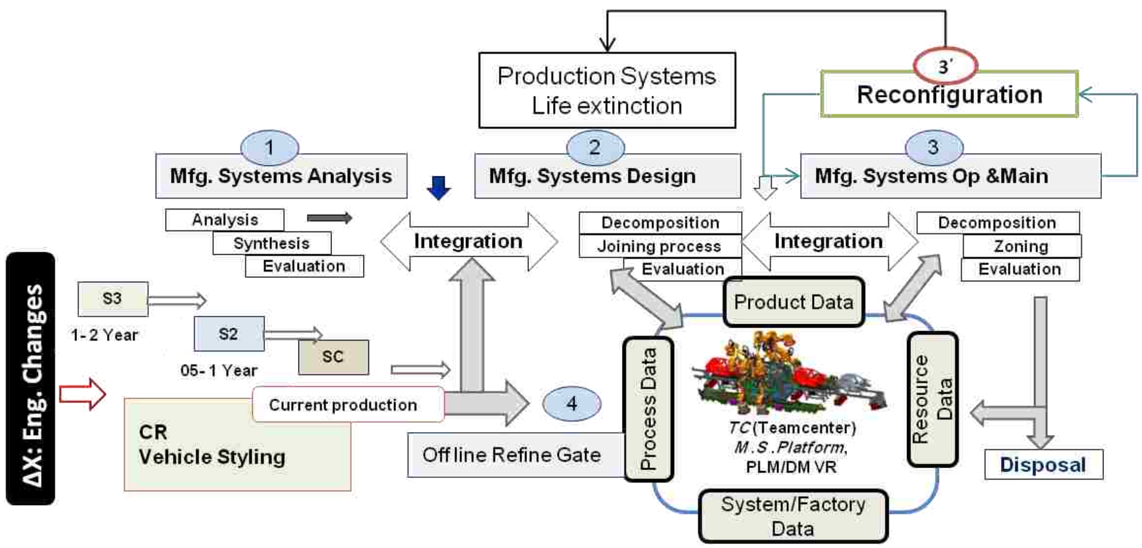


Fig. 1- 19: Framework for RMS of proposed automotive framing systems

Stage 2: Manufacturing Systems Design (PD & MD) - Synthesizing Stage

At this stage, more focus is given to the manufacturing process and production systems than the products. The main inputs for this stage are the requirements of the manufacturing system in terms of reconfigurability, which is the result of the assessment the outputs evaluation for engineering changes more details in Ch.5

Stage 3: Manufacturing Systems Operation & Maintenance; Evaluation Stage

The third stage of the framework is the implementation or the launching of the manufacturing systems (integration stage of manufacturing systems). Once the manufacturing systems are in operation, it is important to establish operational matrices aligned with the design objective and the performance of the line rate.

Stage 4: Refine Offline Gate; Synchronization Stage

This stage is the verification step to ensure the synchronization between virtual and physical representations. For the process of transporting and zoning for robots during the execution of assembly process, more data is needed and it is impossible to account for in the modeling stage. Thus, using ***Offline Gate*** as a parallel process for testing new controls or new processes prior to the implementation in the real world production systems; once the new process is tested and proved then can be added to virtual process. It is very important to note that the best practice is to closely examine the sources of breakdown in the production systems and the cost associated with that. If the cost is too high, and it is more than the cost of building the entire systems, then the cost to incorporate flexibility at the construction stage is justified. One of the contributions of this framework is the feedback of continuous improvement in the production systems to the design stage of product and processes. The limitation of the scope of this dissertation is the flexibility in the production systems which are determined by predefined product design variables such wheelbase, track, and horsepower. This is not an automated process – the challenge is to determine how much flexibility is needed and at what cost.

1.4: Research Focus and Approach

Thesis statement: This research focuses on production systems, and attempts to identify flexible elements of product platform design and to identify their physical interaction with production tooling reconfigurable open-gate structure. The hypothesis is that if the right subsets of car body elements (product- product family) and production capabilities are designed with proper care for future flexibility based on the reconfigurability principles, then the production system can better accommodate body styling changes, variants of family production without the need for tooling changeover with significant increase in throughputs.

1.4.1: Research Questions

The questions raised and answered throughout the research are where and how much flexibility is needed to implement the production systems of automotive framing systems and at what cost?

The new design of framing systems can be cost effective compared to the current state of practice if the systems provided achieve the following functions:

- RMS reduces time to launch a new product

- o Reduce hours per vehicle (improve throughput)
- o Improve maintenance
- o Reduce engineering cost
- o Minimize/eliminate downtime
- o Improve virtual commissioning (VR) to lunch changes by connecting process design to simulation model.

1.4.2: The Research Gap

Most of the existing work deals with product development design or testing. There is no published research design methodology linking all processes of the design stages yet. Automotive framing is very subjective and depends on expertise and knowledge based on design of experience Fig.1-20 shows the research gap represented by a) end-to-end process, b) access to processing data or production data presented, and c) systems documentation to capture knowledge and expertise.

Current production systems of BIW vehicle framing are rigid and complex unlike the product structure. Manufacturing process design and integration are subjective, based on expertise and knowledge.

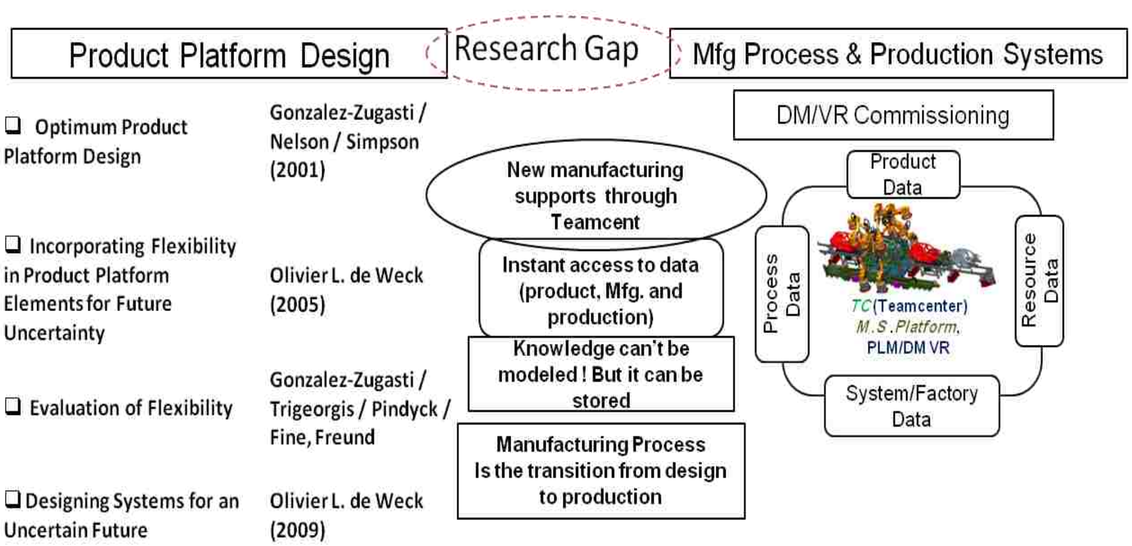


Fig. 1- 20: Previous related work and research gap

There are industrial needs to develop a systematic methodology as a guideline for systems designers and developers in order to respond quickly and more economically to uncertainty of market change by utilizing flexibility in both product and production systems. The hypothesis is that if the right subset of car body elements is designed with proper care for future flexibility, then the proposed corresponding production system can better accommodate body styling changes, variants of family production, without the need for tooling changeover.

1.4.3: Research Goal

The goal is to develop a manufacturing process to identify and incorporate flexibility in the manufacturing process (Design Configuration DC, and manufacturing capability) of production and respond to a specific set of future predefined boundaries of uncertainties of the car body styling.

1.4.4: Research Approach and Tools Used

- Devolve modular structure of Open-Gate systems to respond to styling variety within a platform family.
- Axiomatic design is used as a tool for design strategy as well as the implementation process of the strategy.
- Graph Network (NW), Change Propagation Index (CPI), and Hybrid Design Structure Matrix (HDSM) are used to:

- Establish connectivity between sub-systems (modules) before mapping design changes,
- Measure the degree of changes in design attributes and variables (DT, DC, and MC) due to ΔX: Eng**.** Changes propagate through the entire systems,
- Estimate how much embedded flexibility is needed for these elements (design variables) to absorb future changes,
- Use simulation to model the state of practice for vehicle framing systems using GSL programming***;*** Delmia (IGRIP) Digital Manufacturing and Production
- Analyze the developed simulation model to identify the sources of uncertainty that contribute to high cost in the production line (the focus is on the manufacturing design and production systems)
- Compare and discuss results through case studies;

- Case (a): styling upper the beltline (U-Body common)
- Case (b): styling upper/lower the beltline (U-Body common)
- Case (c): styling upper/lower the beltline (U-Body flexible)

It was established that manufacturing systems are too complex to analyze analytically with a mathematical model. Hence simulation was used to make decision and connect to all processes.

The software simulation used here is Delmia IGRIP simulation. This software is the complete comprehensive digital manufacturing systems solutions that deliver innovation by linking all manufacturing disciplines together with product engineering from process layout and design, process simulation and validation, to manufacturing execution.

Delmia DM and production allows manufacturers in any industry to virtually define, plan, create, monitor, and control all production processes. It provides an array of dedicated applications for industries, combined with an environment for knowledge-sharing, process and resource management, and the ability to capture and implement best practices for manufacturing (more details in Chapter 6).

1.5: Guides to Dissertation

A brief overview and short description of each chapter is presented.

In Chapter 2, the main activities in automotive factory were introduced from a high-level perspective. More details on BIW automotive framing systems and the state of practice in automotive framing systems were discussed.

Chapter 3 presents the state of practice in automotive framing systems. It focuses more on the production systems and attempts to identify flexible elements in product variants of a product family design and how they are related to the assembly processes of production systems, open-gate structure inner/outer Gate line systems (Vehicle framing systems).

Chapter 4 presents the product decomposition into systems/sub-systems and modular are presented. Graph network (NW), Change Propagation Index (CPI) and Hybrid Design Structure Matrix (HDSM) are introduced to help systems designers understand changes in product design and mapping to physical domains (production systems) and evaluate the effect of changes by connecting the process to DM simulation.

Chapter 5 introduces the proposed novel methodology (high level process) of framework using RMS principles for automotive framing systems as well as to provide a guideline to support the structure of different stages of the design methodology. The proposed methodology is presented through a case study using database on actual production systems of three different styles; (process and design data) which supports the hypothesis of the research.

Chapter 6 presents the model development (simulation model) to evaluate the input data and generate output data (production data). Case studies (data of real production line) were used to illustrate the proposed design methodology that is presented in Chapter 5.

Chapter 7 presents and summarizes the conclusion and direction of future work.

Chapter 2

2. Overview of a Car Factory's Main Activities

In this chapter, the four main activities in the final assembly are presented from a high level perspective. The key benefit of this overview is to position the framing systems assembly process within the whole picture of the automotive factory. The four activities are briefly described as follows:

a) Parts stamping and modules assembly: Sheet metal components assemblies from suppliers were received "in white," unprimed or painted, protected only from oxidation.

b) The body-in-white assembly operations started with the complete assembly of lower-body (under-body complete platform) then followed by the upper-body assembly secured to the lower-body in two steps, which are called inner/outer framing systems.

c) Paint operation: final body inspection and repair before painting was performed to the assembled bodies-in-white. The paint operation then began in a very closed and controlled environment; the process may take 10-12 hours in a separate building and in larger buffer areas.

d) The final assembly started with the return of painted car body; interior and exterior parts/components are fitted on painted body in assembly plant that generally constitutes:

(i) Trim line,

(ii) Chassis and power-train, and

(iii) Final assembly line.

2.1: Main Modules of Car Body Structures

The total stamped parts needed for the completion are ~ 180-200; some parts are single parts, i.e. roof boos, hoods and D-Ring, and some are left hand (LH) and right hand (RH) parts, i.e. body side (BS) inner and outer, rocker panel (RKP), assembled at the supplier site then shipped to the final automotive assemblies. Building car body structures and styling will likely remain one of the key in-house activities to have control on the product developments (see Fig. 2.1); (a) internal mating panels, (b) external (skin) panels, and (c) embedded critical components for variation or interface with other components of other modules.

Auto-manufacturers prefer to procure the medium and small sized panels from vendors depending on the availability (nearby facility) and capability to meet demanded specifications. Automotive trends in outsourcing are to outsource as much as possible, as well as to move assembly/ies and subassemblies, such as closures, hydro-forming and chassis, to specialized vendors. The automobile plants are trying to concentrate on assembly operations, leaving specific technology related manufacturing, such as machining and pressing, as separate facilities.

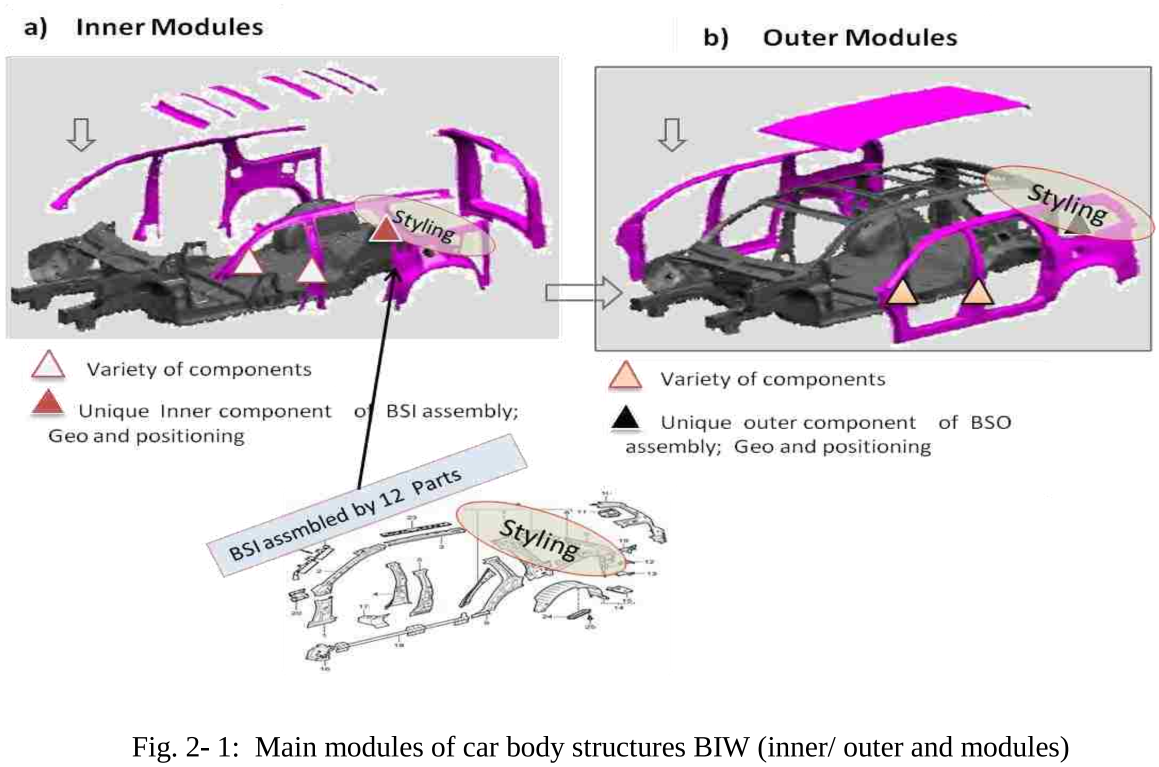


Fig. 2- 1: Main modules of car body structures BIW (inner/ outer and modules)

2.2: Overview of the Main Activities in a Car Factory

The automobile assembly plant represents only the final phase in the process of vehicle manufacturing, parts, and modules of final assemblies arrived via transportation to the right departments by 3000-4000 outside suppliers, usually 300–400 truckloads daily to deliver parts, with no parts having been produced in the plant.

Fig. 2-2 shows the scope/size of a high volume, highly automated assembly plant in North America or other industrialized region. In developing countries, the manufacturing footprint is considerably different, with much less automation, and much lower volume, but also usually much more flexible and capable of building a wider variety of models.

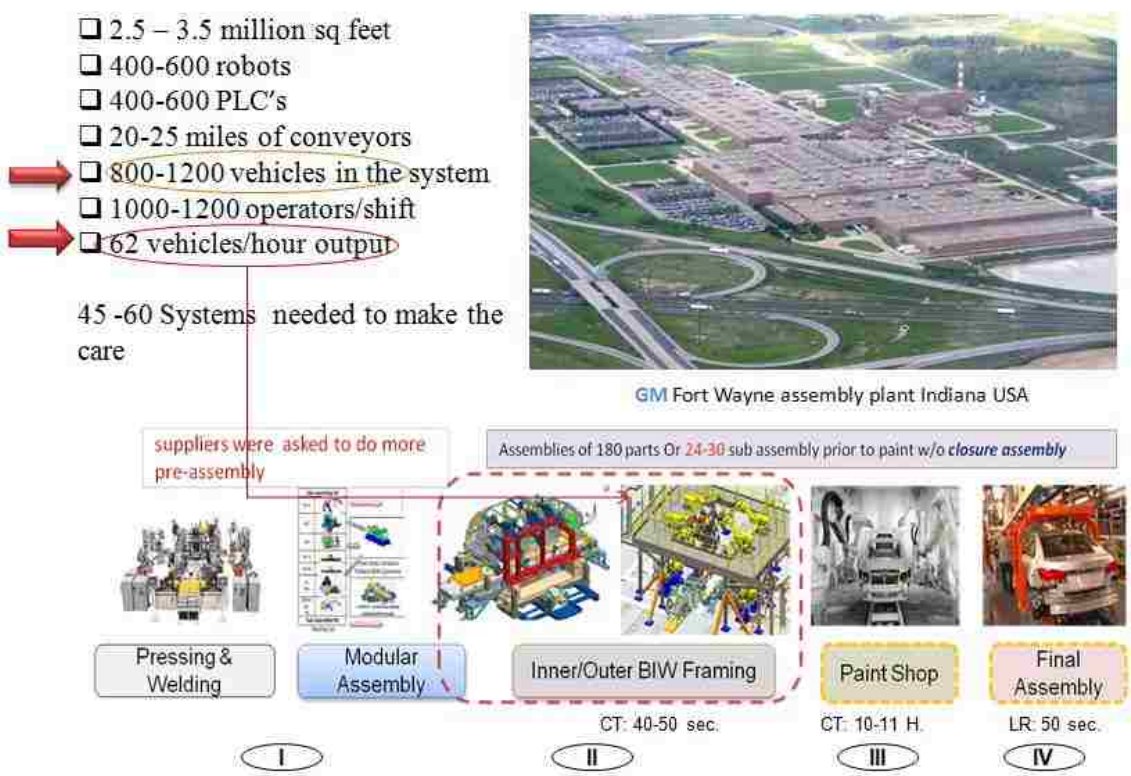


Fig. 2- 2: Typical final assembly plant (280,000 vehicles annually)

The main processes are grouped into four stages as shown in Fig.2-3: Parts stamping and modular assembly, BIW framing, paint, and final assembly

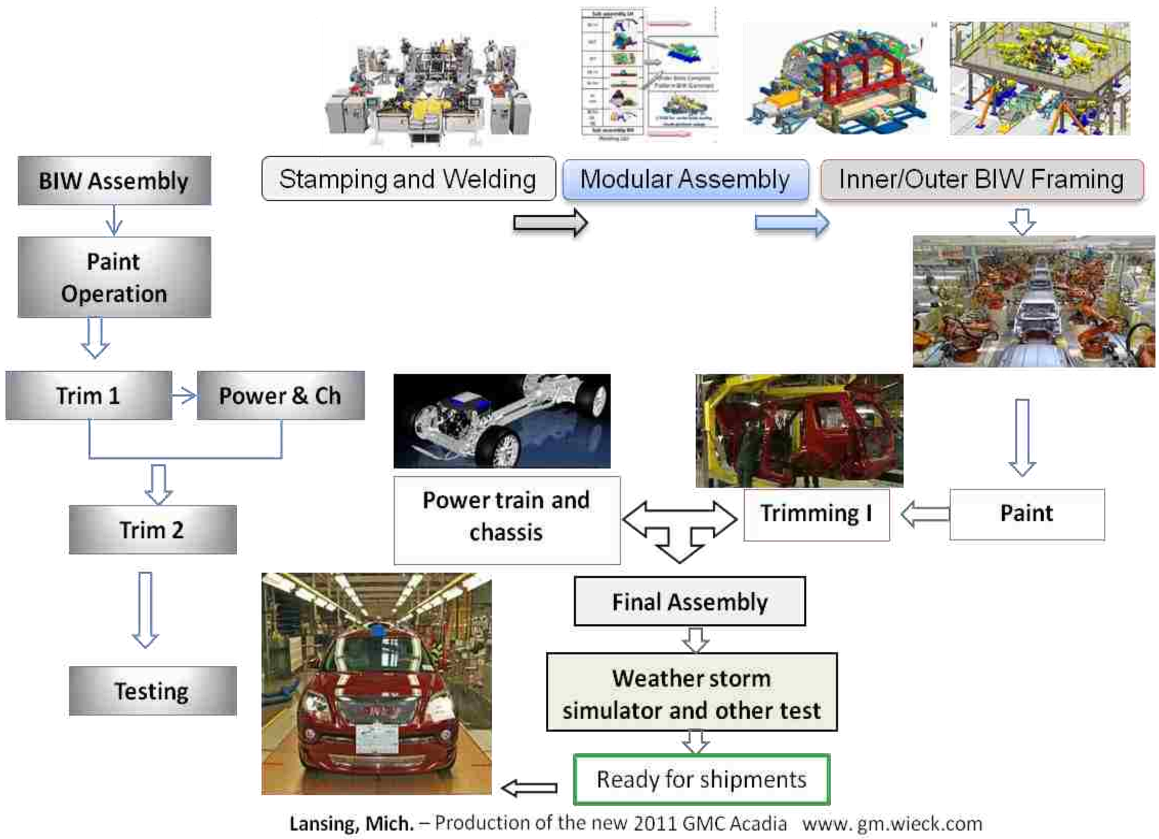


Fig. 2- 3: Shows the main activities in the automotive manufacturing and assembly

2.2.1: Parts Stamping and Modules Assembly

The process starts with producing parts in various locations with different technology, such as stamping, hydro-forming, machining and others. Subsequent activities follow before or after shipping parts/components to the right department prior to sub-assemblies and assemblies of modules. Some parts were assembled and shipped (closures) to be painted, and then offline assembly will take place (trimming zone).

Fig. 2-4 shows the assembly processing steps for car's door modules assembly; front and rear doors can be run in one assembly process.

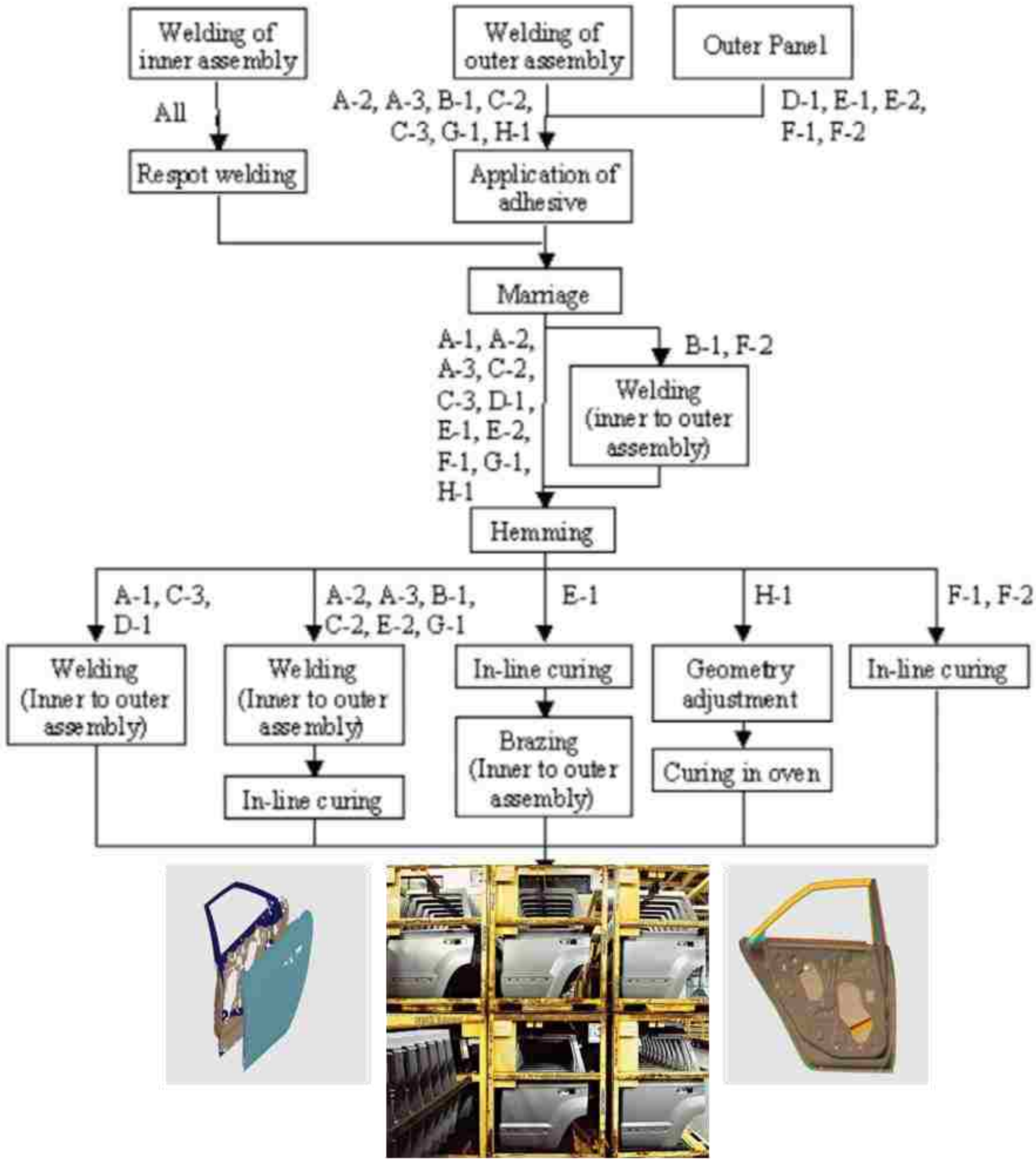


Fig. 2- 4: Manufacturing process of modules assemblies (stamped parts)

The process assembly of Fig. 2-4, were presented in virtual simulations (work-cell of modules assemblies of stamped parts) are shown in Fig. 2-5.

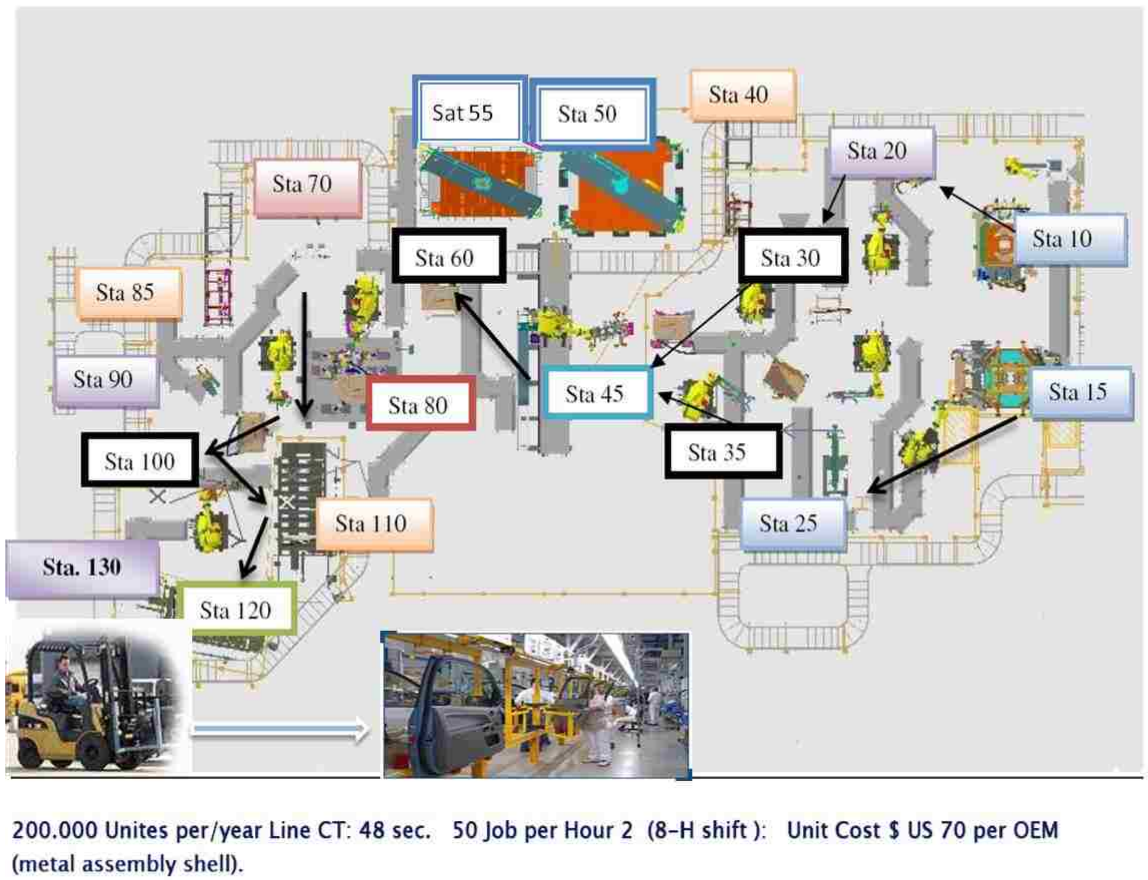


Fig. 2- 5: Work-cell of modules assemblies of stamped parts

2.2.2: Vehicle (inner/outer) Framing Systems

The body-in-white assembly operations started with the complete assembly of lower-body (under-body complete platform), then followed by upper body assembly secured to the lower-body in two steps which are called framing systems. The framing system can be divided into three systems, as shown in Fig. 2-6:

i) ***Under-body platform;*** the underbody complete or BIW platform consisting of up to 10-12 sub-assemblies in three main sub-assemblies (1) motor compartment (MC), (2) floor panel assembly (FP), and (3) rear motor compartment (RMC). The complete assemblies of these sub-systems grouped into up to 10 assembly cells with 120 robots for modules assembly. Recent trends, less robotics, and new technology and processes have been used in recent assembly lines.

ii) ***Inner framing*;** inner modules (IV) were loaded to under-body complete (UB) as an input to the gate framing systems. The output of this stage is the completion of vehicle inner body structures. To complete the inner framing (5-9 sub-assemblies added prior to framing), needs more than 30 robots, grouped into up to 3-4 assembly cells.

iii) ***Outer Framing*;** outer skin modules (BSO) were loaded to the completed inner structures as an input to outer gate framing cell, then follows re-spot. Inspection is prior to the final step, adding a roof panel. Outer framing (3-5 sub-assemblies added prior to framing), needs more than 30 robots, grouped into up to 4 assembly cells.

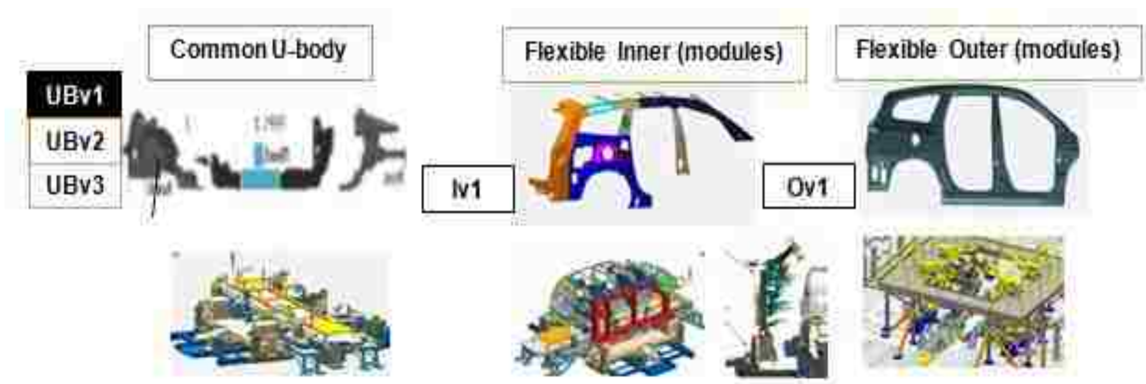


Fig. 2- 6: Assembly process of BIW framing systems

Following the completion of assembling the bodies, they were then transferred to conveyor lines for subsequent activities, such as solder metal filling, adhesive, anti-corrosion compound and for vibration, prior to final body inspection and repair, before painting was performed.

2.2.3: The Paint Shop

Vehicle painting is considered the biggest bottleneck in car production, positioned between body-in-white structure and final assembly. This represents a particular constraint to production of batch sizes of one. The typical average batch is currently twelve bodies. Today, robots do much of the work, but they were supplied with paint through long hoses from storage tanks. Changing color requires stopping the line, flushing the old color, cleaning the hoses, and reloading a new color. This process threw away or wasted more than 30% of paint when switching colors, and this is the practice at most paint shops.

For painting of a passenger car body, the typical processes to be followed are as follows:

- Pre-cleaning
- Multi-stage phosphate pretreatment
- Electro-deposition of primer coating (universal for a modern automotive paint shop)
- Underbody PVC & sealer application
- Filler primer application
- Top coat or dual coat application
- Wax application.

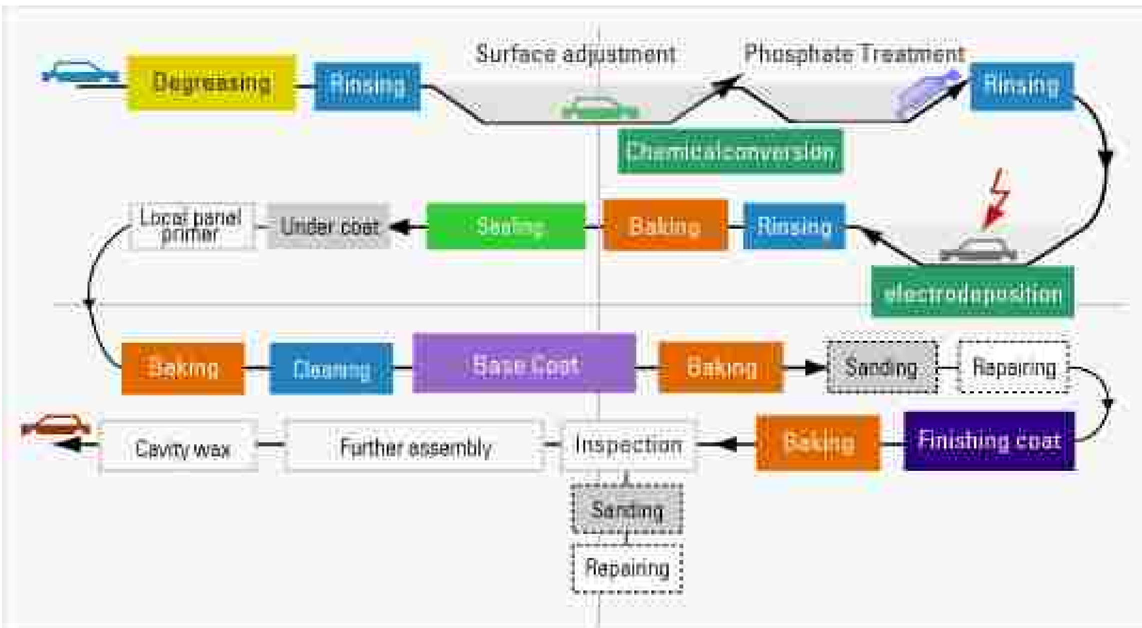


Fig. 2- 7: Main operation in typical paint shops of automotive plants (Eisenmann.com)

Currently, there is a new method being used at the Toyota plant in Georgetown, . Each painting robot—eight per car—selects a paint cylinder (paint cartridge). A whirling disk at the end of the robot arm flings out a mist of top-coat paint. When a car is painted, it takes a few seconds to change a cartridge or switch color; no hoses need to be flushed; no cleaning between cars is required. All the paint is in the cartridges, which are refilled automatically from reservoirs. The paint shop changes the product, and the color is automatically adjusted. Cars do not need to be batched by color, a system that saved paint but caused constant delays. Cars now spend 8 hours in paint, instead of 10 hours.

2.2.4: Final Assembly of the Vehicle

Trim line assembly operations are carried out in logical sequence and differ from manufacturer to manufacturer. The operations are mostly manually performed from both sides of a slat conveyor. Most of the activities in the trim lines require skilled workers, and the number of trimming zones depends on the line rate. The length of each zone depends on the time required for completion of installation; different parts are handled in different ways, using different tools.

Some require bolting, others are just inserted, and others are fitted together. Sealing, wiring, and other processes are also carried out. Each of these operations requires many closely controlled steps to assure high quality.

Trim line includes;

- Harnesses and controls,
- Pedal assembly, insulator,
- Air duct, heater, head liner,
- Weather-strip, horn, stop switch,
- Front/rear shock absorber, shift cable,
- Wiper link, washer tank,
- Condenser, rear seat belt, radiator insulator.

Chassis Line:

Car bodies from trim line are picked up by overhead conveyor of chassis line that may be power and free type. Mostly, the parts are fitted from the bottom side. Some of these manual processes require uncomfortable postures, because of the inconvenient position of the car bodies. Tilt conveyors and electric carriages incorporating elevators are being used to overcome the problems. Electric carriages with elevators eliminate a lot of discomfiture to the workmen who had to squat down or crawl into the cars for the processes. The tilt conveyor is used so that the workers can work on the bodies in comfortable postures without having to stretch or crane their necks. *The chassis line includes:*

- Brake tube, filler neck, splash shield,
- Fuel pipe, fuel tank and canister,

- Rear axle, stabilizer,
- Clutch tube, heat protector, engine,
- Knuckle, tie rod,
- Exhaust, undercover,
- Tire, front /rear seat,
- Front/rear bumper.

Fig. 2- 8: Car body marriage over power train and rear axle trolleys

At the end of chassis line, chucking of safety critical items and the adjustments are completed and tiers are checked.

Final Assembly: Bodies on tires come down on double slat conveyor of final assembly, as shown in Fig. 2.9. In final assembly, all the remaining fitments are carried out. Near the end of the line, the doors are mounted. The door assembly line is generally located near the door mounting stations.

The final assembly includes:

- Rear pillar trim, trunk-lid latch,
- License plate lamp, radiator, hose,
- Heat hose, steering shaft,

- Parking brake, garnish,
- Rear combination lamp, sun-visor,
- Battery cable, silencer,
- Front turn signal lamp, console box,
- Front/rear glass, roof molding,
- Console bracket, carpet, trunk room trim,
- Seat belt, centre pillar trim,
- Air-conditioner pipe,
- Glove box, battery tray, seatbelt anchor cover,
- Air cleaner, front/rear seat,
- Front grille, drip molding,
- Combination meter, A/C gas.

Fig. 2- 9: Car body at final assembly (seat installation) (GM, Lancing)

2.2.5: Vehicle Testing

After the vehicle comes out of the final assembly line, it is driven on its own power to the Vehicle Testing area. Inspection equipment includes:

- Wheel alignment tester,
- Turning radius tester,
- Headlight tester,
- Side slip tester,
- Drum tester,
- Brake tester.

2.3: Present Trends in Final Assemblies

New trends in the final assembly process show an increase in automation and more robots in the final assembly and trimming.

What is more important than the technology is the corporate culture; the fundamental reason for an enterprise success in the global marketplace lies in its corporate philosophy – the set of rules and attitudes that govern the use of its resources.

2.4: The Toyota Way of Success (4 sections & 14 principles)

The Toyota way is not the Toyota Production System (TPS) (Liker, 2004). The 14 Principles of the Toyota Way is a management philosophy used by the Toyota Corporation that includes TPS, also known as lean manufacturing. TPS is the most systematic and highly developed example of what the principles of the Toyota Way can accomplish. The Toyota Way consists of the foundational principles of the Toyota **culture**, which allows the TPS to function so effectively;

I. Having a long-term philosophy that drives a long-term approach to building a learning organization;

- Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.

II. The right process will produce the right results;

- Create a continuous process flow to bring problems to the surface,
- Use "pull" systems to avoid overproduction,
- Level out the workload,
- Build a culture of stopping to fix problems, to get quality right the first time,
- Standardized tasks and processes are the foundation for continuous improvements,
- Use visual control so no problems are hidden,
- Use only reliable, thoroughly tested technology.

III. Add value to the organization by developing its people and partners;

- Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others,
- Develop exceptional people and teams who follow your company's philosophy,
- Respect your extended network of partners and suppliers by challenging them and helping them improve.

IV. Continuously solving root problems to drive organizational learning;

- Go and see for yourself to thoroughly understand the situation,
- Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly,
- Become a learning organization through relentless reflection and continuous improvement.

Chapter 3

3. The State of Practice of Vehicle Framing Systems

In this chapter, the state of practice in automotive framing systems is discussed. It focuses more on the production systems and attempts to identify the flexible elements of modular assembles within product variant of one family, then how these elements related to the assembly processes of production systems, open-gate structure inner/outer gate line systems (vehicle framing systems). Efficiently operating the manufacturing (automotive) systems, required understanding the current practice of car body assemblies, interaction between sub-assemblies (modules/components) product and production, and how customers' requirements propagate to design variables then translate to design tasks to manufacturing capabilities. Systems' manufacturing performance was evaluated under breakdown generated by changing in production demand or introducing new styles of family product, and—among others—maintenance issues.

3.1: What are the Automotive Framing Systems?

Automotive framing system is a process and the related infrastructure for a precise positioning and securing of under-body platform with the upper body components (Baulier, 2010).

3.1.1: Main Function of the Vehicle Framing Systems

Figure 3.1 shows the three main functions in vehicle framing systems and their activities. The functions considered for incorporation flexibility are:

1. Geometry (positioning) function, which includes all necessary means to ensure accurate positioning of parts in relation to each others.

2. Handling (transferring) function, which includes all equipment necessary to move parts, tooling, etc. Accuracy level is lower than that required for geometry function.

3. Process (tooling) function, which includes all equipment adding value to the product being manufactured (welding guns specifications.).

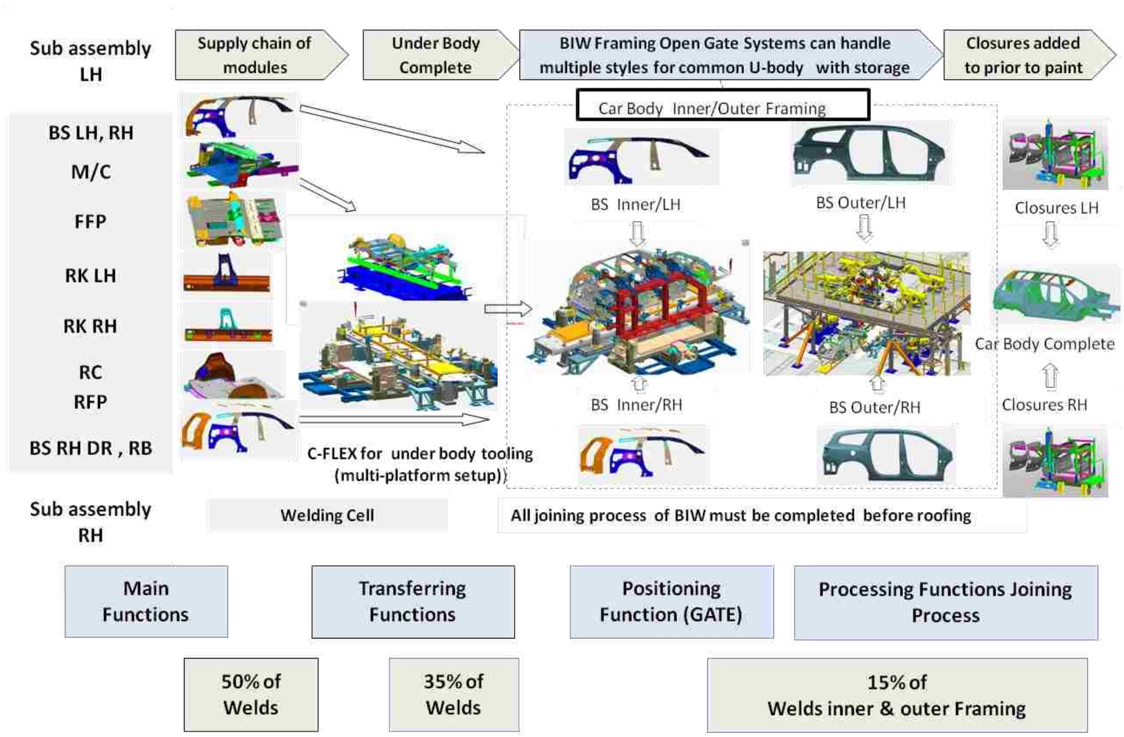


Fig. 3- 1: The main functions in vehicle framing systems

In the automotive industry, line rate of production systems (cycle time) determines layout equipment number of station, etc. Cycle time tells us how often we can produce the product with current resources and staffing, and it is an accurate representation of how the line is currently set up to run. Time is very expensive in the final assembly, especially in the main line (line A-A), in the strategies (decoupling of processes), and in special training for highly skilled engineers to get any malfunction up and running of any equipment—machine or tooling—in a very short time.

3.1.2: Car Body Structures Challenges

Figure 4.2 shows the benefit of the future car body structure development. Automakers aim to reduce 30-40% of the total mass of vehicle; 28% of this mass reduction is related directly to body-in-white structures (Taub, 2006). Introducing these changes requires knowledge and strategies on how changes apply to body structures. The manufacturing process includes equipments, tooling, and eventually changes the performance of the whole system.

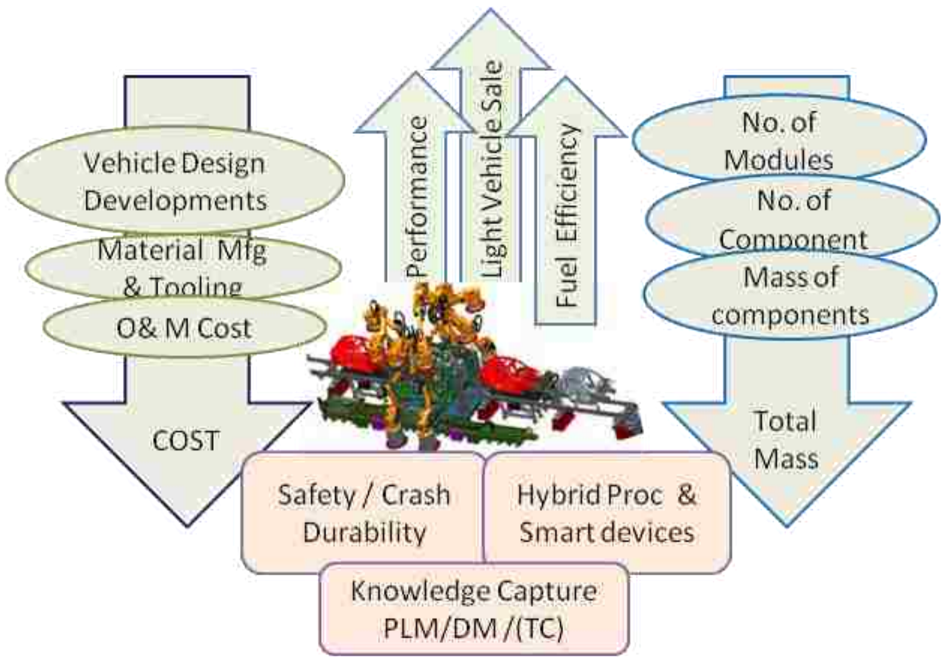


Fig. 3- 2: The benefit of future steel vehicle (adapted fromEta.com, 2012)

The challenges facing the automotive industries in the global market are in:
(a) the product development process, including multi-dimensional issues, which in some cases are contradicting each other (more details will be discussed), (b) cost reduction to compete in the global market while continuing to meet the existing requirement quality, safety and performance, (c) crash safety requirement BIW structures while meeting anticipated safety requirements in 2020 (Eta.com, 2012), (d) important factors, such as fuel economy emission standards, (e) customer demand for better quality, high performance, and availability of new energy sources such as eclectic/hybrid vehicle, and fuel-cell.

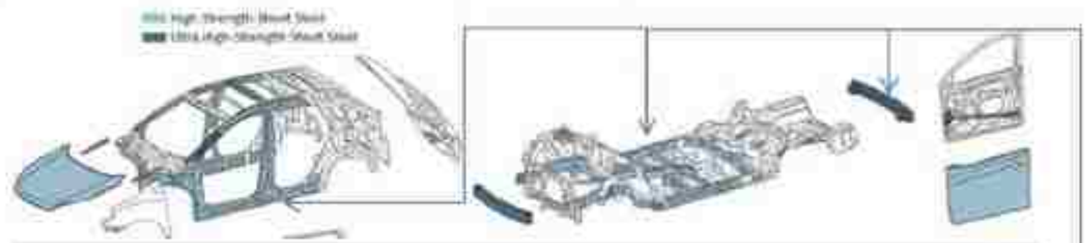
3.1.3: Steel Selection of Car Body Structures

New advanced materials offer solutions for cost reduction while addressing mass reduction multi-material solutions, and challenging the steel industry to enable additional mass reduction capability with steel for the vehicle body-in-white (BIW) and closures. This is the new direction in the automotive industry and the future product development challenges of this magnitude. It requires a new process that incorporates all of these enablers implemented at the initial stage of product design and development.

For product development, engineers need to work closely with manufacturing and production managers to introduce changes or body upgrading (body styling). Figure 3-3 shows the steel grade of different components of the body-in-white. The material selection needs to agree with crash energy managements to avoid buckling forces or weak point in the BIW structures and knowledge of how the crash forces are transmitted through the body structure during the first 40 - 100 ms.

Structural performance is based on measurements indicating the amount and pattern of intrusion into the occupant compartment during the offset test. This assessment indicates how well the front-end crush zone managed the crash energy and how well the safety cage limited intrusion into the driver space.

Engineers use virtual design tools to evaluate material and manufacturing process to select the optimization-based process while trying to reduce cycle time with new advanced materials (less weight), and require more cycle time to join their structures hybrid process.



		Grades used	Typical usages	Tensile Strength (mPa)
Mild steel		Low Carbon	Large underbody closeout panels, highest quality outer panels.	260 - 270
Bake hardenable		180-210-300	Stiffness dominant parts and formability restricted parts.	300 - 390
HSLA		340-410-550	Strength dominant parts with minimal energy absorption.	440 - 650
Dual Phase		DP600 DP800 DP1000	Strength dominant energy absorption parts and high strain parts.	590 - 980
Martensitic		Grade 9 Grade 13	Parts requiring highest ultimate strength.	900 - 1300

Fig. 3- 3: Steel selection strategies at GM (Adapted from Autosteel.org)

3.1.4: OEM Data to Start Vehicle Framing Systems Design

The cost to build the final assemblies of systems in car factories is between 4-6 billion dollars; 40-55 systems (under-body, doors systems, BS systems, etc.), 500-600 robots, 150 stamping dies in press lines. Therefore, multiple models can now be assembled on a single production line. Typically, more than 80 percent of the tooling and equipment are common (Drishtikona.com, 2012). The remaining 20 percent are unique to variation and styling focuses more on differentiation in product and production systems, and requires knowledge and understanding to create flexibility at the production systems at the early stage. Fig. 3-4 shows the input (high level of CR), output and the design constraints of manufacturing systems (more details will be given to the sources of cost reduction).

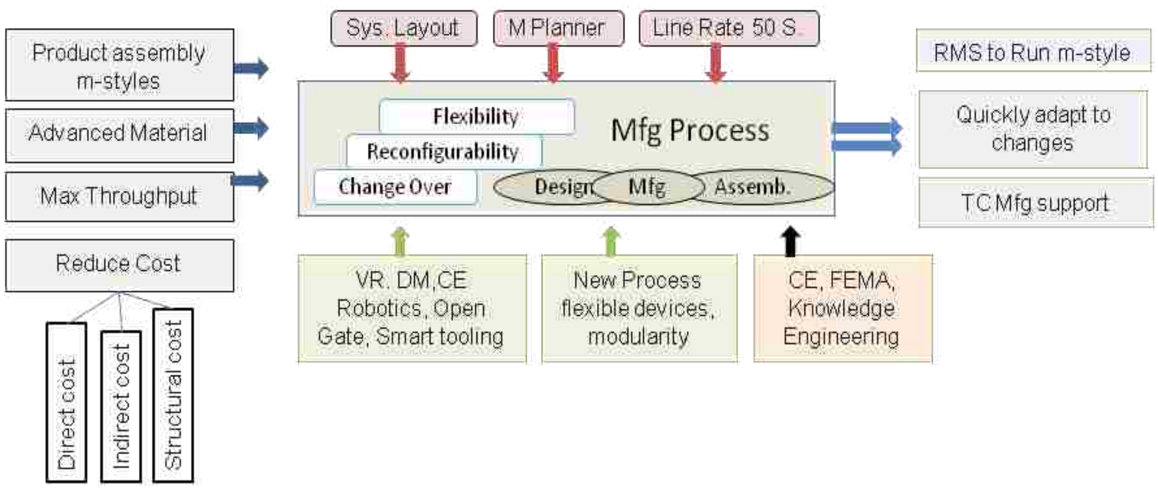


Fig. 3- 4: Automotive framing systems, processing steps (concurrent Process)

Fig. 3-5 shows the hierarchy of data needed to start the process & design of the automotive framing systems. The degree of flexibility in the automotive manufacturing systems is still very subjective to designer and vehicle stylist as mentioned previously. The following steps are the state of practice of vehicle framing systems design in which plants managers and systems planners determine type and makers of equipments for automation and controls purposes:

- *OEM Data*
  - Product assembly (vehicles assembly/sub-assemblies of modules)
  - M-planer
  - Master weld data

- *Product assembly*
  - Systems lay-out
  - Throughput of main line
  - Sub-system line-rate discreet event study
- *Equipment includes; (plants preferences)*
  - Robotics types
  - Robots dressing pack.
  - Weld types (weld controllers, tip dressers)
  - Standards components
  - Hemming equipments
  - Dispensing equipments
  - Inspection equipments

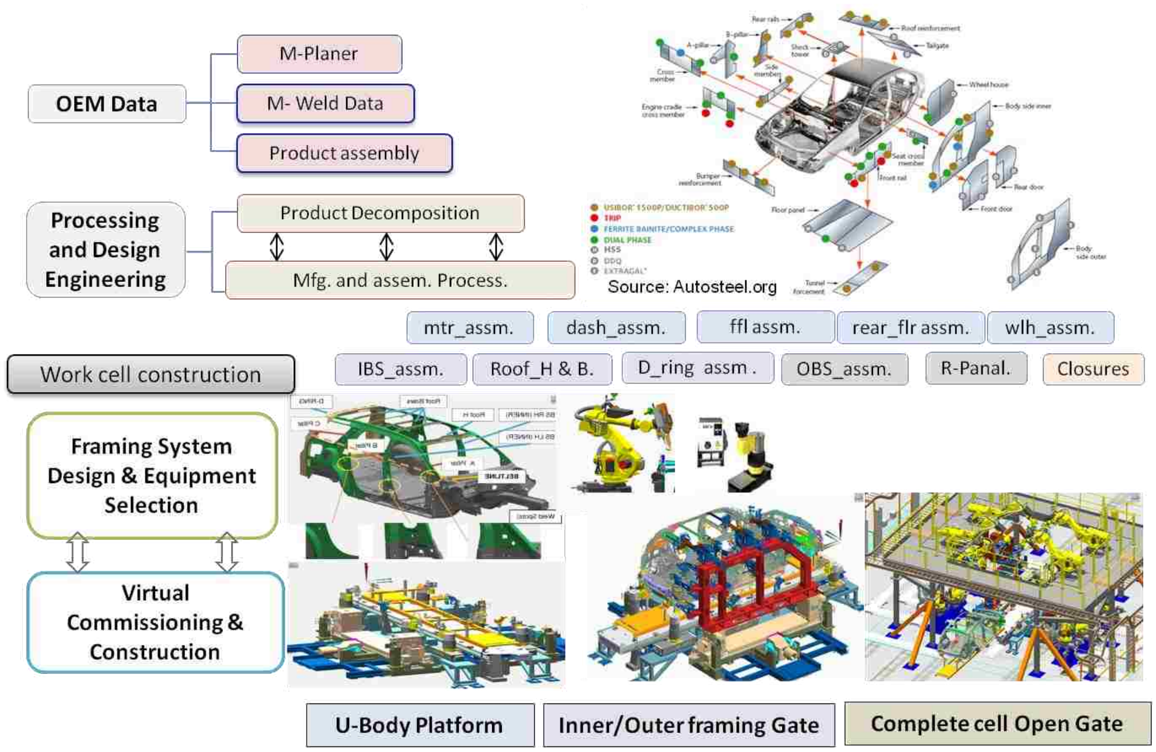


Fig. 3- 5: Automotive framing systems hierarchy of processing data & design

Current vehicle framing systems use open-gates systems with storage gate systems and changeover mechanisms. Production systems need scheduling ahead to avoid downtime (due to changeover), and as a result, decreases of throughput (add quantitative* charts).

Conversely, quantitative methods include hard facts illustrated in surveys and polls.

Reconciling continuously evolving product designs and expanding styling variants, including new materials and new processes, with the throughput required for profitable car assembly plant operations (3-Shift, mixed model production on 240 days a year, assuring annual throughput of 360,000 units or hourly rate of 62-70 units) poses a great challenge.

A similarity between RMS and modular product families, known from Mass Customization (MC), is seen and based on this similarity as a potential to maturing reconfigurable manufacturing (RMS) further.

3.1.5: Selecting the Best Joining Method for State-of-the-Art Body-in-White

Cost and weight reduction have been, and will remain, the prime targets for the automotive industry for each vehicle. Customers are looking for a better structure for future vehicles that last longer and better quality of body structure. Automakers are introducing more, of the Ultra-High Strength Steel (UHSS) and Advanced High Strength Steel (AHSS) on the body structure of the new vehicles for enhancing their safety and fuel economy.

With the new hybrid joining methods in the automotive industries, such as laser welding, structural adhesive bonding, and others, a car body engineer has only three parameters to combine for an optimal solution: geometric shape, material type, and joining method. Selecting the best joining method for state-of-the-art body-in-white (BIW) is a challenging task for engineering and manufacturing. It is essential to choose the appropriate joining technique, or the most suitable joining method for each application (there is no clear cut way in methods selection).
There are some advantages to using these methods for the assembly of car body parts by using either laser welding or structural adhesive bonding; because they generate a continuous bond line, they create a larger area for load transfer between parts. This larger load transfer results in better crash performance, increased durability, and improved torsion and bending stiffness, that, in turn, makes it possible to down-gauge material thickness and reduce weight, while maintaining good car body performance.

I) Rules of thumb for Joining Selection:

For recommendations for using laser welding or adhesive bonding, the following rules of thumb can be given:

- Flange Width Reduction < Laser Welding
- New Single-sided-access Designs < Laser Welding
- Invisible Joints < Laser Brazing
- Torsion Stiffness < Adhesive Bonding
- Fatigue Improvement < Adhesive Bonding
- Better Crash Properties < Adhesive Bonding

The rules can be simplified even more with the following:

- Under-body < Adhesive Bonding
- Upper Structure < Laser Welding

The laser applications are primarily on the under-body and body sides, in the framing, and in a number of subsequent re-spot welding stations.

II) New advanced material introduced to car body structure helps crash energy managements:

Today's designers manage the impact of crash forces before it reaches the occupants. To introduce and integrate new and advanced material in the design and body structure needs a carefully planned strategy especially for existing assembly lines. This plan and strategies are required for product designers and process manufacturing engineers to have a good knowledge and understanding of the following:

a) How the crash forces are transmitted through the body structure during the first 40-100 ms (large print shows how forces are transmitted through the body structure); and

b) Crash zone in the vehicle and their properties;

III) Advanced-composite material for automotive body structure:

Carbon-fiber composite is very possible to be used in the near future for outer body in mass scale, and currently, automakers are focusing development on hybrid-electric and fuel-cell drive-systems. Additional changes will be required to the entire vehicle platform to make these advanced drive-systems cost competitive with conventional drive-systems. Limitations from widespread industries adoption is still very expensive, is a limited material and is a new market source (see Fig. 3-6).

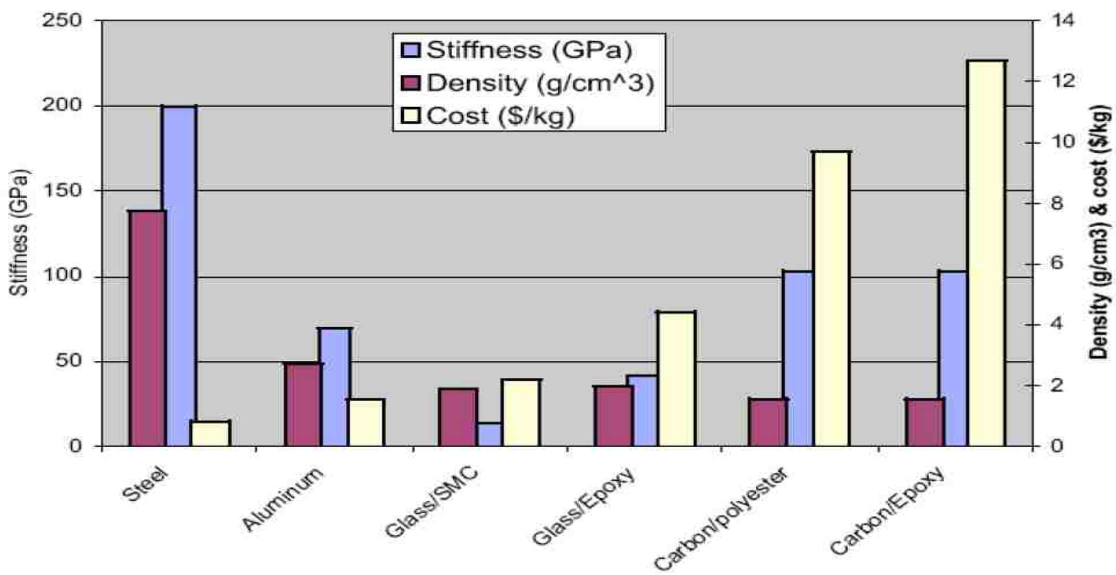


Fig. 3- 6: Relative materials properties & costs (Source: Hypercar, 2011)

Here are some questions that have been developed:

Q1: What are some advantages and disadvantages of using hybrid joining process methods (Weld spots and adhesive bonding) in BIW body structure?

Q2: How do these techniques contribute to the safety and enhancement for body structure, and provide more opportunities for design flexibility?

3.2: Automotive Customization and Styling

Automobile customization refers to individual car modifications in terms of either visual appearance or performance. The trend toward customization of vehicles is paralleled by increasing modularization of vehicle design. While desire to respond to market needs is one of its drivers, the other is the need to keep the manufacturing costs in check. Vehicle manufacturing, however, is no longer a matter of a single, vertically integrated original equipment manufacturer. Increasingly, OEMs are taking on a role of final assemblers or system integrators. Thus manufacturing systems can be viewed as vast, global supply networks providing necessary components for the final assembly in a time-coordinated fashion. Traditional manufacturing facilities still exist but have to be much more responsive to product changes and demand variations. New concepts, such as reconfigurable manufacturing, are being developed, but it may take some time before they are effectively implemented in the industry. The trend toward outsourcing and increasing the role of the suppliers will continue. According to Dannenberg et al. (2004), over the next ten years, OEMs will shed most of the activities formerly considered as their "core" business, such as power-train and body manufacturing. Notably though, building car body structures and styling will likely remain one of the key in-house activities to have control on the product developments.

3.2.1: The Automotive Approaches to Mass Customization

OEMs give the following general definition for modules: ''A group of components, physically close to each other that are both assembled and tested outside the facilities and can be assembled very simply onto the car'' (Browning, 2001). There are three areas of modular implementation (Pandremenos et al., 2009):

- Modularity in design (MID),
- Modularity in production (MIP),
- Modularity in use (MIU).

Modularity is not developed in the same way in North America and Europe as it is in Japan . North American automakers are mostly interested in MIP by outsourcing to different suppliers. Subsequently, the biggest challenge is to deal with the inconsistencies or conflicts created between MIP and MID across supplier networks. In contrast, the Japanese automakers have shown an inclination toward in-house MIP and focus on continuous quality and efficiency improvements. That difference in product architectures and production process hierarchies has created a strategic advantage for the Japanese automakers and they are ahead of their counterparts by 4-5 years in terms of product/process management (Brown, 2004).

3.2.2: Modular Design of the Under-body Complete Structure

The under-body complete (under-body platform) design structure may consist of five (5) main modules: the motor compartment assembly (MC), the floor, the rocker (LH and RH), and rear end compartment. Front floor assembly module ($FFP_{1,2}$) and the rear compartment (RC_1, RC_2) are considered flexible modules (see Fig. 3-7).

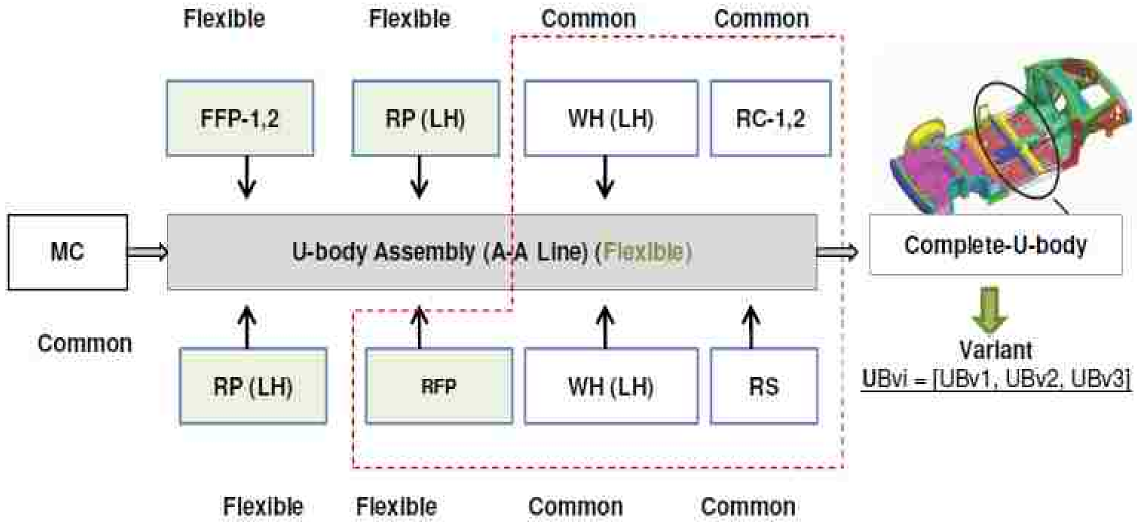


Fig. 3- 7: Under-body complete platform modules structure

Using the design variants of these modules, scalability in the longitudinal dimension of the under-body structure can be easily achieved. Based on this scalability feature, multiple alternative design variants—for example, three variants—of the Under-body structure can be generated,

UBvi = [UBv_1, UBv_2, UBv_3]

and each one is considered as a platform segment in terms of shape and dimensions.

3.2.3: Modular Design of the Upper-body Structure:

The upper body modules design structure may consist of the following modules: body side inner assembly (A-Pillar, B-Pillar, and C-Pillar), body side outer and roof rails, roof headers and roof bows (see Fig. 3-8). All modules of the inner assembly are considered to be flexible. This flexibility allows for variations along with A, B and C pillar components. For each variant of

UBv_i = [UBv_1, UBv_2, UBv_3]

There is a corresponding set of three variants of inner modules

Iv_i = [Iv_1, Iv_2, Iv_3]

That can be produced.

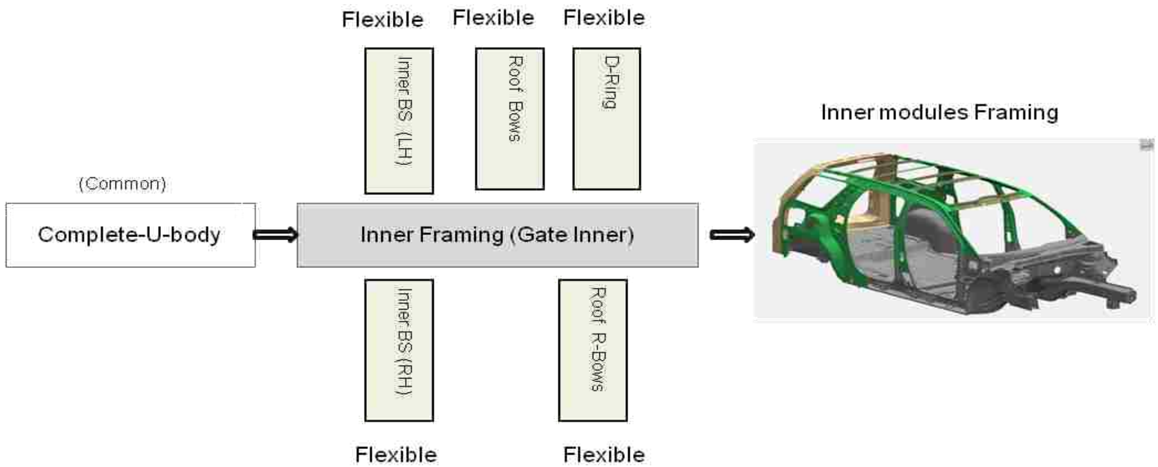


Fig. 3- 8: Inner modules structure (SUV platform framing)

The final modular assembly is the outer skin LH/RH and a roof panel; both modules are considered as model-specific and correspond to a set of outer variant modules.

$Ov_i = [Ov_1, Ov_2, Ov_3]$.

As a result of this modular flexibility, different body styles can be properly referenced to the BIW Under-body.

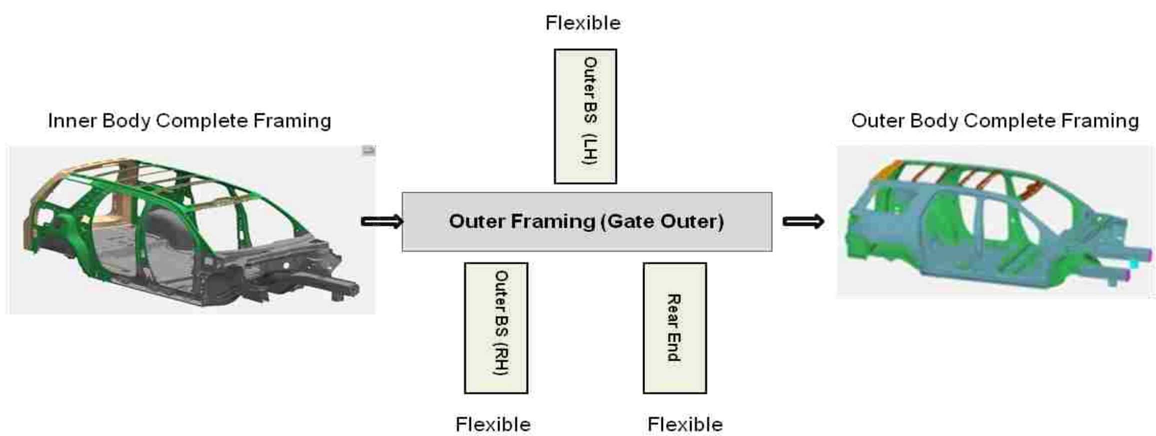


Fig. 3- 9: Outer modules structure (SUV platform framing)

3.2.4: Vehicle Styling and Beltline

Designing the body assembly system to be responsive to the market requires thorough analysis of company's product line to create product families and platforms, but from the point of view of the manufacturing process. Mapping the product characteristics into the manufacturing system requirements under constraints of product families allows, on one hand, to build-in necessary functionality, and on the other, to leave room for predictable future changes and their proper management. Alignment of some common features across the product lines is also critical for cost-effectiveness. Therefore, system designers and planners need to fully understand vehicle styling. It is impossible to start from scratch all over again whenever a new style is developed.

When it comes to the tooling design, there is rather little understanding of the significance of the beltline. The beltline (see the dashed line in Fig. 3-10) is an imaginary horizontal (or slightly inclined) line below the side windows of a vehicle, starting from the hood and running to the trunk or the lift gate; it separates the glass area from the lower-body. *The beltline* is an important element in a vehicle's styling and it is important for the tooling designer to understand the relation between the inner/outer assembly modules and the underbody to the corresponding framing gate (inner/outer).

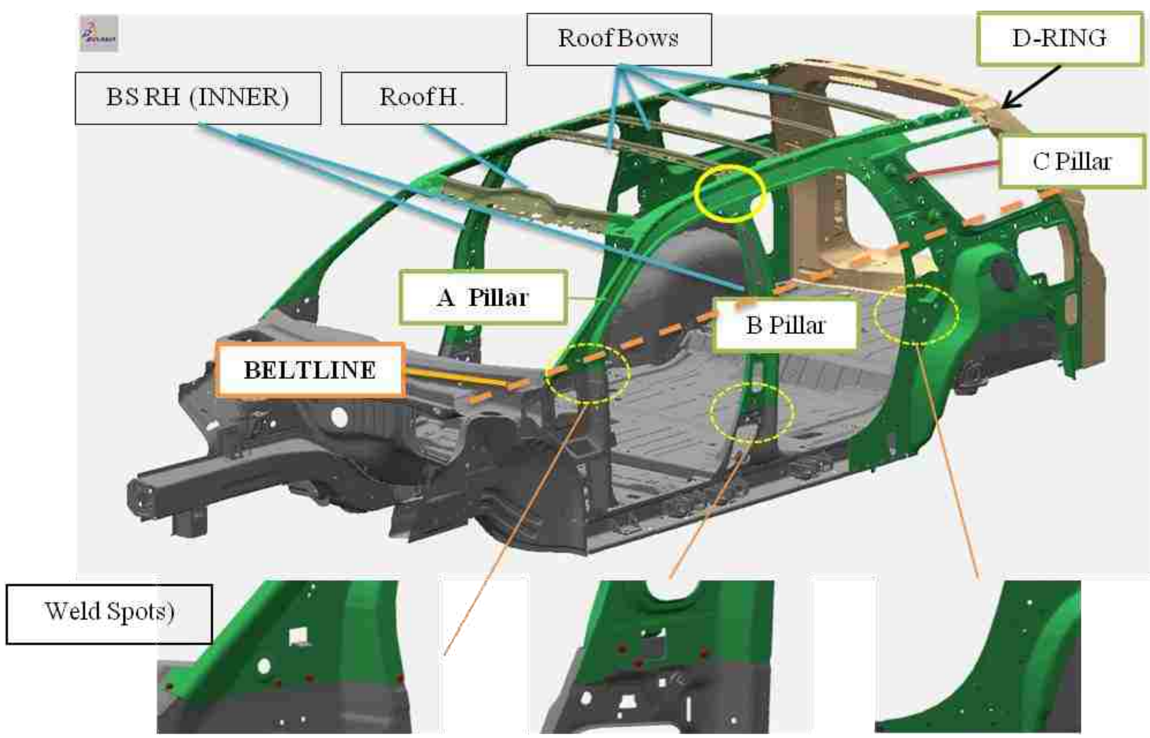


Fig. 3- 10: Beltline of SUV & BS inner module to under-body complete

The task is to reduce the magnitude of change propagation through the design of flexible segment of tooling, and in return, reduce the economic impact of potential future changes on the system (platform) costs.

3.3: Current Practice of Automotive Framing Systems

Car body final assembly of body structures starts with the completion of under-body complete, inner modules loaded. The loading process mechanism depends on the modules manufacturing process it can be loaded by M/H robots or loading mechanism. In order to assure that the final body geometry is according to design specifications, the panels to be welded are positioned (by pins and NC blocks), constrained by clamps, and presented to the process by highly complex, automated fixture devices. The spot welds are typically laid out by robotic arms with multiple degrees of freedom, carrying the welding guns. Vehicle framing system can be divided into three systems as shown in Fig. 3-11:

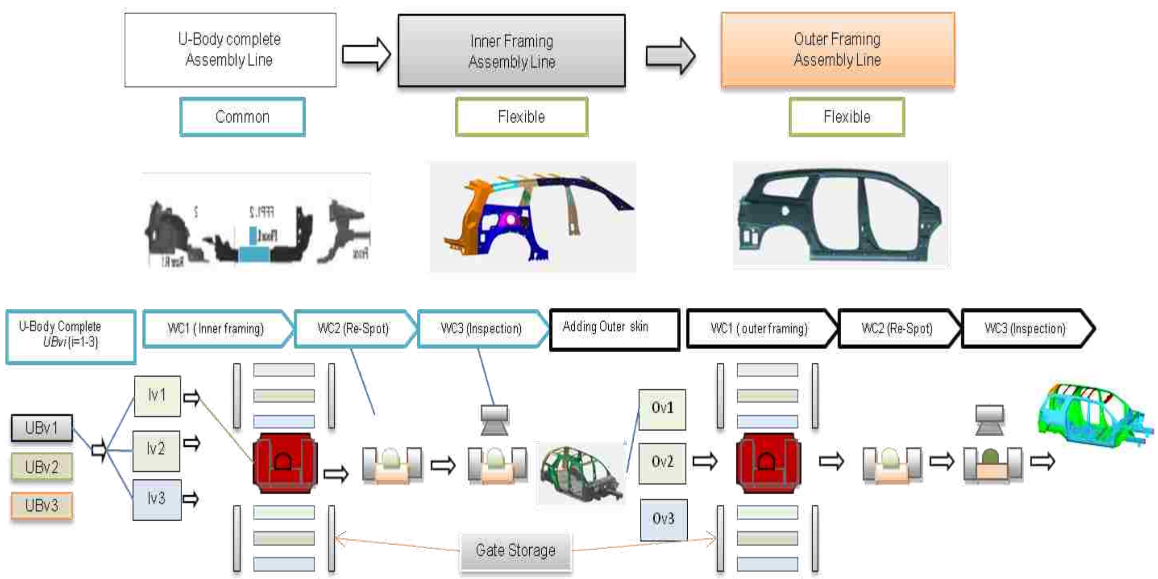


Fig. 3- 11: Assembly process of BIW framing systems

(I) Under-body platform (consisting of up to 10-12 sub-assemblies) needs more than 120 robots for assembly. In recent trends, less robotics are needed and new technology and processes have been used;

(II) Inner framing (5-9 sub-assemblies added prior to framing) needs more than 40 robots, grouped into up to 4 assembly cells.

(III) Outer framing (4-5 sub-assemblies added prior to framing) needs more than 40 robots, grouped into up to 4 assembly cells.

During the framing process, all of the work modules have to be position-ally secured with respect to the UB-platform and inner/outer skin, as only then the welds attaching the roof skin can be placed. The time required for all these activities amounts to 45 to 56 s, depending on the vehicle style (smaller times for smaller bodies). The time required for framing also determines the cycle time (CT) of the whole line, and hence this is a bottleneck operation.

3.3.1: Under-body Platform Tooling

Under-body tooling is developed usually for a specific platform product or assembly. In the next two figures (Fig. 3-12, Fig. 3-13), transfer heights, pin locators for skid and under-body tooling are determined. Once skid data is given or developed for new styles or future styles, it is important to design and build skid and under-body tooling as a module tooling for readjustment and reuse.

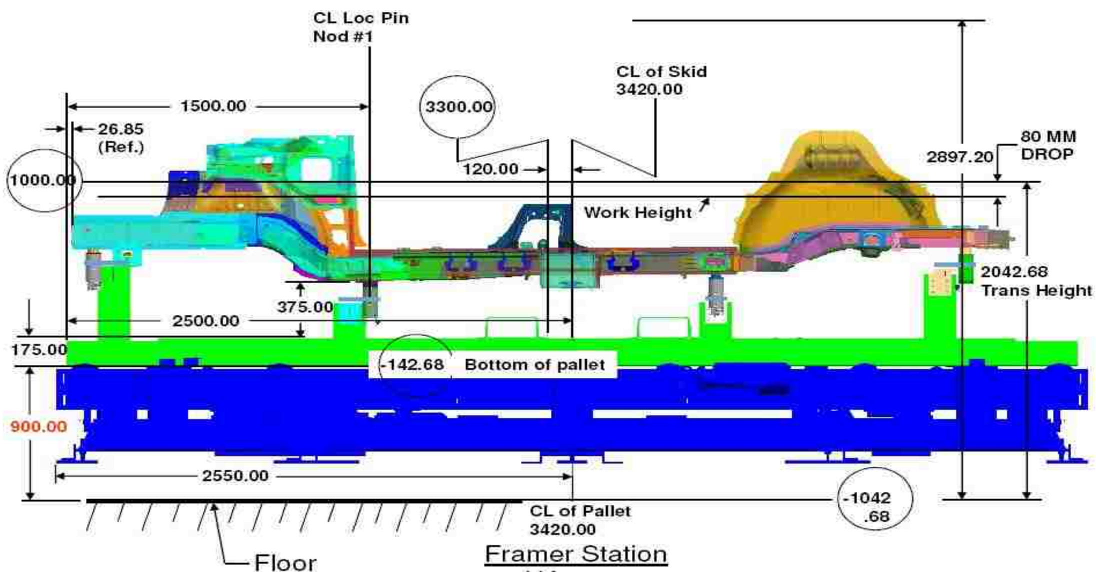


Fig. 3- 12: Under-body complete platform skid design

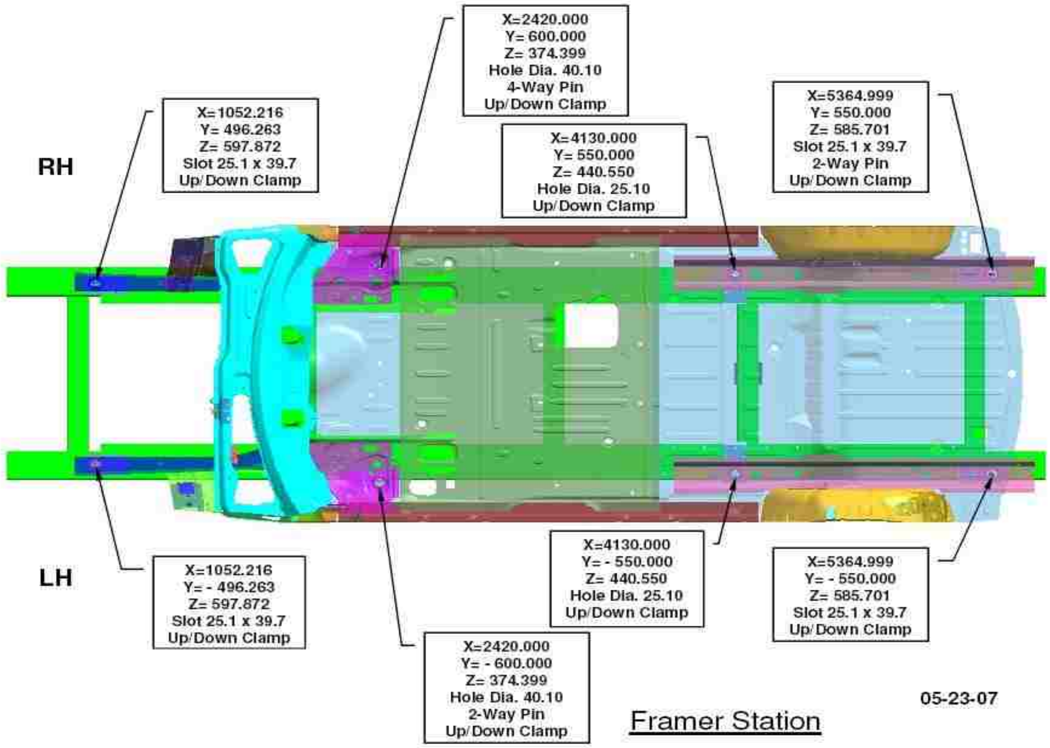


Fig. 3- 13: Under-body complete pins location and C-Flex tooling pins

There has been a new under-body tooling developed in the last 3-4 years from C-Flex tooling by Fanuc; it is programmable, and just recently, teach pendent can be used for reprogramming. Each C-Flex will have a number of homes (Home_S_1, S_2, .. . S_n). All C-flex are programmed to execute steps macros to insure all C-flex are synchronized to move as one device for each under-body complete platform..

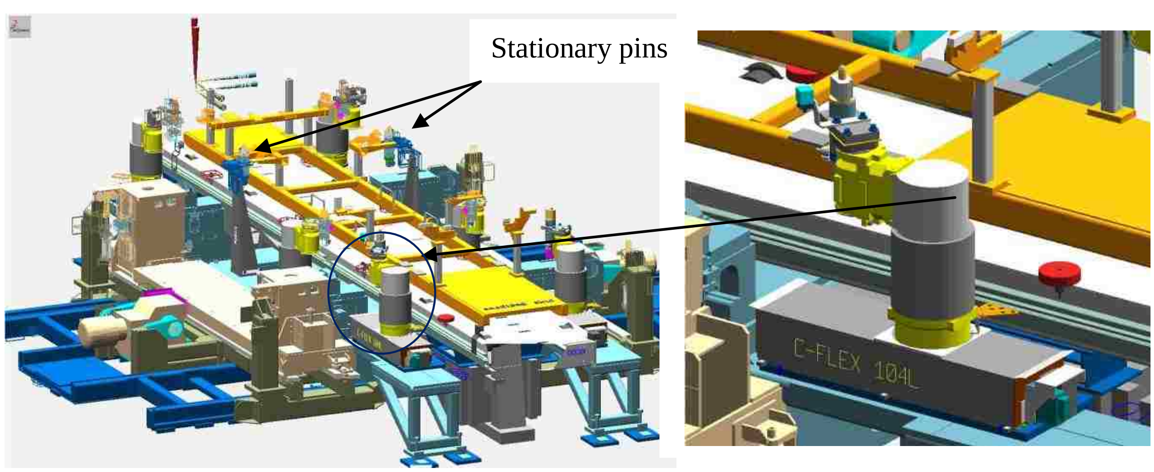


Fig. 3- 14: Under-body complete platform C-Flex devices & tooling

A total of six devices of C-Flex are used for the entire under-body tooling, in addition two stationary pins are also used for support and as reference points for C-Flex calibration. With the new capability of C-Flex, it may become the future of under-body tooling for multi-platform setup (RoboTechCanada.com, 2010).

3.3.2: Inner / Outer Framing Systems Open-Gate Framing Systems

During the framing process, all modules have to be position-ally secured with respect to the under-body-platform and inner/outer skin, as only then the welds attaching the roof skin can be placed. In most production systems, the time required for all these activities is set to between 45 to 56 s, depending on the vehicle size (smaller times for smaller bodies). The time required for framing also determines the cycle time (CT) of the whole line, and hence causes a bottleneck operation. Historically, all current framing systems have evolved from the Open-Gate and Robo-Gate systems, initially developed in the 1980s. The Open-Gate framing (Fig. 3-15) accommodates the use of multiple, exchangeable, dedicated gates. Only a single gate (Geo station; fixture) can be in operation at any given time.

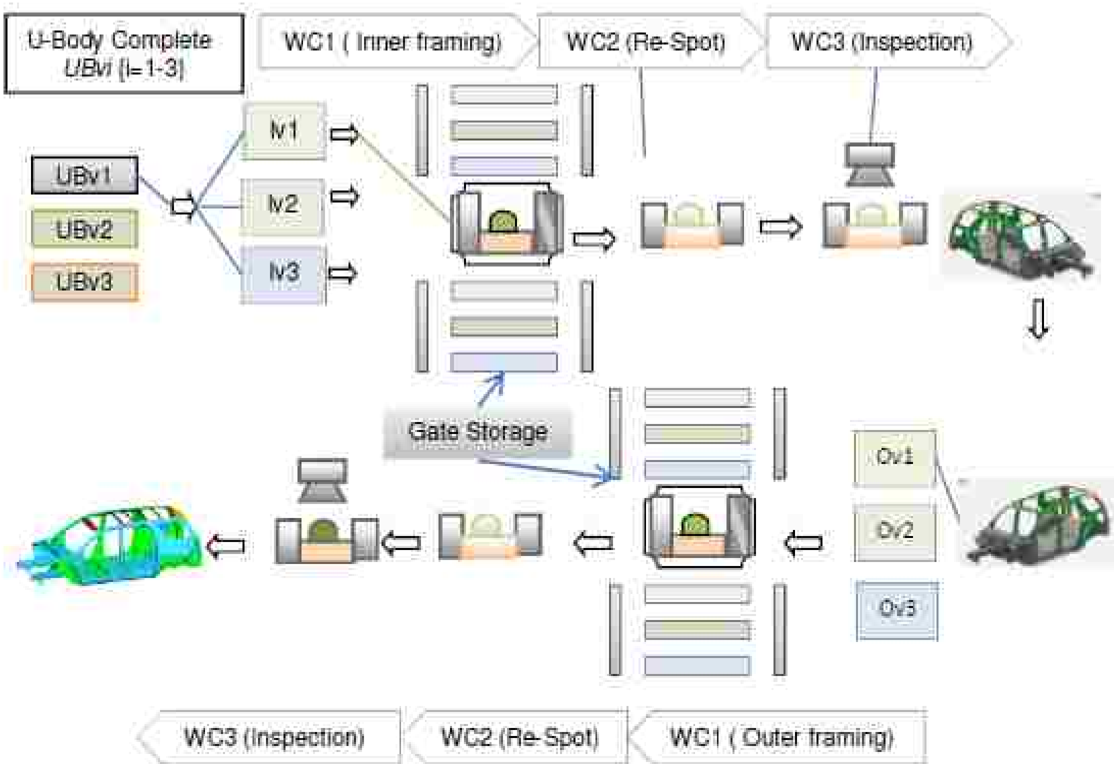


Fig. 3- 15: The state of practice using Open-Gate framing system with gate storage

When a body style change is required, the changeover can be performed in an average amount of time of 40 minutes (loss of production at about 40-50 jobs). Otherwise, the operation of the gate is the same as described previously for Robo-Gate. The cost of lost production due to the changeover is about 400,000 USD (Vrantsidis, 2011).

Product modules-interface components and joining process as stated, is one of the key characteristics of a RMS is modularity. All the major components of the system should be modular, which include structural elements, controls, automation and programming, and joining process. The modules that are used to construct a RMS also need to be customizable so that the system has the flexibility to manufacture or assemble a part family. Table 3-1 shows the state of art decomposition of the automotive framing modules. Inner modules and outer modules are highlighted.

Table 3- 1: Modules/sub modules of the main body-in-white modules

Outer Framing Modules

Front –end (MC)	Floor Pan	Roof	Upper Body	Rear-end (RMC)
Dash Assembly	Rockers (L/R)	Roof Panel	BS outer	Rear floor
Dash panel	Front floor panel	Header	A-Pillar	Tailgate
Dash CM	Seat cross member	Roof bows	B-Pillar	Rear compartment
RS	Tunnel	Adapter Parts	C-Pillar	WH (L/R)
MR (L/R)	-	-	BS Inner	-
Cowl	-	-	Roof Rails (L/R	-
-	-	-	D Ring	-

Inner Framing Modules

Robotics engineers and tooling designers (positioning equipments) require having a common knowledge and understanding of work-cell construction for the geo station (Open-Gate). Interface between modules, which robots and joining process are automatically assigned to a welding window (execution of welding without interference) as shown in Fig. 3-16.

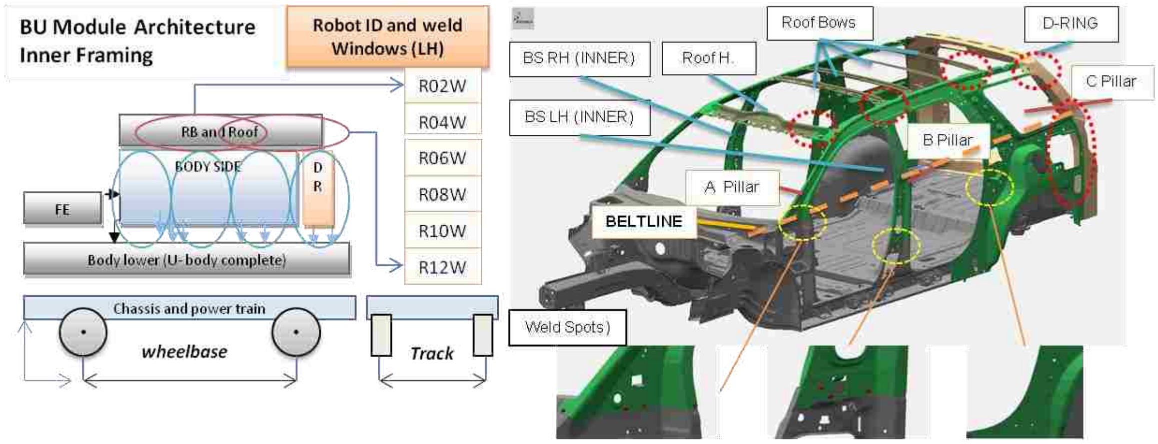


Fig. 3- 16: Inner framing modules interface and robots welding zones

The most recent vehicle framing systems in the automotive industries of North America as shown in Fig. 3-17 includes the following sub-systems:

- Conveyer (skid) subsequently transports body preassemblies to a predetermined assembly station.
- Underbody tooling is used to position and secure lower-body prior to welding.
- Assembly station has at least two gates (left and right hand) secured to each frame at predetermined locations. The frames members extend along the opposite side of the vehicle carrier to secure and clamp reference surfaces of each component.
- Gate mechanism is used to transfer gates position from retracts position to working position, and is used to move both gates in a parallel direction of inward and outward direction.
- Lifter at the assembly station lifts the lower-body and upper-body together with skid from lower position clamped position to elevated position, to disengage the under-body tooling from assembly platform.

These variable components, such as gate to work/retract position (pins clamps, dumps open/close) and joining process time (robot time). More details about time components are found in Chapter 5.

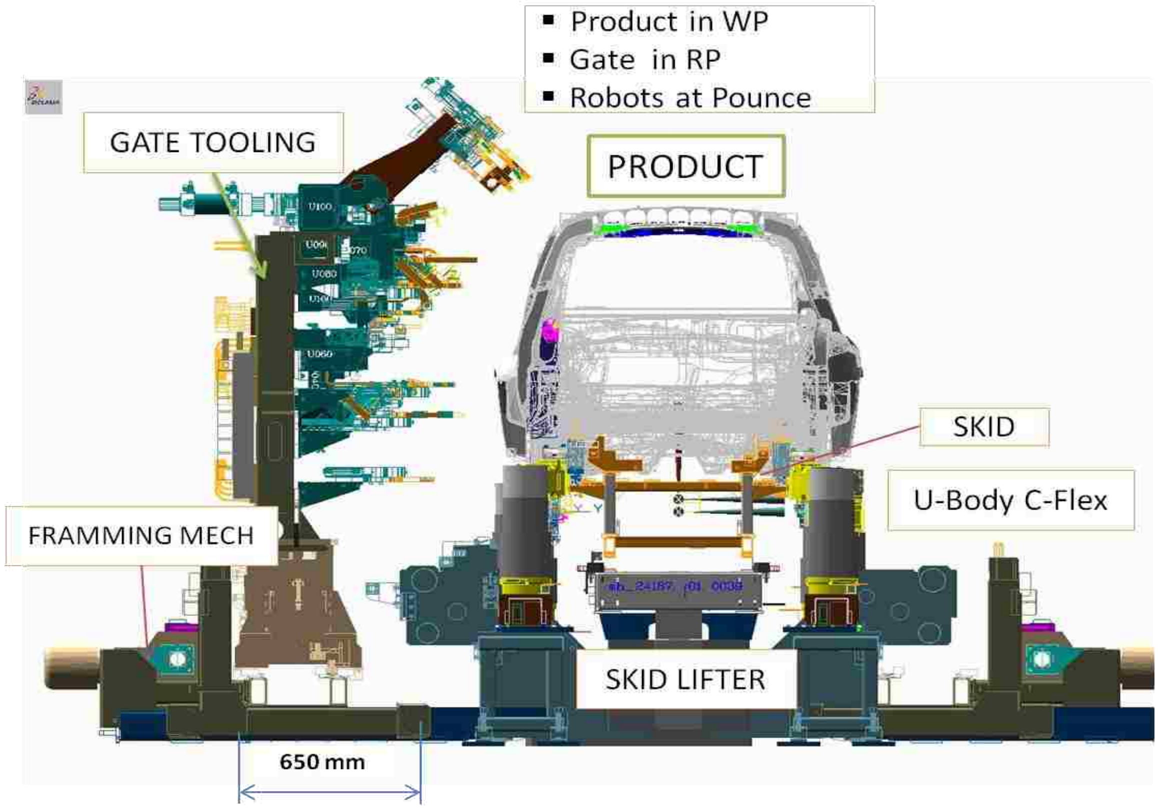


Fig. 3- 17: Open-Gate systems and sub-systems

Gate line sequence of operation (SOO):

- Assembly carrier entered inner assembly station, body side LH and RH parts, roof headers, and roof bow are loaded to under-body complete assemble. Under-body are complete: front floor, dash, motor compartment, rear compartment, D-ring or shelf assembly depends on vehicle type and style;
- At assembly station, under-body tools clamps and locators secured assembly at predetermined positions, gates slide in from opposite direction to secure all reference surfaces of all loose parts;
- Robot gets signal to weld all selected weld spots; usually there are 6-10 robots on the floor level and 2-6 robots on the upper platform level. Total of 60-80 weld spots are tacked at this station. In most cases, there will always be at least one re-spot work-cell to complete the weld spots before the closeout, as shown in Fig. 3-18.

- At the end of the cycle, robot weld is complete, and gates tooling disengage from body assembly and slide to retraced position. Under-body tooling also opens clamps, lifter engaged with skid to lift assembly up about 3-4 IN (75- 100 mm) to raised skid to transfer height.

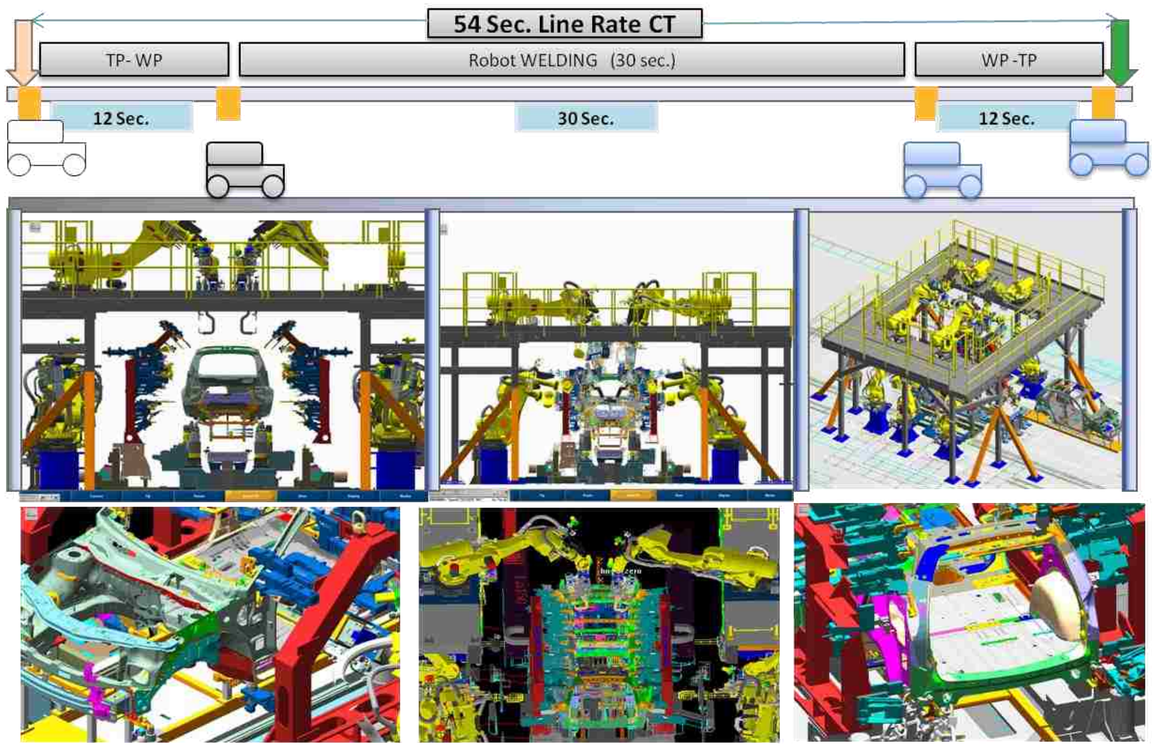


Fig. 3- 18: Vehicle framing; Open-Gate system complete cycle

Next Inspection: Assembly inspects prior to otter framing (see Fig. 3-19).
Outer body side (BSO) LH and RH are loaded to assembly shell (all weld spots before closing out surfaces by otter skin are completed). Conveyer transports assembly to other framing cell, subsequent activities as was disused in inner framing. More welds spots in the outer framing, but cycle time only allows up to get the welds was selected in the process that insure the integrity of the geometry structures. Inspection is critical to insure final assembly quality. The next diagrams (Fig. 3- 19 & 3- 20) show the process of body flow from under-body complete as an entry to inner framing, then final otter framing completed prior to paint process.

Inspection is performed and any part out of specification can be readjusted by the NC blocks through feedback systems to ensure accuracy of 0.5 mm off critical dimension.

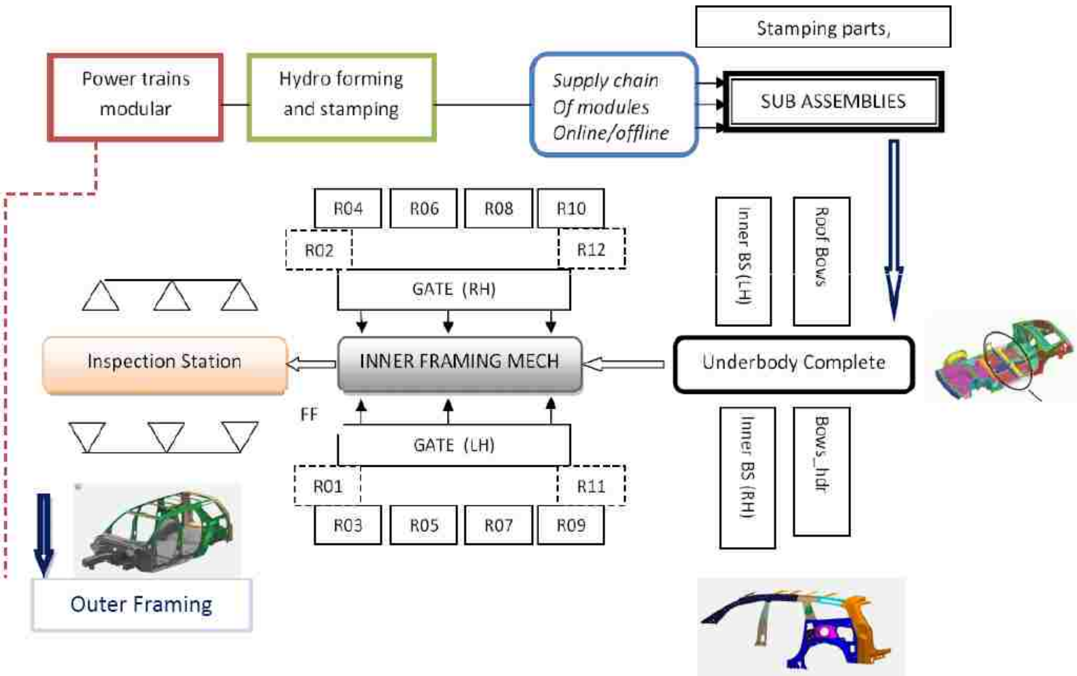


Fig. 3- 19: Inner framing systems work-cell layout

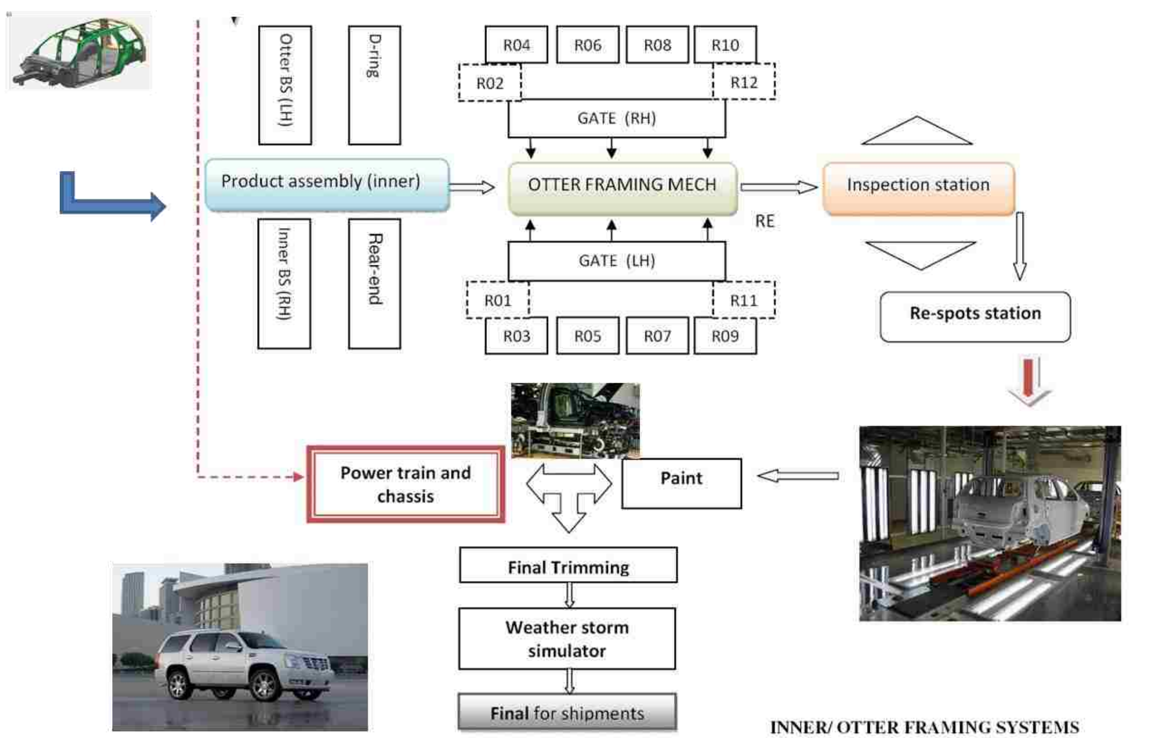


Fig. 3- 20: Outer framing systems work-cells

3.3.3: The Key Issues with Current Vehicle Framing Systems

The key issues with the current framing systems can be summarized as follows:

- Current production systems run batches of styles (using dedicated gates for each styles are used);
- Strongly coupled design, resulting in complex coordination of motion for some work units moving after the gate is in already in the working position; increased both mechanical complexity and overall weight;
- Changeover times have to be accommodated for in the production plan, as the line has to stop running;
- Gates storage systems require significant amount of floor space;
- Overall high cost, high lead-times for engineering, and build time;
- Very expensive to manufacture and maintain;
- High cost of lost production due to downtime (breakdown or retooling);
- High risk in capital investment.

Chapter 4

4. Modular Systems Development and Modeling

This chapter presents the product decomposition into systems/sub-systems and modular. A New Graph Network (NW) representation, Change Propagation Indexes (CPI) and Hybrid Design Structure Matrix (HDSM) were introduced to: (1) establish connectivity between sub-systems (modules) before mapping design changes, (2) measure the degree of changes to state of systems due to Δ*X: Engineering Changes* propagated through the entire system(s), and (3) estimate how much embedded flexibility is needed for these elements (design variables) to absorb future changes. A practical example of actual production systems was presented. Another academically important factor introduced is the new development of HDSM as to transmit knowledge gained to detail the design of production systems.

4.1: Decomposition of Product Automotive Body Structure

Modular design is a technique to develop complex products using similar components (Kamrani, Salhieh, 2002). Modular design emphasizes the minimization of interaction between components of products and production systems, which will enable components (two types of components; one type used for interface between modules and the other a unique component used to create product variation) to be designed and independently produced. Modularity can be applied to product design, design problem, and production systems, or all three at the same time. This can be done by using the modular design process for product design, then by using modular production or a manufacturing process. The decomposition of an automotive product is a result of independently making up the product. The research interest in the example of vehicle systems is in BIW car body structure and in the decomposition into systems. The car bodies are then decomposed into systems/sub-systems and modular as shown in Fig. 4-1.

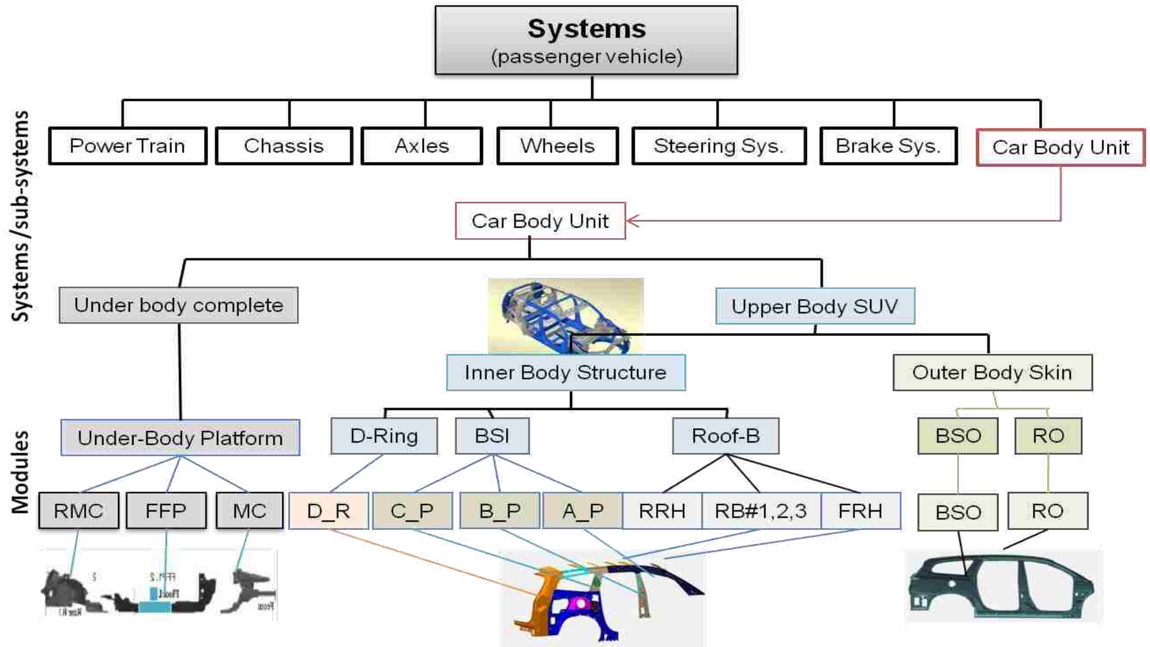


Fig. 4- 1: Decomposition of product automotive body structure.

Figure 4-2 shows the modules structures involved in the design activities of the main systems.

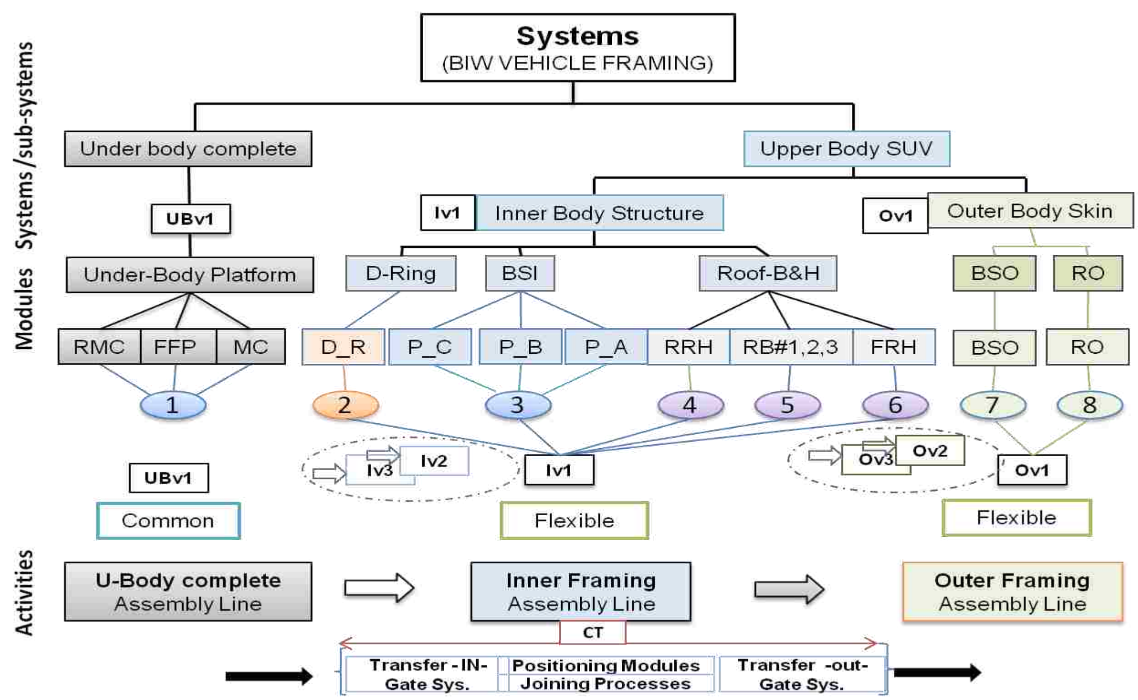


Fig. 4- 2: Decomposition of modules; automotive framing systems.

The main function of each system involved a) transfer function, b) positioning and securing modules, and c) joining processes.

4.2: Modularity of Vehicle Body Structure

Product modularity exploits the independence between physical components in the design. These independent modules, or units, can be designed concurrently, or pre-designed to be used in different products (Kusiak, 1999). A modular design can be justified for a faster product development for a subsequent derivative product (Jose, Tollenaere, 2005) . Fig. 4-3 shows the state of the art decomposition of automotive framing modules.

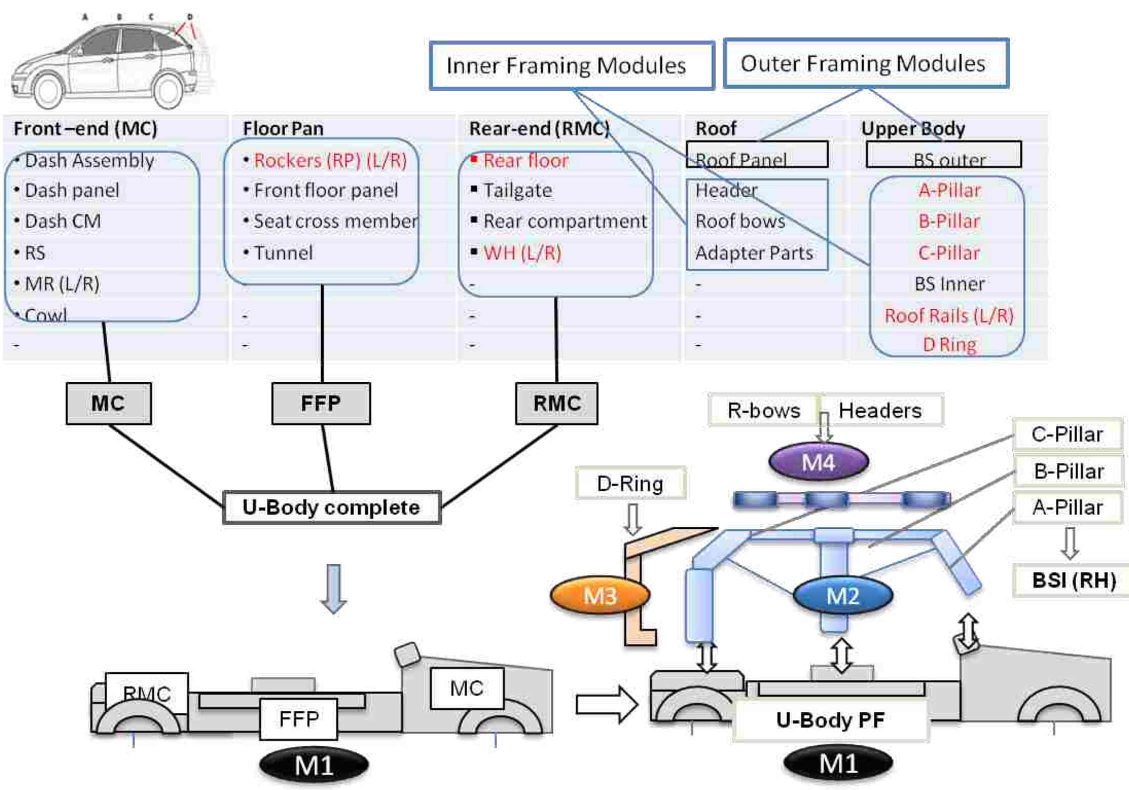


Fig. 4- 3: Car body structures of the main modules/sub-modules (BIW).

4.2.1: Modules Connectivity: Identify Key Critical Elements (KCEs)

It is very important to establish connectivity between modules before mapping systems design variables to product elements and to production systems. The reasons are the following:

- When changes (ΔX: product, process, production) applied or introduced to the systems, design variables are required to be flexible; the key elements—physical components, KECs, and KCGs—must be designed to absorb these changes;
- To build flexibility into the critical emends, CPI must be evaluated through the entire systems for all domains;
- Modular structures for the production systems should establish a strategy to respond to quick and more economic market changes.

This section will explore the physical connection between modules and key elements that completely connect body inner sub-modules to under-body. These are identified in Fig. 4-4, 4-5, and 4-6. Fig. 4-4 explains the simplified processes of adding M2 (BSI Assembly; RH is shown), M3 (D-Ring), and M4 (RFH and RRH) to M1 (under-body complete PF). Usually car body styling BIW is above the beltline every year. S1, S2, and S3 are three common styles of car body based on data of real assembly of production;

- Style S1: represents changes in C-Pillar and D-Ring.
- Style S2: represents changes in B-Pillar, C-Pillar and D-Ring.
- Style S3: represents changes in A-Pillar, B-Pillar, C-Pillar and D-Ring.

In all cases of styling, with common under-body (M1) for all above styles, it is fair to assume that the designer should not consider altering the product or tooling characteristics (KCGs) such as 2-way pin, 4-way pin, slots, clamping packages that are used for positioning upper modules to pre-defined set of dimension as established by the gate tooling function. Fig. 4-5 shows the proposed ROGS with reconfigurable capability on the top device to adjust to styling above the beltline.

4.2.2: Identify Key Characteristic Groups (KCGs)

The three groups based on manufacturing process design; *KCC*s into *Key Characteristic Groups* (*KCGs*) see Fig. 4-4 and 4-5, to perform the following specific functions:
1) Common positioning of body side inners to under-body KCG1 (S1, S2, S3). The physical components are shown in Fig. 4-5, (cp1, cp2 and cp3) and correspond to:

- Front A-Pillar to Dash cross member,
- B-Pillar to Rocker Panel (RP L/R),
- C-Pillar, D-Ring to Wheel House (WH L/R).

2) Top positioning of body side inners and D-Ring with roof headers front and rear M2+M3 with M4) *KCG3* are shown in Fig. 4-6. (tp1 and tp4) and correspond to front and rear headers. Characteristics and attributes of these elements can be standardized as smart tooling, which can be automated and controlled for each style.

3) The middle group KCG2 S1 represents only the controlling points of body surfaces. This means no requirements for pin location (specific location). Therefore, this controlling point can be programmed using smart tooling to execute design task with style specified.

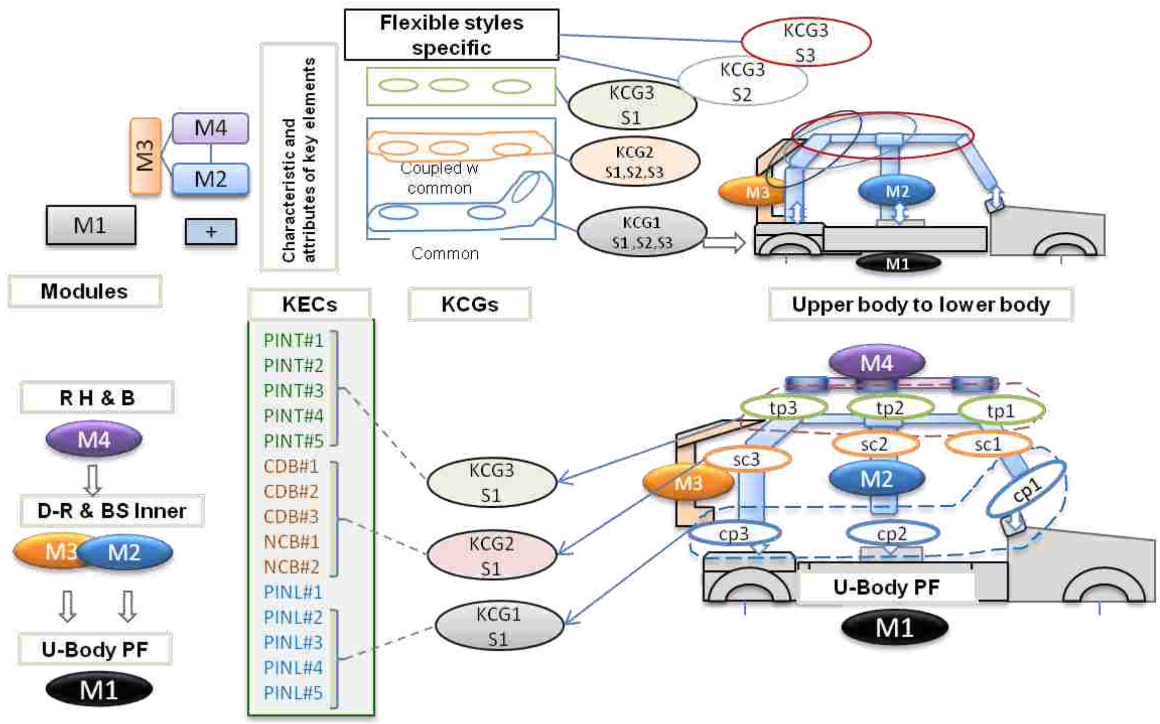


Fig. 4- 4: ID Key elements (KECs) that connect modules, - Group KCCs into KCGs

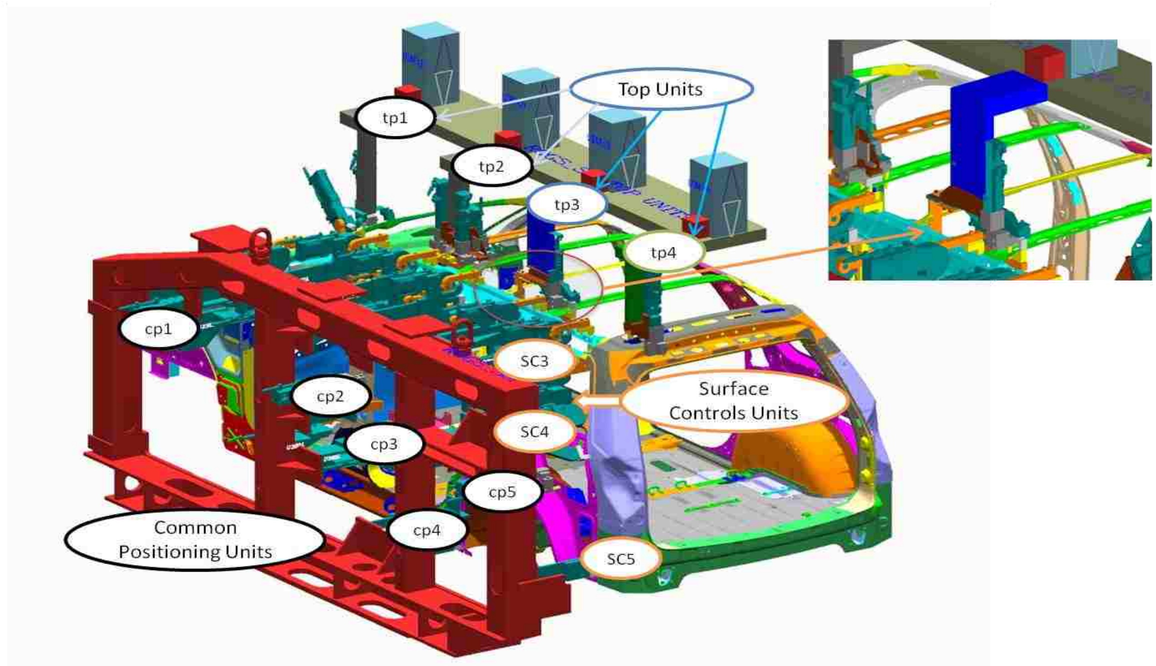


Fig. 4- 5: Conceptual Design of *Reconfigurable Open Gate Systems* (ROGS)

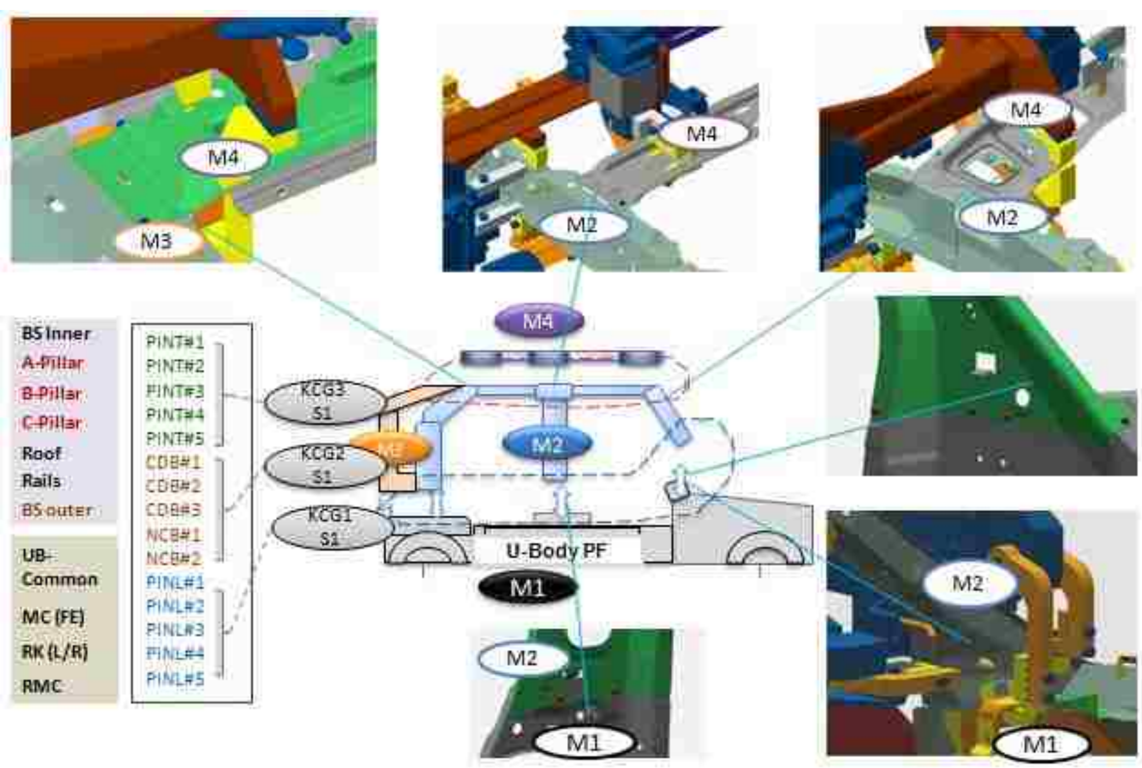


Fig. 4- 6: Physical representation for *Key Characteristic Groups* (*KCGs*)

4.3: Automotive Body Structure & Vehicle Styling

Designing the body assembly system to be responsive to the market requires thorough analysis of a company's product line to create product families and platforms. This must, however, be done from the point of view of the manufacturing process. Mapping the product characteristics into the manufacturing system requirements under constraints of product families allows, on the one hand building in necessary functionality, and on the other, to leave room for predictable future changes and their proper management. Alignment of some common features across the product lines is also critical for cost-effectiveness. Therefore, system designers and planners need to fully understand vehicle styling. It is impossible to start from scratch all over again whenever a new style is developed.

When it comes to the tooling design, there is rather little understanding of beltline significance. In Fig. 4-7, the exterior of the car body profile, beltline, wheelbase and track are shown. The importance of this figure is to show that most of the changes in one car model are located on the rear top quarter of the vehicle body and product's data design are supporting this notion. The importance of these analyses is to devolve knowledge and understanding of how current production systems are developed and how flexibility can be embedded in the early structure of the manufacturing systems.

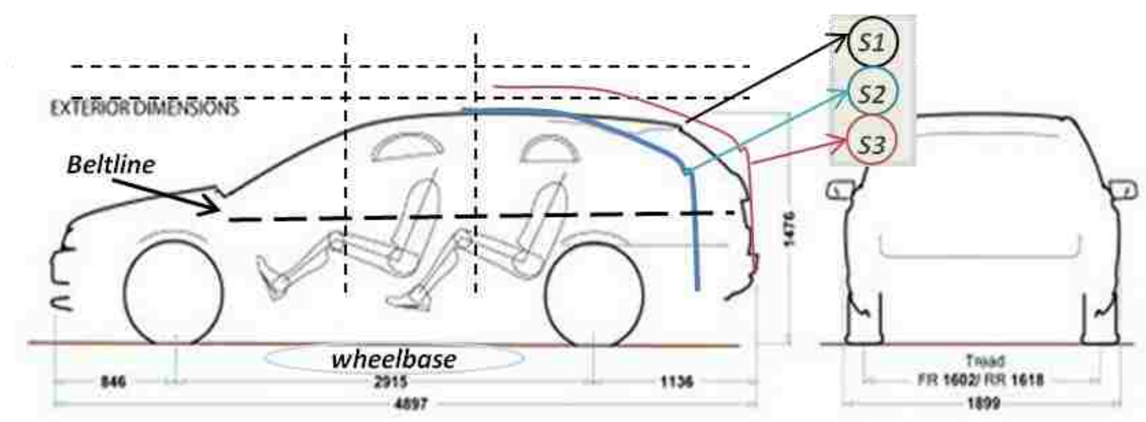


Fig. 4- 7: Vehicle body three-Styles (Adapted from Automobilesreview.com)

Multiple models can now be assembled on a single production line. Typically, more than 80 percent of the tooling and equipment in a body shop are not specific to an individual model but can be used for all models produced.

The *hypothesis* is that if the right subsets of car body elements are designed with proper care for future flexibility, then the proposed corresponding production system can then better accommodate body styling changes, enabling structural flexibility in the gate design supporting and increased number of body variants produced, without the need for tooling changeover, which improves throughput of the systems.

4.4: Modeling the Product Development Process Using DSM

Product development can be viewed as a transformation of data input information about market needs or customer requirements into output information corresponding to manufacturing design, manufacturing processes and production systems, tooling and equipments (Kamrani, Salhieh, 2002).

4.4.1: The Design Structure Matrix (DSM)

The Design Structure Matrix (DSM) introduced by (Steward, 1981), is a method that can be used to manage the design of complex systems based on the information flow identifying the dependencies between task and sequence of processes.

Design Structure Matrix (DSM-*Component-Based Architecture*) is used in the automotive industries as a tool and technique (Kusiak, 2008). It provides a simple, compact and visual representation of a complex system that supports innovative solutions to both breakdown and integrate problems. It is also an effective method for integrating low-level design processes based on physical design parameter relationships. Furthermore, it displays the relationships between modules or components (which depend on the level of details) of a system in a compact, visual, and analytical format. It is important to note that DSM models represent extensive system knowledge. Hence, DSMs can be difficult to build, especially initially, as they depict data that are not always at hand, easily gathered, or quickly assimilated.
For a given change, it is important to establish how it propagates throughout the system(s). Fig. 4-8 shows network (NW) representation of the systems that consist of eight modules M1 to M8, and shows how the final systems configuration is due to Δ*X Changes* in one element. Changes are applied M1, then changes are propagated throughout the systems. The direction of changes is propagated and classified based on the classification of element to changes by Eckert (2004). The classification is as follows:

- Multiplier (M) ; CPI > 0 : generate more changes than they absorb
- Carrier (CA) ; $\Delta Eout,i=\Delta Eini,i > 0$: absorb and cause a similar number of changes
- Absorber (A); CPI < 0: absorb more changes than they cause
- Constant (C); C PI= 0: components unaffected by change.

The question then, is how can these classifications be identified and quantified to help systems engineers create better flexible and reconfigurable production systems?

To measure the degree of reaction in the system due to each of the changes of critical elements, there is a new metric called change propagation index (CPI) using equation (4.1).

$$CPI = \sum_{j=1}^{n} \Delta Ej,\ i - \sum_{k=1}^{n} \Delta Ei,\ k = \Delta Eout,\ i - \Delta Ein,\ i \qquad (4.1)$$

- CPI: Change propagation index used to classify elements as multipliers (*CPI* > 0), carriers (*CPI*=0), and absorbers (*CPI* > 0)
- *n*: the number of elements or area in the systems
- $\Delta Ei,j$ is a binary matrix (0,1) indicating whether the *i* th element is changed because of a change in element *j*.

The rows and columns in DSM is equal to the number of modulus/components of the systems 8x8 as shown in Fig. 4-8 b. CPI can be measured as follows; for each modules i.e. M3 receives one input from M1 and send 2 outputs to M2 and M5,

CPI= $\Delta Eout,M3$*-*$\Delta Ein,M3$*= 2-1 =1 which is classified as a multiplier.* The classifications for the rest of the system components are shown in Fig. 4-8 b. The challenge is that the designer needs to determine how to eliminate or reduce the impact of physical interaction between modules. Multiplier elements can be turned to absorber or carrier by building flexibility abounded (Eun Suk et al., 2007b).

Network representation for car body structures is built as shown in Fig. 4-9. These links between modules represent joining process such as weld spots, arc welding, laser welding or any other methods of joining upper modules to the lower-body. The network graphical represents two types of physical connections:

1) Internal connection in modules or assembly; all these joining processes are done prior to framing systems; and

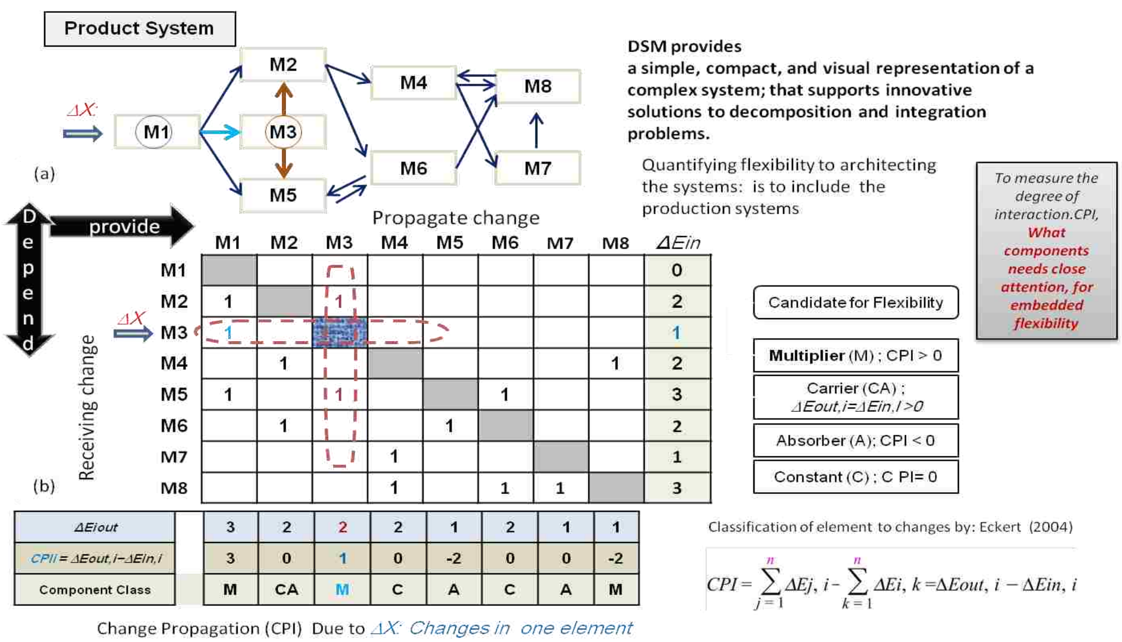


Fig. 4- 8: Change Propagation (CPI) Due to ΔX (Adapted from Eun Suk et al., 2007b)

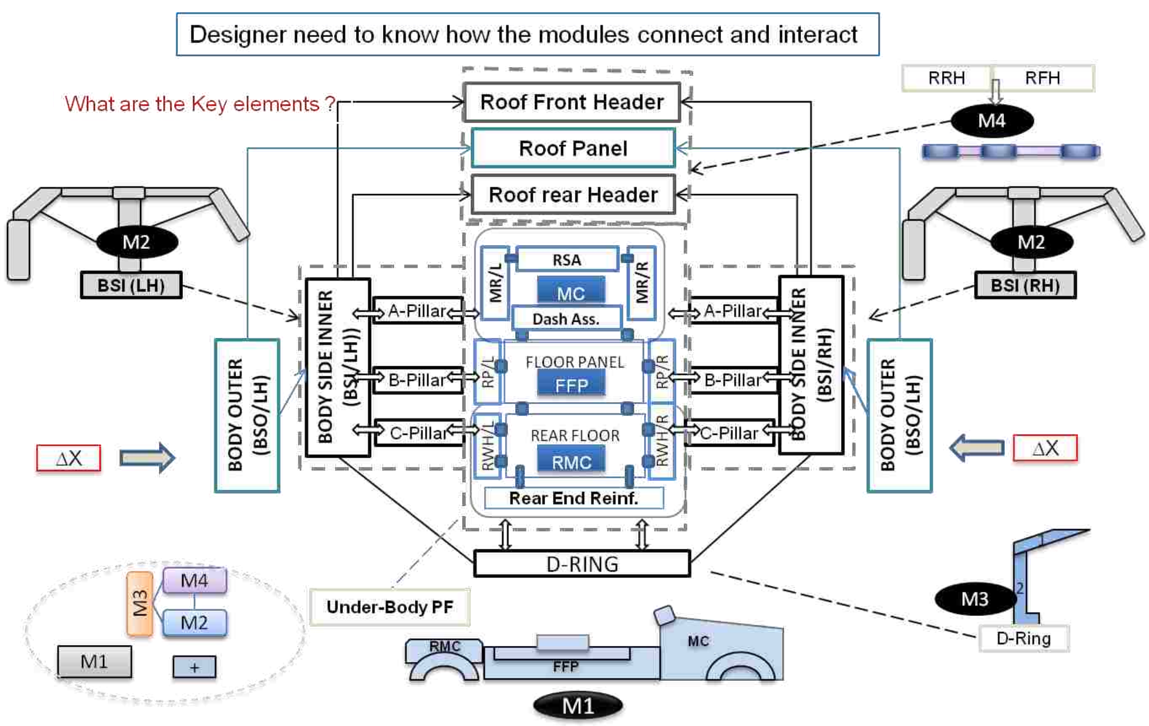


Fig. 4- 9: Network representation *of car body structures BIW.*

2) External connections between main modules; a) Lower connections M2 (L/R)+M3 with M1 (under-body) which is represented by connecting A-Pillar front with Dash, B-Pillar with R P (L/R), and b) Top connections M2 (L/R)+M3 with M4 (RHF and RHR).

As shown in Fig. 4-9, connection between modules of upper-body (M2, M3 and M4) to lower-body (M1 assembly) easily identify changes in propagation throughout the system.

4.4.2: Building the DSM Car Body Styling;

Building the DSM for the systems requires appropriate decomposition methodology capable of identifying all sub-systems or components that form the systems (Kamarani, 2002). The method is used to decompose a certain system into the basic modules or components. In the case of "hardware" systems (such as a mechanical product), physical decomposition is a hierarchal decomposition technique where the systems break down into the smallest components that are used to create their modules and varieties of each module. Once the modules or components are identified by systems experts, they are listed in the DSM as rows and columns in the same order.

Approach for Building Credible DSMs:

This methodology to build DSMs and MDMs is proposed in the following steps (Lindemann et al., 2009):

Step 1: Define the system and its scope.
This step determines the boundaries of the system with focus on the elements' interaction within the systems. Different system definitions result in different output of the DSM.

Step 2: List all the system elements.
Existing project plans or systems definitions can be used as starting points in defining the systems elements. However, experience shows that the initially defined system elements often need to be modified in the process of assigning interactions to them. A critical review of the list of elements in collaboration with engineering staff or other relevant experts is therefore necessary.

Step 3: Study the information flow between system elements.
Reading the design documents as well as interviewing experienced engineers who were working on the particular product is a good source of knowledge.

Step 2 and Step 3 are highly iterative. A deeper understanding of the system usually results in modification of the initial system elements. The system elements in this research were modified many times during the literature survey in order to represent the system accurately.

Step 4: Complete the matrix to represent the information flow.
Initially having collected the elements and the dependencies, a binary DSM can be built to represent the basic dependency structure and information flows between various system elements. A binary DSM serves as a good start for preliminary analysis; however, a better understanding of the system (or project) might require the use of a numerical DSM that will provide better system understanding and allow for a more detailed analysis.

Step 5: Partition the matrix.
Partitioning is the sequencing (i.e., reordering) of the DSM rows and columns such that the new DSM arrangement does not contain any feedback marks, thus transforming the DSM into an upper triangular form.

Step 6: Optimize the matrix.
Enhancing the matrix can be done by tearing the coupling and decoupling it.

Step 7: Give the matrix to the engineers and managers to comment on and use.
DSM provides aid to design engineers and engineering managers to understand the design process better and approach the communication more systematically. Hence, the constructed DSMs are usually provided to the engineers and manager who participated in their building to receive comments.

4.4.3: DSM Analysis Strategies

There several strategies to analyze the DSMs generated. Classically, a DSM is used for:

- *Sequencing*; In sequencing, the rows and columns of a flow oriented DSM are rearranged in a way that as few relations as possible remain below the diagonal, thus reducing the number of active feedbacks, leading to an ideal sequence.
- *Tearing;* Tearing consists of choosing the set of feedback marks that obstruct sequencing in the DSM. The relations that need to be removed are called "tears”. There is no optimal method for the tearing the DSM, but a general guideline for tearing is as follows:

1) Minimize the number of tears.

2) Start tearing in the smallest blocks along the diagonal.

3) Tear where a good estimate can be made.

- *Banding;* Banding rearranges the rows and columns in a way that blocks of parallel entities remain, which, for example, in a process can be executed independently of each other. Thus, a "band" represents a group of elements being active in parallel.
- *Clustering;* Clustering is executed to find those clusters of entities that are mutually related. Figure 4-10 provides an overview.

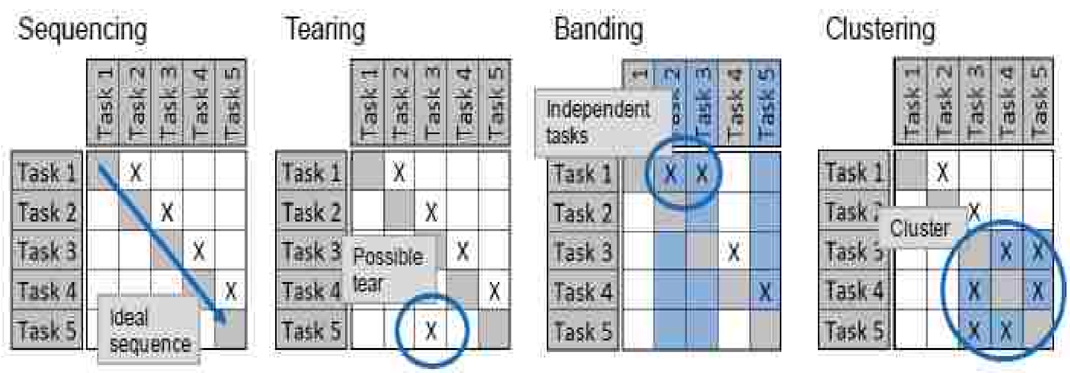


Fig. 4- 10: Classic DSM analysis techniques, sources (Dsmweb.org)

4.4.4: Partitioning the DSM

There are many techniques that can be used to partition a DSM. Most of the techniques are similar. In general, partitioning techniques proceed as follows:

Step 1: Identify the task or element that does not require any input (empty rows), such that the new DSM arrangement does not contain any feedback marks, thus transforming the DSM into an upper triangular form.

Step 2: Repeat Step 1 on all elements.

Step 3: Identify the task or element that does not provide any output (empty columns) and place it at the bottom of the matrix (re-arrange) then remove the element from the matrix.

Step 4: Repeat Step 3 on all remaining elements.

Step 5: If there are no remaining elements, then the DSM is completely partitioned; stop.

4.4.5: DSM Configuration and Analysis Techniques

There are three different configurations of the matrix (Fig. 4.11):

- The Parallel configuration, in which the design elements (e.g., design parameters or activities) are fully independent of each other,
- The Sequential "decoupled" configuration, in which the second parameter is dependent upon the output of the first, and
- The Coupled configuration, in which parameters are interdependent upon each other.

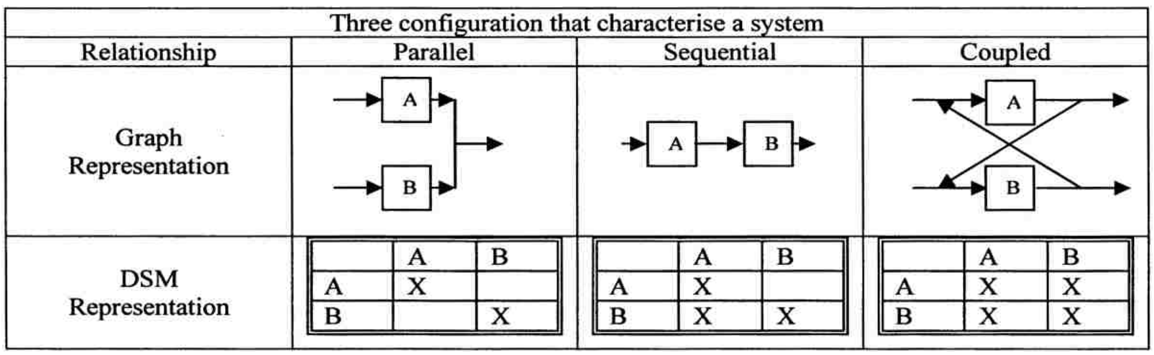


Fig. 4- 11: DSM Configuration, sources: (Dsmweb.org)

The first option (the parallel configuration) is the unique solution (both axiomatic designs are satisfied). Another option can be a combination of the first and the second, and this might be the most economical solution. The main strategy that was identified for design improvements was the decoupling task to speed the design.

4.5: Modeling the Structure of Engineering Design Processes

4.5.1: MDM-based Process Modeling of the Structure of Processes

To model the structure of an engineering process comprehensively and to gain a deeper understanding of it, it should therefore be understood as the multi-layered network and it is important to select and relate all domains that are relevant to such a specific analysis. As a modeling technique, Multiple-Domain Matrices (MDM) is chosen for representing and manipulating a network structure consisting of different domains and relationship types. Equally, an MDM is able to capture different relationship types that coexist concurrently. This makes it an ideal tool for modeling the structure of design processes.

4.5.2: Building the Process Model

Two different generation models are possible: either MDM can start from an existing model, as mentioned for matured production such as automotive industries, or start new; the case will be modification of the existing model. Either choice domains relation is needed to aggregate all domains in one single domain.

The process of aggregate relation type, the rules (Dsmweb.org) are applied for each path calculated by two matrices multiplication (DSM1= DMM1. DMM2). Fig. 4-12 shows how computed DMMs 1 and 2 are multiplied to generate the intermediate DSM of relationships that do not use any logic connector between them. Then, a second intermediate DSM, including the logic operators, is calculated. As a third step, both intermediate matrices are added. This aggregate view thus represents the minimum set of relations among the tasks.

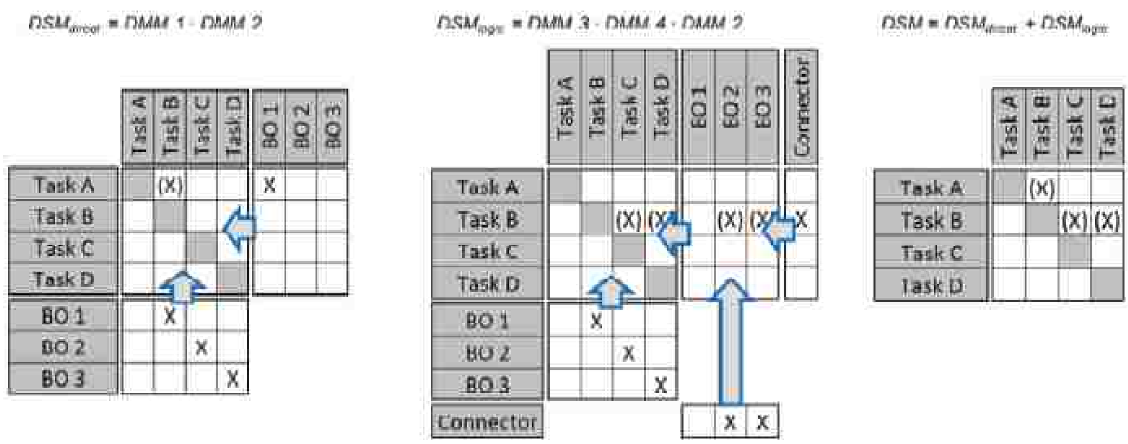


Fig. 4- 12: Computation of aggregate DSM from MDM sources: (Dsmweb.org)

4.5.3: Decomposition of Manufacturing Systems-integration: DM –DSM

In the design of complex systems, the FRs are satisfied by modules, sub-modules or components and therefore the design matrix cannot be represented analytically. For this reason, the structures of matrices co-evolve; this is the decomposition procedure. Fig. 4-13 shows that the decomposition steps start by the construction for DM which presents the FPs and DPs. Then subsequent activities to axiomatic design principles are satisfied by reaching to a triangulate the DM.

The following steps are the transitions to multi domain representation using DSM. DSM is derived only from the functional view of the product. Another factor is that it may lead to grouping components and that may couple the functions; in this case the design parameter needs to change or has to be added see (Guenov, Barker, 2005). These procedures combine Axiomatic Design (AD) design Structure Matrix (DSM). This procedure has been adapted to framing systems to show how DM-DSM arrangements can be used to identify the existing of potential conflict in the design solution.

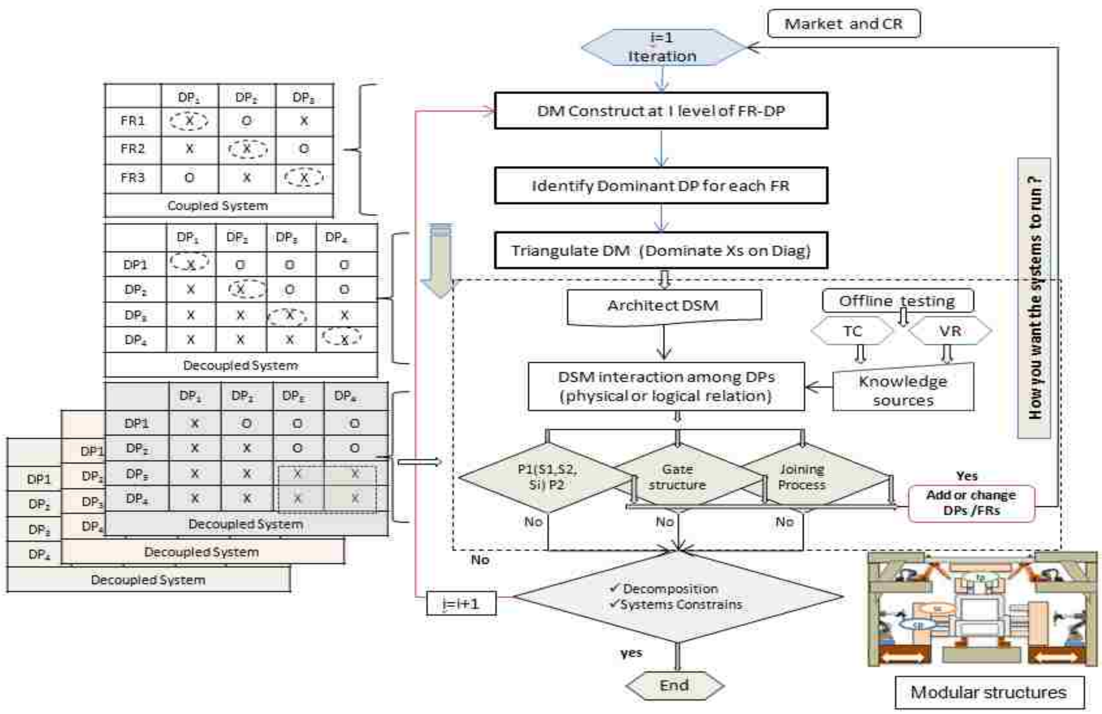


Fig. 4- 13: Automotive framing decomposition–integration; DM and DSM Transition

4.5.4: Hybrid Design Structure Matrix (HDSM) and DSM

Different applications and studies using DSM have been developed by researchers. Browning (2001) reviewed applications of different types of DSMs. Chen et al. (2003) applied the DSM concept to manage new product development projects. Numerous DSM applications are surveyed in (Lindemann et al., 2009). The DSM matrices can be established for parts, sub-assemblies, assemblies, and process activities across various technologies Relationships among components need to be specified; multi-layer of information can be revealed and DSM allows the capturing of bidirectional relationships. In large and complex systems, representing the dependencies of the system with a DSM allows the system to be decomposed into manageable subsystems. In the case of modular interface, considering interface among modular design is not a new idea (Kusiak, 2008). Collecting information and data needed for modular interface from multiple domains and using it in order to reduce the time of developments is a new concept. Once the new data or information of modified interfaces has been established, product structure is determined. Parallel design activities and efforts on different modules become possible and effective, therefore significantly reducing the cycle time of the design process. This is due to the fact that extracting data and information about the interface among components using DM are fast and instant, but it requires proper training and knowledge to make a valid assumption. HDSM, introduced in this research as a new application of DSM to the automotive framing systems, can be classified as a special use in the automotive industry. The new configuration of DSM provides a new perspective of dependency relationships between modules; more details will be in the next section.

4.6: Case Study

This case study shows that the changes originating from the outer body are the most important components perceived by consumers or the market segmentation for vehicle styling. The change propagates throughout the BIW car body inner structures. Two different scenarios are introduced with styling changes from real production data.

Case (a): ***Changes ΔX: in C-Pillar and D-Ring***

The first step is to define what the changes are; types of changes could be geometry, new material, new processes, etc. The changes in case (a) are geometry changes in the components as shown in Fig. 4-14.

- C-Pillar: Geometry Changes in C1 and C2 (see Fig. 4-16)
- D-Ring: Geometry Changes in D1 (upper D-ring).

In the first case (a), changes are geometry changes and material type in both modules as shown in Fig. 4-14, and changes propagate as follows; starting from:

- Body-side Outer (BSO) to Body-side Inner (BSI)
- Body-side to wheel house (WH/RL) through C-Pillar
- D-Ring with assumption geometry changes only above the beltline (D1)
- Using light and high strength material for (C1, C2, D1 and D2).

The final state of the systems is shown in Fig. 4-15. The DSM for changes propagation along with the relevant value of CPI of the components needs more attention in the design stage.

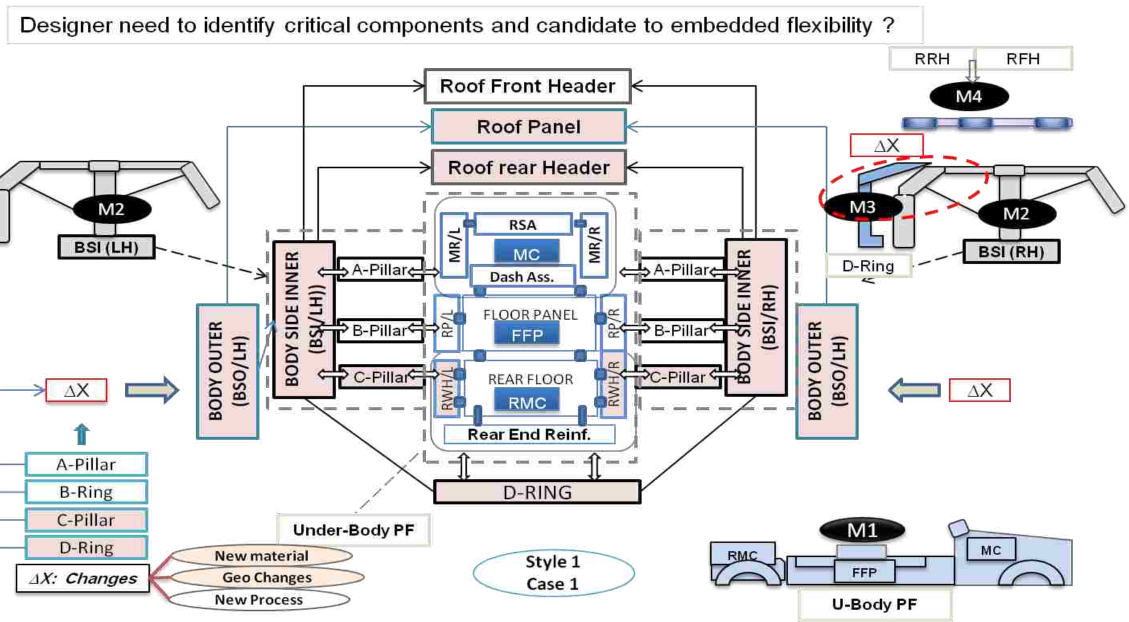


Fig. 4- 14: Network Change Propagation (NW); Due to Δ*X: case study (a)*

Receiving Change

	Module Name	No	01	02	03	04	05	06	07	08	09	10	11	12	13	14	*ΔEin*
Roof Assembly (NA)	FRH	01															0
	RB#1	02															0
	RB#2	03															0
	RB#3	04									I						1
	RRH	05									I	I					2
	Roof Panel & RR	06									I	I					2
Body Inner Assembly (4 MA)	Pillar A	07															0
	Pillar B	08															0
	Pillar C	09				I	I					I				I	5
	D-Ring	10					I				I					I	3
BO	Body Outer	11									I						3
U-Body Complete 3	Front –end (MC)	12															0
	Floor Pan (FFP)	13															0
	Rear-end (RMC)	14										I					1
	ΔEiout		0	0	0	1	2	0	0	0	5	4	0	0	0	2	
	CPIi = ΔEout,i–ΔEin,i		0	0	0	0	0	0	0	0	0	-1			0	-1	
	Component Class					Ca	Ca				C	A				A	

New steel type change on in WH L/R upper components only

Propagation Change (ΔX: Eng. Changes) C-Pillar+ D-Ring

Fig. 4- 15: Change Propagation DSM; Due to Δ*X: case study (a)*

What is important is that systems designers link product developments, namely, how new styles are affecting the production systems. New developments of HDSM for the automotive framing systems are presented in Fig. 4-16 and 4-17.

Fig. 3-16 shows product element that needs flexibility based on previous steps. The new construction of the HDSM requires products, tooling, and joining processes expertise to fill in the required data (see Fig. 4-17).

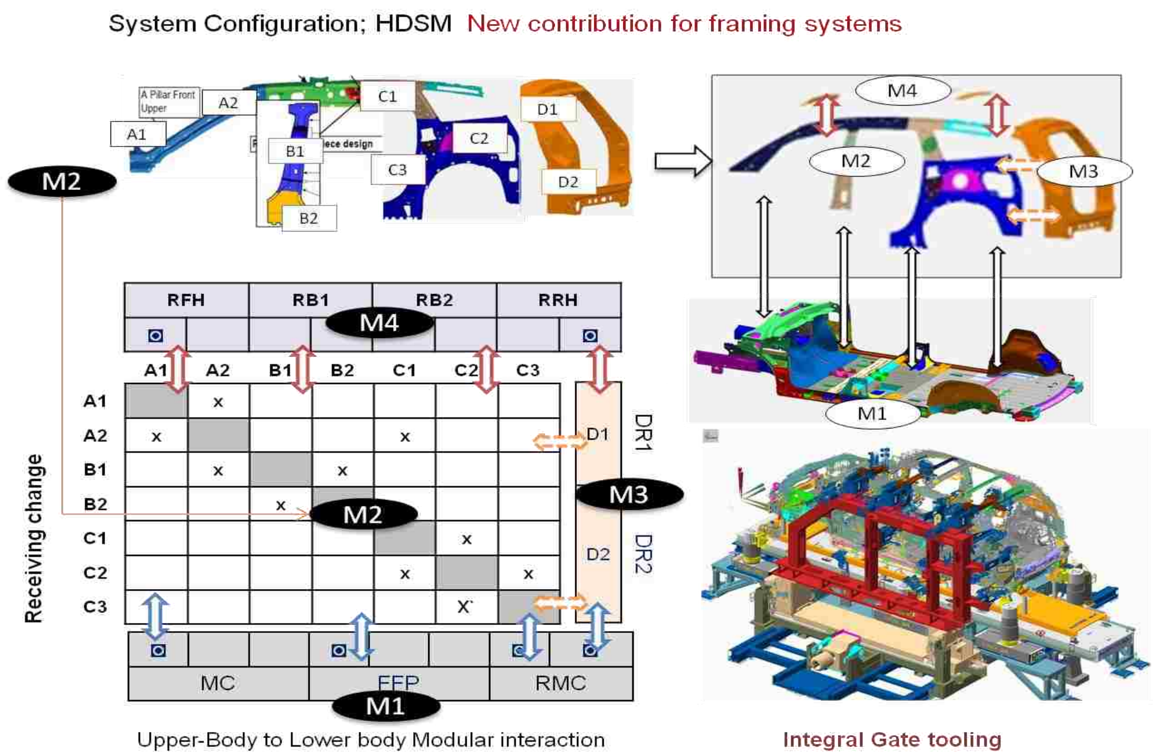


Fig. 4- 16: HDSM mapping production CPI to Design Task (DT) - Δ*X: case study (a)*

For the styling in the product defined in outer body in case (a), the changes are in the rear upper quarter of the car body. The intersecting region can be defined as M2 with M3 and M4.

Within the intersection region (left and right hand of the body), positioning units (Gate devices) can be identified using simulation model. The corresponding modification or changes to the parameters of joining process including welds location attributes and specs of weld equipments can also be identified (using the HDSM mapping) for adjustments or adding flexibility for future changes.

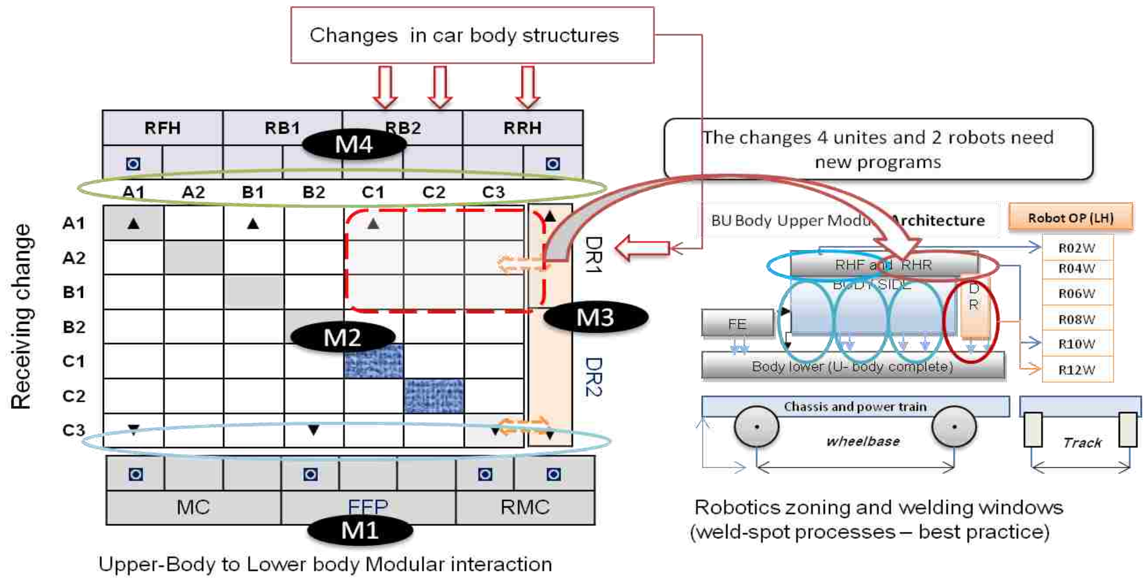


Fig. 4- 17: HDSM mapping DC to Mfg Capability (MC) - Δ*X: case study (a)*

Case (b): ***Changes*** **Δ*X*:** ***in B-Pillar, C-Pillar and D-Ring***

The first step is to define the type of changes (geometry, new material, new processes):

- The changes in case (b) are geometry changes in components as shown in Fig. 4-18
- B-Pillar: Geometry Changes in B1
- C-Pillar: Geometry Changes in C1 and C2
- D-Ring: Geometry Changes in D1 (upper D-ring)
- In case (b) changes, are geometry changes and material type in both modules as shown in Fig. 4-18. Changes propagate as follows; starting from:
  - Body-side Outer (BSO) to Body-side Inner (BSI)
  - Body-side to wheel house (WH/RL) through C-Pillar
  - D-Ring with assumption geometry changes only above the beltline (D1)
  - Using light and high strength material for (B1, B2, C1, C2, D1 and D2).

The final state of the systems is shown in Fig. 4-19. The DSM for changes propagation along with the relevant value of CPI of the components needs more attention in the design stage. The region of interest that shows changes in the body structures, as shown in Fig. 4-20 and 4-21, and using simulation to evaluate changes in production systems.

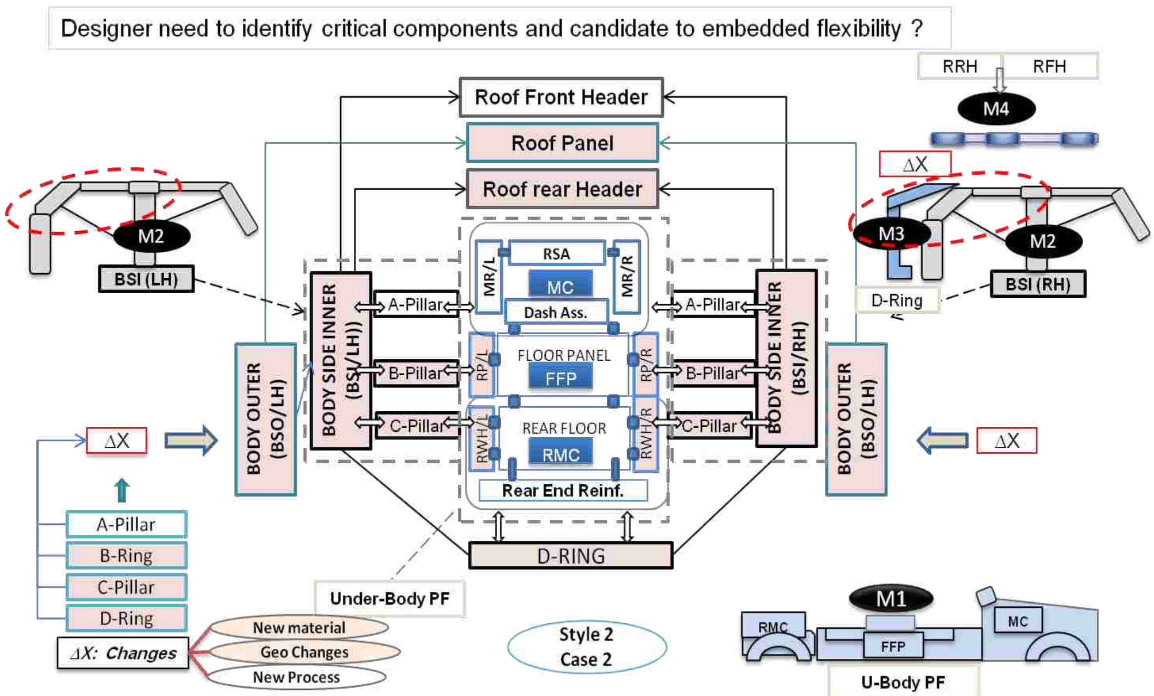


Fig. 4- 18: Network Change Propagation (NW); Due to Δ*X: case study (b)*

Receiving Change

	Module Name	No	01	02	03	04	05	06	07	08	09	10	11	12	13	14	*ΔEin*
Roof Assembly (NA)	FRH	01															0
	RB#1	02															0
	RB#2	03															0
	RB#3	04									I						1
	RRH	05									I	I					1
	Roof Panel & RR	06									I	I					1
Body Inner Assembly (4 MA)	Pillar A	07								I							1
	Pillar B	08							I						I		2
	Pillar C	09								I		I					1
	D-Ring	10					I				I					I	3
BO	Body Outer	11								I	I				I		3
U-Body Complete 3	Front –end (MC)	12															0
	Floor Pan (FFP)	13								I							1
	Rear-end (RMC)	14										I					0
ΔEiout			0	0	0	0	0	0	1	4	5	4	0	0	2	0	
CPIi = ΔEout,i−ΔEin,i			0	0	0	0	0	0	-1	2	4	-1			1		
Component Class									A	M	M	A			M		

New steel type change on in RK panel – interface between B-Pillar and U-body (no effect on UB!

Propagation Change (ΔX: Eng. Changes)

Fig. 4- 19: Change Propagation DSM; Due to Δ*X: case study (b)*

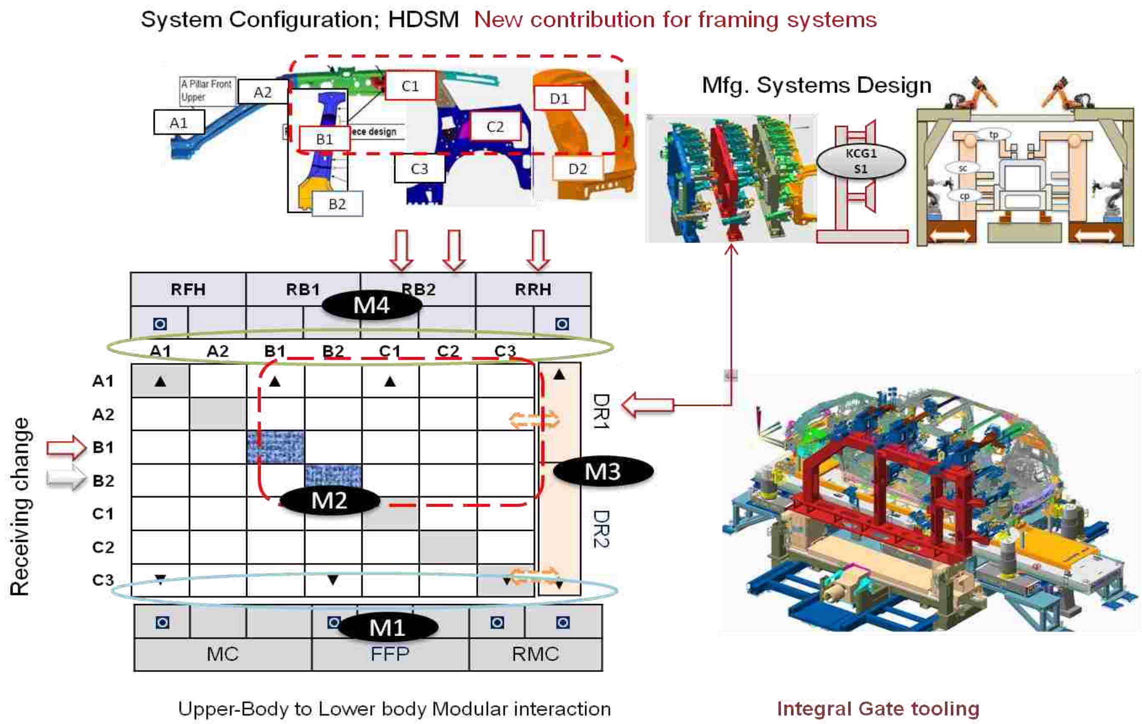


Fig. 4- 20: HDSM mapping production CPI to Design Task (DT) - Δ*X: case study (b)*

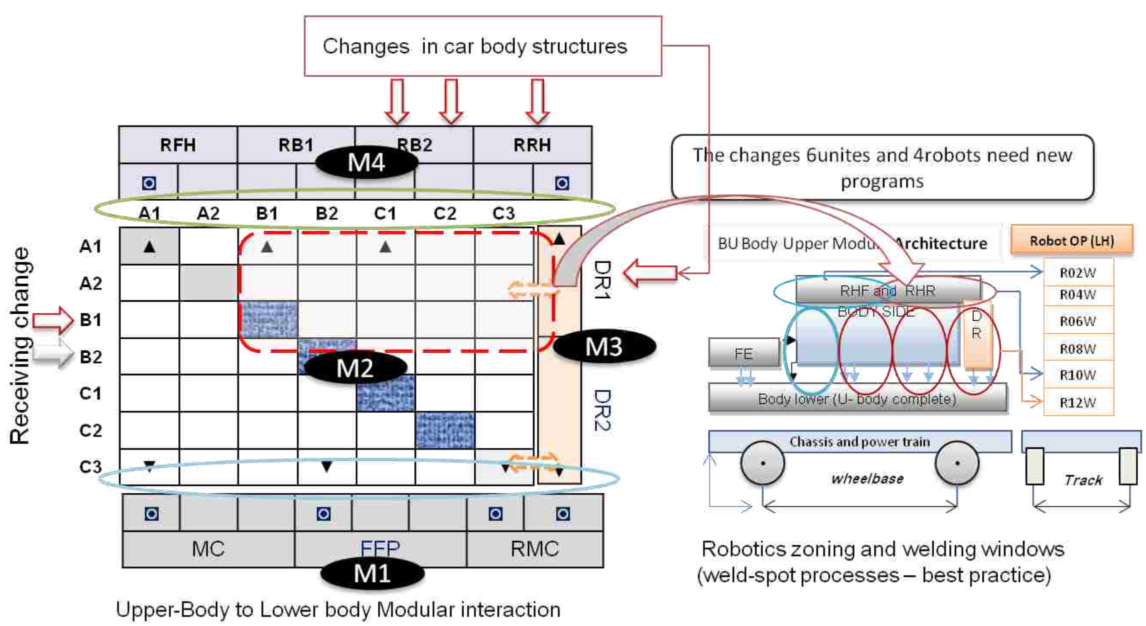


Fig. 4- 21: HDSM mapping DC to Mfg Capability (MC) - Δ*X: case study (b)*

4.7: Multi-Domain Mapping Procedure

Finally, the mapping procedure is summarized as follows:

- Step 1: Use the right re-presentation of NW for car-body structures
- Step 2: Build the DSM, decomposition process of modules and sub-modules with the order as built/ assembled that match the graphical network re-presentation
- Step 3: Apply changes and measure CPI for all interface components calculate the interaction coefficient type to identify the components that needs embedded flexibility
- Step 4: Re-arrange DSM components/ clustering process into five modules. Each module represented by the main component/sub-components depends on the level of detail:
    - M1: Under-body assembly
    - M2 (L/R): Inner body assembly
    - M3: D-Ring
    - M4: Roof modules (RFH, RRH and Roof Bows)
- Step 5: Identify components with physical interaction (interface components) between modules lower and top connection CPs and TPs
- Step 6: Mapping between physical domain called HDSM; product design to production systems:
    - Graphically define region of changes by intersecting inputs/outputs
    - Evaluation for engineering changes on the physical interaction and help designer to turn multiplier to absorber
    - Evaluation on the joining process, type of joining process need to be identified upfront to make the right decision in the tooling selections.

Chapter 5

5. RMS Design Methodology for Automotive Framing Systems

5.1: Overview and Introduction

A novel methodology (high level process) of framework using flexibility and reconfigurability principles for automotive framing systems, as well as providing a guideline to support the structure of different stages of the design methodology, is proposed. This is presented by way of a case study using real production data of production assembly lines (framing systems) to illustrate the mapping and translation between different dolmans.

5.1.1: Definitions

Most of the following definition are referenced (ElMaraghy, 2009):

- Product Platform: a set of sub-systems/modules and their related interfaces and infrastructures, which forms a foundation used to produce a number of products that share common features. The platform features, parts, and components remain unchanged within a product family
- Product Family: a group of related products that share common characteristics, which can be features, components, and/or subsystems (the key successful product family is the product platform).
- Customization: the system capability and flexibility match the application that it was designed for and can be adapted to meet new production requirements within the same product family of similar products.
- Product Modularity: an enabler of mass customizable products
- Product Architecture: the scheme by which the physical element interacts to achieve the desired operation performance.

- Integral Architecture: the product functions all contained in a single structure, with rigid connection.
- Modular Architecture: the product consists of interchangeable elements, or modules, to create and/or alter product function, where each module implements one or a group of functions that are controlled together.
- Mass Customization (MC): the capability of a firm to achieve more variety, high volume and at the same time, low cost and fast delivery. Modularity is one of the primary means of achieving the aforementioned mass customization requirements (Pandremenos et al., 2009).

Reconfigurable Manufacturing Systems (RMS): The key to future manufacturing:

Reconfiguration will allow for adding, removing, or modifying specific process capabilities, controls, software, or machine structure(s) to adjust production capacity in response to changing market demands or technologies. RMS aims to be installed with the exact production capacity and functionality needed and may be upgraded (in terms of both capacity and functionality) in the future when needed, as shown in Fig. 5-1 where both DML and FMS are static; RMS are dynamic with capacity and functionality changing in response to market changes.

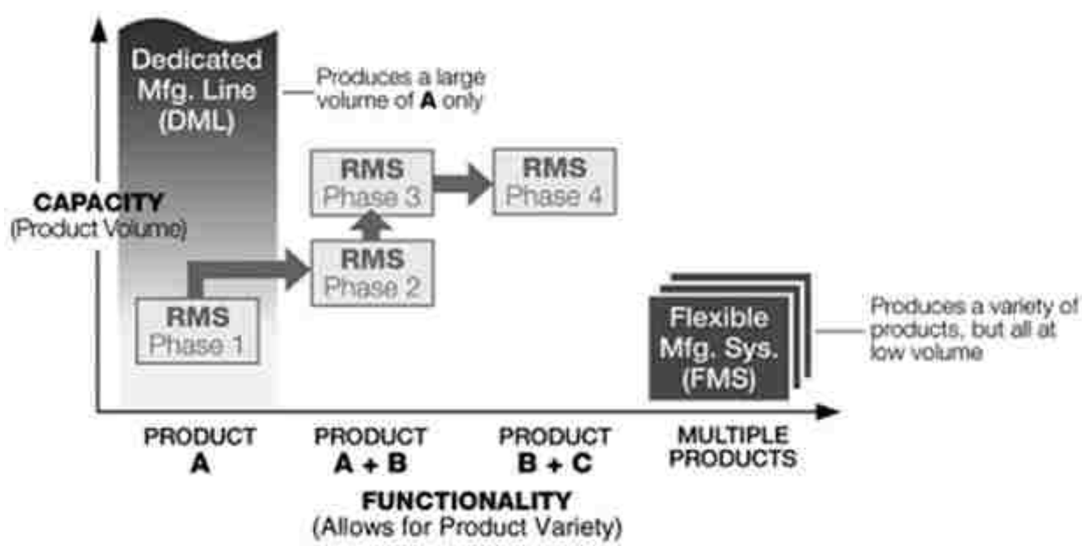


Fig. 5- 1: RMS are dynamic in capacity and functionality changes (Koren, 2010)

One of the key characteristics of RMS is modularity (see Table 5-1). All the major components of the system should be modular, which includes structural elements controls, automation and programming, and joining process. The modules that are used to construct an RMS also need to be customizable so that the system has the flexibility to manufacture or assemble a part family.

Table 5- 1: Key characteristics of an RMS (Mehrabi et al., 2000)

1. Modularity:	*Design all system components, both software and hardware, to be modular.*
2. Integrability:	Design systems and components for both ready integration and future introduction of new technology.
3. Convertibility:	Allow quick changeover between existing products and quick system adaptability for future products.
4. Diagnosability:	Identify quickly the sources of quality and reliability problems that occur in large systems.
5. Customization:	Design the system capability and flexibility (hardware and controls) to match the application (product family).

5.1.2: Evolution of Automotive Framing Systems

The common theme in future production systems is to be able to quickly adjust to product changes. Many successful automakers have developed several working practices and tools, known as a concurrent engineering (CE), to improve their products' development. The main aim of concurrent engineering is to integrate product and process development in order to reduce the design lead-time and to improve quality and cost. Fig. 5-2 shows the main blocks of the concurrent vehicle framing design approach.

Design problems become complex due to multiple components, such as tooling, positioning devices, transfer equipments and the joining process. Manufacturing design processes are subjective based on expertise. Integration is taking a long time to respond to market change, therefore there is a great need to develop a systematic methodology as a guideline for systems designers and developers to respond quickly and more economically to the uncertainty of market change by utilizing flexibility in both product and production systems.

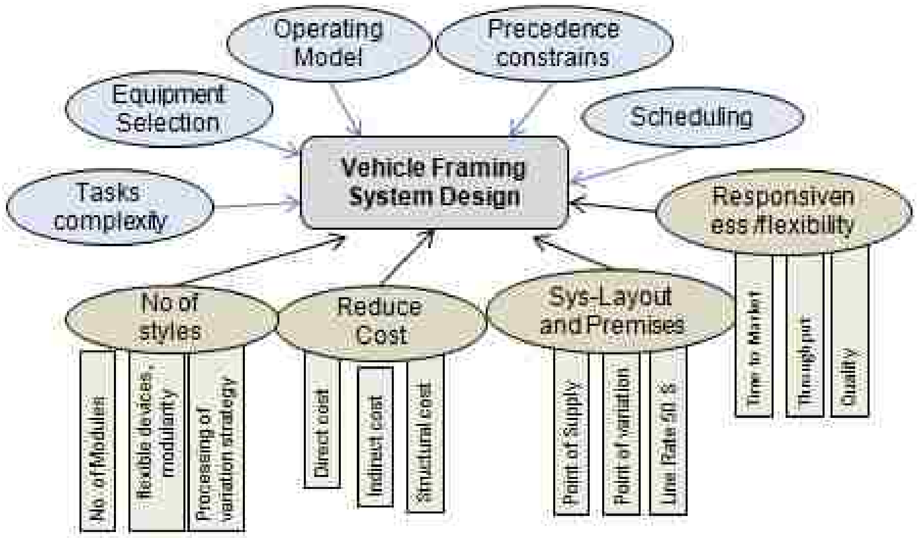


Fig. 5- 2: Concurrent design of vehicle framing system

Fig.5-3 shows reconfigurable manufacturing systems were introduced as manufacturing strategies (ElMaraghy, 2009). A new trend emerged in manufacturing systems, termed knowledge capture, shows the evolution (history of developments) of vehicle framing systems (see Fig. 5-3).

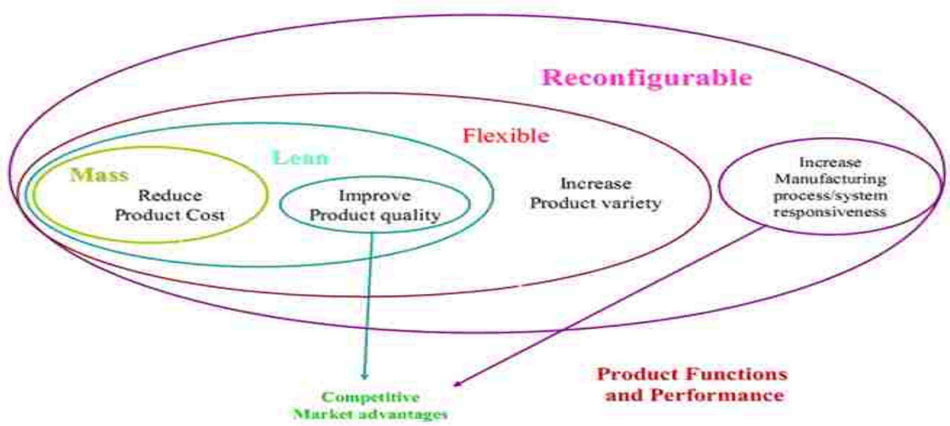


Fig. 5- 3: New Strategies & Manufacturing Systems Paradigms (ElMaraghy, 2009).

In the last few years, markets increasingly require more customized products with shorter life cycles. In response, manufacturing systems have evolved from mass production techniques through flexible automation and mass customization, to produce at mass production costs. Under conditions of uncertainty, manufacturing facilities must incorporate more flexibility and intelligence, evolving towards reconfigurable manufacturing systems (RMS) with design methodologies (DM) support to maintain effective and efficient manufacturing operations with minimum downtime. This is mostly due to complexity in mechanical design.

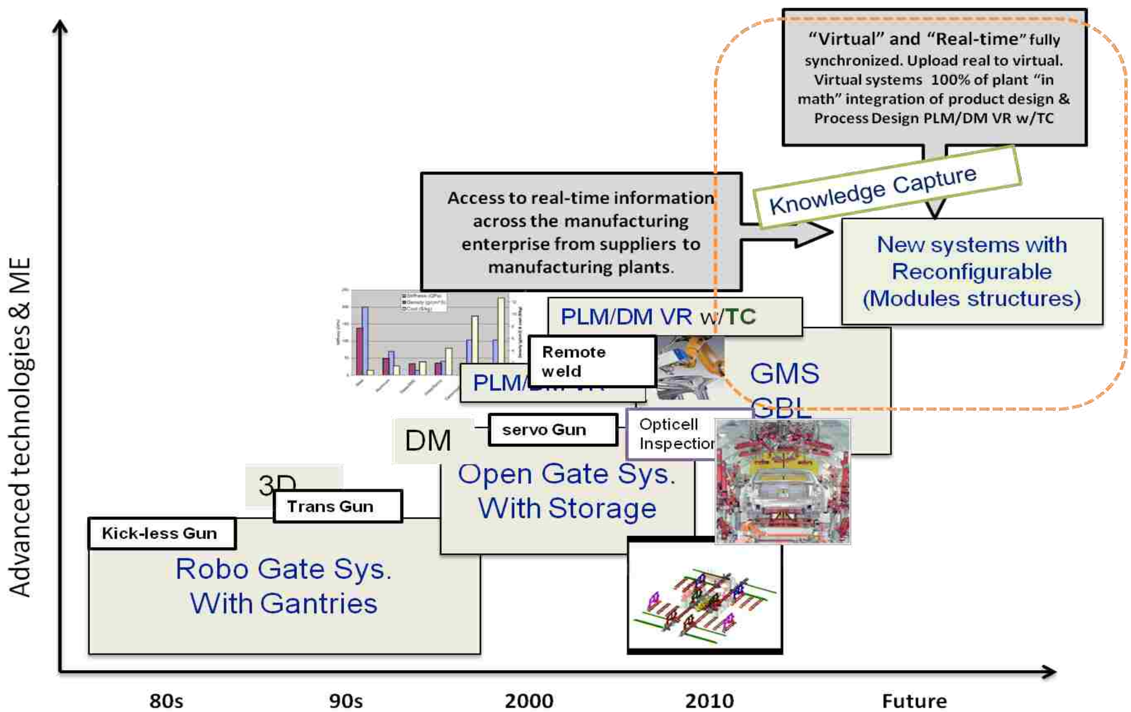


Fig. 5- 4: Evolution of automotive framing systems

Key issues with the current framing systems were listed in Chapter 3, section 3.3.3: The State of Current Practice of Automotive Framing Systems.. The main issues that need to be addressed by the proposed systems are:

a) Current systems using a specific dedicated gate line for each style, therefore current systems structures running production in batch mode in the real world.

b) Throughputs of the systems decreased, due to the switch to new gate need 1-2 H. This takes too long and is very expensive; the production lost in two hours is 130 vehicles and almost 1 million dollars.

c) Breakdown in the production line due to current gate structure; major breakdown in 2-3 months is required to stop production for the entire shift, yet that is too expensive.

The proposed systems in Fig. 5-5 show the layout of the proposed systems that should address most of the issues of the current systems with the following approaches:

1) Run mixed production of different styles of the same family within the same gate line; this requires a re-design and re-build of the gate systems with modular structures.

2) Simplify the design structure by reducing coupling to decoupling of the design configuration.

3) Once items 1 and 2 are achieved, the new systems will automatically:

- Have a better design structure that is easy to modify – to extend the life cycle of the production systems by embedding flexibility in the position devices,
- Improve the gate line cycle time,
- Significantly improve throughputs.

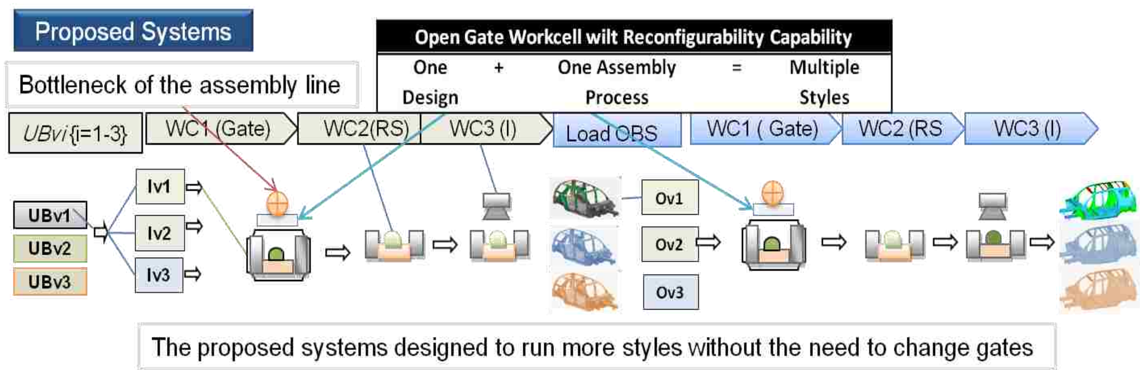


Fig. 5- 5: The proposed systems: to run more styles using same Gate

5.1.3: The Proposed System & Comparison with Current Systems:

Fig. 5-6 shows the layout of product flow in both systems; current practice and proposed systems. Also, the Table 5-2 lists the differences between the two systems

- In both systems, the gate line is still a bottleneck in the production line with improvement of 8- 10 percent in the new open gate systems.
- Storage mechanism is not needed for new systems within a common underbody.
- Gate's shuttle mechanism will run with a better cycle in new systems.

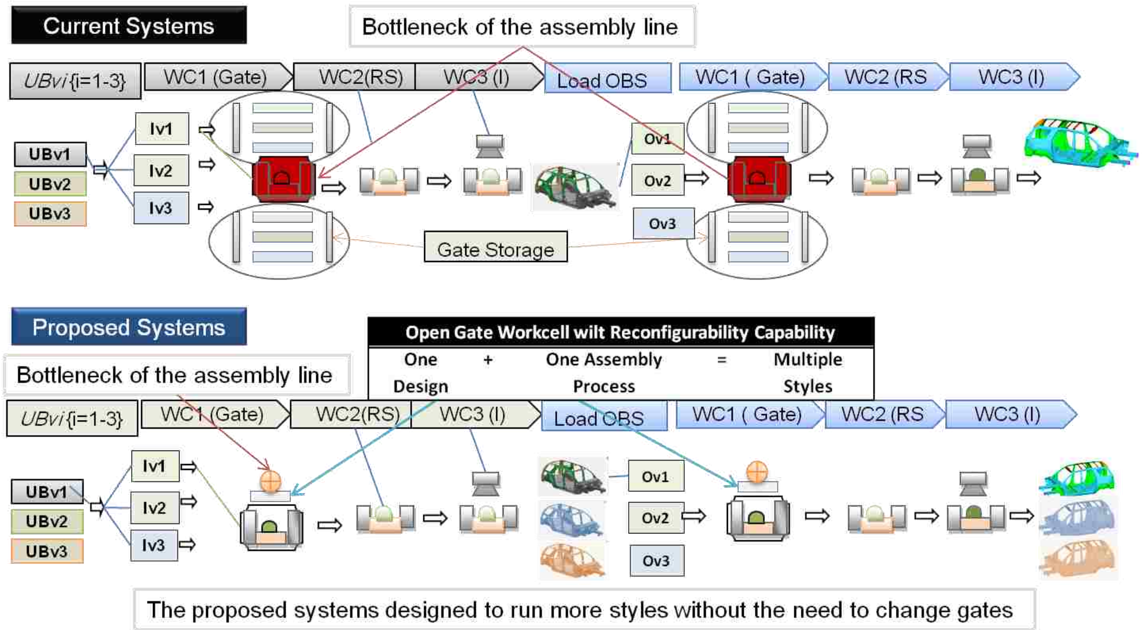


Fig. 5- 6: RMS with Open Gate system comparison with current system

Table 5- 2: Inner vehicle framing sys WC is the Bottleneck of the assembly line

Main function of the Gate line		*Current systems*	*Proposed systems*
Gate Line:			
Design Structure		Integral	Modular
Design Task		Coupled	Decoupled
Positioning Function Time		-------------	Improved by 10 %
Storage Systems:		Required	Not/ Required
Case (a)	Wheelbase & Track (Common)	Required	Not/ Required
Case (b)	Wheelbase & Track (Variable)	Required	Required
Downtime for Changeover (New style)		1-2 H	Not / Required
Cycle Time		-------------	(8-10)% improved
Throughputs of the Systems		-------------	Improved by 24%
Cost Reduction		-------------	Saving
Style 1: Current production		New Gate	Cost increases 30%
Style 2: Adding new style of product family		New Gate	Gate kit saving 80%

5.2: PLM/DM with TC platform support to the MFG systems

5.2.1: Modularity Matrix of Vehicle Body Structure (the State of Practice)

Fierce competition in the automotive industries forced automakers to develop a family of products and their production systems during the design stage. Product variety in one family (styling) is designed to quickly modify and adjust to market needs. The challenges are not in the products and their unique variations, rather in the production systems. They need to be quickly adjustable within a reasonable time.

The states of practice of sub-modules/modules of the automotive framing are shown in Fig. 5-7. The highlighted components that are used as a physical interaction between lower body and upper body need to be design with extra care to be absorber to changes.

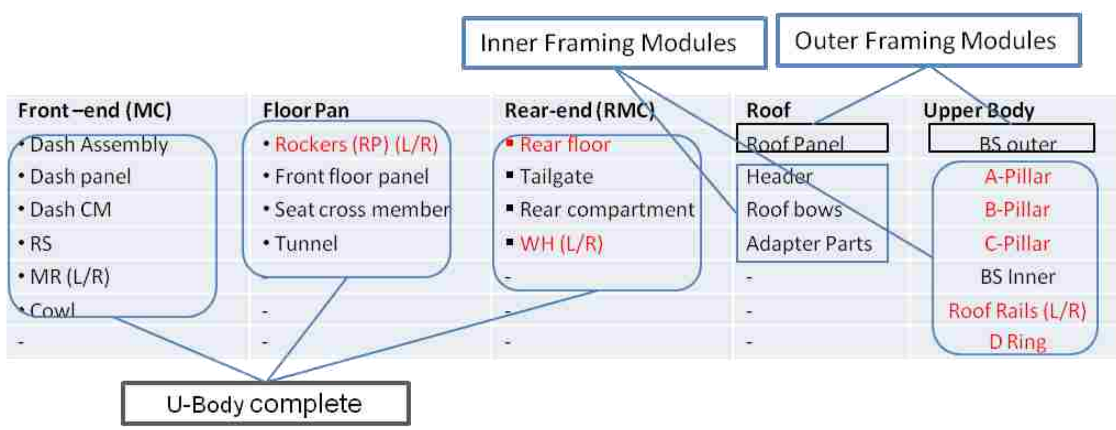


Fig. 5- 7: Sub-module of the main body module

A modularity variation matrix of vehicle body structure was developed for different styling based on production data, as shown in Fig. 5-8.

Two different segments of a product family help designers to visualize what modules are affected by changes for each styling in each segment. This representation is a high level at the (Device level) modules and sub modules, and there are low levels of details for all parts built in the simulation work-cells.

Seg1 (P1): all changes are above the beltline; with common under-body, there are three styles (S1, S2, and S3).

- P1 (S1) the changes in styling are at Pillar – C
- P1 (S2) the changes in styling are at Pillar – B & C
- P1 (S3) the changes in styling are at Pillar - A, B, & C

Seg1 (P2): the changes are within under-body; what kind of changes. The assumptions made are a common motor compartment (MC) for all three styles (S1, S2, S3), and a common wheelbase (fixed dimension).

- P2 (S1) the changes in styling are at Pillar – C
- P2 (S2) the changes in styling are at RC, Pillar – B & C
- P2 (S3) the changes in styling are at FFP, RC and Pillar - A , B & C

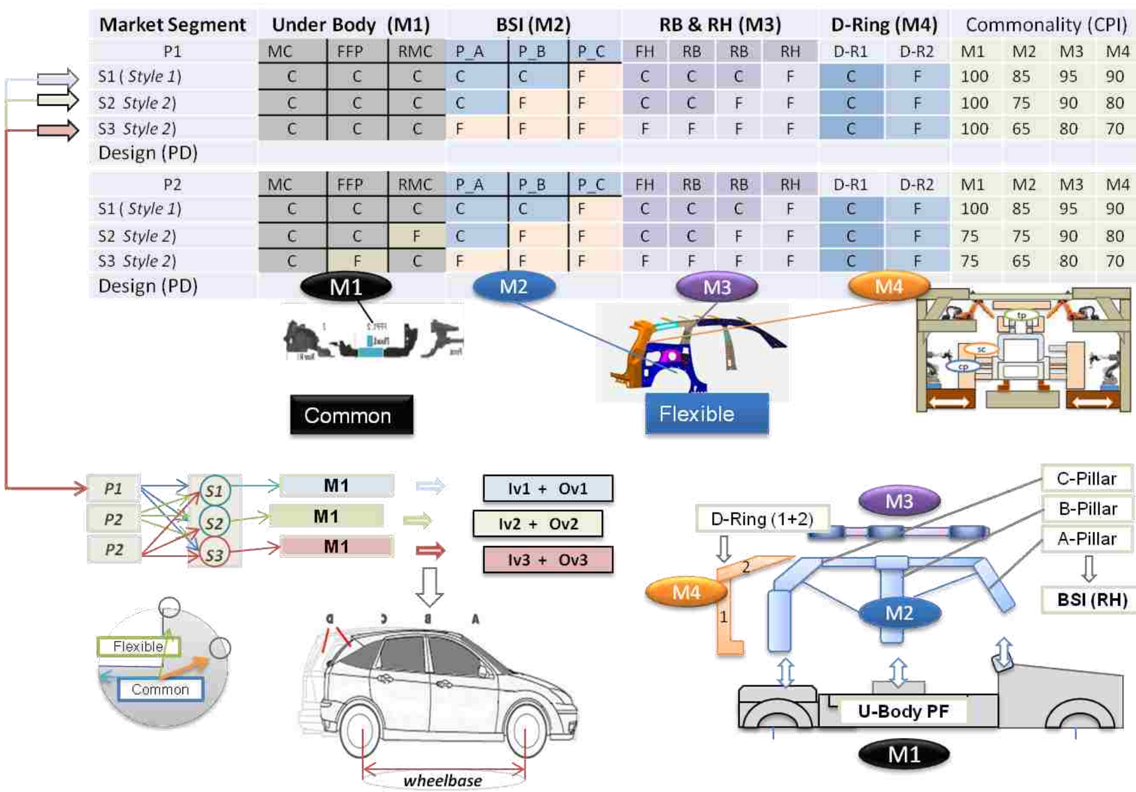


Fig. 5- 8: Modularity variation matrix of vehicle body structure BIW

The following recommendation is a key to organizing the styling database:

(a) Product developers should show changes in key components for styling affecting the production systems.

(b) Manufacturing and production engineers should align commonality and increase flexibility.

(c) The hypothesis is that the right subset of car body elements has to be designed with proper care for future flexibility.

(d) Manufacturing & production systems can then better accommodate body styling changes, enabling structural flexibility in the gate design without the need for tooling changeover, which improves throughput of the systems.

5.2.2: DM Requirement of the Automotive Assembly Process

(1) Digital Pre-Assembly (DPA):

For a new car, usually 20,000 DPAs are needed. Each DPA is simulated and tested in 3D virtual environments to ensure it is free of problems. The DPA's task is to validate product design and validate assembly sequence.

(2) Digital Process Planning (DPP):

Define product variants:

- Define the operations at every workstation, determine the sequence of operations within a workstation, optimize and integrate the whole production process within one tool module, and establish a model that can calculate man-hours, analyze costs, manage documents and manage product changes;
- Define all tools and clamping fixtures on an assembly line, which involves all the resources, e.g. clamping fixtures, slide rails, lifting equipment, etc;
- Define the detailed operations of every workstation and acquire the accurate times needed for various operations at every workstation and use this as the basis for assembly line balancing and optimization;
- Analyze assigned operations, and tooling assigned limitation and how to switch between variants or styles.

(3) Digital Planning Validation (DPV):

DPV provides 3D simulation and workstation layout optimization for the whole workplace and validates any mutual interference between workstations; it can design the layout of a production line to ensure logical and continuous operation; it can dynamically simulate a production line, assess its production capability, check bottlenecks and assess the utilization of production resources; it can provide managers and workshop operators with the current process plan and receive feedback from them.

(4) Production management and supplier collaboration: Efficient production management requires making full use of the manufacturing execution system, real-time process and control and process planning capabilities.

5.2.3: DM with TC Support for Automotive Assembly's BIW Process

It is mainly used for planning body-in-white welding process and for planning the welding and assembly production lines. Fig.5-9 shows the PLM/DM is the hub and the centre for all CE manufacturing process (Source: Siemens Teamcenter webinar)

(a) The planning of body-in-white process starts with users creating the layered description of the body-in-white manufacturing process and defined business, resources for manufacturing and parts/components, and then allocates the welding points to the corresponding operations and resources, and use the standard equipment and tools in the system resources library and non library equipments. The system can also track and manage product design changes and check their impacts on the manufacturing process.

(b) Designing, optimizing and offline programming: Automatically select the welding gun from the system resources library and check it via the sectional function; simulate the robot path in a 3D environment to check collisions, the reach zone and the optimization cycle time. Use the discrete event process to simulate the production line performances, including output, utilization of resources, bottleneck searching, and buffer size;

(c) Finally, automatically generate robots, programmable logic controllers, and operational instructions. Information exchanges within the whole enterprise. It allows users to access various customized production reports, cost estimations, training materials and process simulations stored in the system. All the complete-vehicle manufacturers, production line builders, and constructors can cooperate in a collaborative environment focusing on contents, and finally form a continuous cycle of development and improvement.

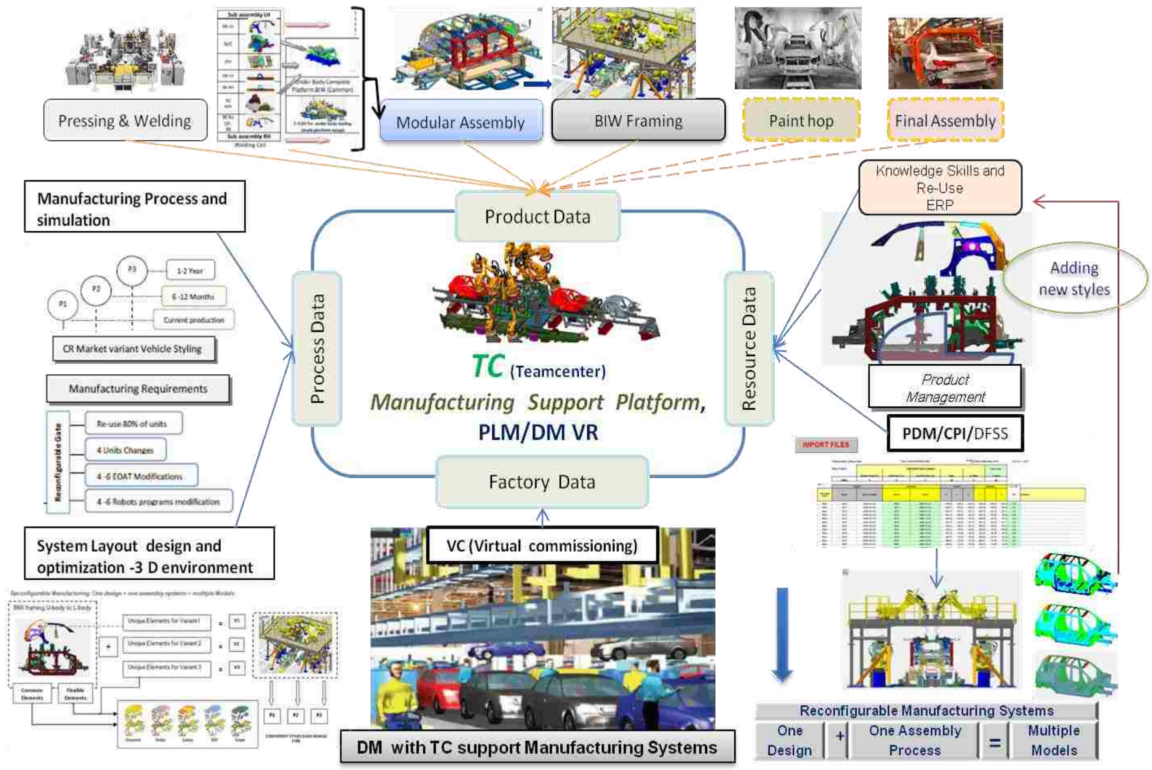


Fig. 5- 9: DM with TC support manufacturing process for BIW framing systems

5.3: Life Cycle of Framework for RMS (*vehicle framing systems*)

Manufacturing system life-cycle refers to the evolution of a manufacturing system from concept through development to production, operation and its ultimate disposal (Phoomboplab, Ceglarek, 2007). The manufacturing system design framework is proposed to support the RMS design methodology execution and to clarify communication and collaboration among the design team. The framework provides a guideline to support and to structure the different stages of the design methodology. This framework is mainly based on the system life-cycle concept. Fig. 5-10 shows the four main stages of the proposed framework.

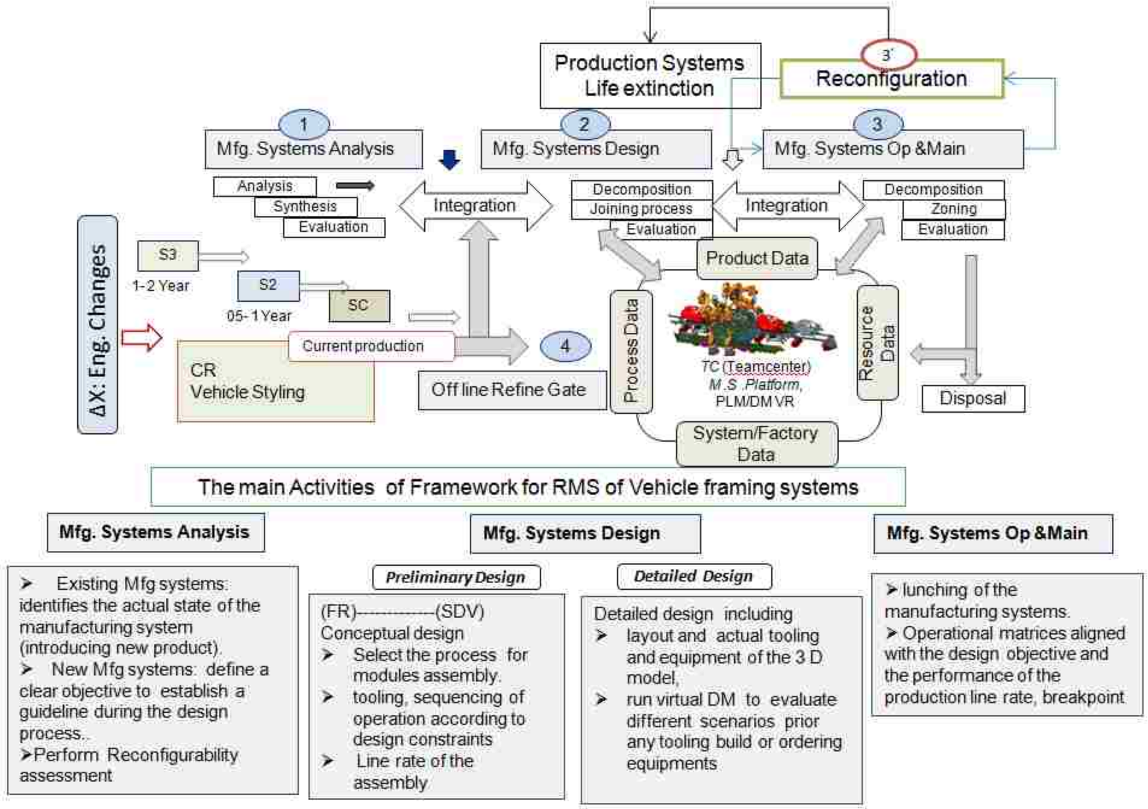


Fig. 5- 10: Framework for RMS of Automotive framing systems

(1) Manufacturing systems analysis, (2) Manufacturing systems design, (3) Manufacturing systems operation & maintenance, (3') Reconfigurability stage or the life cycle extension of production systems, and (4) Refine offline gate combined with manufacturing support centre. A brief explanation for each stage follows.

5.3.1: Motivation for the Proposed Methodology

The newly proposed framing systems (ROGFS) should address the issues with the current systems (state of practice) and fulfill the needs of the market dynamics in the global economy of automotive industries:

- Robustly accommodate the growing number of product variants within a family without change of gates,
- Utilize standard components (platform) to reduce cost, improve maintainability, and quality,

- Extensively utilize math-based engineering concepts (to validate the production process prior to physical implementation) and PLM/DM with TeamCenter to facilitate broad engineering collaboration,
- Develop and enhance new manufacturing strategies and operational tactics.

5.3.2: The RMS Framework of Automotive Framing Systems

The design process is considered a problem solving process approach, which is a widely accepted approach, performed by the Analysis, Synthesis and Evaluation method (Wu, 2001). The first stage diagnoses, defines, and prepares the information about the problem to be solved; the second stage synthesizes possible solutions; and lastly, the evaluation stage tests the possible solutions against the goals and requirements.

Stage 1: Manufacturing Systems Analysis – Analyzing Stage

The manufacturing systems analysis is the first stage of the life-cycle where the formulation and definition of the manufacturing system is performed to satisfy specific needs. The main constraints at this stage are the manufacturing strategy, the characteristics of the product and the process. Therefore, the output of this stage is the definition of an information model that represents and captures information describing the product characteristics, process, manufacturing resources, and strategies of the manufacturing system. The automotive framing systems have complex product and processes; systems designers and product developers need to have a perfect knowledge of the decomposition and integration of all the modules and components of each module (interface components and their process) in order to upgrade to new vehicle styling.

Stage 2: Manufacturing Systems Design -- Synthesizing Stage

At this stage, more focus is given to the manufacturing process and production systems than to the products. The manufacturing system design is the second stage of the manufacturing system life-cycle. The main elements of this stage are:

- The translation of function requirements to systems design variables (SDV),
- Process design (conceptual design),
- System design detailed design (DT),
- Production and operation.

The main inputs for this stage are the requirements of the manufacturing system in terms of reconfigurability, which are the results of the assessment.

Once the design parameters are linked to product's key critical elements (KECs) and grouped into key characteristic control (KCCs) with clustering process applied to establish the DOF of each group, flexibility and capabilities of manufacturing systems can be defined. Thus, production and operation is a set of models where information of manufacturing systems represents how the manufacturing system will operate. The models are logic, information, and virtual validated through the use of virtual manufacturing tools that support the design and reconfiguration of manufacturing systems. Virtual design of manufacturing systems with TeamCenter manufacturing supports is set to be the future hub of the framework. This set provides (a) instant information, more detailed of production systems and the operation process, and (b) instant evaluation for different alternatives of joining processes, controls and layout to satisfy the best choice according to the defined objectives.

Stage 3: Manufacturing systems operation & maintenance

The third stage of the framework is the implementation or the launching of the manufacturing systems. Once the manufacturing systems are operating, it is important to establish operational matrices aligned with the design objective and the performance of the production line rate, breakpoint in the production by changes in demand, introduction of new products, and engineering changes in product, among others. Using DM with a platform base as to support and integration tools (Teamcenter) is the place where all the data synchronized from the real production line to the virtual manufacturing systems.

Stage 3': Reconfigurability stage -- Evolvabilty and survivability of the systems

Reconfigurability means enhancing the systems and extending the life-cycles of the systems (Siddiqi, de Weck, 2008). This stage was represented in Fig. 5-9 by a parallel step, and it can be partitioned into phases and apply it when is needed.

Stage 4: Refine offline gate – Evaluation and testing stage

During the design activities, more detail is needed. The manufacturing characteristics such as product, operations, processes, and alternatives of layout are designed. The control of the manufacturing system is designed and the human and technological resources are identified. More data is needed for the process transportation and zoning of robots during the execution of assembly process. However it is impossible to account for it in the modeling stage. Thus, using Offline Gate as a parallel process for testing new control or new process prior to implementation in the real production systems, once it is tested and proven, can then be added to the virtual processes.

Fig. 5-11 shows and summarizes the input/output of the activities of four stage of the RMS framework. It is important to visualize the main activities.

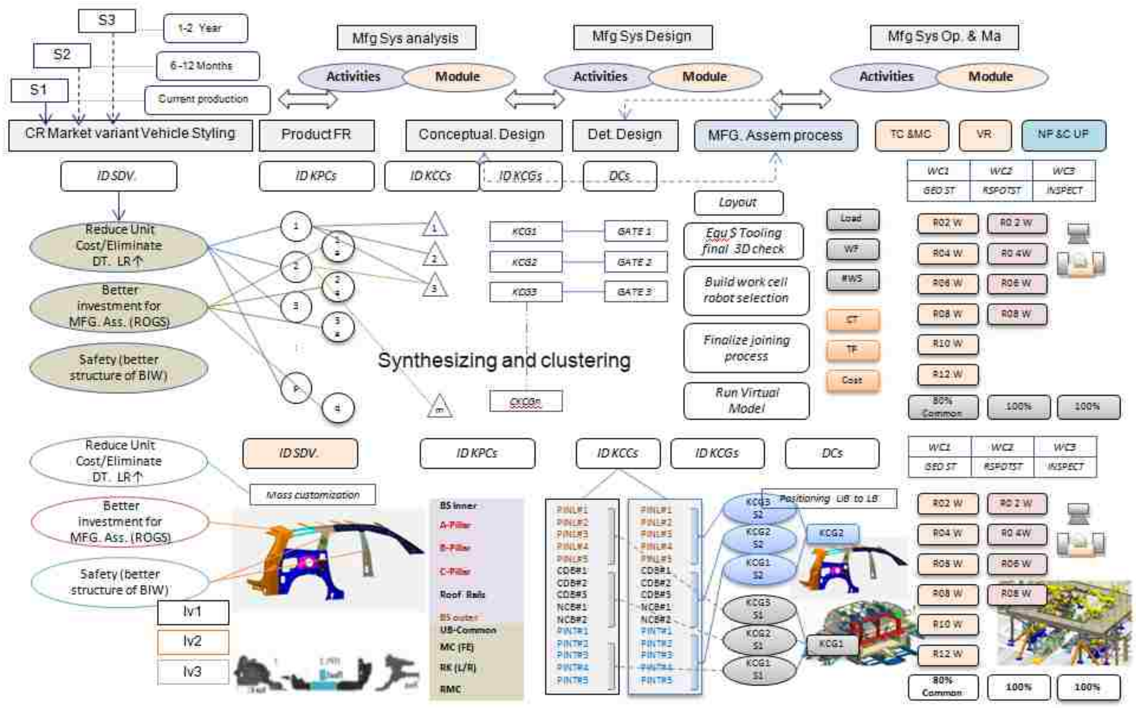


Fig. 5- 11: Structure of RMS design methodology for automotive framing systems

5.3.3: The RMS Design Methodology of Automotive Framing Systems

Lastly, the methodology is the integration of these four stages by the RMS design framework, which is proposed to decompose each stage into activities in order to analyze, evaluate and synthesize the inputs and outputs of each stage to design/ reconfigure a manufacturing system (Al-Zaher, 2012). Fig. 5-12 shows the main stages of the methodology with PDM/DM; Siemens Teamcenter manufacturing support was utilized as a hub to the design methodology based on the proposed framework. On the integrating side, not only are the design, techniques and manufacturing more easily coordinated, the imitation analysis and optimization of the manufacturing process in the virtual environment become more convenient than ever.

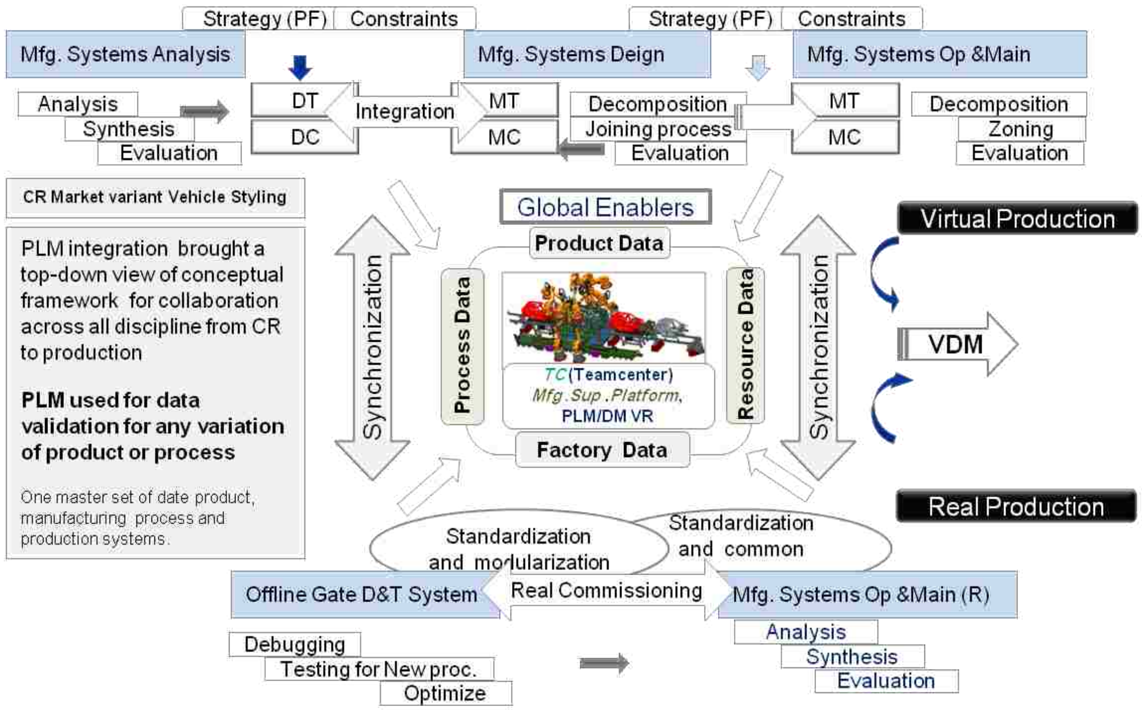


Fig. 5- 12: PLM/DM is the hub of RMS design methodology

Network graph representation and DSM used in the automotive industries were introduced in Chapter 4. Design Structure Matrix (DSM - Component-Based Architecture) is used in the automotive industries as a tool and technique. It provides a simple, compact, and visual representation of a complex system that supports innovative solutions to decomposition and integration problems. It is also an effective method for integrating low-level design processes based on physical design parameter relationships. Furthermore, it displays the relationship(s) between modules or components (which depends on the level of details) of a system in a compact, visual, and analytical format. It is important to note that DSM models represent extensive system knowledge. Hence, DSMs can be difficult to build, especially initially, as they depict data that are not always at hand, easily gathered, or quickly assimilated.

The concurrent processing to all steps using the new methods follows:

I) The first stage is evaluating the impact of engineering changes:

The evaluation of engineering changes (ΔX) of the manufacturing and production systems usually received as a complete kit of data - geometry changes, weld data and processes (simulation input) are described below:

- Product changes (new style, new process, etc),
- Manufacturing and production systems (current production line),
- Manufacturing and production engineers need to clearly identify the interaction at the components level and modules level in order to evaluate changes in the manufacturing (part stamping) and modules assembly prior to framing systems,
- Decoupling for all Manufacturing processes and assemblies due to changes at the components level and module level.

Network graph representation for the car body structures BIW, as shown in Fig. 5-13, is used to help visualize the changes propagation throughout the systems.

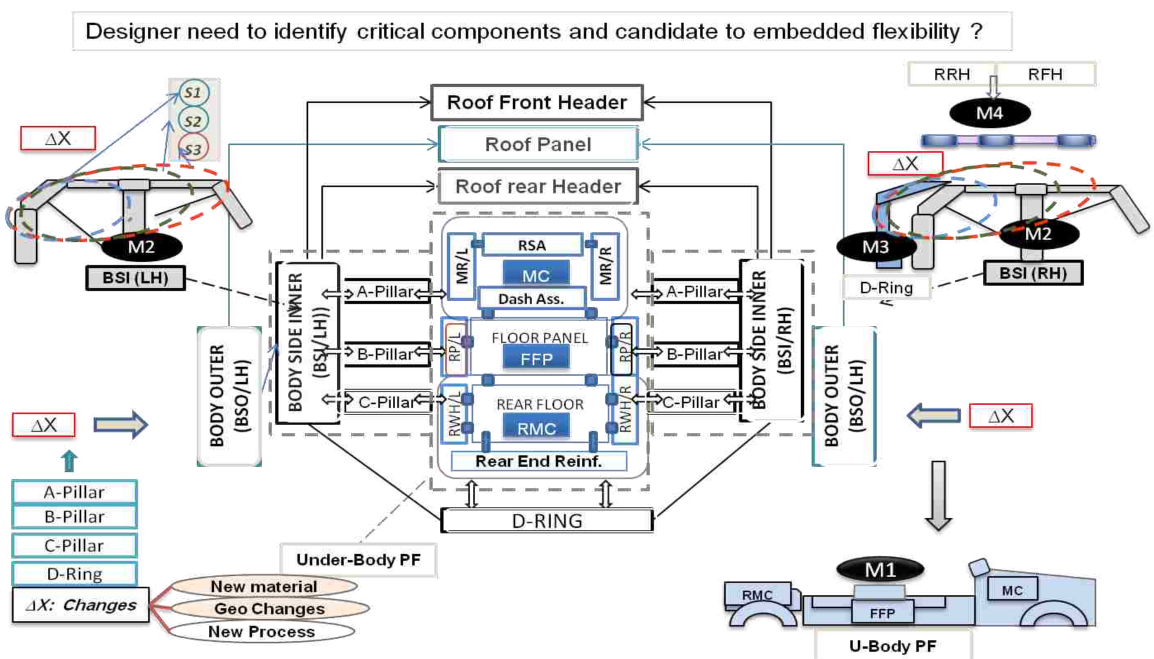


Fig. 5- 13: Network representation *of car body structures BIW*

Once the evaluation is completed, CPI can be calculated, as shown in Fig. 5-14, to measure the physical interaction between modules assembly. More details on CPM evaluation are in Chapter 4, Section 4-5. The outputs of this stage are the identification of the key elements or components that need to have flexibility.

Receiving Change

	Module Name	No	01	02	03	04	05	06	07	08	09	10	11	12	13	14	ΔEin
Roof Assembly (NA)	FRH	01															0
	RB#1	02															0
	RB#2	03															0
	RB#3	04									I						1
	RRH	05									I	I					2
	Roof Panel & RR	06									I	I					2
Body Inner Assembly (4 MA)	Pillar A	07															0
	Pillar B	08															0
	Pillar C	09				I	I					I				I	5
	D-Ring	10					I				I					I	3
BO	Body Outer	11									I						3
U-Body Complete 3	Front –end (MC)	12															0
	Floor Pan (FFP)	13															0
	ar-end (RMC)	14										I					1
$\Delta Eiout$			0	0	0	1	2	0	0	0	5	4	0	0	0	2	
$CPIi = \Delta Eout,i - \Delta Ein,i$			0	0	0	0	0	0	0	0	0	-1			0	-1	
Component Class						Ca	Ca				C	A				A	

New steel type change on in WH L/R upper components only

Propagation Change (ΔX: Eng. Changes) A,B,C-Pillars+ D-Ring

Fig. 5- 14: Developing DSM for BIW Vehicle Styling

II) The second stage is the system design:

Start with conceptual design with virtual evaluation and make changes to the systems to achieve the design objective.

New systems configuration HDSM; for mapping of product function to design configuration, as shown in 5-15; (two stages)

The structure of HDSM is a high level representation of modules interaction of upper-body (M2, M3 and M4) with lower-body (M1); changes are initiated in M2 which is represented by square matrix 7x7, M3 to the right, then M4 at the top (roof modules) and M1 (under-body complete). It is a straightforward mapping of low-level physical interaction as first stage indicates. The second stage is the evaluation for the positioning units (tooling) & joining processes (robot programs) of gate tooling as shown in Fig. 5-16.

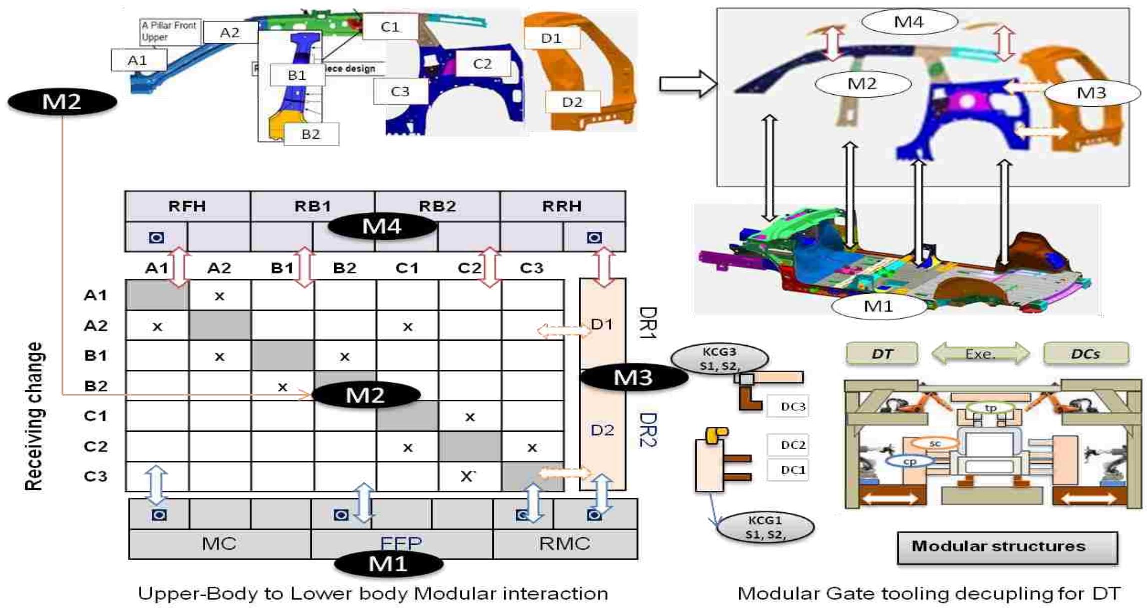


Fig. 5- 15: HDSM key elements physical interaction for all modules

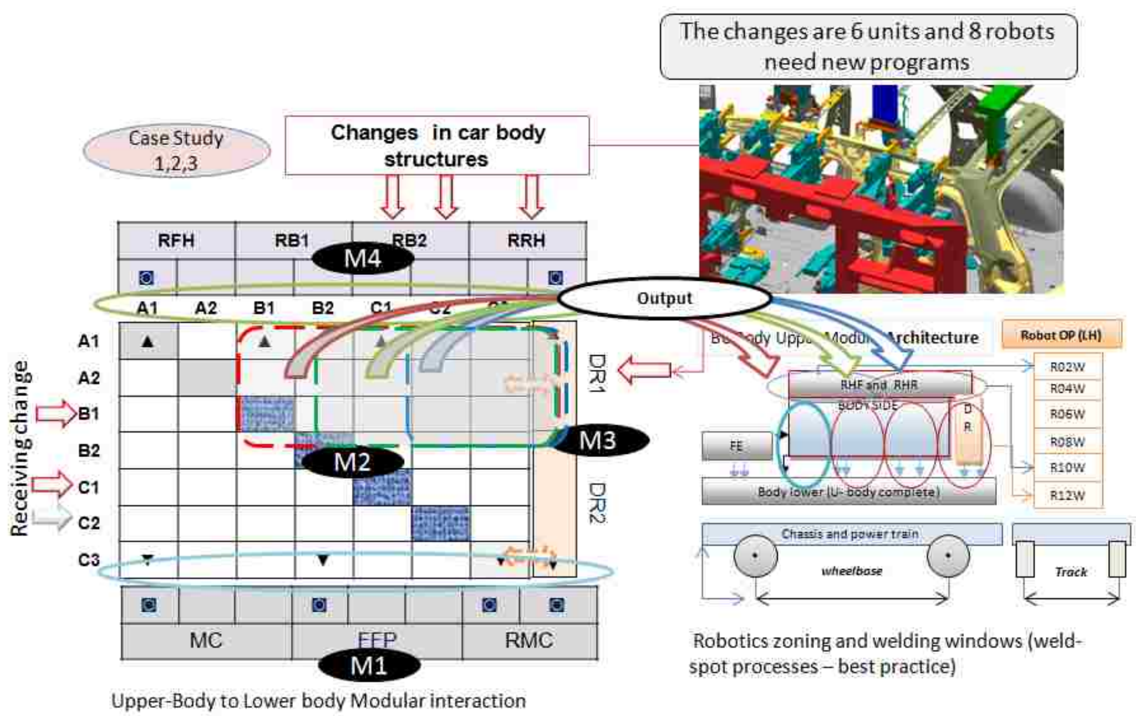


Fig. 5- 16: HDSM evaluation of changes in positioning units & robot programs

Design task is grouped into three groups for each style, as shown Fig. 5-17. The proposed method used decoupled the design task. Hybrid DSM is used to show the coupling between DT (design tasks) and DC Columns represent design configuration which resulted from mapping *KECs, KCCs and KCGs.* The second half of it shows the manufacturing capabilities, specifications and constraints of the production line, as shown in Fig. 5-18.

III) The third stage is the manufacturing processes:

The output of this stage is the production data including tooling functionality, sequencing of operation, systems layout, cycle time for stations and robotics. Programming and automation to run virtual simulation of the production was done. Simulation outputs are used and can refine the design prior to building. The actual tooling will be shown in the case studies in the next chapter.

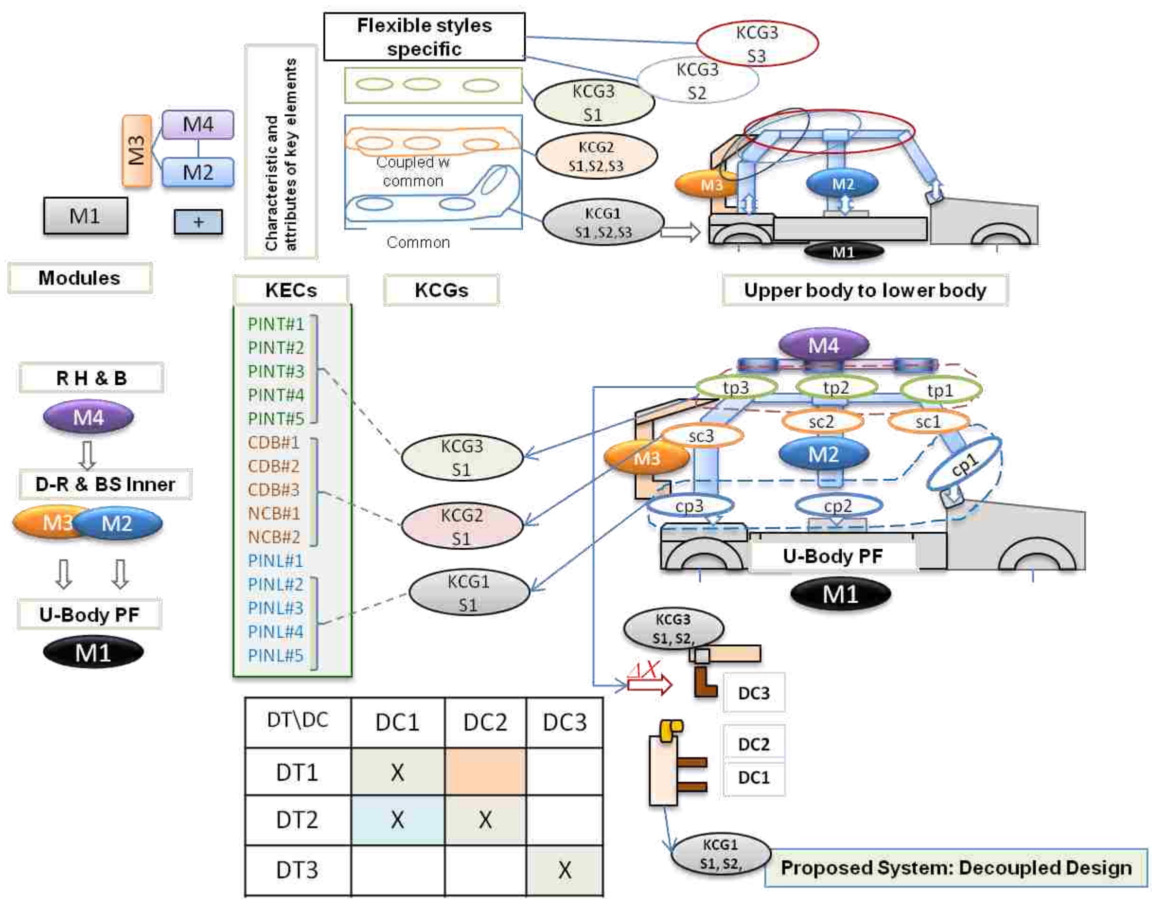


Fig. 5- 17: Synthesizing and Clustering DT, DC and MC.

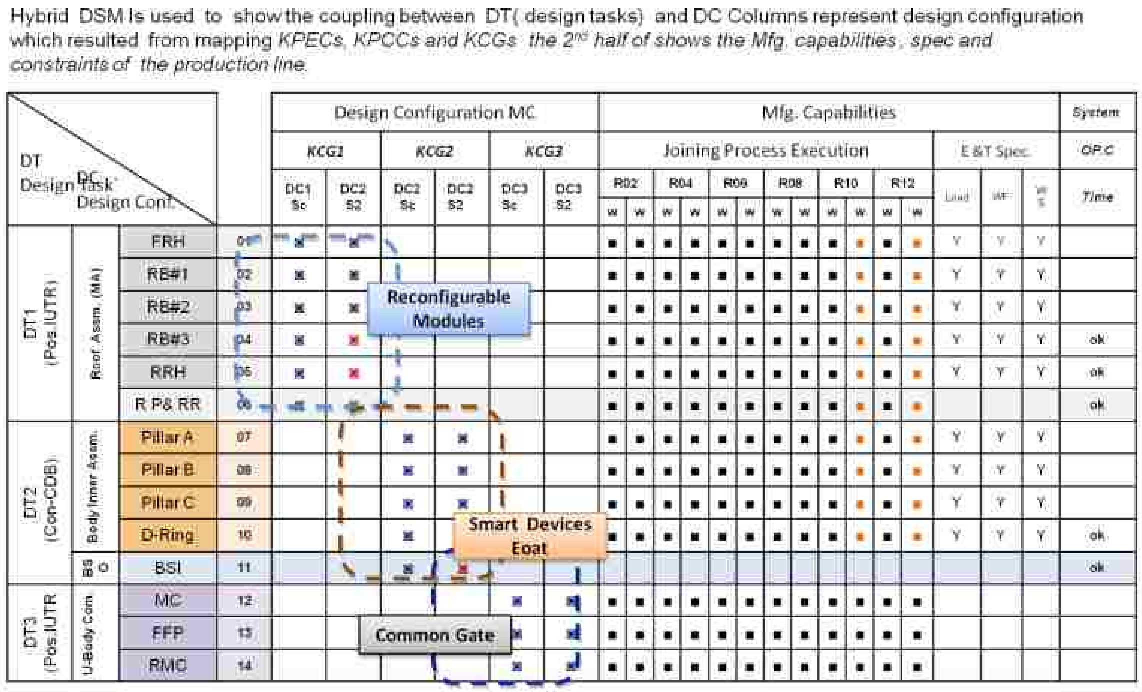


Fig. 5- 18: Formulation of Hybrid DSM for BIW Vehicle Styling

5.4: Assumption & Limitation of Design Method:

To use one gate without changeover, the following assumptions need to be considered:

- Fixed wheelbase: Under-body complete (platform) is common to all styles (variation of one same family)
- Fixed track
- Expansion for rear overhang can be accommodated
- Interface components locations under beltline are common for tooling and product.

5.5: Bottleneck Time Analysis of Gate Line:

It is important to visualize the main activities (transfer, positioning and joining function) in the complete cycle in the Open Gate System and is shown in Fig. 5-19. Automation and controls of the process are simulated and calibrated to real production data. By default, the gate line in the automotive assembly lines is the ***Bottleneck*** work-cell. Therefore any improvement in the performance of the system requires deep time analysis.

Total cycle time is required to pass through the gate line in 54 seconds. Simulation was calibrated to the production line rate. The equation is:

Tct (TP-WP) = Tsk(TI ,Apr,Wp) + TGat(Wp,RP) + TRobt(P-weld, Clr)+ Tsk (Wp, Apr.TO) (5.1)

- T_{CT} (TP-WP): Total cycle time
- T_{SK} (TI ,Apr,Wp): Time required (approach to work position)
- T_{Gate} (Wp,RP): Time required (Work position to Retract position)
- T_{Robt} (P-weld, Clr): Time required for robot from pounce to weld to clear
- T_{SK}(Wp, Apr.TO): Time required (Work position- approach- to transfer out).

Terms 2 and 3 are skid and product transfer (fixed time),

Terms 3 and 4 are variable time.

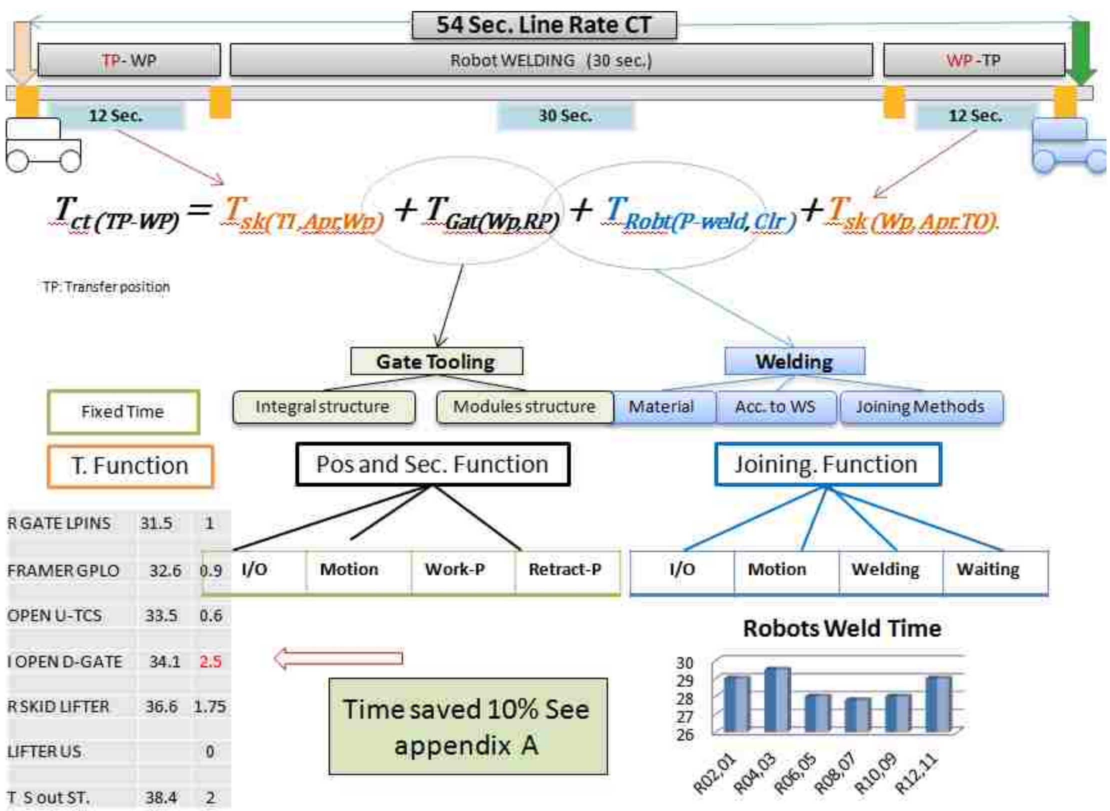


Fig. 5- 19: Bottleneck time analysis of the gate line

Running the simulation program, *Delmia IGRIP*, using the three modules structures (preliminary 3D conceptual geometry models- see Fig. 5-20).

The time saving in line rate is 10 % of the CT; This result is in 5 seconds (10% of the 54 CT) due to two components (1) dumping units eliminations, and (2) reduction of gate size in heights. This time can be used to increase the time available for all robots in the three work-cells. Further details are in the next chapter, in the section on sequence and operation.

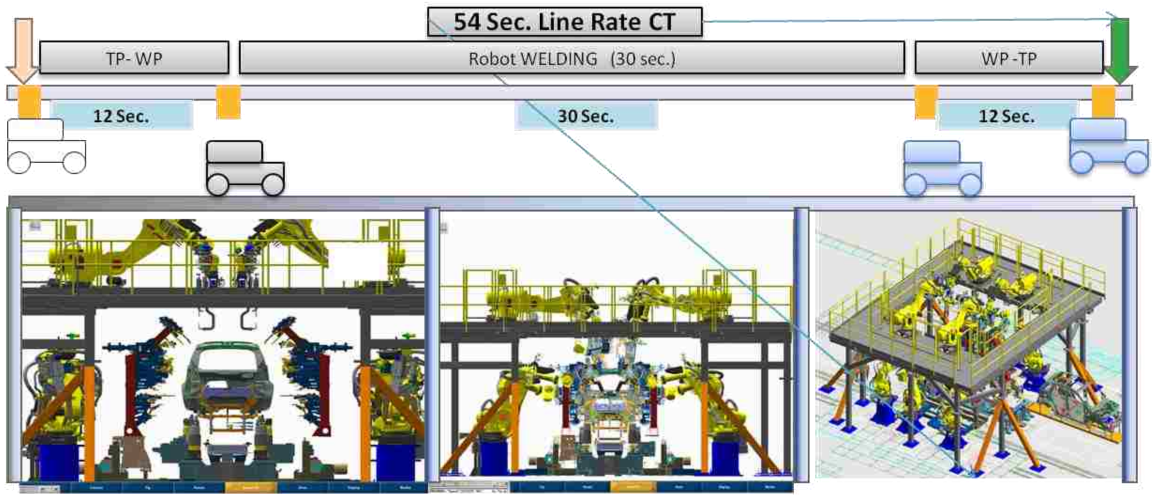


Fig. 5- 20: Bottleneck time work-cell simulation of gate line

5.6: Results and Discussion

Once the initial data and information (CPM- Change Propagation Matrix), DSM and HDSM model are built, they can serve as a knowledge base or platform for continuous learning improvement and innovation. Teamcenter is used as manufacturing supporting center to make data and information quickly accessible and available to all partners across the enterprise. The tools and equipment are built and selected by finding experts knowledgeable about each activity and eliciting their expert opinions by filling in the rows and columns of the DSM and HDSM. Propagation charts can then be produced quickly. By completion of these matrices, the input and output of each stage’s activities becomes available.

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Chapter 6

6. Simulation Model through Case Studies: Vehicle Farming

The need for simulation in manufacturing and assembly systems is discussed here. This chapter also presents and discusses the benefits of connecting the simulation model to the process. Throughputs saving and cost as a direct effect on the HPV saving are further discussed. *Delmia IGRIP* simulation: DM/Virtual assembly line assembly software used for molding this. The proposed methodology is applied through an assembly line(s) case study of three styles of real production data and validation of the method using the simulation model.

6.1: Manufacturing Systems and Simulation

Being too expensive to build a real world system to test the concepts of reconfiguration, an analysis technique is required that is able to test the concepts without the costs of actually building the system. Virtual simulation was chosen as the analysis technique, since it is able to model a dynamic system at a relatively low cost. It was established that manufacturing systems are too complex to analytically analyze with a mathematical model. Hence, simulation was used to make decisions and connect to all processes for real concurrent engineering approaches at all levels.

Simulation modeling techniques are powerful for manipulation of time system inputs and logic. They are cost effective for modeling a complex system and with visual animation capabilities they provide an effective means of learning, experimenting and analyzing real-life complex systems, such as FMS. Table 6.1 characterized the use of simulation into three groups: (a) Manufacturing environments, (b) Manufacturing issues and (c) Performance measurements of the manufacturing and assembly systems. Some of issues and performance measures are highlighted within the table of interest in the case studies.

Table 6- 1: Simulation use in manufacturing system

MFG Environments	MFG Issues	Performance Measurements
○ Lay out of plant grids existing, presses, point variation in supplies. ○ A new product will be produced in all or part of an existing building. ○ Upgrading of existing equipment or its operation. ○ Concerned with producing the same product more efficiently. ○ Changes may be in the equipment or in operational procedures.	○ Number and type of machines for a particular objective. ○ Location and size of inventory buffers. ○ **Evaluation of a change in product mix (impact of new products).** ○ Evaluation of the effect of new equipment on an existing manufacturing line. ○ Evaluation of capital investments. ○ Manpower requirements planning. ○ **Throughput analysis.** ○ Make-span analysis. ○ **Bottleneck analysis.** ○ **Evaluation of operational procedures.** ○ Evaluation of policies for component part or raw material inventory levels. ○ Evaluation of control strategies.	○ **Throughput (number of jobs produced per unit of time).** ○ Time in system for jobs (make-span). ○ **Times jobs spend in queues or work-cell (Details times of process).** ○ Time that jobs spend being transported. ○ Sizes of in-process inventories (WIP or queue sizes). ○ Utilization of equipment and personnel. ○ Proportion of time that a machine or process is blocked interferences zone. ○ Proportion of jobs produced which must be reworked or scrapped. ○ **Return on investment for a new or modified MFG.**

6.2: Simulation Principles

Definition of Simulation

Simulation is the imitation of the operation of a real-world process or system over time. In order to imitate the workings of a real-world process, generating an artificial history that can be studied to be able to draw inferences concerning the operational characteristics of the system is required. If the simulation model imitates the operation of the real-world system to a predetermined degree of accuracy, it can be used to describe and analyze the behavior of the system, to ask what-if questions about different scenarios, and to aid in the design of real world systems. Existing as well as conceptual systems can be modeled with simulation (Banks, 1998).

Why Simulation?

Simulation is used to study the system and identify its problem. Once the problem has been identified, the analyst can start to investigate analysis techniques that will not only satisfactorily solve the problem, but do so in a cost effective way. There are many analysis techniques available, such as queuing theory, linear programming, assignment algorithms, integer programming and dynamic programming, to mention a few Preez, Bekker (2011). Some of these techniques will try to analytically solve the problem with the aid of a computer. When the problem is of a complex nature and cannot be solved analytically, simulation will be strongly considered by the analyst. In addition, if the problem is of a complex stochastic nature, then simulation is a suitable analysis technique.

The manufacturing system is dynamic because all of its activities are dependent on time. The state of the system will change as time advances but these changes happen at discrete points. Analytical methods will only represent the system at a fixed point in time while a simulation model can take the passage of time into account. It has been established that when a system is of a complex stochastic nature, has variation in the process, and is dependent on time, simulation is strongly considered as an analysis technique.

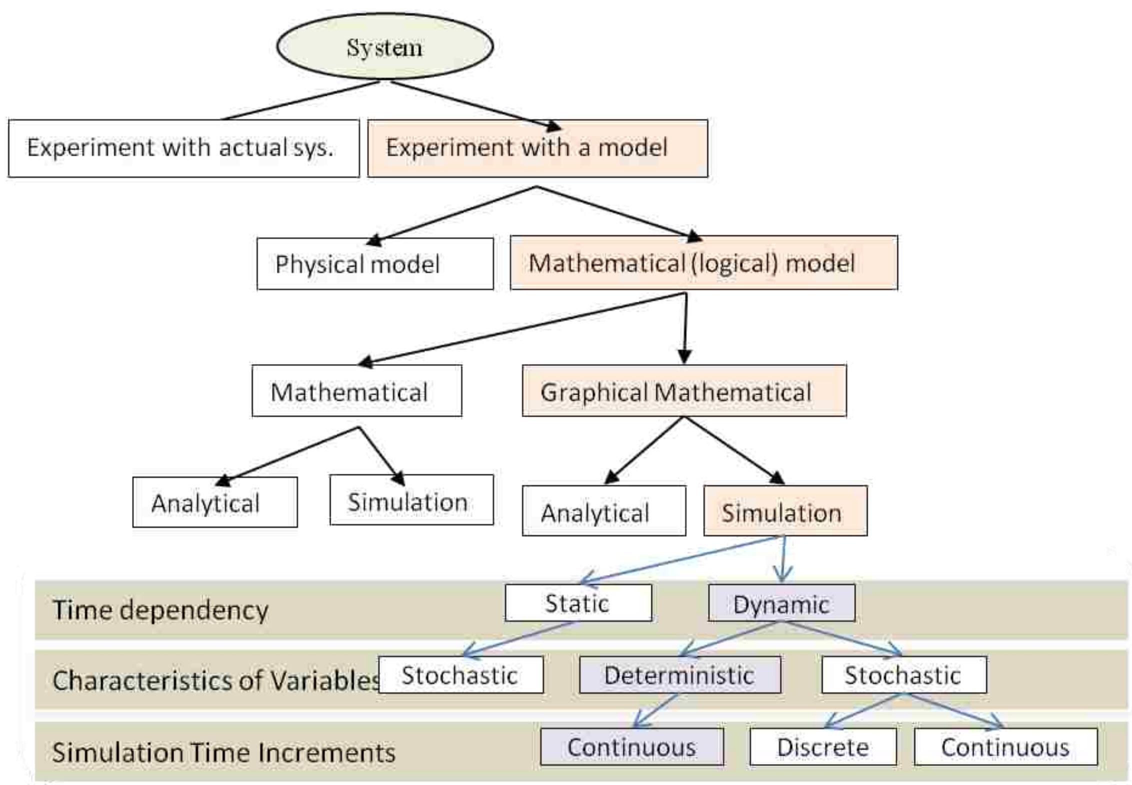


Fig. 6- 1: Different methods to study a system (adapted fromPreez, Bekker, 2011)

6.3: Model Development in DM and Virtual Manufacturing Lines

6.3.1: Virtual Manufacturing Assembly Lines (VMALs)

Once the manufacturing assembly sequence is finalized, the MES will generate the relevant stations, work-cells tasks and supervise production on the production line. As the products move through the manufacturing and assembly sequences, tasks completion at each level are monitored automatically or semi-automatically. Automation and controls were designed on different levels (cell levels and systems level). The reason for this is to ensure production is running and allows a maintenance crew to correct and fix a minor malfunction of tools or equipments without delay.

To run an accurate virtual execution of assembly of production line, accurate real-time date from the shop floor for each operation (work-cells tasks) is required. Lack of information (real-time information) with complex systems results in many unnecessary setup times, slowed production, and ultimately degraded system productivity (Tang, Qui, 2004). DM and virtual design assemblies are used in *automotive and aerospace industries* using special software as complete solutions. Fig. 6-2 shows the lifecycle of the manufacturing systems linked to the simulation at every stage from conception to the final stage of production.

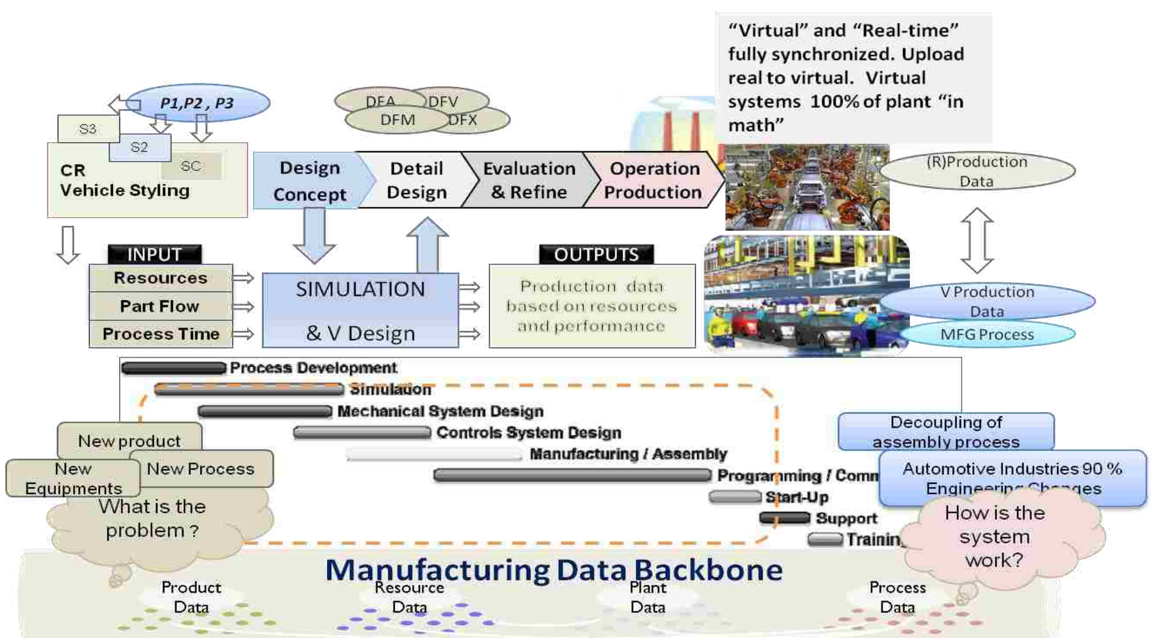


Fig. 6- 2: Connecting simulations to the all manufacturing process model

6.3.2: Software Used to Build the Model

Delmia IGRIP simulation software is used. This software is a complete comprehensive digital manufacturing systems solution that delivers innovation by linking all manufacturing disciplines together with product engineering from process layout and design, process simulation and validation, to manufacturing execution. Delmia DM and production allows manufacturers in any industry to virtually define, plan, create, monitor, and control all production processes. It provides an array of dedicated applications for industries, combined with an environment for knowledge-sharing, process and resource management, and the ability to capture and implement best practices for manufacturing. Some of the following functional areas will be used, such as:

- Translation of design data to manufacturing,
- Full process planning,
- Production operations planning and machining process planning,
- Assembly definition and sequencing,
- Detailed line, cell, station and task design,
- Quality measurement and reporting,
- Manufacturing documentation, shop floor instruction and collaboration.

6.3.3: What is Needed to Build the Models?

To use the software for manufacturing execution requires a comprehensive knowledge in the following areas:

- Full knowledge of different translators for data-in at the CAD/CAM levels to create devices for product, tooling, stations, equipments, robots, C-flex safety controls, and automation;
- Product decompositions, automotive experts to create product devices with product flow down streams;
- Building 3D virtual work-cells per process and assign tasks to each equipments;
- Knowledge in writing GSL programming, DOF for each device to create the necessary kinematics to imitate motion of stations, equipments and calibrate per real-time production.

For programming languages used to run the virtual assembly line, simple temples can be written and saved in the project lib.

Writing the GSL programming and codes to execute the command function and run simulation is not difficult to teach or train. What, then, is most difficult to execute in the systems programs with I/O commendation at different levels? The completion to run the entire systems has two existing scenarios:

I) It can usually be done by a team of engineers specialized in different areas,

II) Under highly supervised expert systems, engineers can divide the work to different levels and assign tasks to different engineers at the same time (concurrent approach).

With the second approach, there is more time savings but needs equal training for the entire team.

6.3.4: Simulation Process Flow in Manufacturing Systems

Simulation flow starts with a defined process and aims of the process (target of the process). Simulation and validation for the process prior to execution requires accurate date of the production equipments; the process of getting accurate data is as follows:

- Manufacturing specs of the equipments at work environment can be assigned to machine attributes (follow kinematics creation);
- Robots and C-Flex need to get the latest RCS with accurate payload date and complying with safety roils (this should be good enough);
- GSS data requires hands-on expertise to assign attributes to (via, weld) pints to create weld path (joining process execution).

In Fig. 6-3, the inputs, outpost for the simulation for processing levels (conceptual design), and final design are shown.

Simulation Inputs:

Simulation inputs in the case of car body styling as follows:

1: Geometry changes; modification of modules, sub-sequent data are needed such material type, weld data and existing processes.

2: Material upgrades it may require new geometry new weld data needed.

3: New equipments or processes.

Simulation testing is required for any inputs for both level conceptual and details design.

Simulation Outputs:

Simulation outputs can be divided to levels; processing level to evaluate changes using conceptual tools to finalize welding gun selection, weld spots distribution and selection. Previous archived work-cell can be stored at the TeamCenter to be used by other users (current practice storages use only). With the evolution of new technologies of DM systems, cycle time accuracy is almost approaching 98-100 percent, as shown in Fig.6-4. These results for BIW integration can be used for validation of the final design.

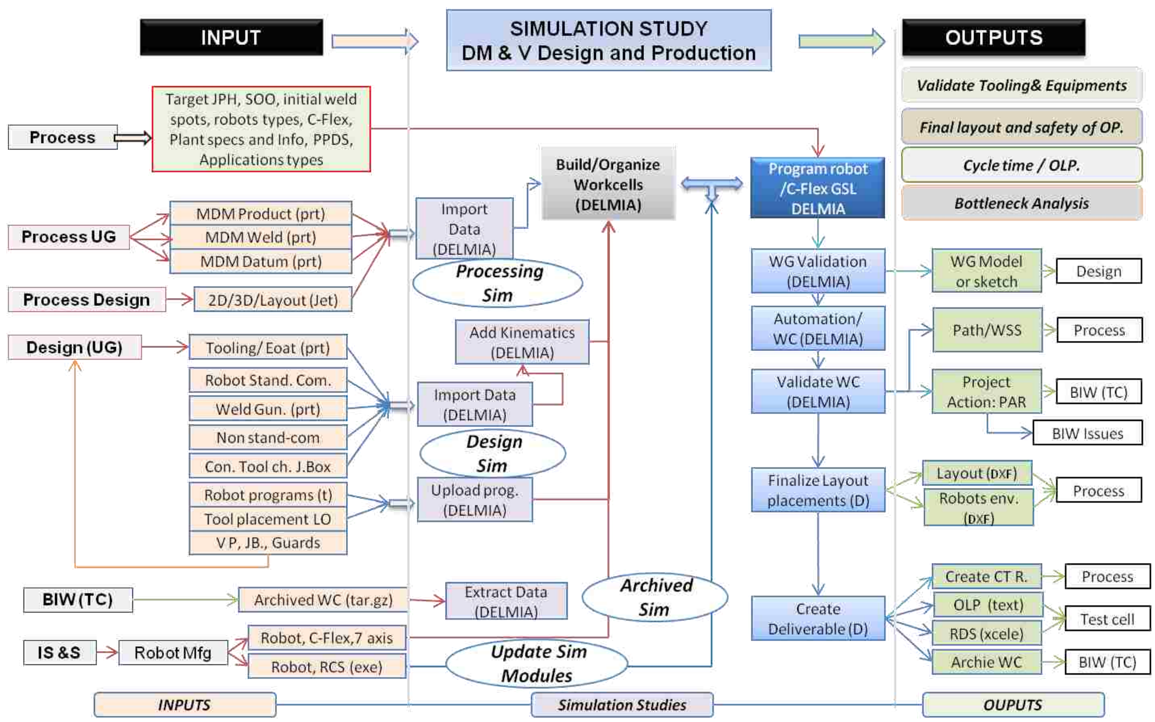


Fig. 6- 3: Simulation Process Flow in MFG Systems

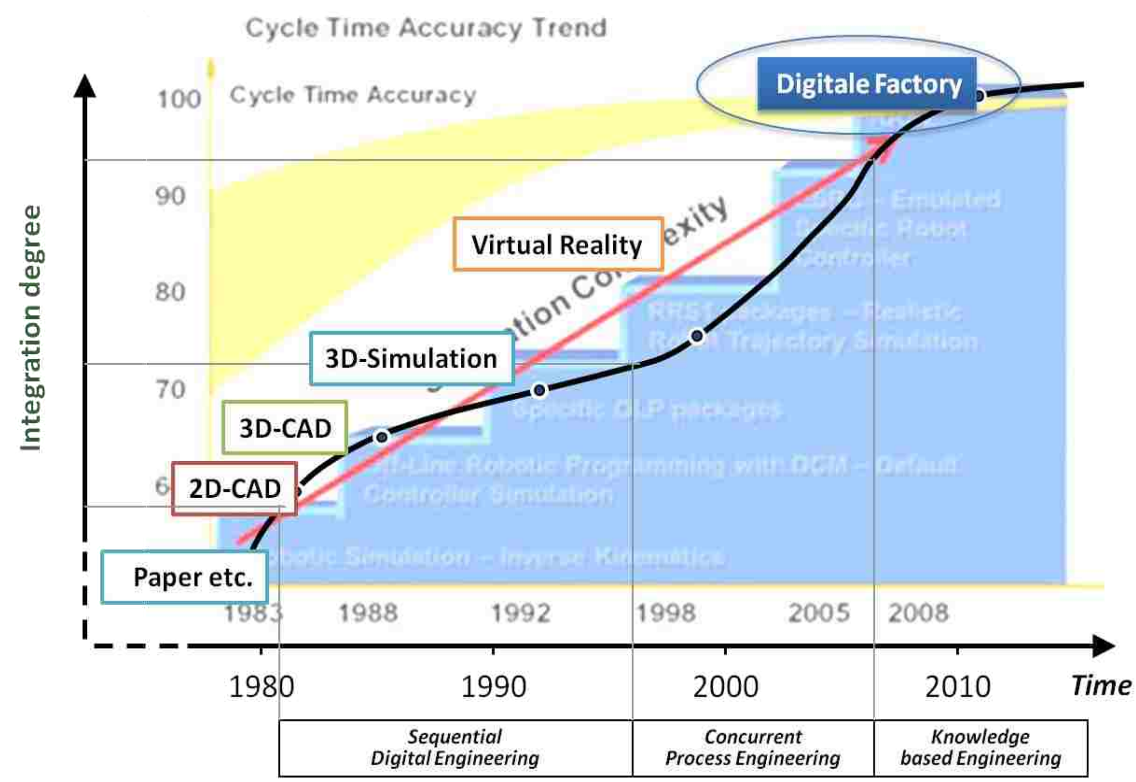


Fig. 6- 4: Cycle time accuracy and integration (adopted from Adam Opel AG, 2012, Prof. Dr. Egon Müller)

6.3.5: Connecting Simulations to the Process Model

Current practice in the automotive industries stands alone as systems or network storage data for archived work-cells used to retrieve data for completed work or tooling to be used for similar assembly lines. There have been new trends in the last two years due to the use of Teamcenter as manufacturing supports, allowing engineering suppliers to work and collaborate and share one copy of data.

Fig. 6-5 shows the type of stand-alone simulation and connecting to Teamcenter through e-planner. Teamcenter for Simulation (fact sheet by PLM/Siemens) is a natural extension to the world's most popular design and manufacturing data management system. As an integrated source of product information for design and engineering analysis, it enables:

- Standardization and repeatable processes for simulation all users,
- Access to simulation data by increasingly diverse users across the globe,
- Access to specific simulation (physical test) specific area and applications,

- Robust and persistent integration with the corporate product structure, including management of configurations and variants.

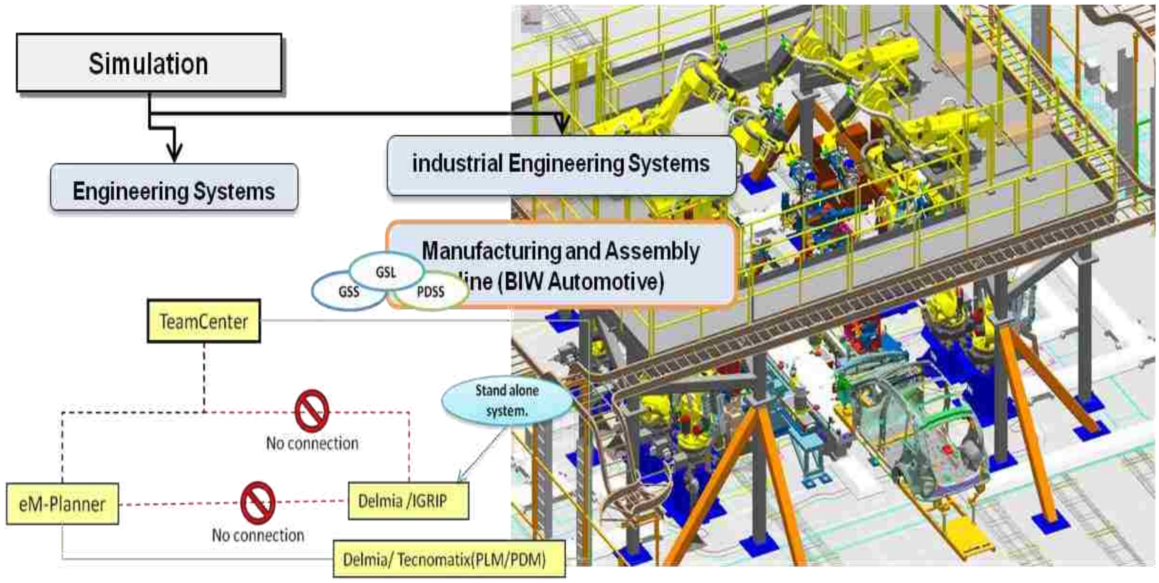


Fig. 6- 5: Connecting simulation with TeamCenter

Teamcenter for Simulation provides unique simulation process and data management capabilities that enable companies to cost effectively implement a complete digital product development environment, beginning upfront with conceptual design and continuing through detailing. Teamcenter key capabilities include:

- Allowing Computer Aided Engineering (CAE) engineers to leverage existing information technology resources (hardware, software, training, support),
- Tight integration with digital lifecycle management and digital product development which enables "always current" access to configured design data, product structures, requirements, and other relevant information in a visual 3D context,
- Full configuration management and product structure management to coordinate Computer Aided Design (CAD) geometry and CAE models and processes so that "as analyzed" represents "as designed" and "as built",
- Ensuring geometry changes re-analysis and results are fed back to product development,
- Providing access to simulation data by an increasingly diverse "cross enterprise" population of users,

- Structure Mapping which automates the delivery of the correct geometry for each specific analysis project and CAE discipline,
- Complete integration with the corporate BOM, including management of configurations and variants,
- Batch Meshing Support to enable automation of key simulation process steps, and
- Scalability, because it is based on Teamcenter.

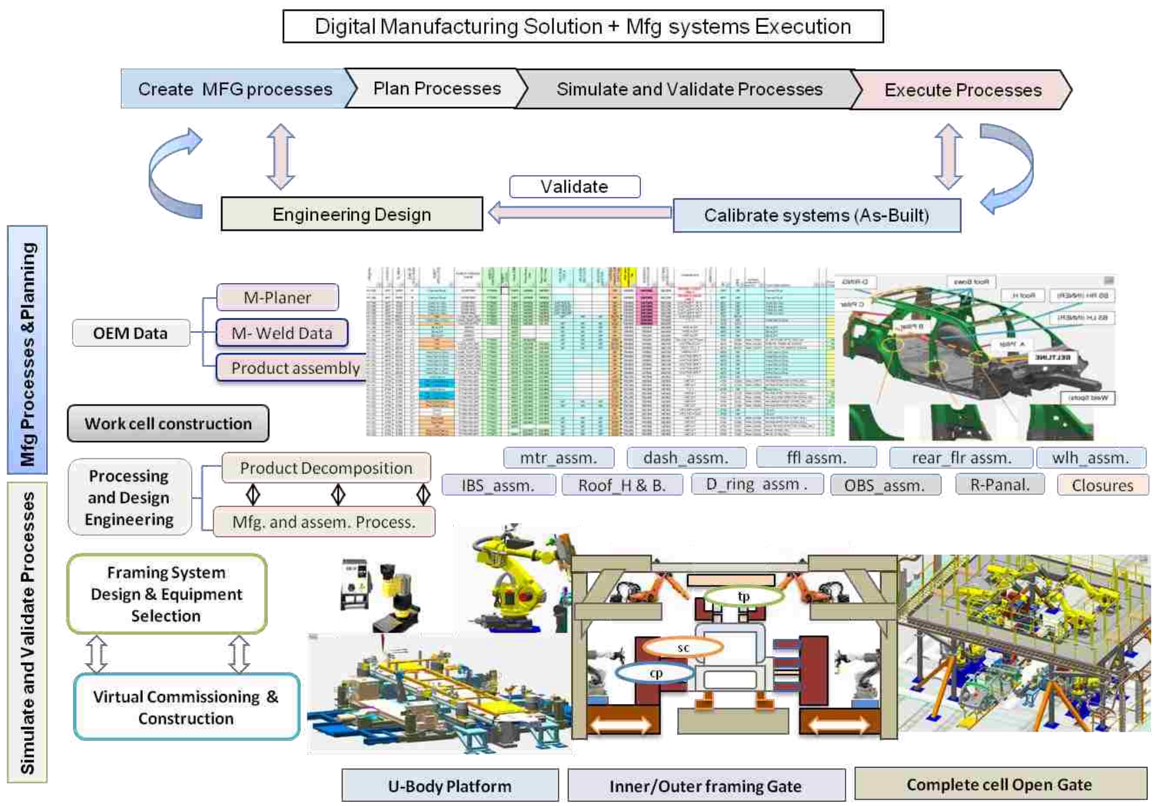


Fig. 6- 6: Digital MFG Solution & MSE (Automotive framing systems)

6.4: Building the Simulation Modeling

6.4.1: Assembly Process of the Gate Line

Assembly process of the product was detailed in Chapter 3. Product modules are loaded to under-body complete, then proceeds to Gate work-cell, (Inner assembly work-cell) product schedules per week for two shifts. Fig. 6-7 shows the three level of GSL programming, which are:

1) System level: Systems controls and automation communicates with the entire work-cell as shown in the systems layout. In addition, it controls the transfer skids between the work-cell of the systems.

2) Cell level: Workcell *GSL programs* are used control the product flow through stations in one work-cell and ensure the execution of each task of production equipments. Execution and timing to start and end assembly tasks accomplished by Dual I/O commutations (Hand shaking I/Os for confirmation). Gate station, robot, weld gun, each have their own GSL; all the activities are coordinated by cell controllers.

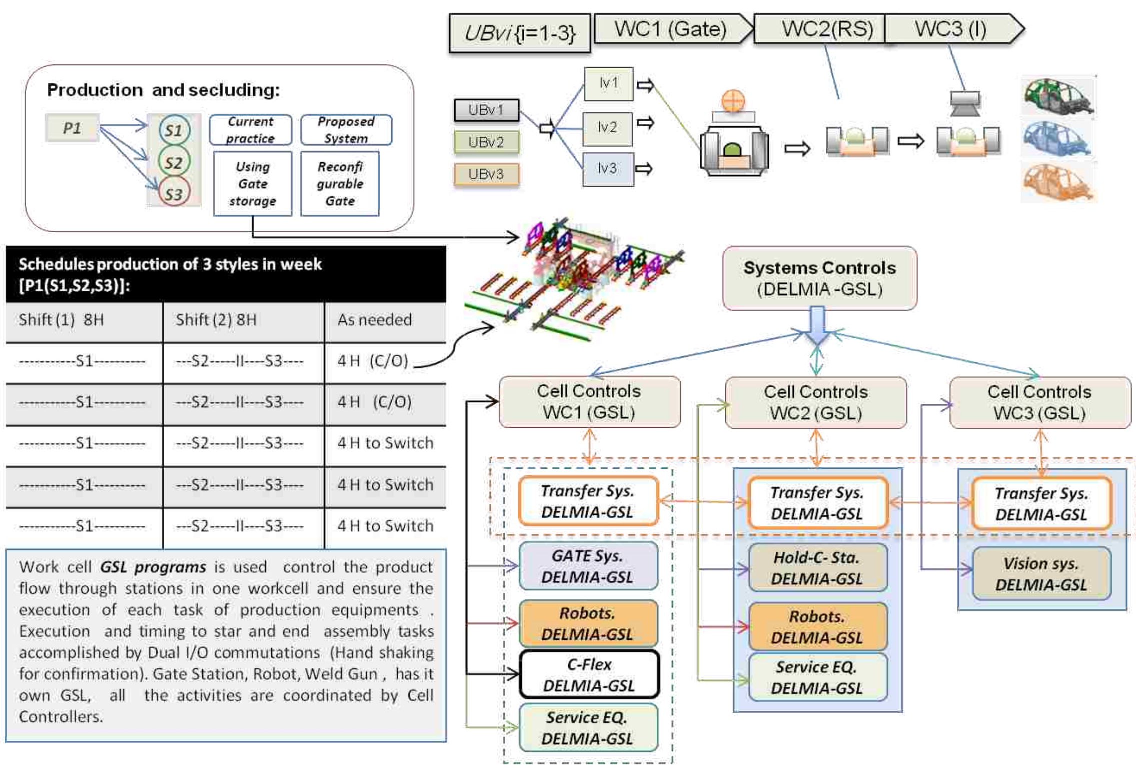


Fig. 6- 7: GSL programming structures system level (Automotive framing systems)

3) Device level: Simulation communicates with cell controllers via GSL for each device. DELMIA software provides setup modules Robots and C-Flex, and also tooling. To run proper simulation attributes, specs are needed for proper entries (see Fig. 6-8), of devices/ equipments, weld attributes and weld controller types.

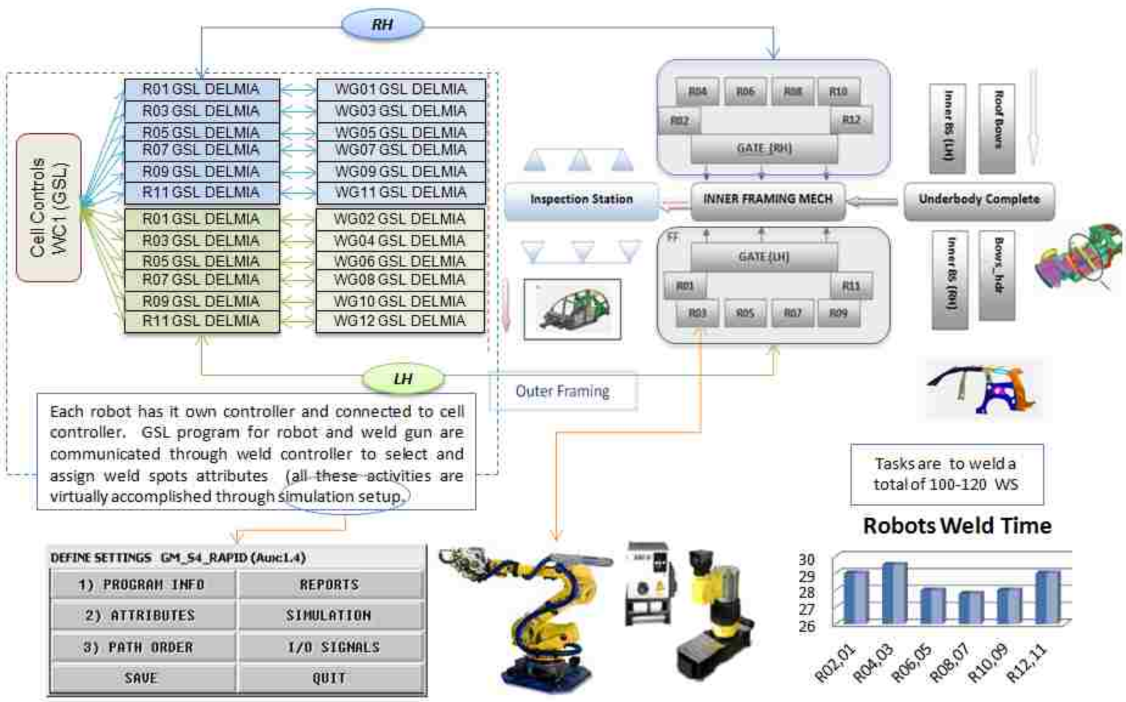


Fig. 6- 8: GSL programming structures cell level Inner Gate work-cell

6.4.2: Sequence of Operation Open Gate Systems

Sequencing of operation of the production systems is crucial to establishing the interaction between tasks to be included in framing systems. The reason is that framing Gate work-cell is the bottleneck of the main assembly line (with direct effect on the throughputs). To write the operation sequence of the product flow, details are required so the operation and overlapped timing due to tooling is sequenced as shown in Fig. 6-9 and Fig. 6-10. Proper analysis for throughputs, need proper I/O builds in the GSL (Digital I/O communications) according to work order of equipment as shown in the following Tables 6-2, to 6-7. In the corresponding three sequences of operation, each table has two parts:

Design and entry parts are at the top of the excel sheet, and the lower portion has the graphical parts; it shows the mapping time (top parts) of all tasks in the sequence of operation.

Changes of equipments such as robots, tooling parts, or any components that had a function in the process need to be entered with their cycle time based on simulation results. Synchronization with the production line needs upload sequencing and timing as it is built.

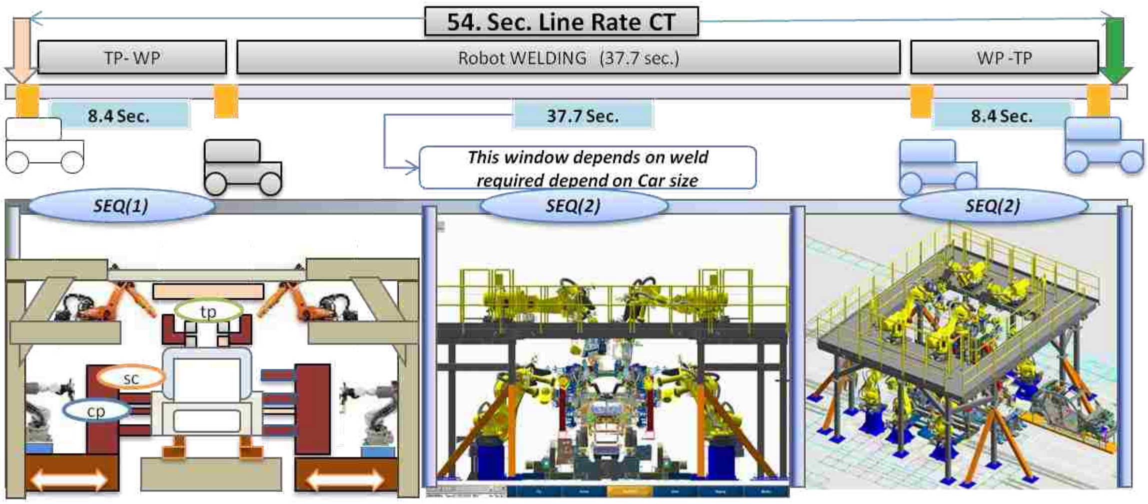


Fig. 6- 9: Sequence of operation and tasks of the Inner Gate work-cell

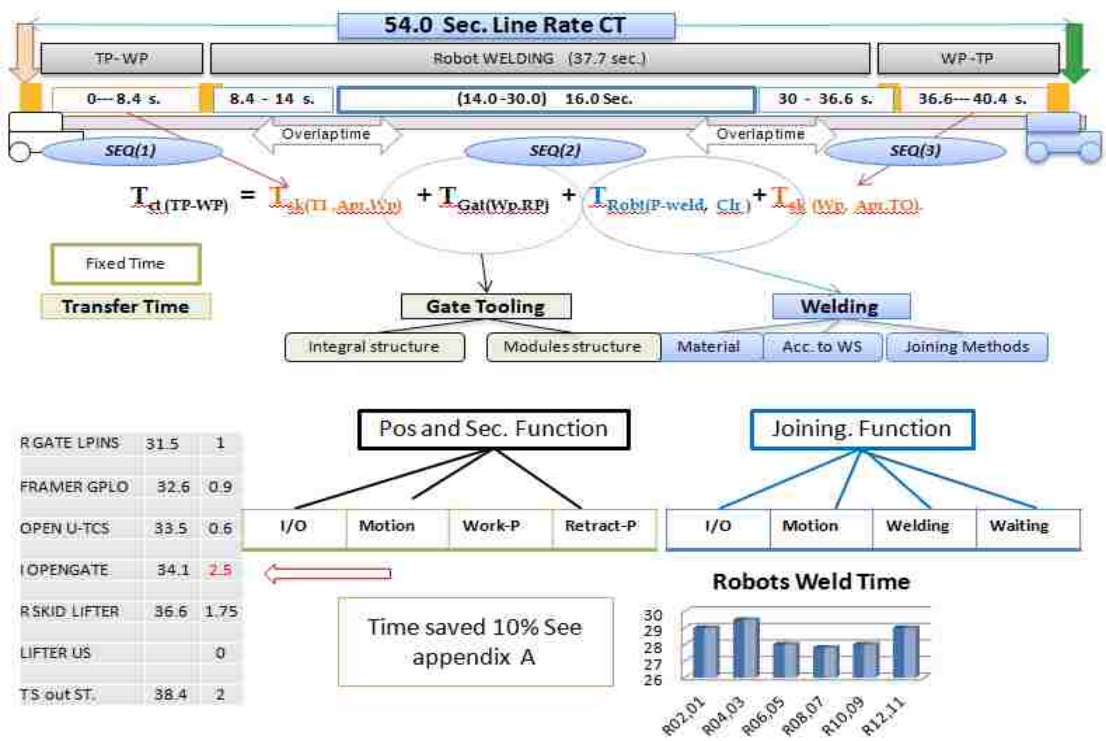


Fig. 6- 10: Bottleneck time analysis sequence of the Inner Gate work-cell

Systems integration required simulation engineers and automation engineers work closely during the integration period to match and update digital communication and update all documentation as built. In the real world, the common style requires more time than the addition styles.

Table 6- 2: Sequence of operation of the Inner Gate work-cell Seq. (1)

MECHANICAL DESIGN SOURCE **RoboTech Canada Consulting Inc.**
CONTROLS DESIGN SOURCE **Al-Zaher Abdo May 2012**

Green = Column's that need to filled IN
Yellow = Should not have to typed in but, are permitted to do s

Rev	Func	Q ST	FUNCTION SEQUENCE	DESCRIPTION	DEVICE (CYL	ULT ING	WELD SPOT	OUTPUT TAG/DEVI	RESULTING SENSOR	P SWITCH	ERENCE	A cm²	STK. mm	T TIME	TIME	DURATION
	T	1	SKID INDEX IN											0.0	5.95	5.95
	T	2	SKID MAKES DECEL SWITCH											5.5	0	5.5
	T	3	SKID MAKES STOP SWITCH											6.0	0	5.95
	T	4	CLOSE SKID POSITIONER CLAMP											6.0	0.6	6.55
	T	5	LOWER SKID LIFTER											6.6	1.75	8.3
	T	6	OPEN SKID POSITIONER CLAMP											8.3	0.6	8.9
	T	7	MAKE LIFTER DOWN SWITCH											8.3	0	8.3
	F	8	MAKE UNDERBODY TOOLING PA											8.3	0	8.3
	F	9	CLOSE UNDERBODY PIN CLAMPS											8.3	0.6	8.9
	F	10	INDEX OPENGATE TO WORK POS											8.9	2.5	11.4
	R	11	INITIATE ROBOT TO POUNCE		R01									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R02									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R03									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R04									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R05									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R06									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R07									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R08									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R09									11.4	3	14.4
	R	11	INITIATE ROBOT TO POUNCE		R10									11.4	3	14.4
	T	12	ADVANCE GATE LOCK PINS											11.4	1	12.4
	F	13	READ PART PRESENTS	REINF - QTR OTR PNL UPR						PPX01				11.4	0	11.4
	F	13		FRAME - W/S INR SI						PPX02				11.4	0	11.4
	T	14	FRAMER GATE POSITION LOCKS											11.4	0.9	12.3
	F	15.A	ADVANCE DUMPS	DUMP CYLINDER	C01	E		PM1V1S14	C01PX2		0	81	102	11.4	1.1	12.5
	F	15.A		DUMP CYLINDER	C04	E		PM1V1S14	C04PX2		0	81	102	11.4	1.1	12.5
	F	15.A		DUMP CYLINDER	C07	E		PM1V1S14	C07PX2		0	81	102	11.4	1.1	12.5
	F	15.B	CLOSE CLAMP BACK-UPS	LOCATOR CLAMP @ 39§	C15	E		PM1V2S14	C15PX2		0	31	24	11.4	0.6	12
	F	15.B		LOCATOR CLAMP @ 31§	C25	E		PM1V2S14	C25PX2		0	31	24	11.4	0.6	12
	F	15.C	ENGAGE LOCATING PINS	RETRACTABLE PIN @ 45	C10	E		PM1V3S14	C10PX2		0	31	48	11.4	0.6	12
	F	15.C		RETRACTABLE PIN @ 22	C24	E		PM1V3S14	C24PX2		0	31	48	11.4	0.6	12
	F	15.C		RETRACTABLE PIN @ 39	C30	E		PM1V3S14	C30PX2		0	31	25	11.4	0.6	12
	F	15.C		RETRACTABLE PIN @ 47	C33	E		PM1V3S14	C33PX2		0	31	25	11.4	0.6	12
	F	15.C		RETRACTABLE PIN @ 32	C34	E		PM1V3S14	C34PX2		0	31	23	11.4	0.6	12
	F	16	READ PART PRESENTS	REINF RF PNL FRT						PPX03				12.0	0	12
	F	16		BOW ROOF PNL #3						PPX04				12.0	0	12
	F	16		PANEL - RF RR INR UPR						PPX05				12.5	0	12.5
	F	16		PNL RF FRT INR						PPX06				12.5	0	12.5
	F	16		BOW ROOF PNL #2						PPX07				12.5	0	12.5

SYSTEM CYCLE TIME **54.5 SEC/66JPH**

= FIXTURE FUNCTION
= TRANSFER
= WELDING
= MANUAL LOAD
= OPERATOR FUNCTION
= ROBOT FUNCTION

BIW METRIC

Table 6- 3: Graph of the sequence of operation Inner Gate work-cell Seq. (1)

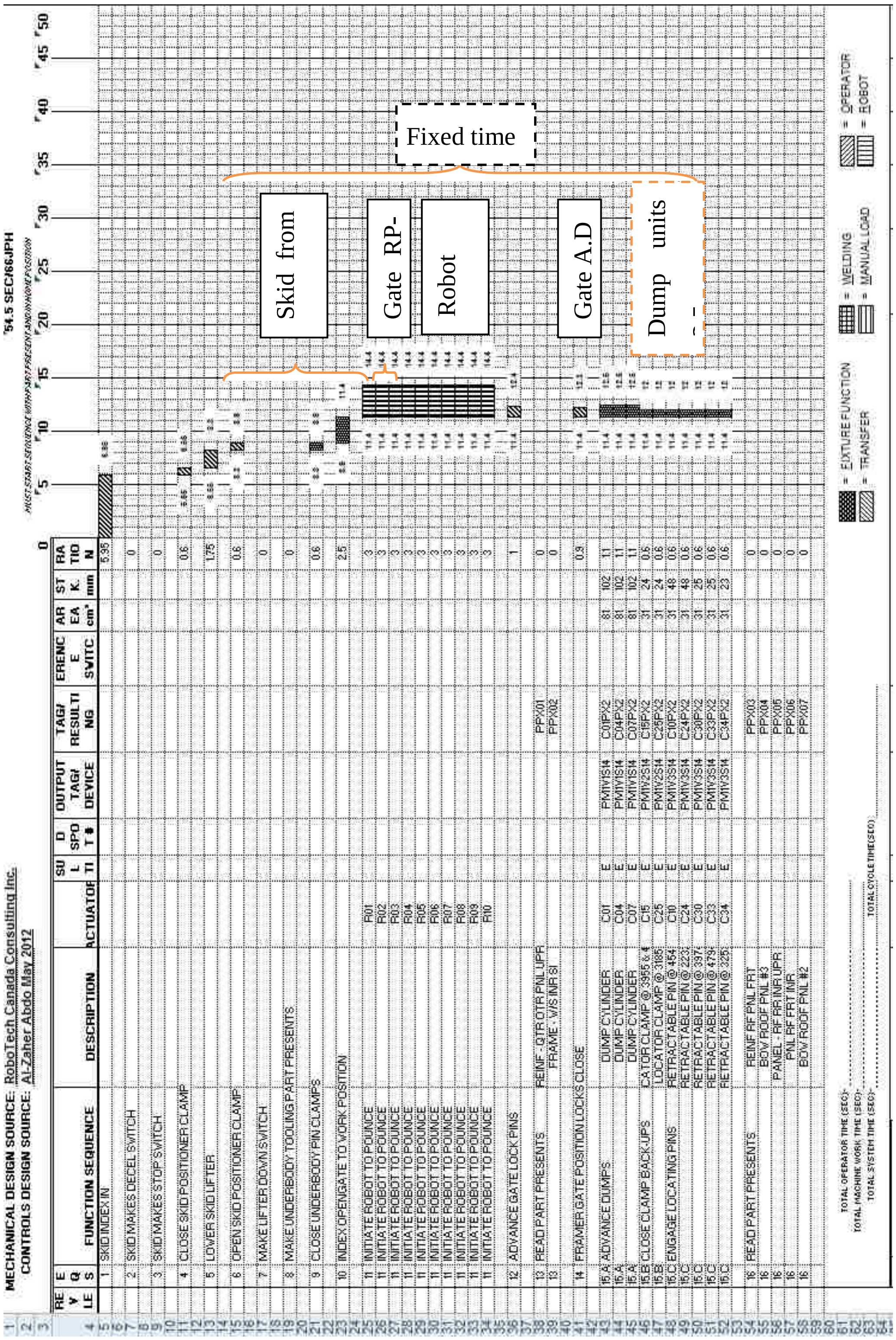


Table 6- 4: Sequence of operation of the Inner Gate work-cell Seq. (2)

MECHANICAL DESIGN SOURCE **RoboTech Canada Consulting Inc.**
CONTROLS DESIGN SOURCE **Al-Zaher Abdo May 2012**

Green = Column's that need to filled IN
Yellow = Should not have to type in but, are permitted to do so

Rev	Func	Q ST	FUNCTION SEQUENCE	DESCRIPTION	DEVICE (CYL	ULT ING	WELD SPOT	OUTPUT TAG/DEVI	RESULTING SENSOR	SWITC	E SWITCHES	A cm²	STK. mm	T TIME	TIME	DURATION
	F	17.A	CLOSE CLAMP BACK-UPS	RETRACTABLE LOCATOR @	C20	E		PM1V4S14	C20PX2		0	31	25	12.5	0.6	13.1
	F	17.A		RETRACTABLE LOCATOR @	C11	E		PM1V4S14	C11PX2		0	31	25	12.5	0.6	13.1
	F	17.B	ENGAGE LOCATING PINS	RETRACTABLE PIN @ 300	C03	E		PM1V5S14	C03PX2		0	13	23	12.5	0.6	13.1
	F	17.B		RETRACTABLE PIN @ 300	C06	E		PM1V5S14	C06PX2		0	13	23	12.5	0.6	13.1
	F	17.B		RETRACTABLE PIN @ 317	C09	E		PM1V5S14	C09PX2		0	13	25	12.5	0.6	13.1
	F	18	CLOSE CLAMPS	CLAMP @ 4616	C12	E		PM1V6S14	C12PX2		0	31	72	13.1	0.6	13.7
	F	18		LOCATOR CLAMP @ 4345	C13	E		PM1V6S14	C13PX2		0	31	35	13.1	0.6	13.7
	F	18		CLAMP @ 1220	C14	E		PM1V6S14	C14PX2		0	31	72	13.1	0.6	13.7
	F	18		CLAMP @ 3955 & 4041	C16	E		PM1V6S14	C16PX2		0	31	44	13.1	0.6	13.7
	F	18		CLAMP @ 940	C17	E		PM1V7S14	C17PX2		0	31	63	13.1	0.6	13.7
	F	18		CLAMP @ 1355	C18	E		PM1V7S14	C18PX2		0	31	72	13.1	0.6	13.7
	F	18		CLAMP @ 2135 & 2194	C19	E		PM1V7S14	C19PX2		0	31	72	13.1	0.6	13.7
	F	18		CLAMP @ 2705 & 2660	C21	E		PM1V7S14	C21PX2		0	31	44	13.1	0.6	13.7
	F	18		CLAMP @ 398	C02	E		PM1V7S14	C02PX2		0	31	82	13.1	0.6	13.7
	F	18		CLAMP @ 5085	C22	E		PM2V1S14	C22PX2		0	31	63	13.1	0.6	13.7
	F	18		CLAMP @ 1098	C23	E		PM2V1S14	C23PX2		0	31	72	13.1	0.6	13.7
	F	18		CLAMP @ 3185	C26	E		PM2V1S14	C26PX2		0	31	44	13.1	0.6	13.7
	F	18		CLAMP @ 1250	C27	E		PM2V1S14	C27PX2		0	31	53	13.1	0.6	13.7
	F	18		CLAMP @ 3405 & 3434	C29	E		PM2V1S14	C29PX2		0	31	53	13.1	0.6	13.7
	F	18		CLAMP @ 435	C05	E		PM2V2S14	C05PX2		0	31	72	13.1	0.6	13.7
	F	18		CLAMP @ 317	C08	E		PM2V2S14	C08PX2		0	31	72	13.1	0.6	13.7
	F	18		CLAMP @ 710	C31	E		PM2V2S14	C31PX2		0	31	63	13.1	0.6	13.7
	F	18		CLAMP @ 4945	C35	E		PM2V2S14	C35PX2		0	31	24	13.1	0.6	13.7
	F	18		CLAMP @ 275	C36	E		PM2V3S14	C36PX2		0	31	82	13.1	0.6	13.7
	F	18		CLAMP @ 4345	C28	E		PM2V3S14	C28PX2		0	31	44	13.1	0.6	13.7
	R	19	ROBOT TO SPOT WELD AI		R01									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R02									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R03									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R04									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R05									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R06									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R07									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R08									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R09									13.7	16	29.7
	R	19	ROBOT TO SPOT WELD AI		R10									13.7	16	29.7
	F	20	OPEN CLAMPS	CLAMP @ 4616	C12	R		PM1V6S12	C12PX1		0	31	72	30.3	0.6	30.9
	F	20		LOCATOR CLAMP @ 4345	C13	R		PM1V6S12	C13PX1		0	31	35	30.3	0.6	30.9
	F	20		CLAMP @ 1220	C14	R		PM1V6S12	C14PX1		0	31	72	30.3	0.6	30.9
	F	20		CLAMP @ 3955 & 4041	C16	R		PM1V6S12	C16PX1		0	31	44	30.3	0.6	30.9
	F	20		CLAMP @ 940	C17	R		PM1V7S12	C17PX1		0	31	63	30.3	0.6	30.9
	F	20		CLAMP @ 1355	C18	R		PM1V7S12	C18PX1		0	31	72	30.3	0.6	30.9
	F	20		CLAMP @ 2135 & 2194	C19	R		PM1V7S12	C19PX1		0	31	72	30.3	0.6	30.9
	F	20		CLAMP @ 2705 & 2660	C21	R		PM1V7S12	C21PX1		0	31	44	30.3	0.6	30.9
	F	20		CLAMP @ 398	C02	R		PM1V7S12	C02PX1		0	31	82	30.3	0.6	30.9
	F	20		CLAMP @ 5085	C22	R		PM2V1S12	C22PX1		0	31	63	30.3	0.6	30.9
	F	20		CLAMP @ 1098	C23	R		PM2V1S12	C23PX1		0	31	72	30.3	0.6	30.9
			STEP #20 CONTINUED ON													

SYSTEM CYCLE TIME **54.5 SEC/66JPH**

BIW METRIC

= FIXTURE FUNCTION
= TRANSFER
= WELDING
= MANUAL LOAD
= OPERATOR FUNCTION
= ROBOT FUNCTION

Table 6- 5: Graph of the sequence of operation Inner Gate work-cell Seq. (2)

MECHANICAL DESIGN SOURCE: RoboTech Canada Consulting Inc.
CONTROLS DESIGN SOURCE: Al-Zaher Abdo May 2012

REV LE	Q STE	FUNCTION SEQUENCE	DESCRIPTION	ACTUATOR	SUL TI	D SPO T #	OUTPUT TAG/ DEVICE	TAG/ RESULTING	RFEREN CE	AREA cm²	STK. mm	RATIO N
	17.A	CLOSE CLAMP BACK-UPS	TRACTABLE LOCATOR @ :	C20	E		PM1V4S14	C20PX2		31	25	0.6
	17.A		RETRACTABLE LOCATOR @ 4	C11	E		PM1V4S14	C11PX2		31	25	0.6
	17.B	ENGAGE LOCATING PINS	RETRACTABLE PIN @ 300	C03	E		PM1V5S14	C03PX2		13	23	0.6
	17.B		RETRACTABLE PIN @ 300	C06	E		PM1V5S14	C06PX2		13	23	0.6
	17.B		RETRACTABLE PIN @ 317	C09	E		PM1V5S14	C09PX2		13	25	0.6
	18	CLOSE CLAMPS	CLAMP @ 4616	C12	E		PM1V6S14	C12PX2		31	72	0.6
	18		LOCATOR CLAMP @ 4345	C13	E		PM1V6S14	C13PX2		31	35	0.6
	18		CLAMP @ 1220	C14	E		PM1V6S14	C14PX2		31	72	0.6
	18		CLAMP @ 3955 & 4041	C16	E		PM1V6S14	C16PX2		31	44	0.6
	18		CLAMP @ 940	C17	E		PM1V7S14	C17PX2		31	63	0.6
	18		CLAMP @ 1355	C18	E		PM1V7S14	C18PX2		31	72	0.6
	18		CLAMP @ 2135 & 2194	C19	E		PM1V7S14	C19PX2		31	72	0.6
	18		CLAMP @ 2705 & 2660	C21	E		PM1V7S14	C21PX2		31	44	0.6
	18		CLAMP @ 398	C02	E		PM1V7S14	C02PX2		31	82	0.6
	18		CLAMP @ 5085	C22	E		PM2V1S14	C22PX2		31	63	0.6
	18		CLAMP @ 1098	C23	E		PM2V1S14	C23PX2		31	72	0.6
	18		CLAMP @ 3185	C26	E		PM2V1S14	C26PX2		31	44	0.6
	18		CLAMP @ 1250	C27	E		PM2V1S14	C27PX2		31	53	0.6
	18		CLAMP @ 3405 & 3434	C29	E		PM2V1S14	C29PX2		31	53	0.6
	18		CLAMP @ 435	C05	E		PM2V2S14	C05PX2		31	72	0.6
	18		CLAMP @ 317	C08	E		PM2V2S14	C08PX2		31	72	0.6
	18		CLAMP @ 710	C31	E		PM2V2S14	C31PX2		31	63	0.6
	18		CLAMP @ 4945	C35	E		PM2V2S14	C35PX2		31	24	0.6
	18		CLAMP @ 275	C36	E		PM2V3S14	C36PX2		31	82	0.6
	18		CLAMP @ 4345	C28	E		PM2V3S14	C28PX2		31	44	0.6
	19	ROBOT TO SPOT WELD AND CLEAR		R01								16
	19	ROBOT TO SPOT WELD AND CLEAR		R02								16
	19	ROBOT TO SPOT WELD AND CLEAR		R03								16
	19	ROBOT TO SPOT WELD AND CLEAR		R04								16
	19	ROBOT TO SPOT WELD AND CLEAR		R05								16
	19	ROBOT TO SPOT WELD AND CLEAR		R06								16
	19	ROBOT TO SPOT WELD AND CLEAR		R07								16
	19	ROBOT TO SPOT WELD AND CLEAR		R08								16
	19	ROBOT TO SPOT WELD AND CLEAR		R09								16
	19	ROBOT TO SPOT WELD AND CLEAR		R10								16
	20	OPEN CLAMPS	CLAMP @ 4616	C12	R		PM1V6S12	C12PX1		31	72	0.6
	20		LOCATOR CLAMP @ 4345	C13	R		PM1V6S12	C13PX1		31	35	0.6
	20		CLAMP @ 1220	C14	R		PM1V6S12	C14PX1		31	72	0.6
	20		CLAMP @ 3955 & 4041	C16	R		PM1V6S12	C16PX1		31	44	0.6
	20		CLAMP @ 940	C17	R		PM1V7S12	C17PX1		31	63	0.6
	20		CLAMP @ 1355	C18	R		PM1V7S12	C18PX1		31	72	0.6
	20		CLAMP @ 2135 & 2194	C19	R		PM1V7S12	C19PX1		31	72	0.6
	20		CLAMP @ 2705 & 2660	C21	R		PM1V7S12	C21PX1		31	44	0.6
	20		CLAMP @ 398	C02	R		PM1V7S12	C02PX1		31	82	0.6
	20		CLAMP @ 5085	C22	R		PM2V1S12	C22PX1		31	63	0.6
	20		CLAMP @ 1098	C23	R		PM2V1S12	C23PX1		31	72	0.6

STEP #20 CONTINUED ON NEXT SHEET

TOTAL OPERATOR TIME (SEC)-

TOTAL MACHINE WORK TIME (SEC)-

TOTAL SYSTEM TIME (SEC)- TOTAL CYCLE TIME(SEC)

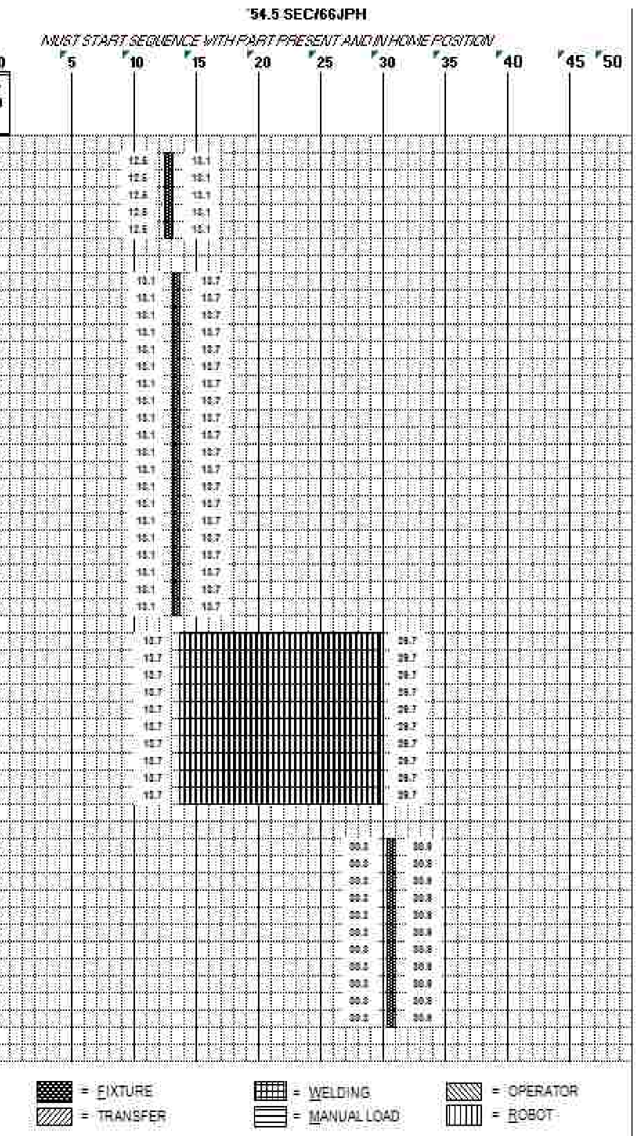


Table 6- 6: Sequence of operation of the Inner Gate work-cell Seq. (3)

MECHANICAL DESIGN SOURCE **RoboTech Canada Consulting Inc.**
CONTROLS DESIGN SOURCE **Al-Zaher Abdo May 2012**

Green = Column's that need to filled IN
Yellow = Should not have to type in but, are permitted to do so

Rev	Func	Q ST	FUNCTION SEQUENCE	DESCRIPTION	DEVICE (CYL	ULT ING	WELD SPOT	OUTPUT TAG/DEVI	TAG/ RESULTIN	SWITCH	E SWITCHES	A cm²	STK. mm	T TIME	TIME	DURA TION
			STEP #20 CONTINUED FRO													
	F	20		CLAMP @ 3185	C26	R		PM2V1S12	C26PX1		0	31	44	30.3	0.6	30.9
	F	20		CLAMP @ 1250	C27	R		PM2V1S12	C27PX1		0	31	53	30.3	0.6	30.9
	F	20		CLAMP @ 3405 & 3434	C29	R		PM2V1S12	C29PX1		0	31	53	30.3	0.6	30.9
	F	20		CLAMP @ 435	C05	R		PM2V2S12	C05PX1		0	31	72	30.3	0.6	30.9
	F	20		CLAMP @ 317	C08	R		PM2V2S12	C08PX1		0	31	72	30.3	0.6	30.9
	F	20		CLAMP @ 710	C31	R		PM2V2S12	C31PX1		0	31	63	30.3	0.6	30.9
	F	20		CLAMP @ 4945	C35	R		PM2V2S12	C35PX1		0	31	24	30.3	0.6	30.9
	F	20		CLAMP @ 275	C36	R		PM2V3S12	C36PX1		0	31	82	30.3	0.6	30.9
	F	20		CLAMP @ 4345	C28	R		PM2V3S12	C28PX1		0	31	44	30.3	0.6	30.9
	F	21.A	OPEN CLAMP BACK-UPS	RETRACTABLE LOCATOR @	C20	R		PM1V4S12	C20PX1		0	31	25	30.9	0.6	31.5
	F	21.A		RETRACTABLE LOCATOR @	C11	R		PM1V4S12	C11PX1		0	31	25	30.9	0.6	31.5
	F	21.B	DISENGAGE LOCATING PIN	RETRACTABLE PIN @ 300	C03	R		PM1V5S12	C03PX1		0	13	23	30.9	0.6	31.5
	F	21.B		RETRACTABLE PIN @ 300	C06	R		PM1V5S12	C06PX1		0	13	23	30.9	0.6	31.5
	F	21.B		RETRACTABLE PIN @ 317	C09	R		PM1V5S12	C09PX1		0	13	25	30.9	0.6	31.5
	F	22.A	RETURN DUMPS	DUMP CYLINDER	C01	R		PM1V1S12	C01PX1		0	81	102	31.5	1.1	32.6
	F	22.A		DUMP CYLINDER	C04	R		PM1V1S12	C04PX1		0	81	102	31.5	1.1	32.6
	F	22.A		DUMP CYLINDER	C07	R		PM1V1S12	C07PX1		0	81	102	31.5	1.1	32.6
	F	22.B	OPEN CLAMP BACK-UPS	LOCATOR CLAMP @ 3955 8	C15	R		PM1V2S12	C15PX1		0	31	24	31.5	0.6	32.1
	F	22.B		LOCATOR CLAMP @ 3185	C25	R		PM1V2S12	C25PX1		0	31	24	31.5	0.6	32.1
	F	22.C	DISENGAGE LOCATING PIN	RETRACTABLE PIN @ 4541	C10	R		PM1V3S12	C10PX1		0	31	48	31.5	0.6	32.1
	F	22.C		RETRACTABLE PIN @ 2232	C24	R		PM1V3S12	C24PX1		0	31	48	31.5	0.6	32.1
	F	22.C		RETRACTABLE PIN @ 3974	C30	R		PM1V3S12	C30PX1		0	31	25	31.5	0.6	32.1
	F	22.C		RETRACTABLE PIN @ 4794	C33	R		PM1V3S12	C33PX1		0	31	25	31.5	0.6	32.1
	F	22.C		RETRACTABLE PIN @ 3253	C34	R		PM1V3S12	C34PX1		0	31	23	31.5	0.6	32.1
	T	23	RETURN GATE LOCK PINS											31.5	1	32.5
	T	24	FRAMER GATE POSITION L											32.6	0.9	33.5
	F	25	OPEN UNDERBODY TOOLIN											33.5	0.6	34.1
	F	26	INDEX OPENGATE											34.1	2.5	36.6
	T	27	RAISE SKID LIFTER											36.6	1.75	38.35
	T	28	MAKE LIFTER UP SWITCH											38.4	0	38.35
	T	29	TRANSFER SKID OUT OF S											38.4	2	40.35
			REPEAT SEQUENCE													

SYSTEM CYCLE TIME **54.5 SEC/66JPH**

= FIXTURE FUNCTION
= TRANSFER
= WELDING
= MANUAL LOAD
= OPERATOR FUNCTION
= ROBOT FUNCTION

BIW METRIC

MECHANICAL DESIGN SOURCE: RoboTech Canada Consulting Inc.
CONTROLS DESIGN SOURCE: Al-Zaher Abdo May 2012

REV LETTER	Q STEP	FUNCTION SEQUENCE	DESCRIPTION	ACTUATOR	SULTING	WELD SPOT #	OUTPUT TAG/ DEVICE	INPUT TAG/ RESULTING SENSOR	INTERFERENCE SWITCHES	AREA cm^2	STK. mm	DURATION
		STEP #20 CONTINUED FROM PREVIOUS SHEET										
	20		CLAMP @ 3185	C26	R		PM2V1S12	C26PX1		31	44	0.6
	20		CLAMP @ 1250	C27	R		PM2V1S12	C27PX1		31	53	0.6
	20		CLAMP @ 3405 & 3434	C29	R		PM2V1S12	C29PX1		31	53	0.6
	20		CLAMP @ 435	C05	R		PM2V2S12	C05PX1		31	72	0.6
	20		CLAMP @ 317	C08	R		PM2V2S12	C08PX1		31	72	0.6
	20		CLAMP @ 710	C31	R		PM2V2S12	C31PX1		31	63	0.6
002	~~20~~		~~CLAMP @ 680~~	~~C32~~	~~R~~		~~PM2V2S12~~	~~C32PX1~~		~~34~~	~~82~~	~~0.6~~
	20		CLAMP @ 4945	C35	R		PM2V2S12	C35PX1		31	24	0.6
	20		CLAMP @ 275	C36	R		PM2V3S12	C36PX1		31	82	0.6
	20		CLAMP @ 4345	C28	R		PM2V3S12	C28PX1		31	44	0.6
	21.A	OPEN CLAMP BACK-UPS	ETRACTABLE LOCATOR @ 2	C20	R		PM1V4S12	C20PX1		31	25	0.6
	21.A		RETRACTABLE LOCATOR @ 49	C11	R		PM1V4S12	C11PX1		31	25	0.6
	21.B	DISENGAGE LOCATING PINS	RETRACTABLE PIN @ 300	C03	R		PM1V5S12	C03PX1		13	23	0.6
	21.B		RETRACTABLE PIN @ 300	C06	R		PM1V5S12	C06PX1		13	23	0.6
	21.B		RETRACTABLE PIN @ 317	C09	R		PM1V5S12	C09PX1		13	25	0.6
	22.A	RETURN DUMPS	DUMP CYLINDER	C01	R		PM1V1S12	C01PX1		81	102	1.1
	22.A		DUMP CYLINDER	C04	R		PM1V1S12	C04PX1		81	102	1.1
	22.A		DUMP CYLINDER	C07	R		PM1V1S12	C07PX1		81	102	1.1
	22.B	OPEN CLAMP BACK-UPS	ICATOR CLAMP @ 3955 & 40	C15	R		PM1V2S12	C15PX1		31	24	0.6
	22.B		LOCATOR CLAMP @ 3185	C25	R		PM1V2S12	C25PX1		31	24	0.6
	22.C	DISENGAGE LOCATING PINS	RETRACTABLE PIN @ 4541	C10	R		PM1V3S12	C10PX1		31	48	0.6
	22.C		RETRACTABLE PIN @ 2232	C24	R		PM1V3S12	C24PX1		31	48	0.6
	22.C		RETRACTABLE PIN @ 3974	C30	R		PM1V3S12	C30PX1		31	25	0.6
	22.C		RETRACTABLE PIN @ 4794	C33	R		PM1V3S12	C33PX1		31	25	0.6
	22.C		RETRACTABLE PIN @ 3253	C34	R		PM1V3S12	C34PX1		31	23	0.6
	23	RETURN GATE LOCK PINS										1
	24	FRAMER GATE POSITION LOCKS OPEN										0.9
	25	OPEN UNDERBODY TOOLING CLAMPS										0.6
	26	INDEX OPENGATE										2.5
	27	RAISE SKID LIFTER										1.75
	28	MAKE LIFTER UP SWITCH										0
	29	TRANSFER SKID OUT OF STATION										2
		REPEAT SEQUENCE										

TAL OPERATOR TIME (SEC)-
MACHINE WORK TIME (SEC)-
TOTAL SYSTEM TIME (SEC)- TOTAL CYCLE TIME(SEC)

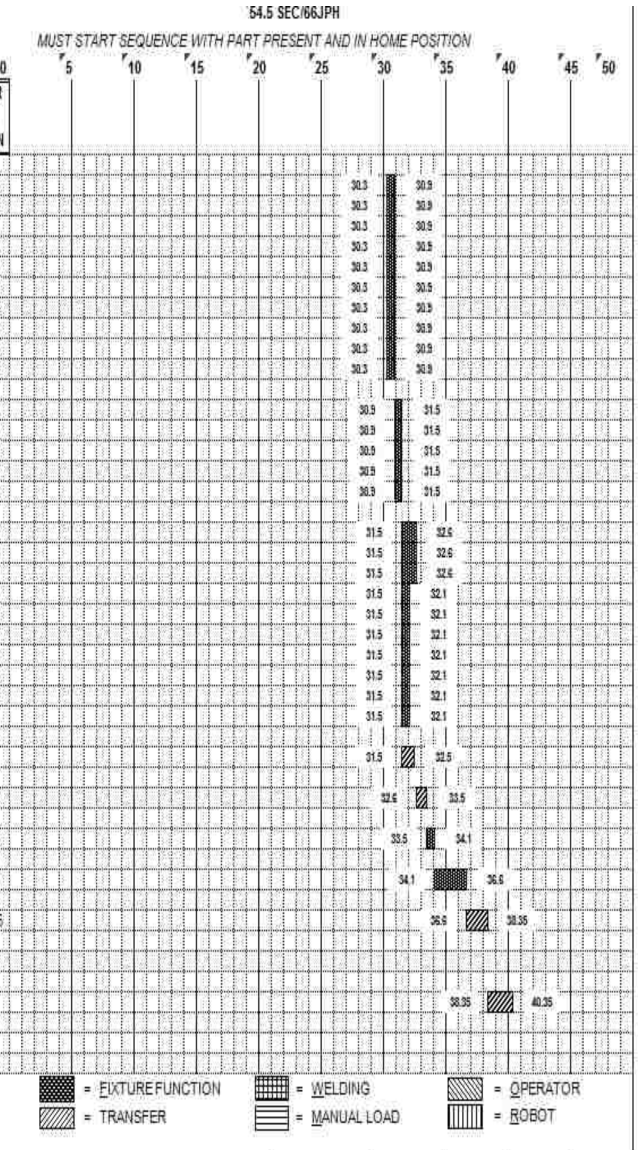


Table 6- 7: Graph of the sequence of operation Inner Gate work-cell Seq. (3)

6.4.3: Building Model (Simulation Model)

Model developments of digital manufacturing (DM) and production simulation may take a long time to gather all the parameters and variables that are needed; in order to build the final model, the following data is required:

- Product decomposition; devices with proper addition of parts at each stations,
- Define operation and processes according to defined layout,
- Building complete and functional work-cell; write all needed GSL,
- Establish communication (D I/O in the GSL programming) between devices through cell controller,
- Then run set-up and define output needed (processing level or final design),
- Create visual documentation to help in speeding the integration process and run production.

Once the model is developed for the automotive system, the accuracy of the simulation model should be 95-98 percent as a standard to be used for production data. Many engineers can use the model to test the behavior of the production systems and/or to evaluate various strategies in case of product developments. With the DM and production, simulation model engineers and systems engineers can make a quick and reliable decision.

Input/output of the model (systems analysis processing or final deliverables) were shown in Fig. 6-3;

- Model inputs: Product upgrades (adding new style), this includes new design geometry, weld spots file, and also might be required for the weld equipments.
- Model outputs: Production date as verifying tooling design cycle time for equipments and robots, placements of tooling, OLP, and bottleneck time analysis of Gate line (discussed in Chapter 5.5).

A final simulation model was developed for the state of practice of vehicle framing systems, GSL simulation for Gate work-cell. As requirements to run the simulation models Delmia and IGRIP, proper licenses are needed, either to use archived work-cell then put the work-cell in order to create the project library. New projects with updated parts need to create new projects to run set-up with different programs of new styles using the same model.

6.5: Case Studies Using the RMS Designs Methodology

The below case study is based on an actual production data of three styles for the same vehicle; the case study used two styles; same under-bodies for S1 and S2, the third style S3 very similar under-Body. The three work-cells are capable of running the production with changing gate using storage systems. The current systems' issues were discussed in Chapter 3-3. The proposed RMS with Open Gate (ROGS) is to be used (as proposed in Chapter 5) to run multiple styles with one gate without needing to changeover (eliminate down time 2 H/per changeover), as shown in Fig. 6-11.

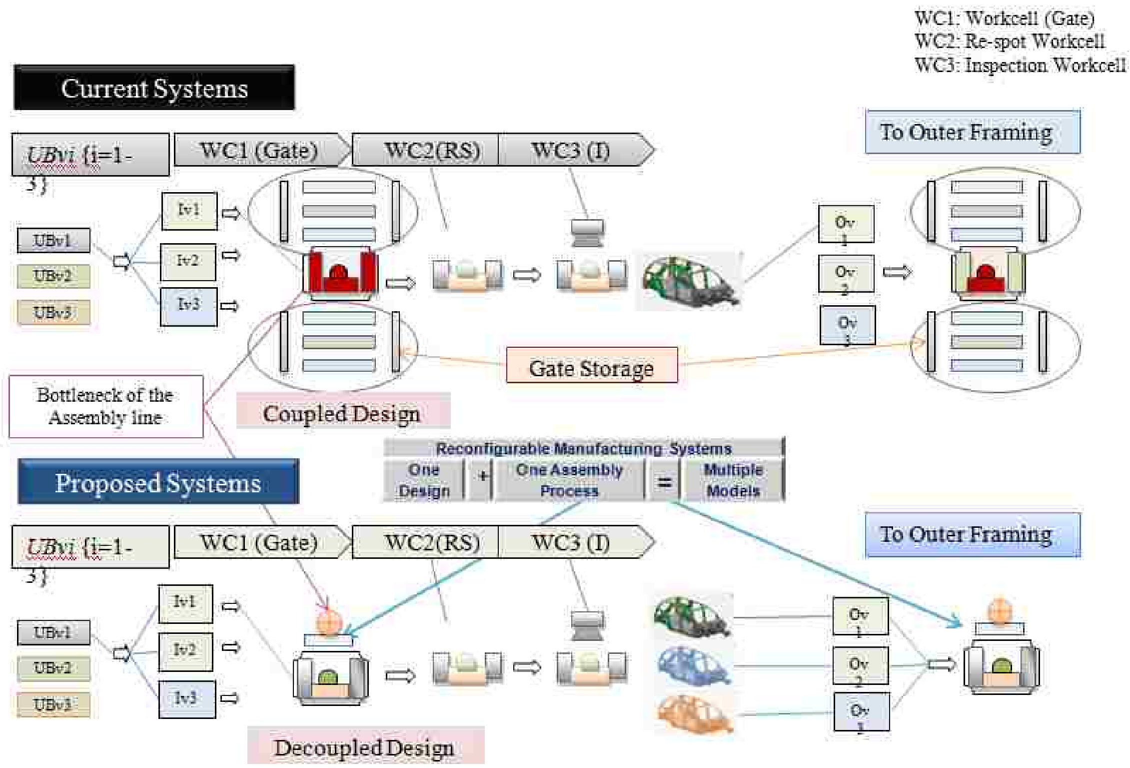


Fig. 6- 11: RMS with OGS- (proposed systems) comparison with current systems.

The motivation behind this is that high cost in a platform leads to the increase of a variety of product family platforms to justify the capital investment in production equipments. The frequency of car body styling is shown in Fig. 6-12. Body styling above the beltline every year needs a major change/update every five years. Usually, equipment and tooling life cycle (with the exception of control updates) can run up to 20 years as shown in Fig. 6-12. The most important is the use of DM production simulation with direct connections to the modeling processes for all disciplines.

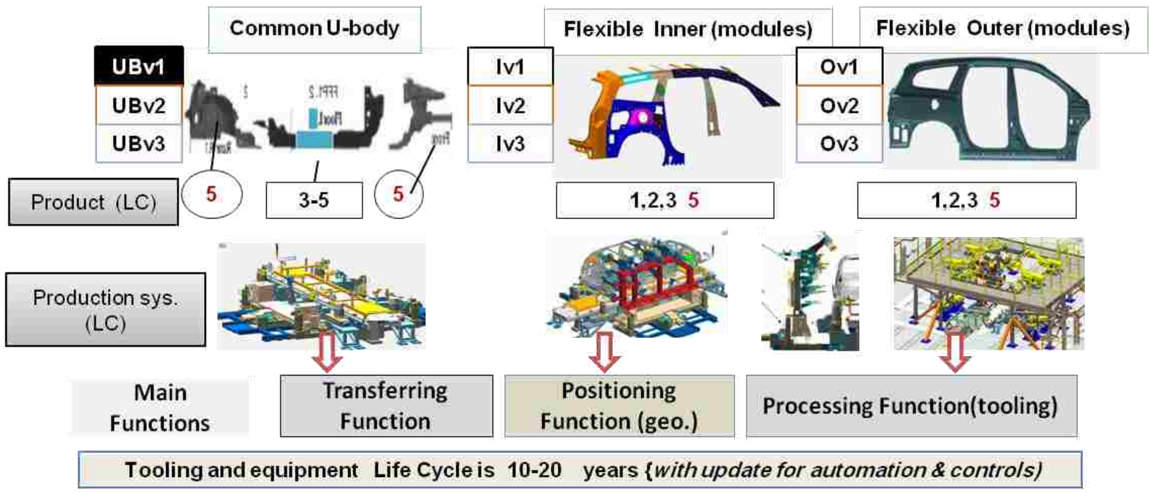


Fig. 6- 12: Frequency of car body styling and LC of manufacturing systems

6.5.1: Data Collection of the Case Studies

a) Product data:

Product dates of the three case studies are real production data of three SUV styles running in the same assembly lines in North America. A Modularity Variation Matrix of the car body structures was developed by the author for the 3 case studies (see Fig. 6-13).

- ***Case Study 1***: is the 1st style (P1-S1)
  - Changes in C-Pillar + D-R1 only

- ***Case Study 2***: is the 2nd style (P1-S2)
  - Changes in B-Pillar, C-Pillar and D1-R1

- ***Case Study 3***: is the 3rd style (P1-S3)
  - Changes in A-B-C Pillar, and RK panel (new advanced material)

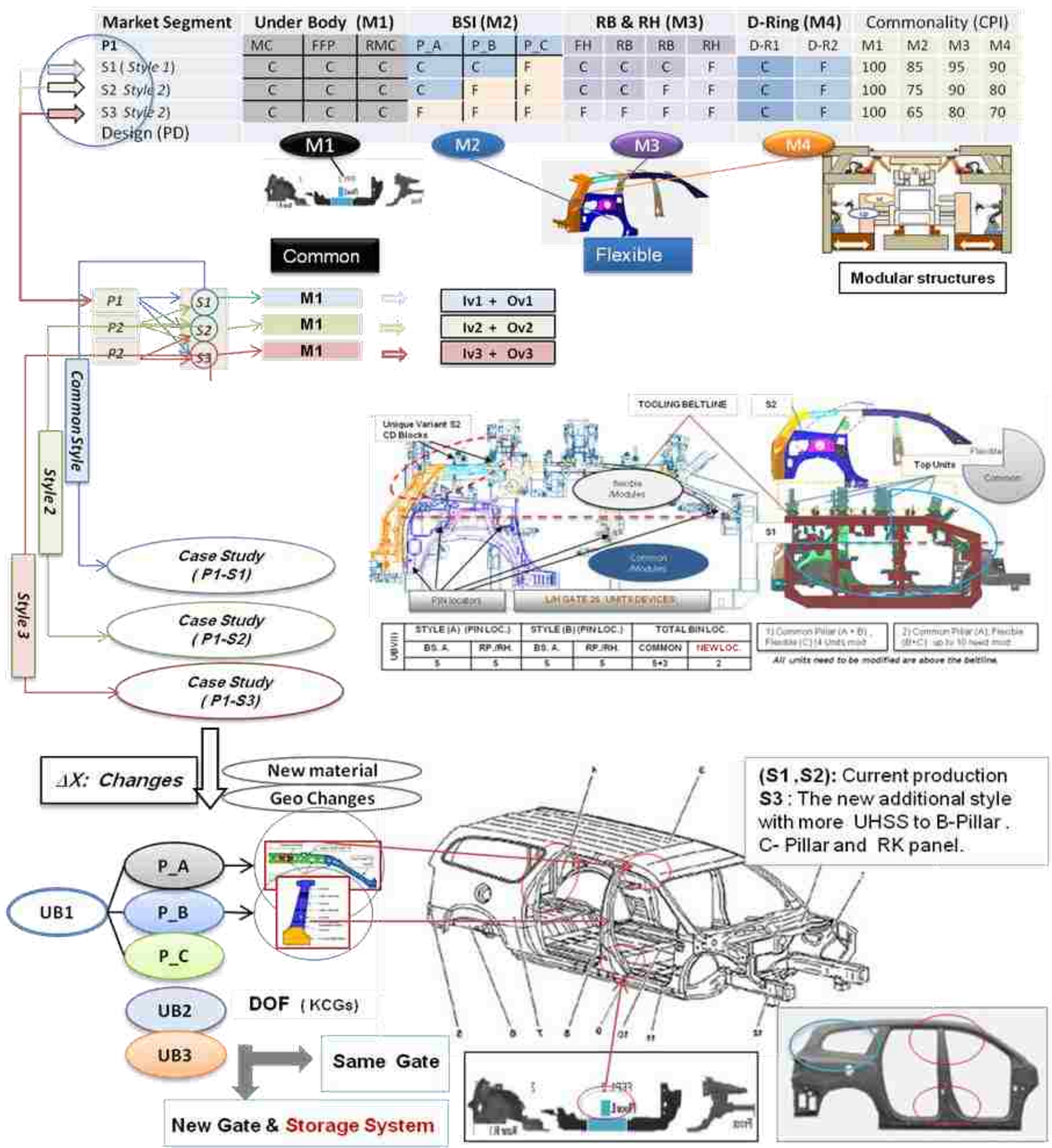


Fig. 6- 13: Modularity Variation Matrix of car body styles (3 case studies)

b) Production systems:

Analysis for the final data of the production systems designed for the three styles were summarized in Fig. 6-14; data sources are *Delmia* simulation archived work-cells. All three styles were produced in the same assembly line with three work-cells;

- WC.1: is the inner Gate geometry work-cell: using 12 robots (6 robot on the LH and 6 robots on the RH), all robots with using servo Trans-gun for all styles. Production run in batch mode, changeover gates most of the time done between shifts.
- WC 2: is the re-spots work-cell using 8 robots, with 4 robots on each side running three styles using the same weld guns.
- WC 3: is the vision work-cell using the latest technology, usually adding new styles, require adding an extra camera which corresponds to geometry changes.

First work-cell, WC1, is the bottleneck for the three styles with line-rate as follows:

- Style (S1- common style): running at 54.0 sec.
- Style (S2): running at 56.0 sec.
- Style (S3): running at 55.0 sec.

What is important here is to establish a relationship between the sources of increasing the cycle time and tasks related, whether in positioning function or joining function. *The focus is on the first work-cells only.*

Market Segment	WC1								WC 2		WC 3		Workcell CT		
	Inner Gate Systems								Re-Spot		Vision				
P1 Segment 1	Tools	WG	R1-2	R3-4	R-,6	R7-8	R9,10	R11,12	T	R	H	S	WC1	WC2	WC3
S1(Style 1) Common	DG1	6 WG	x	x	x	x	x	x	x	x		x	54	50	45
S2 Style 2)	DG2	6WG	x	x	x	x	x	x	x	x		x	56	52	45
S3 Style 2)	DG3	6WG	x	x	x	x	x	x	x	x		x	55	51	45
Legend	DG: Dedicated Gate, T: tool, R: Robot, H: hard changes, S: soft Changes														

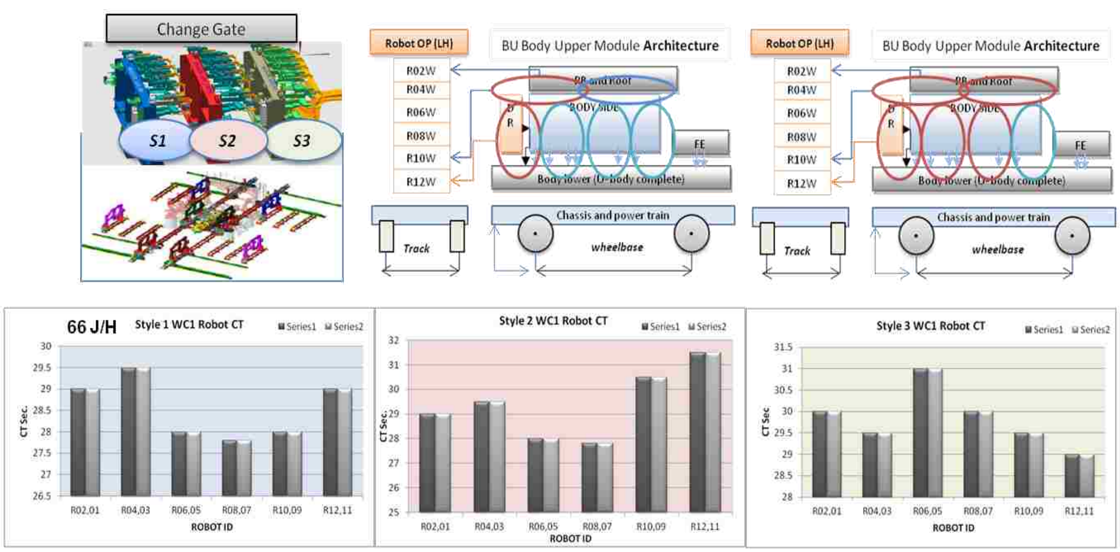


Fig. 6- 14: Data analysis of production systems for the case studies

The next section focuses on the production systems to develop systematic methods in order to help system designers to pinpoint key elements of product, which requires embedded flexibility in the production systems to accomplish the design objective;

- Run multiple styles with same tooling gate (bottleneck of the systems),
- Redesign the gate with modular structures to achieve reconfigurability in Open Gate Systems,
- Redesign for the upper dumping devices (two feet extension to reach and secure roof headers and RBs); the current system's design of these devices is coupled, dynamic interaction caused quality issues and unexpected breakdown.

It has been established that time increases occur in seq2 (see Fig. 6-10), seq1 and seq3 are almost fixed (more details will follow).

6.5.2: Application of the RMS Design Methodology

Three case studies parallel process using RMS design method
Case Studies: (1), (2) and (3):
Concurrent processing to all steps using the new methods as follows:

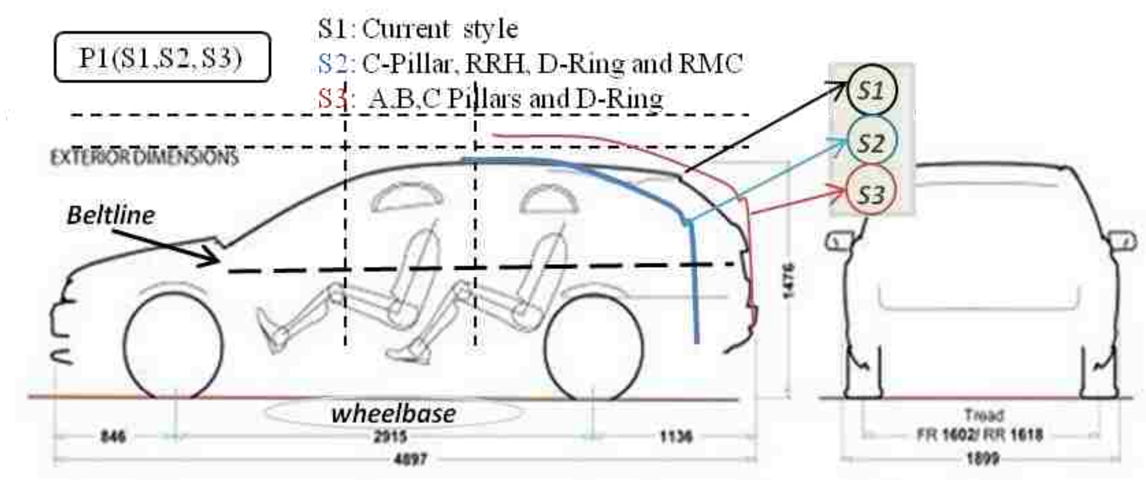


Fig. 6- 15: Case studies body styling (3 styles) (Adapted from Automobilesreview.com)

I) The first stage is the evaluation (impact) of engineering changes (ΔX) on the manufacturing and production systems.

a) Designers need to identify critical components and candidates to embedded flexibility. By using NWG, it shows how changes propagate through the entire body structures. Engineering changes are usually presented to the systems designer as a complete processing kit which includes geometry changes with initial weld spots locations. Most modular components are pre-design with different varieties. Product changes for all styles, as an input to evaluate the physical interaction between modules are shown in Table 6-5.

Table 6- 8: Modular /sub-modular upgrading for 3 styles (case studies)

Product Modular	Case (1) Style 1	Case (2) Style 2	Case (3) Style 3
Under-body M1	c	c	c
A-Pillar	c	c	c
B-Pillar	c	x	x
C-Pillar	x	x	x
D-Ring 1	x	x	x
D-Ring 2	c	c	c
Legend	c: common for all styles	x: geometry changes	

b) Manufacturing and production systems (current production line);

Manufacturing and production engineers need to clearly identify the interaction at the components level and modules level in order to evaluate changes in the manufacturing (part stamping) and modules assembly prior to framing systems.

c) Decoupling for all manufacturing processes and assemblies due to changes at the components level and module level;

Each styling case is presented in one Network Graph representation for the car body structures BIW, as shown in Fig. 6-17, Fig. 6-18, Fig. 6-19, which are used to help visualize the changes propagation throughout the systems. Once the evaluation is completed, CPI can be calculated (as shown in Fig. 6-20) to measure the physical interaction between modules assembly; for more details on CPM evaluation, see Chapter 4-4 The outpour of this stage is the identification of key elements or components that are more candidate o have flexibility.

d) Reconfigurability assessments of the current assembly line have been established through all case studies. The current gate structures are a couple and complex interaction for the upper devices, therefore new modular structures were proposed as shown in Fig. 6-21.

To summarize stage one, the method is as follows:
Critical components were evaluated by using NWG and DSM; all three cases indicated that BSI components (M2) such as A, B, C, D Pillars, each sub-modules consists of more than one key elements (physical connection) interact with lower modules (M2) and with upper modules (M4).

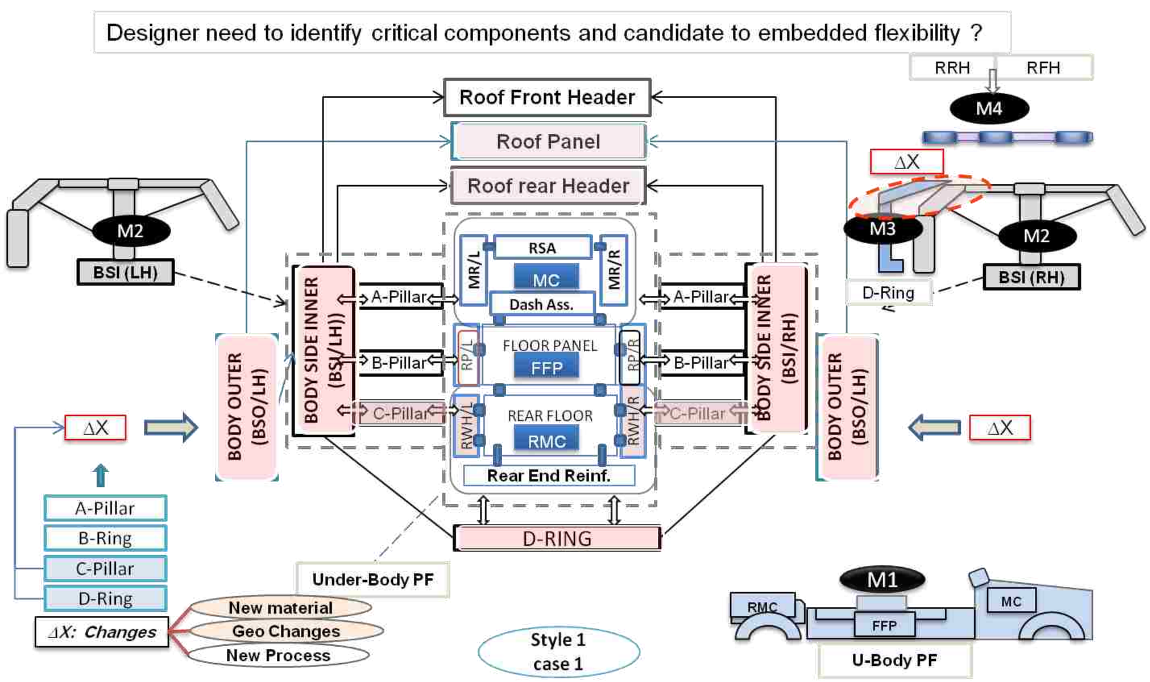


Fig. 6- 16: Case 1, Network representation of car body structures BIW

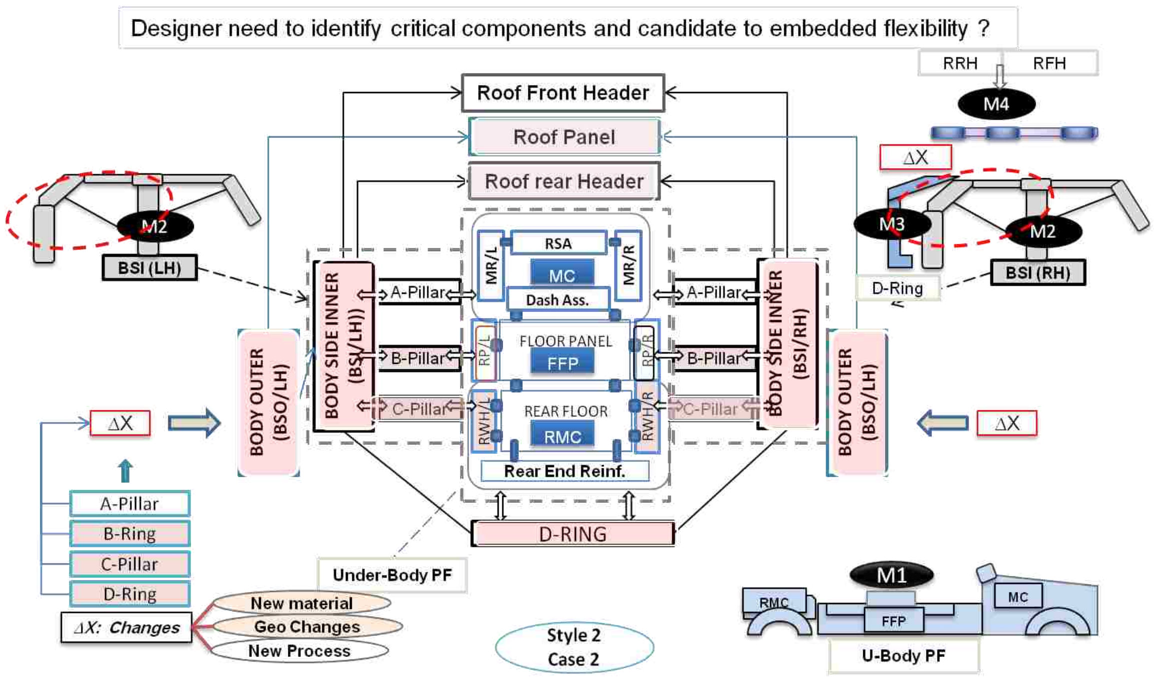


Fig. 6- 17: Case 2, Network representation *of car body structures BIW*

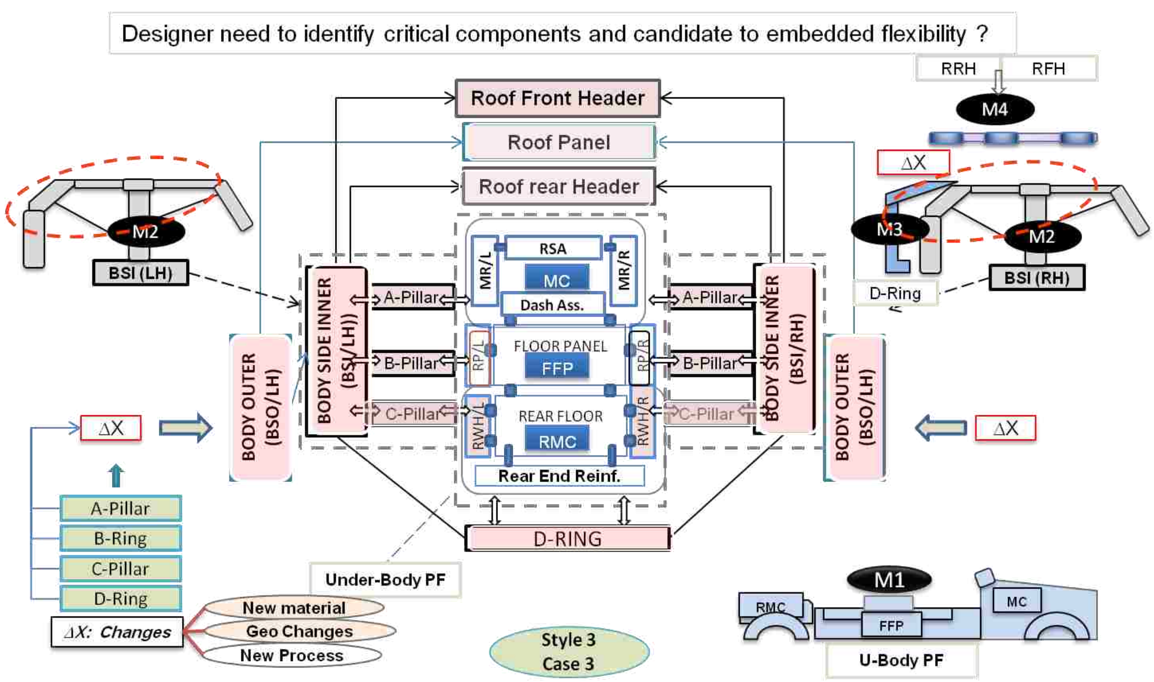
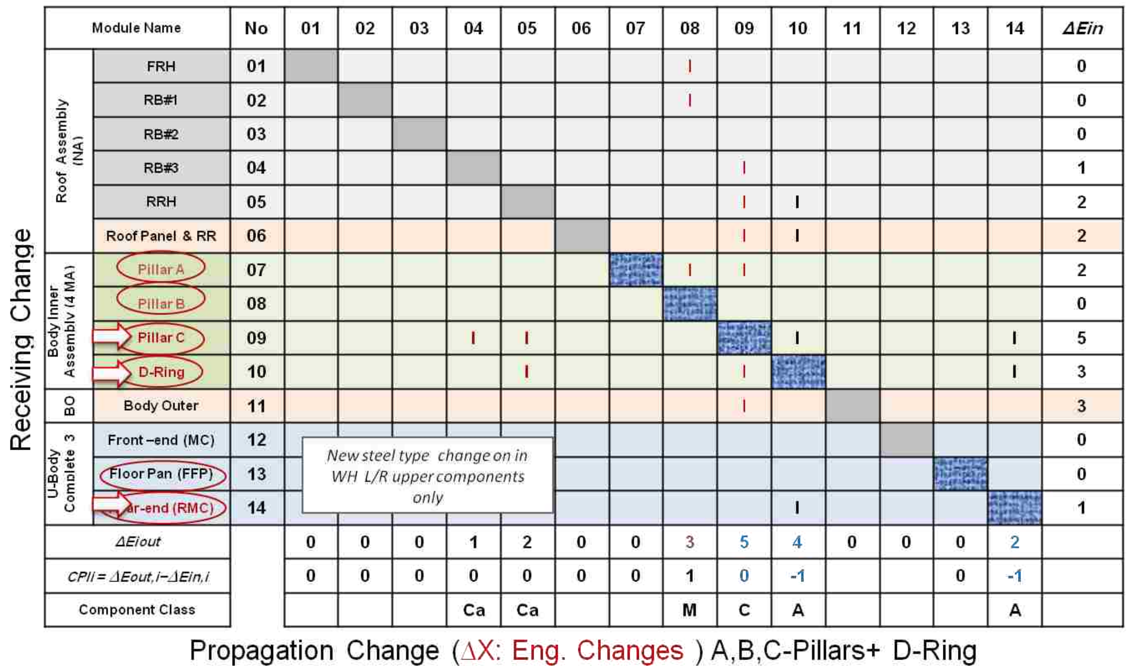


Fig. 6- 18: Case 3, Network representation *of car body structures BIW*



Group	Module Name	No	01	02	03	04	05	06	07	08	09	10	11	12	13	14	ΔEin
Roof Assembly (NA)	FRH	01								I							0
	RB#1	02								I							0
	RB#2	03															0
	RB#3	04									I						1
	RRH	05									I	I					2
	Roof Panel & RR	06									I	I					2
Body Inner Assembly (4 MA)	Pillar A	07								I	I						2
	Pillar B	08															0
	Pillar C	09				I	I					I				I	5
	D-Ring	10					I				I					I	3
BO	Body Outer	11									I						3
U-Body Complete 3	Front-end (MC)	12															0
	Floor Pan (FFP)	13															0
	ar-end (RMC)	14										I					1
	ΔEiout		0	0	0	1	2	0	0	3	5	4	0	0	0	2	
	CPII = ΔEout,i−ΔEin,i		0	0	0	0	0	0	0	1	0	-1			0	-1	
	Component Class					Ca	Ca			M	C	A				A	

Fig. 6- 19: Developing DSM for BIW Vehicle Styling

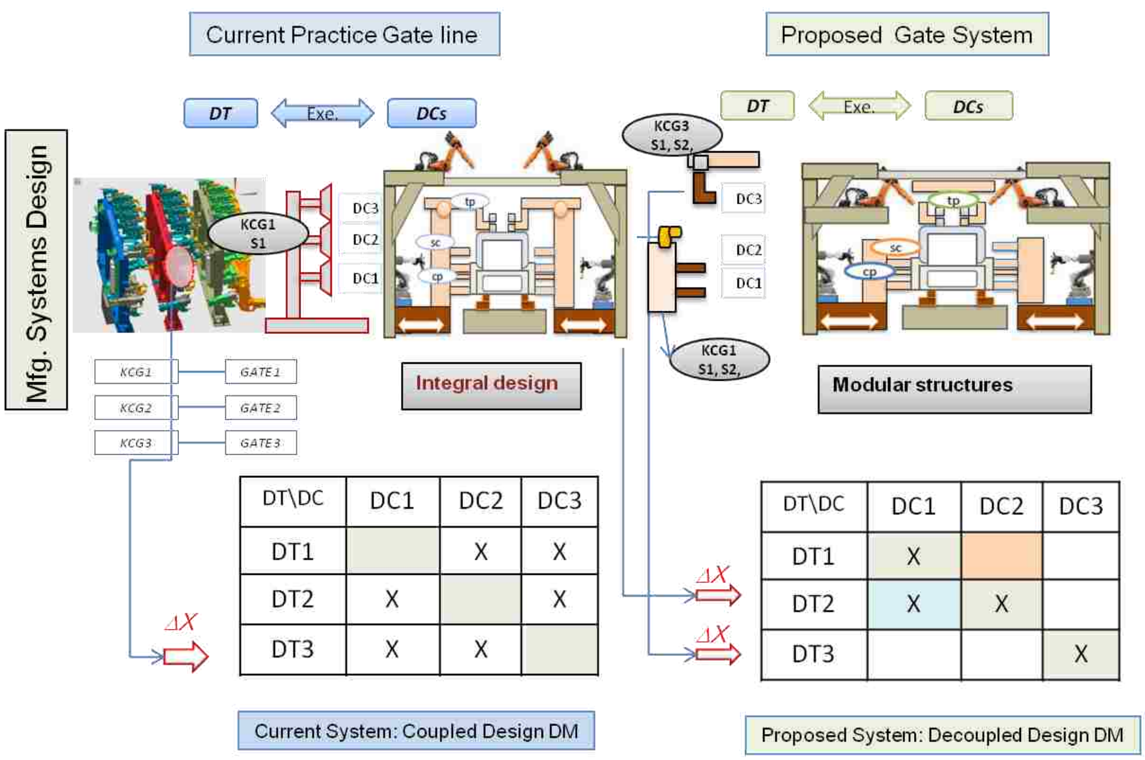


Fig. 6- 20: Proposed modular structure OGS for all case studies

II) The second stage is the system design.

It starts with a concept design with virtual evaluation and makes changes to achieve design objective. Manufacturing systems engineers and product developers are required to have a common understanding of how new structures of the proposed systems work by building data and an information model which can be presented by CPM, DSM and HDSM. The change originates from the new elements of new styles S1, S2 or S3, and propagates throughout the BIW. Data and information of CPM can be used as an input to construct the evaluation chart, see Fig. 6-21.
The data and information that are presented in the evaluation chart summarize the processing design of current manufacturing systems prior to detailed design to estimate cost of the new styling.

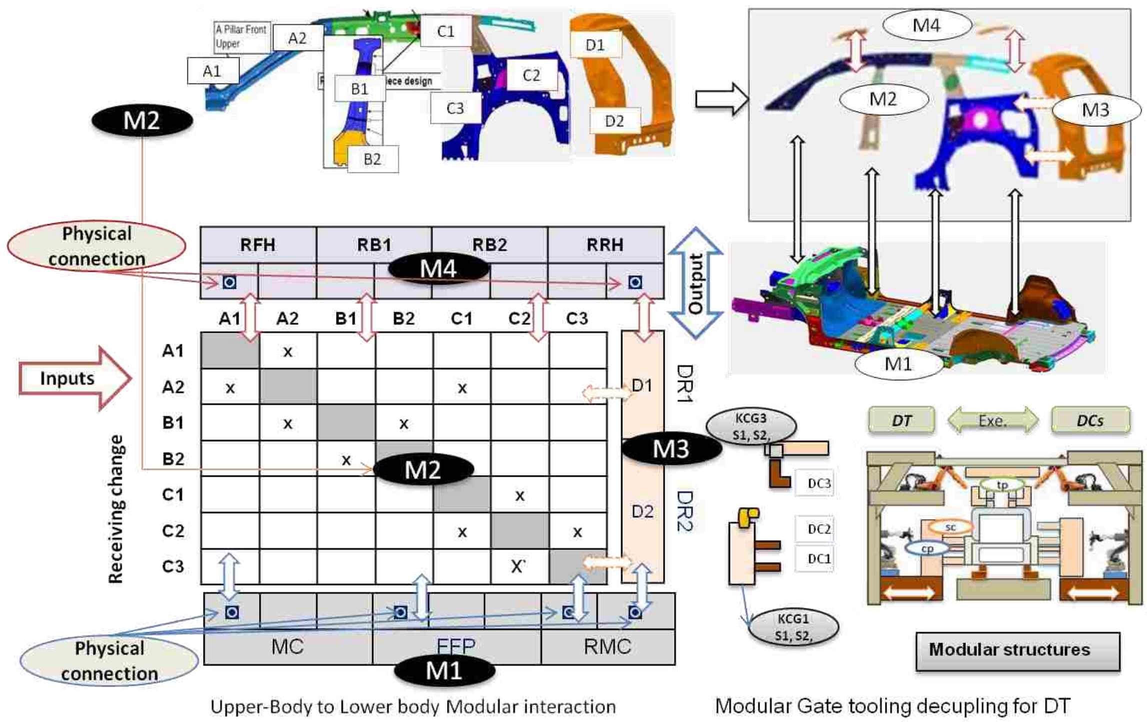
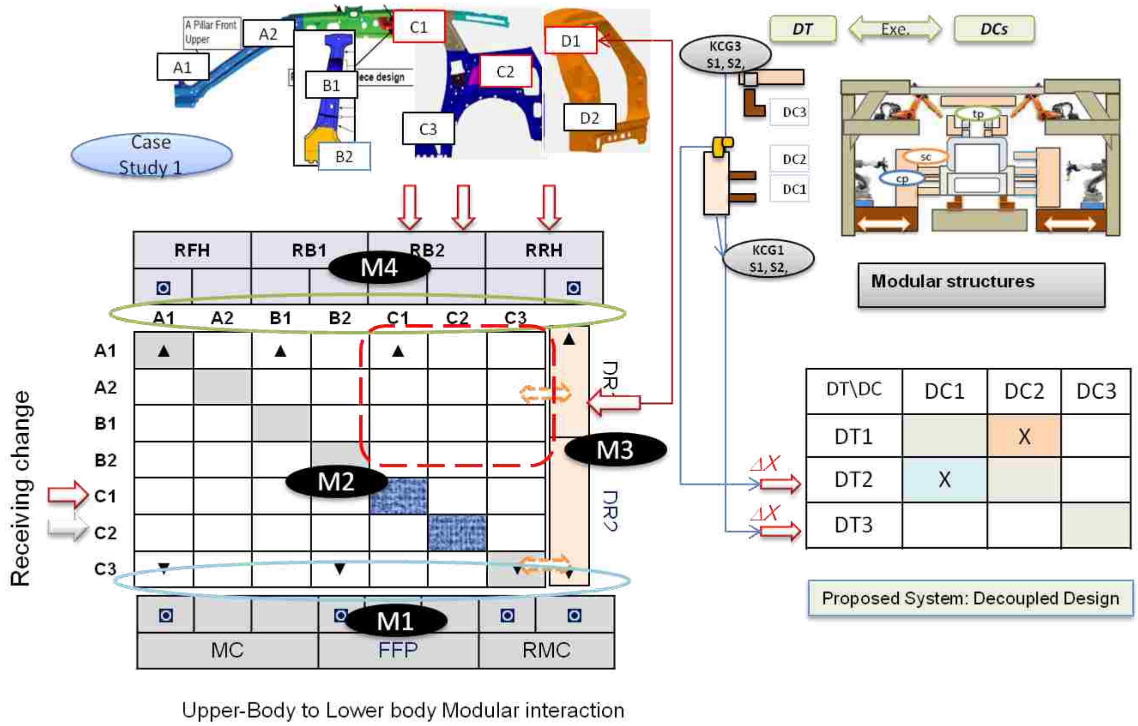


Fig. 6- 21: HDSM; key elements physical interaction for all modules

New systems configuration HDSM for mapping of product function to design configuration is as shown in Fig. 6-23 (two stages). The structure of HDSM is a high level representation of modules interaction upper-body (M2, M3 and M4) with lower-body (M1); stage. The second stage is the evaluation for the positioning units (tooling) & joining processes (Robot Programs) of gate tooling were shown as follows:

- The three cases are shown in the following figures



DT\DC	DC1	DC2	DC3
DT1		X	
DT2	X		
DT3			

Fig. 6- 22: Case 1, HDSM; key elements physical interaction for all modules

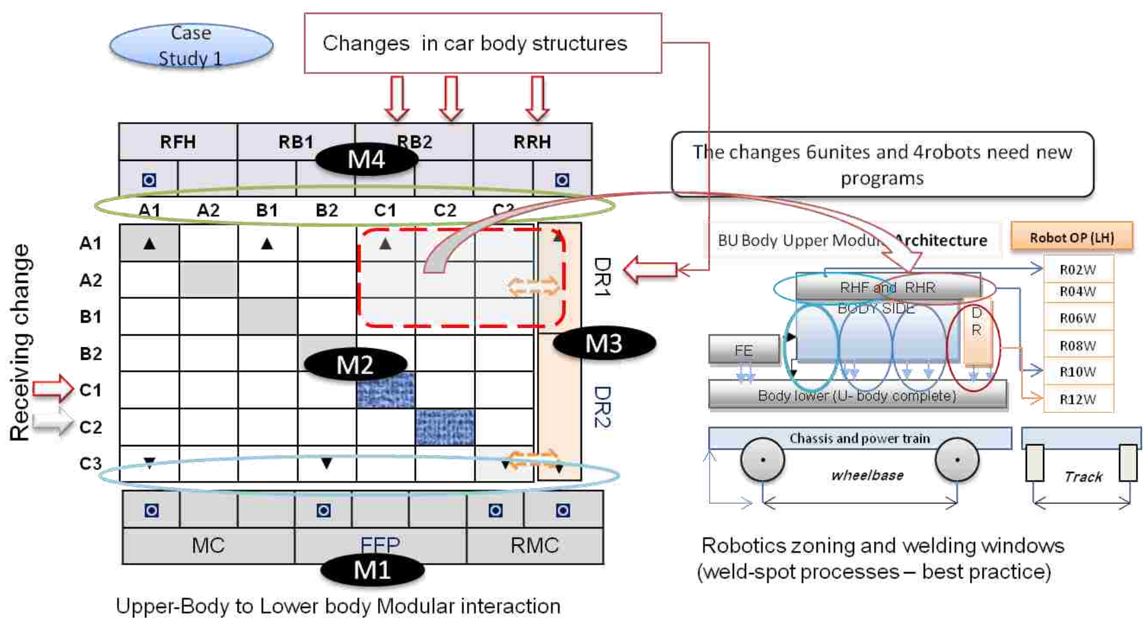


Fig. 6- 23: Case 1, HDSM; evaluation of changes in positioning units & robot programs

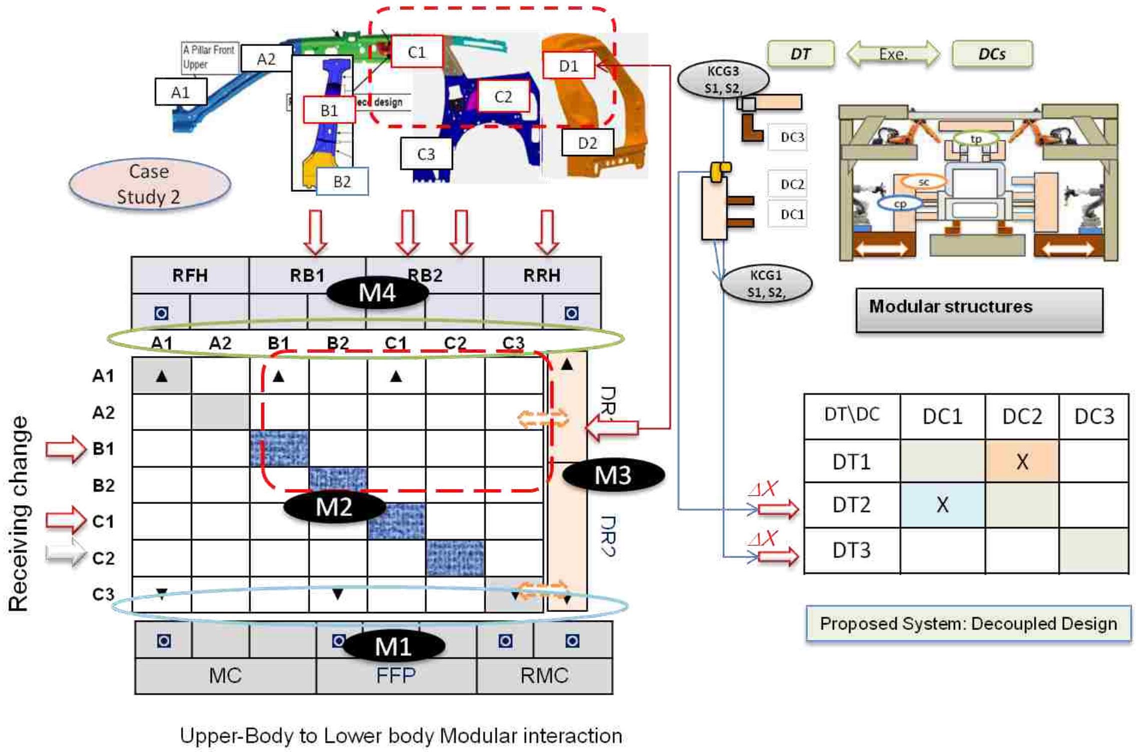


Fig. 6- 24: Case 2, HDSM; key elements physical interaction for all modules

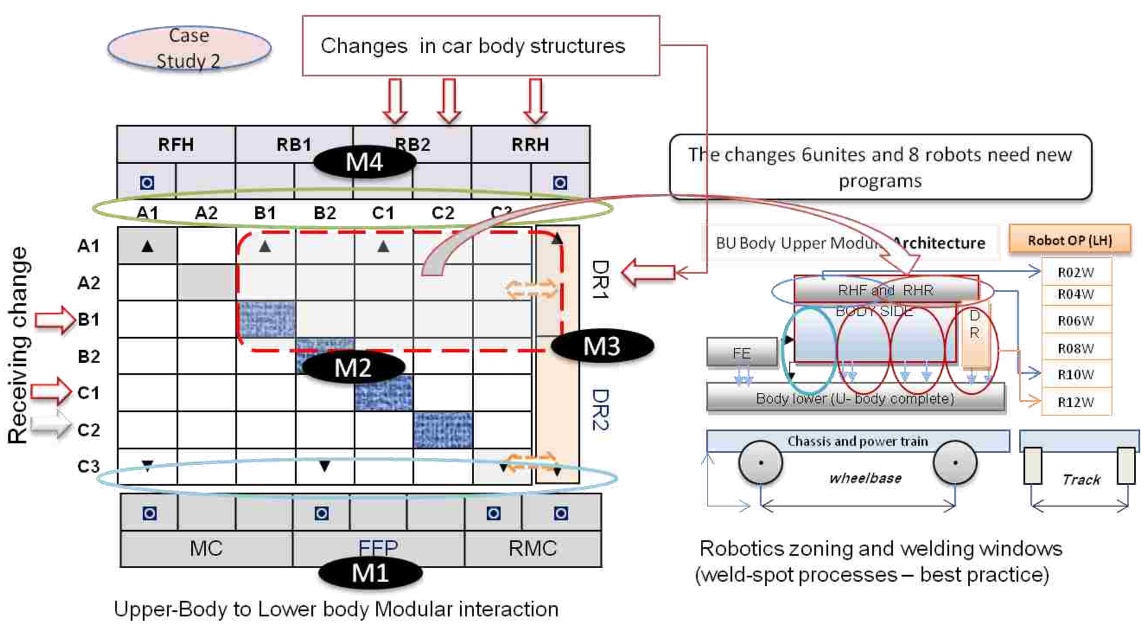


Fig. 6- 25: Case 2, HDSM; evaluation of changes in positioning units & robot

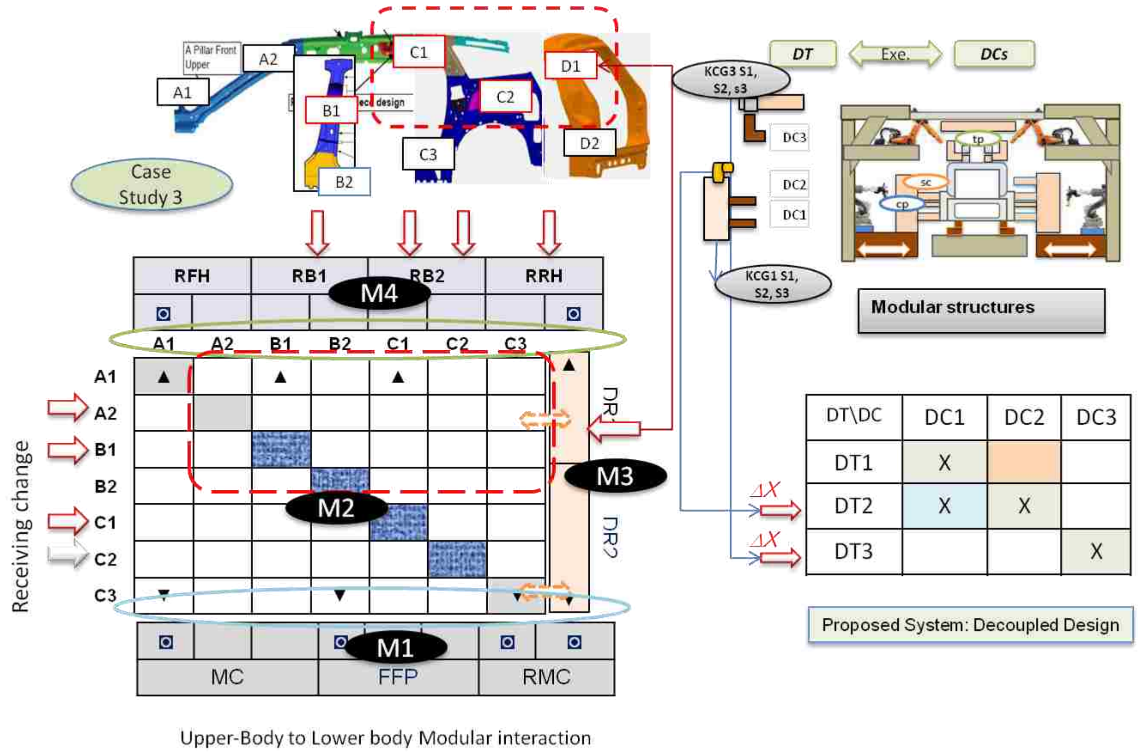


Fig. 6- 26: Case 3, HDSM; key elements physical interaction for all modules

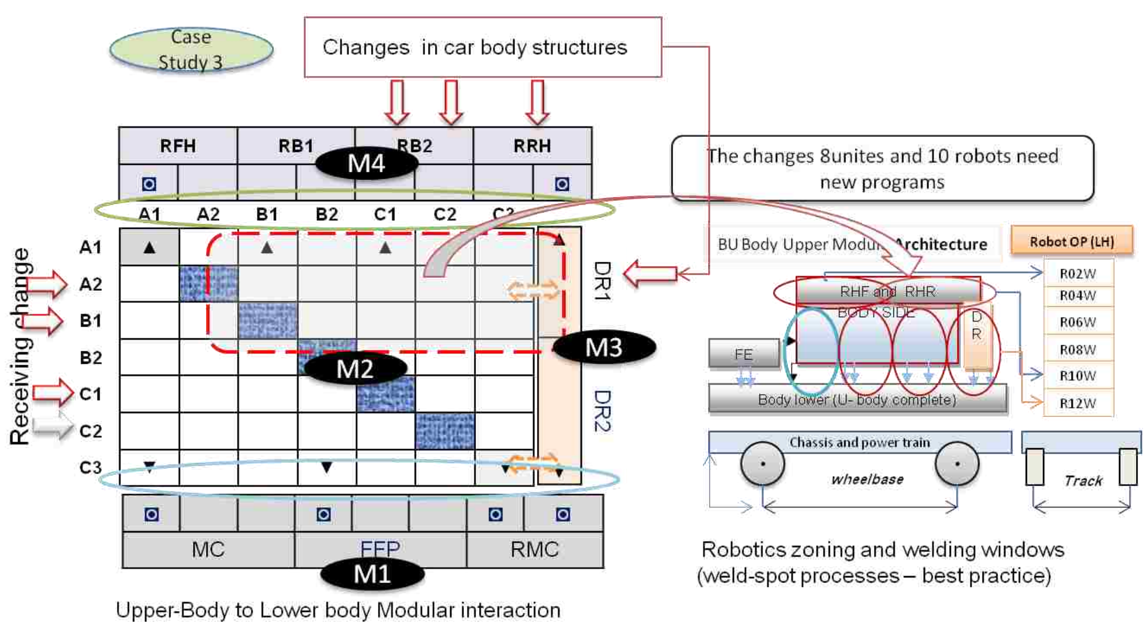


Fig. 6- 27: Case 3, HDSM; evaluation of changes in positioning units & robot

III) The third stage is the manufacturing processes.

The output of this stage is the production data including tooling functionality, sequencing of operation, systems layout, cycle time for stations and robotics. Programming and automation to run virtual simulation of the production was done. Simulation outputs are used and can refine the design prior to building.

6.5.3: Connecting Simulation Model with Design Process

The challenge is to identify and manage engineering changes;

- Manage simulations in an environment where changes can be automatically propagated to all simulations, Fig.6-28, shows both status when simulation connected to the process and when it is not.

Enhancements

- Reduced time to update simulations and report on impact of change (80%),
- Increased awareness of the proposed change before a change is even made,
- Can see how many stations will be effected by a pending change,
- Reduce possible errors prior to construction or integration.

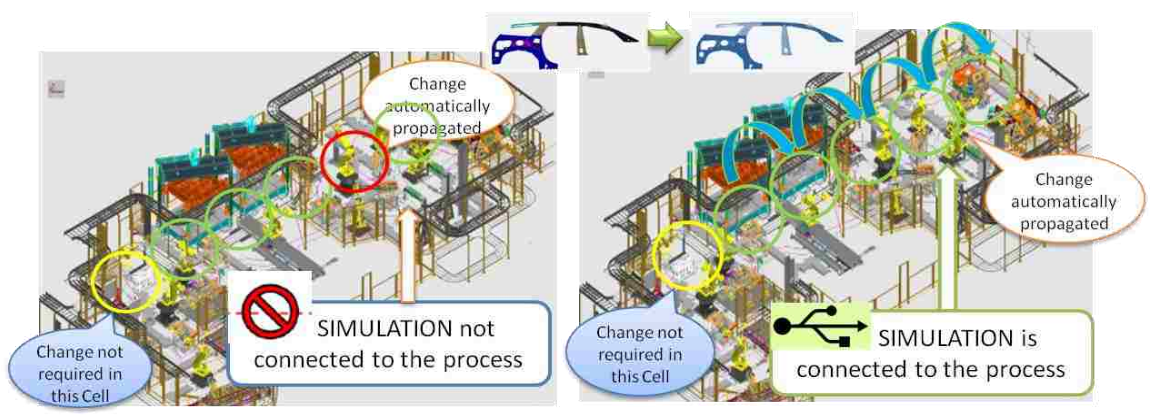


Fig. 6-28: Connecting simulations to the process model

Fig.6-29 shows the simulation work flow, starting from receiving engineering concept, then evaluation for the impact on manufacturing and assembly of components prior to checking the impact on final assembly is shown. More data of one of the case studies starting from receiving the engineering kit going through the steps 1 to 8 can be included in the appendix.

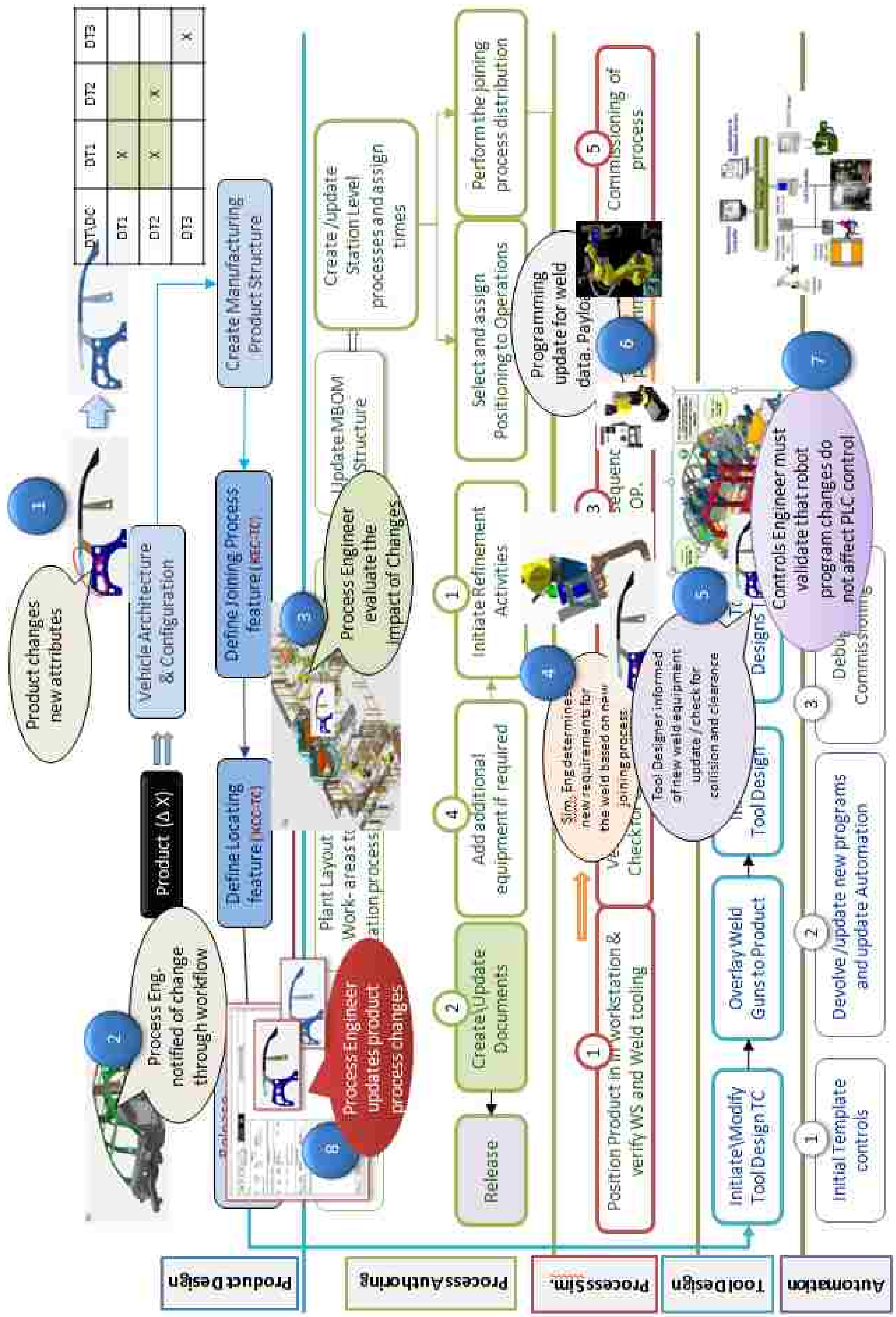


Fig. 6- 29: Evaluation of engineering changes using simulation with TC supports

6.6: Cost of final assembly and HPV.

6.6.1: Cost of Manufacturing and Assembly

The most effective cost saving on HPV is the throughputs, which includes both assembly levels: (Level 1: this assembly referred to components, sub modules and modular assemblies, most of the level 1, assemblies were assembled and tested by suppliers,

and Level 2: this assembly referred to the final modular assembly (Inner / Outer Framing systems).

There are several components contributing to the cost of each unit (final assembled unit), as shown in Fig. 6- 32:

- Structural cost: one time only, and is a very small effect.
- Indirect cost such as overhead cost.
- Direct cost, such as assembly of modules and final assembly cycle time.
- Cost of lost production not mentioned or included; this cost has a very significant effect on HPV, especially in the final assembly.

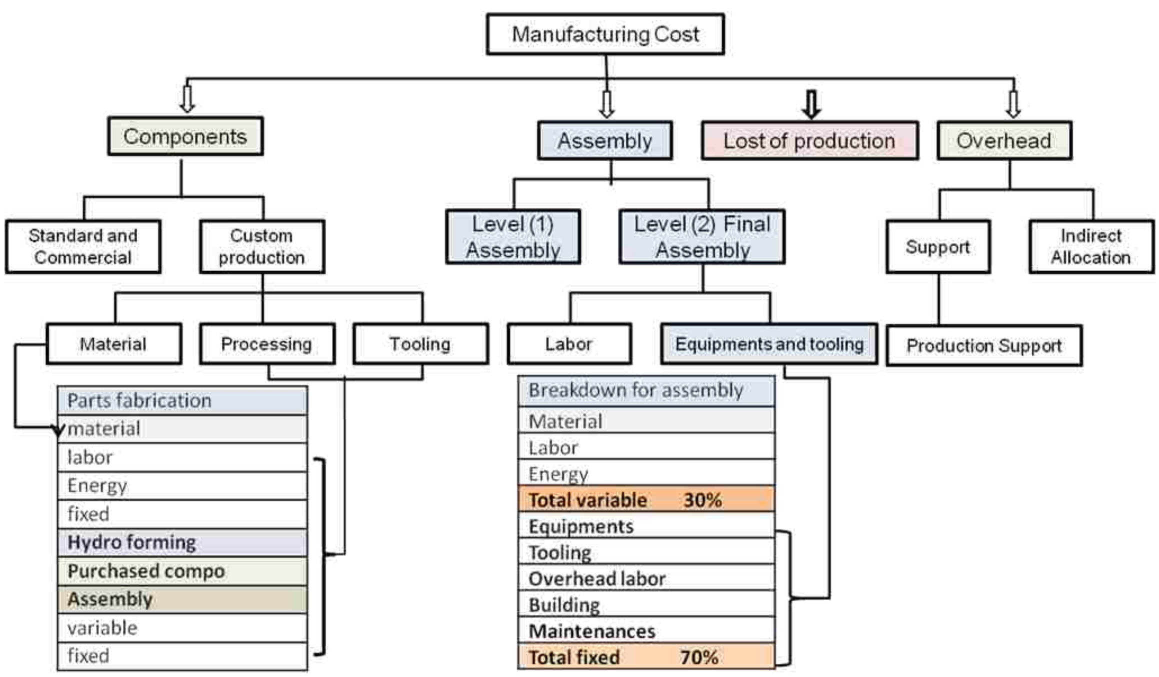
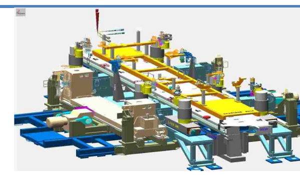


Fig. 6- 30: Elements of the Manufacturing Cost of automotive Product

The following is the structural cost, including installation debugging and dressing, of framing systems for inner framing (SUV's)

Tooling Assembly	Total Cost Ready for Production	Images of Final Assembly
Work cell Inner framing	7 Million USD, This price in North America Automotive Market	
Commercial equipments Customs weld guns (EOAT)	1. 5 Million for 12 robots ready The price for each robot as follow is 30.000 USD Servo Gun with wild controller up 75.000 USD	
Commercial equipments with coast tooling	0, 5. Million USD Underbody tooling with six C-flex programmed	
Custom tooling Standard comp. & Customs comp	1 Million USD for each Gate Inner Gate Tooling	
Custom Platform	1 Million USD Platform, fencing cable try including electrical work.	
Commercial Systems	1.5 Million USD Storage mechanism (6- Gate L/R) with shuttle systems	

As mentioned early in Chapter3, the cost to build a final vehicle assembly is between 6- 10 Billion USD. The prices depend on the throughputs of the systems (throughputs determined by the inner work-cell cycle time). The next section discusses the line-rate of the framing systems and throughputs.

6.6.2: Results and Discussion How Proposed Methods Improve HPV

To compare the effect of throughputs on HPV, the production rate before and after using the new methods needs to be calculated. Assuming a production line is running for three shifts, five days a week using the weekend for maintenance, real line rate (WC1) cycle time for the three styles is as shown in Table 6-5 and Table 6-6. Breakdown due to malfunction was not included.

– Throughputs improved by using the new proposed systems in two parameters;
– Bottleneck CT for inner gate systems reduce 8-10 %;
– Changeover time to switch gates not required (1 hour per change).

Table 6- 9: Total production of 3 styles for 1 quarter before using 3 gate systems

Schedule production of 3 styles ;WC1: CT: 54.s (S1), CT: 56.s (S2), CT: 55.s (S3)			
Shift (1) S1- 7H	Shift (2) S2- 7H	Shift (3) S3- 7H	Total Per/D,W,M
466	450	458	13374 (D)
2330	2250	2290	6870 (W)
9320	9000	9160	27480 (M)
27960	27000	27480	82440 (1q)
111840	108000	109920	329,760 (Y)
Change/over switch gates 1H between shift			

Table 6- 10: Total production of 3 styles for 1 quarter using ROGS

Schedule production of 3 styles: WC1: CT: 50.s (S1), CT: 52.s (S2), CT: 51.s (S3)			
Shift (1) S1- 8H	Shift (2) S2- 8H	Shift (3) S3- 8H	Total Per/Day
576	554	565	1695 (D)
2880	2770	2825	8475 (W)
11520	11080	11300	33900 (M)
34560	33240	33900	101700 (q)
138240	132960	135600	406800 (Y)
Bottleneck CT reduced by 4 sec (8-10%), eliminate C/O time 60 Min. (12.5%)			

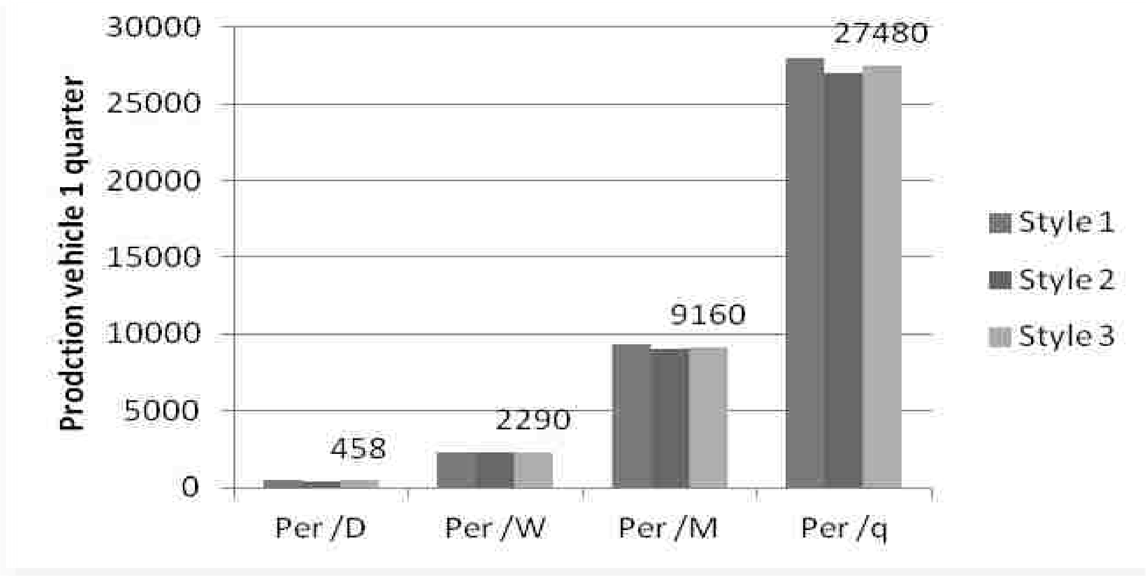


Fig. 6- 31: Total production of 3 style production per/quarter with changeover

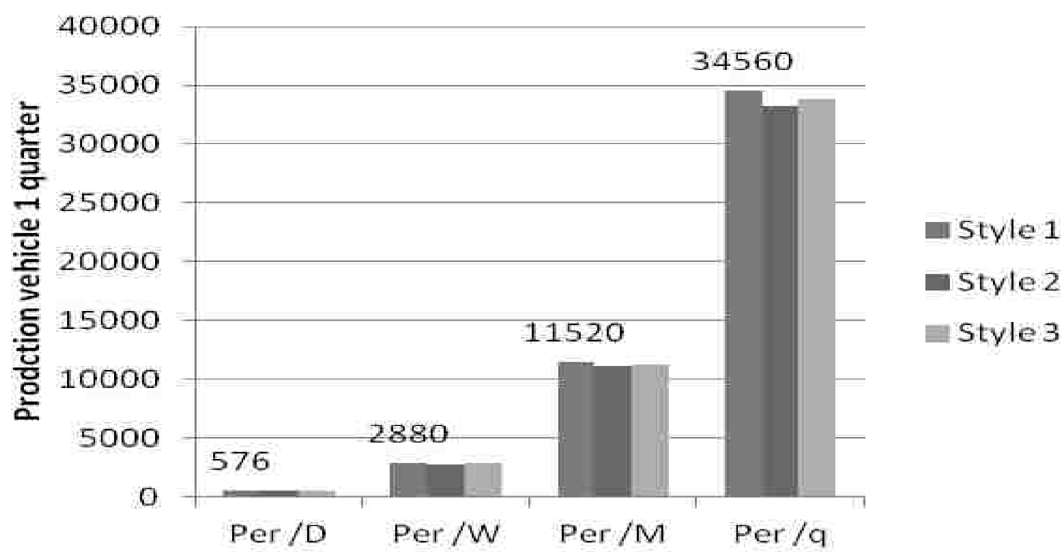


Fig. 6- 32: Total production of 3 style production per/quarter using ROGS

<u>The following assumptions were used to plan one quarter of production:</u>

– Running production on style per shift to minimize the downtime needed to changeover to new style (one change per/shift).
– Time improved by 8% per line rate using decoupled design of the gate structures.

– Throughputs of the framing systems are improved by 24% due to the two factors.

These improvements contribute to the direct cost (saving) of HPV. The improvements of throughputs are very encouraging to redesign the new Gates structure as proposed, decoupled modular structure with smart devices at the top units. The costs of these units are more expensive but are justified. Final throughputs improvements is shown in Fig. 6-33

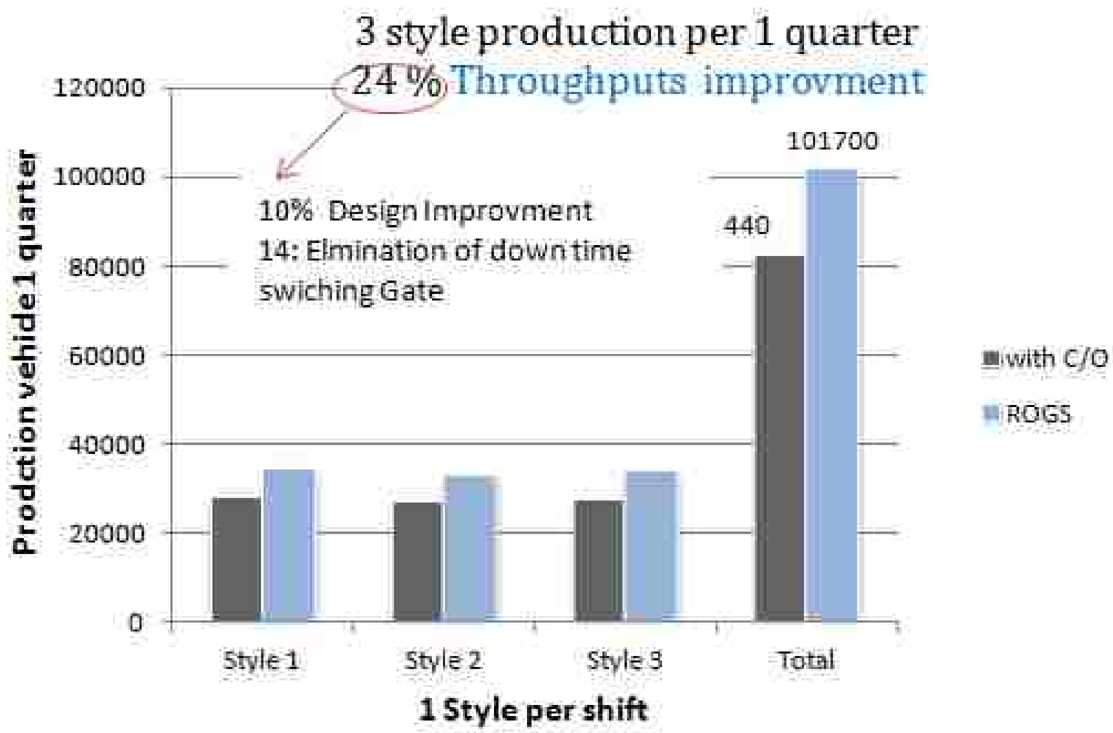


Fig. 6- 33: Throughputs of production by using ROGS

The cost of lost production due to breakdown on the framing work-cell is very high (complete shutdown of the plant with the exception of a buffer of 30 minutes production). It has also been mentioned early that one hour shutdown costs in a plant of 66 J/h is nearly 0.5 to 0.6 million USD. Most shutdowns in the framing work-cell are caused by mechanical interaction of the dumping units, and so it is a good reason to redesign the current structure of open-gate framing systems.

Chapter 7

7. Conclusions and Future Work

7.1: Conclusions

The proposed design method shows how to systematically pinpoint and value flexible elements in modules, despite a 30-50% higher initial investment in equipment and tooling. In return, it offers significant savings of up to 50% for each new style addition. When simulation is connected to process design and builds, lead-time is reduced by 80%. This work is the first systematic attempt at mapping product design-driven flexibility into manufacturing system capabilities. Historically in BIW design, it was extremely difficult to apply process improvement techniques or technology innovations to make it more efficient; a modular approach presented may change that perspective. By breaking down the body-in-white process into its major components, sub-contractors can drive significant optimization initiatives into each module of the process and then integrate the modules together to form a more streamlined and flexible overall process.

The new proposed design structure (modular approach) for the open-gate framing systems will both eliminate the coupling design and enable increases of mixed variants within a family without the need for switching gates during production (in this case no consideration for changeover time). This concept may lead to a new method of gate construction, allowing a reduction in the heavy tubing and unnecessary heavy dumping units, reducing at least 30% of the gate weight. PLM/PDM with Teamcenter support helps developers and designers to understand a product in its entirety, including the organizational processes to plan, develop and manufacture.

The key tooling beltline, which can correspond to the product beltline concept, was investigated for the first time (Al-Zaher et al., 2011). Product and process are closely coordinated to achieve optimal matching of requirements for effective cost, quality and delivery.

7.2: Contributions

The research presented in this dissertation contributes to the field modular structures and car body structures with more focus on manufacturing and production systems.

7.2.1: Results Achieved

- Better presentation and mapping for the entire system to help designers directly pinpoint the critical element in product platform and to design a more modular and robust production system.
- Conceptual design for gate tooling to eliminate coupling in the current systems (integral structure to modular structures).
- Developed a simulation model of the state of practice for vehicle framing systems using GSL programming***;*** *DELMIA's Digital Manufacturing (IGRIP),* detailed in Chapter 6.
- Analyzed the developed simulation model to identify the sources of uncertainty that contributed to high cost in the production line (with focus on the manufacturing design and systems).
- Increase for line rate by 10%; this time can be invested to solve many issues (i.e. new material required more CT).
- Increasing throughputs of production systems and reducing cost.
    - Elimination for the gate storage systems, no need to changeover.
    - Eliminate source of dynamics interaction uncoupled DT and DC.

7.2.2: Significance of Research to the Discipline

- This framework is a new method with a complete end-to-end design process of production systems. The uncertainty of styling (car body structure BIW) within the product family is mapped to product attributes and manufacturing process, and then mapped into the production line. The relevant costs for economic evaluation can be calculated for all levels; from parts manufacturing to final assembles prior to final design decisions.
- Hybrid Design Structure Matrix (HDSM) are introduced to help systems designers understand changes in product design and mapping to physical domains (production systems) and to evaluate the effect of changes by connecting the process to DM simulation.
- Most of the previous work deals with very simple examples, thus not capturing the intricacy of true engineering systems design.

- The case study data based on actual production systems of three different styles; (design and production data) support the hypothesis of the research.
- Justifying upfront the initial cost of flexibility to achieve production flexibility by using a reconfigurable line.

7.2.3: Framework Design Methodology of Framing Systems

Figure 7-1 shows the four main stages of the proposed framework to support the RMS design methodology execution (as detailed in Chapter 5, Fig. 5-9). With simulation connected to the process, a new approach, "end-to-end process", not depending on the inputs and outputs of each stage rather depend on the overall process, results and planning, especially the manufacturing of parts. Most people study, evaluate and make decisions based on the final assembly. Unfortunately, this decision ignores manufacturing. Why? The reason is data are not available. Therefore, with the new proposed methods, the database will be available and connect all processes to simulation.

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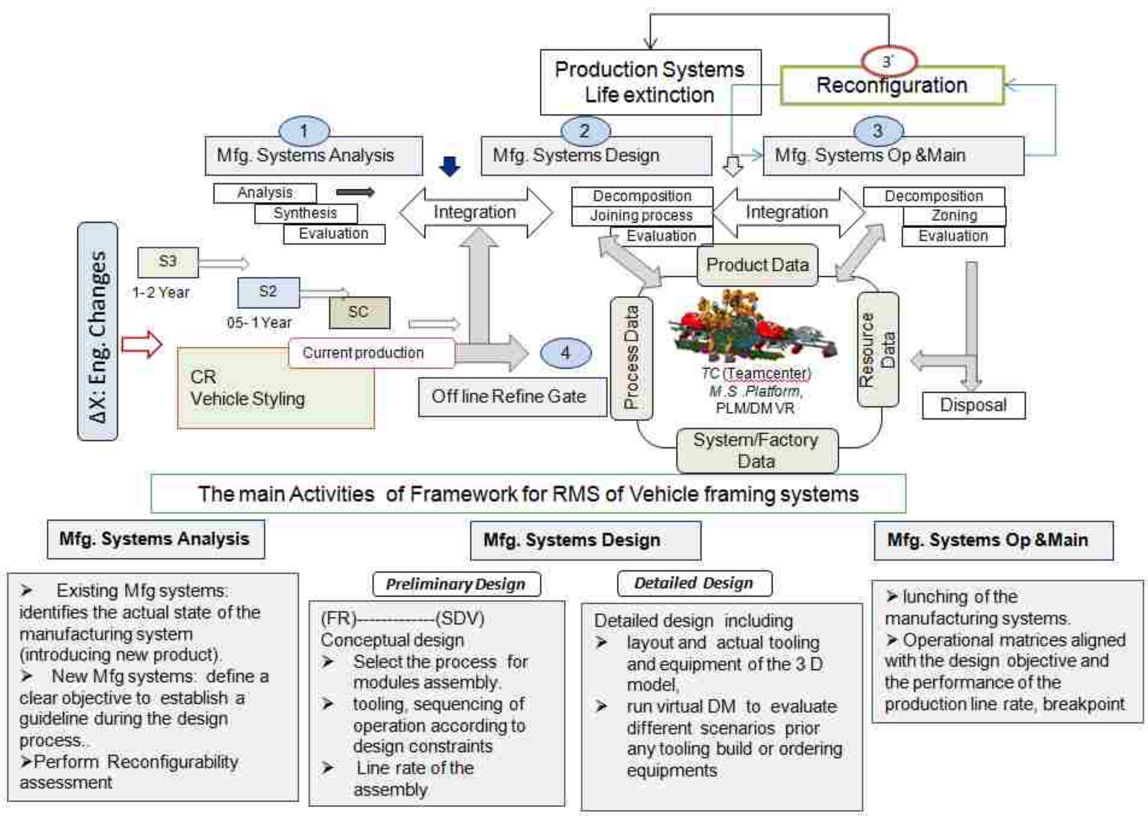


Fig. 7- 1: Framework for RMS of Automotive framing systems

7.2.4: Network graph Representation (NW) in Vehicle Body Styling

Network graph representation for the car body structures were developed as shown in Fig. 7-2. This is used to help visualize the changes propagation throughout the systems.

It is also used to identify physical interface for modules connection and used to calculate CPI coefficients, as detailed in Chapter 5.3, Fig. 5-12.

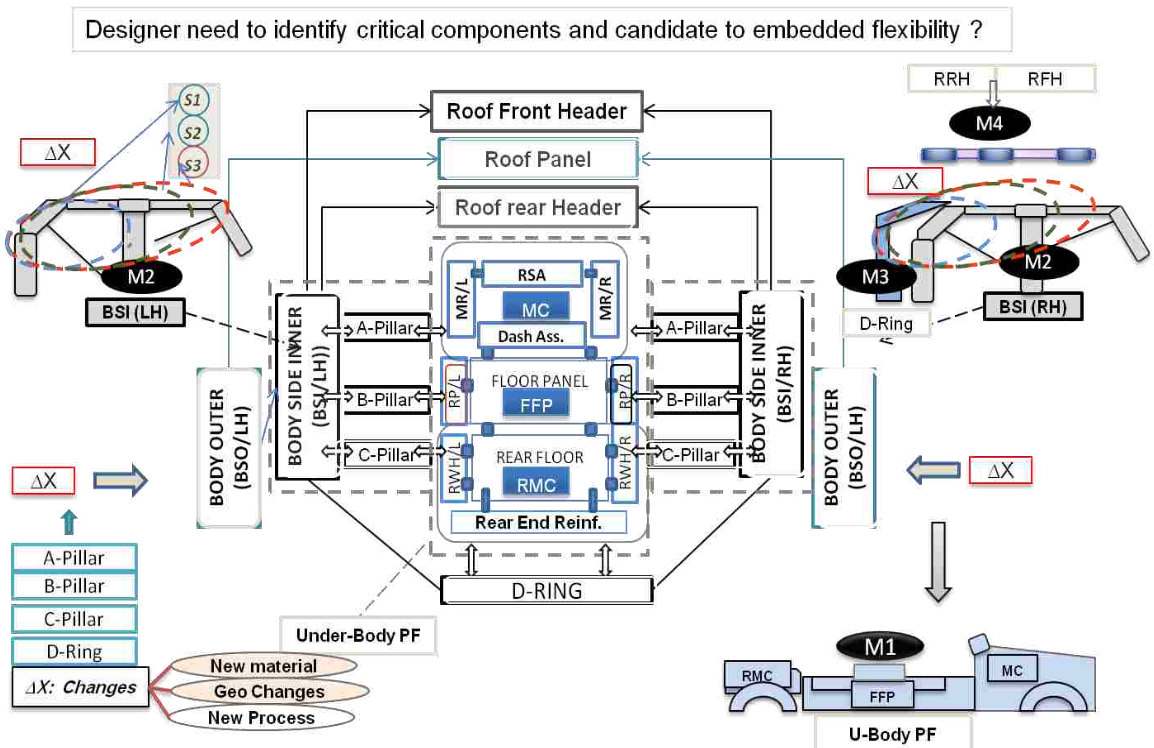


Fig. 7- 2: Net-Work Graph representation of Automotive framing systems

7.2.5: New Design Configuration of HDSM for Vehicle Framing

HDSM, introduced in this research as a new application of DSM to the automotive framing systems, can be classified as a special use in the automotive industry. The new configuration of DSM provides a new relationship perspective of dependency between modules (see Fig. 7-3; more details in Chapter 4 and through the case studies). The use of this application helps in the following ways:

- Mapping domain process using the Hybrid Design Structure Matrix (HDSM) were introduced as a new contribution to automotive framing systems; procedure steps were summarized in Chapter 4.
- To help systems designers understand changes in product design and mapping to physical domains (production systems) and to evaluate the effect of changes by connecting the process to DM simulation.
- Used to map engineering changes of car body structures to production systems; including positioning devices and joining process at the highest level; it can be used for low-level representation as well.
- To map engineering changes of car body structures to production systems.

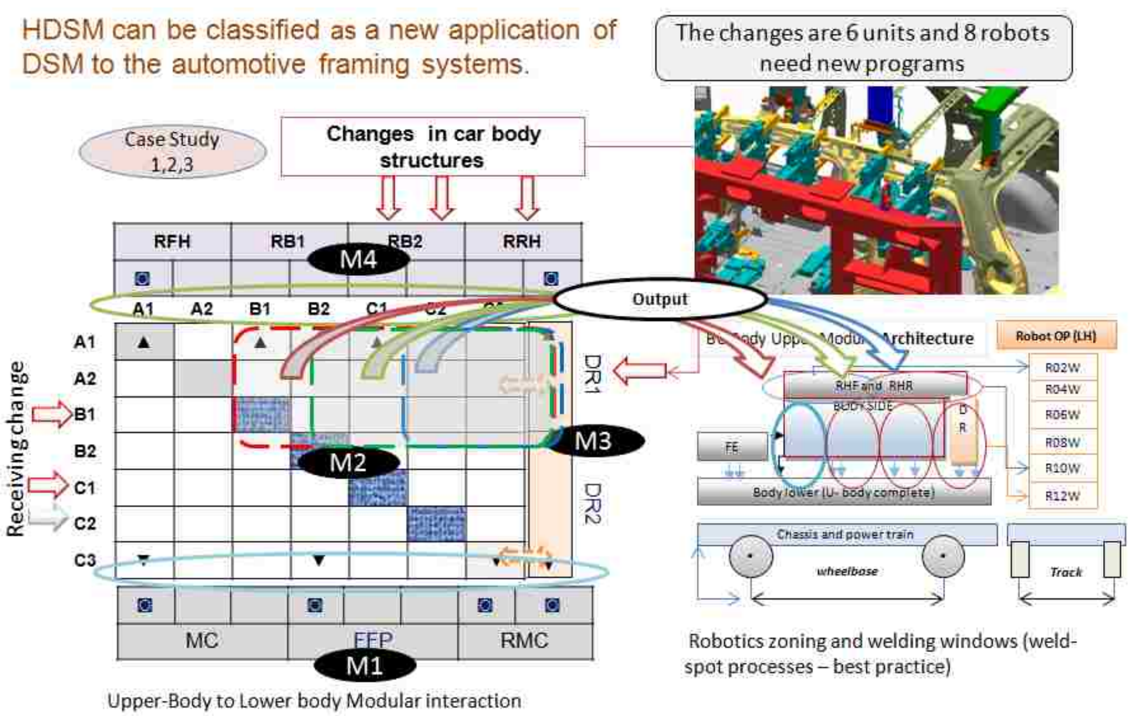
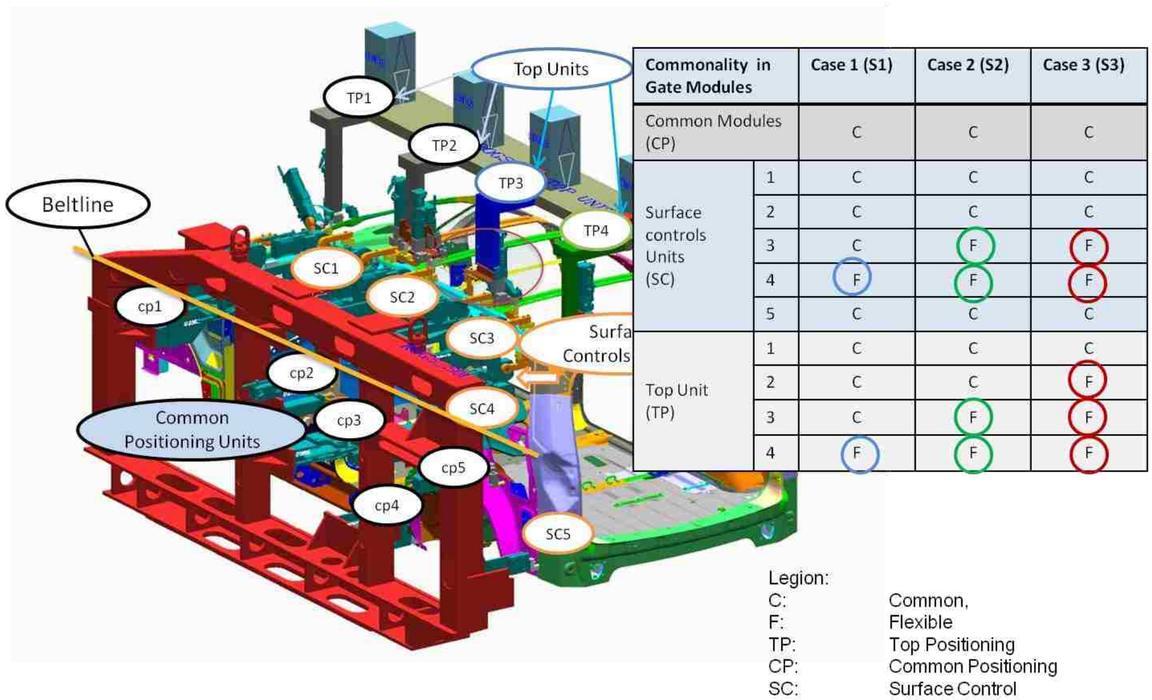


Fig. 7- 3: MDM using HDSM physical interaction; Interface between modules



Commonality in Gate Modules		Case 1 (S1)	Case 2 (S2)	Case 3 (S3)
Common Modules (CP)		C	C	C
Surface controls Units (SC)	1	C	C	C
	2	C	C	C
	3	C	F	F
	4	F	F	F
	5	C	C	C
Top Unit (TP)	1	C	C	C
	2	C	C	F
	3	C	F	F
	4	F	F	F

Fig. 7- 4: Commonality of modular units for the proposed open gate framing systems

7.3: Limitation of Dissertation Scope

The dissertation focuses on the development of a systematic methodology as a guideline for systems designers and developers to respond quickly and more economically to uncertainty of market change(s) by utilizing flexibility in both product and production systems.

The main emphasis of this research is to identify the critical and key elements of product; physical connection components (car body modular interface BIW) and incorporate flexibility in the production and manufacturing systems tooling equipment to be less sensitive to future variants of product family (pre-defined boundary of changes). To use one gate without changeover, the assumptions below need to be considered:

Assumption & Limitation of Design Method:

As discussed, flexibility in the production systems needs to be defined for cost purposes such as no use for seven axis robots (except the 2 robots at rear end, as they may be needed for future extended style).

- Fixed wheelbase: Under-body complete (platform) are common to all styles (variation of one same family),
- Fixed track,
- Expansion for rear overhang (it can be defined),
- Interface components locations under beltline are common for tooling and product,
- Joining process for inner framing is weld spots with servo weld gun,
- Different joining process can be used for outer framing.

7.4: Future Work

The future work will aim to:

Continue to develop more low level details for multi domain interface product design to production systems with more interactive simulation.

A very promising future research topic is one where the limitations of using this method, such as wheelbase and track to be variables, are explored.

Define key components or elements of under-body modules, since the new trend in the automotive platform is moving more flexibility to accommodate different upper body (styling) and under body (chassis and power train),. They are used as a physical connection with power train modules to plan future flexibility in the under-body tooling.

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9. Vita Auctoris

Full Name: Abdo Al-Zaher

Place of Birth: Syria

Citizenship: Canadian Citizen

DEGREES RECEIVED:

Degree	***Area***	***Institution***	**year**
Ph.D.	Industrial and manufacturing Systems Cost effective design methodology of Automotive framing System.	University of Windsor, Windsor, Ont., Canada	2012
Mechatronics Technology	PLC Programming, Hydraulic electro-equipments, pneumatic and sensors	Conestoga College/ Festo Inc., Kitchener, Ont., Canada	1996
M.Sc.	Mechanical and manufacturing Engineering Automatic controls, flexible systems, path and task planning of mobile robots	University of Manitoba, Winnipeg, Mb., Canada	1994
B.Sc. Upgrade	Mechanical Engineering Mechanical Design and Quality Control	McMaster University, Hamilton, Ont., Canada	1992
CNC/CAD/CAM Programming	Geometry Modeling and CNC Programming using CAMAX, Cisgraph 3D	Hamilton Industrial Training Centre, Hamilton, Ont., Canada	1991

PROFESSIONAL EXPERIENCE:

Assignments	**Institution or company**	**Location**	**Date**
Research Engineer	*University of Windsor*	Windsor, Ont, Canada	2009 - Present
Systems Processing and Design Engineer	*Contracted to GM- CRW through Robotech Canada Consulting, Inc.* o Automotive BIW systems	Troy, MI. USA	1996 - 2008

	design; tooling, controls and joining processes. o participated in more than 100 project and two dozen of final framing assemblies installed in most of north America plant, Spain and Germany		
CAD/CAM Programmer	*Nova Tool and Technology* o Performed wire-frame design, surfacing, EDM, and tool path design for injection molded parts using CAMAX and CISIGRAPH software. Subsequent activities prior to the NC Program	Windsor, Ont, Canada	1994 - 1995
Research Engineer	*University of Manitoba* o Developed math model and dynamic simulation flexible systems, path and task planning of mobile robots o Developed three different algorithms for robot motion control (load insensitive system, pressure feedback system, and acceleration and force feedback system).	Winnipeg, Mb, Canada	1992 - 1994
Instructor	Polytechnic College o Developed and administrated courses material at the college level	Overseas	1985 - 1989
Design Engineer	Engineering Consultants Unit o Design, Maintenance and installation of heating, air-conditioning and solar energy equipment	Overseas	1982 - 1984

PUBLICATION JOURNAL & CONFERNCES:

Al-Zaher, A., ElMaraghy, W., Pasek, Z. J. 2010. Robust and Cost-Effective Design of Automotive Framing Systems Using Reconfigurability Principles. *In:* The 2nd Canadian Quality Congress, 2010 Toronto, ON, Canada.

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Al-Zaher, A., ElMaraghy, W., Pasek, Z. J., ElMaraghy, H., 2012, *Design of Reconfigurable Automotive Framing Systems BIW*, the 23rd CIRP Design Conference 2013 march 11th - 13th, 2013 in Bochum, Germany.