

Enabling Manufacturing Flexibility Issue Resolution in Advanced Vehicle Development

By

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Bachelor of Science in Mechanical Engineering, the University of Michigan (2001)

Submitted to the MIT Sloan School of Management and the Mechanical Engineering Department
in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration

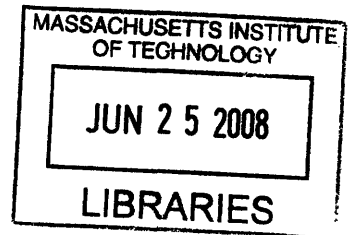
AND

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1. Abstract

Manufacturing Flexibility is a broad term used to describe a metric that can be measured in many different ways. Current industry experts agree that Flexibility is one of the key measures that will help the automotive industry reduce current overcapacity and remain competitive. In addition to flexibility, General Motors is also focusing on fewer, interbuildable product architectures.

To maintain and implement flexible manufacturing systems, General Motors has developed a list of Flexibility Enablers. These enablers identify critical product characteristics which affect the interbuildability of the product and the flexibility and of the subsequent manufacturing process.

Market forces drive product requirements, and lead to designs that potentially violate the Flexibility Enablers. This thesis will look at GM's internal structure and how it has developed to support design decisions and issue resolution. It will then study cases in which the design requirements led to design, manufacturing and cost tradeoffs in an attempt to understand and document the different unwritten resolution processes in disparate groups.

Keywords: Manufacturing Flexibility, Product Development, Flexibility Enabler, Interbuildability

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Biographical Note

Grace Tomlin was born in 1978 and grew up in Plymouth, Michigan. She graduated from the University of Michigan in August of 2001 with a Bachelor of Science in Mechanical Engineering. During this time, she worked for UofM's Engineering Research Center for Reconfigurable Manufacturing Systems and was a member of the Marian Sarah Parker Scholars.

After graduation, she joined Eaton Corporation's Leadership Development Program, and worked functions such as Marketing, Sales, Finance and Lean implementation on the shop floor. She then joined Goodrich Corporation in 2004 as a Program Manager supporting the EDM phase manufacturing of canard control units for Lockheed Martin's Advanced Gun System program. Grace also worked for The Timken Company as a Sales Engineer before returning to graduate school. After graduation from MIT, Grace will return to General Motors' Manufacturing group.

Grace enjoys both arts and sports. She plans to continue singing and performing when she returns to Michigan, as well as compete in her first half Ironman.

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2. Flexibility Background and Definition

2.1. Flexibility and Interbuildability: Definition

The definition of manufacturing flexibility itself is nebulous and constantly changing. Manufacturing Flexibility is defined by a number of organizations in a number of ways. For the purposes of this thesis, we will use flexibility as defined by General Motors. GM's definition is broad: Flexibility is the ability to change or react to customer demands for quality products with little penalty in time, effort, cost or performance¹.

Another close relative of flexibility is interbuildability. Interbuildability was coined by GM vice chairman, Bob Lutz. It focuses on the product side of flexibility and describes the ability to build a variety of vehicle styles based on the same architecture. (Gardner Publications, Inc., 2004)

2.2. Flexibility Metrics in Industry

This section will review industry publications that measure manufacturing flexibility and related metrics. It will discuss what metrics are used, and the overall purpose of the reports.

The Prudential Flex Report, published by the Prudential Equity Group, LLC for the auto industry, defines a flexible plant as a "plant that can vary its output between different vehicles on a single production line." Prudential claims that "flexibility is enhanced and capacity utilization can be maximized if the life cycles of the plant's vehicles are 'out of phase'". (Prudential Equity Group, LLC, 2005, p. 1) Their thesis is "automakers with the greatest flexibility in their plants can run at the highest capacity utilization and are enabled to roll out the strongest cadence of new models." (Prudential Equity Group, LLC, 2005, p. 2) Prudential measures flexibility success by % capacity on flexible lines. It claims flex is critical to compete because it improves capacity utilization, lowers equipment and tooling investment, increases model introduction speed, and eases quality control. Flexibility to produce models in a number of plants also increases the

¹ Internal GM publication

automaker's leverage with the labor force and suppliers, and reduces the risk of meeting demand. According to Prudential, the value of flexibility is that the ability to alter production levels drives higher utilization in each plant, and therefore higher profitability. The Prudential Flex Report was discontinued after the 2006 publication.

The Aberdeen group reports on manufacturing flexibility as it relates to the shop floor operations and supply chain, and includes industries such as automotive, high tech, metals, aerospace/defense, medical, and retail. Aberdeen defines Flexibility as “convergence of supply chain visibility, production capacity, and dynamic decision making.” (Aberdeen Group, 2007, p. 3) Its three key performance indicators are on time delivery, finished goods inventory, and manufacturing cycle time. These metrics track overall operational success rather than a specific flexibility competency. In other words, after the flexibility strategy has been implemented, the “measure, control, improve” actions optimize operations and flexible execution. Aberdeen's most recent report on flexibility identifies the number one manufacturing flexibility challenge as “conflicting views of how to optimize production planning decision making”. (Aberdeen Group, 2007, p. 12) Aberdeen concludes that “Improving the ability of a given set of production assets to deal with changes in demand... [relies] heavily on the configurability of the assets”. (Aberdeen Group, 2007, p. 17) In this case, flexible assets enable manufacturing flexibility.

The Harbour Report, an industry publication by Harbour Consulting, provides competitive analysis of automotive manufacturers². This report is not meant to measure or analyze flexibility, but focuses on productivity rankings, sourcing data, capacity utilization, profit and cost analysis.

Overall, these flexibility reports focus on flexibility as it relates to manufacturing and execution of production on the plant floor. While GM recognizes these as industry benchmark mechanisms, GM is also using its product architecture portfolio and advanced vehicle development to drive flexibility. The focus of this study is on the advanced development of the vehicle manufacturing system and design of the architecture well before the vehicle is launched.

² http://www.harbourinc.com/harbour_report/

2.3. Interbuildability in Industry

This section will discuss how flexibility is improved through common architecture development and interbuildability.

Many international companies are focusing their efforts on manufacturing flexibility.

Volkswagen (VW) is moving towards a more flexible line, as it has traditionally used a one-platform, one plant strategy. VW is looking to build a line that could produce Audi, Skoda, Seat and VW vehicles. (Stein, 2007) Honda is also following a facility flexibility strategy, which has allowed it to expand its product line up without adding as many new assembly facilities.(Wortham, 2007)

Yet despite the trend toward flexible lines, more than 60 percent of North American assembly lines are still dedicated to a single model, according to Harbour Consulting, a manufacturing consulting company based in Troy, Michigan.(Kisiel, 2006) However, as companies update models on two to three year increments, flexibility improvements will emerge. Kevin Reale, research director in the automotive practice at AMR Research, believes that in 10 years time 90% of assembly lines could be flexible.(Kisiel, 2006)

The need for flexibility results in a push to consolidate architectures, so many models can be built globally based on a few architectures. Discipline in the architecture definition process is very important as each geographic region develops its models. Each architecture shares a common underbody, and may be used as a base for a number of vehicle models in different global regions. A vehicle style is developed based on specific regional demand, and helps define the designs of the customer facing components: body side, doors, etc. During architecture and subsequent model development, it is a challenge to adhere to the standard architecture. Designers must guard against architecture deviation, because deviation deteriorates flexibility. (Kisiel, 2006)

Bob Lutz coined the phrase 'interbuildability' at GM. By interbuildability, Lutz is referring to "distinct products that can be built off the same or compatible architectures". (Cowger, March 31, 2006, p. 3)

Wolkonowicz of Global Insight believes that it will take another vehicle generation for the industry to produce vehicle architectures with interbuildable models. (Henry, 2007)

At GM, this global coordination of product development is expected to reduce development costs by up to 40% and cut the number of vehicle architectures in half without compromising the variety of models. It will also reduce material costs by 20%, and engineering costs and overall investment by 25%. (Forster, 2007)

Study of general industry also reveals evidence that product commonality reduces total production costs. Park and Simpson develop a production cost estimation framework for product family development purposes. They state, *“If additional costs are required to add flexibility, the costs should be justified by expected cost reduction.”* (Park & Simpson, February 2005, p. 18) They go on to identify the following factors as key product development levers to reduce production costs: Raw material sharing, Partial feature sharing, tooling sharing, process sharing, facility sharing, setup sharing, inventory sharing, material handling sharing, and material transfer sharing. This article concludes,

“As commonality increases, the possibility of the cost benefit also increases. When the cost benefit occurs due to commonality, the cost benefit increases as production volumes rise. As a result, when mass producing a variety of products, commonality is one of the best design strategies to reduce total production cost if the relative costs of components are small enough not to incur cost burdens.” (Park & Simpson, February 2005, pp. 34-35)

It is generally accepted that common vehicle platforms that allow interbuildability help automakers realize scale economies, improve productivity, offer low volume niche vehicles at low marginal cost, and be overall more competitive.

2.4. Flexibility and Interbuildability at General Motors

If industry and research both laud 100% flexibility, then General Motors is behind the curve. Figure 1 is a graph of GM’s current and future ‘flexibility’, defined as percentage of plants that can produce multiple architectures. Ideally, complete flexibility would be obtained by building Greenfield plants and using a copy exact formula, similar to the Intel model. This means that all

equipment and all processes would be the same in every plant. One would not be able to distinguish a difference between a plant in China and one in Kentucky. As a result, any product could drop into any line with no impact to cost or timing.

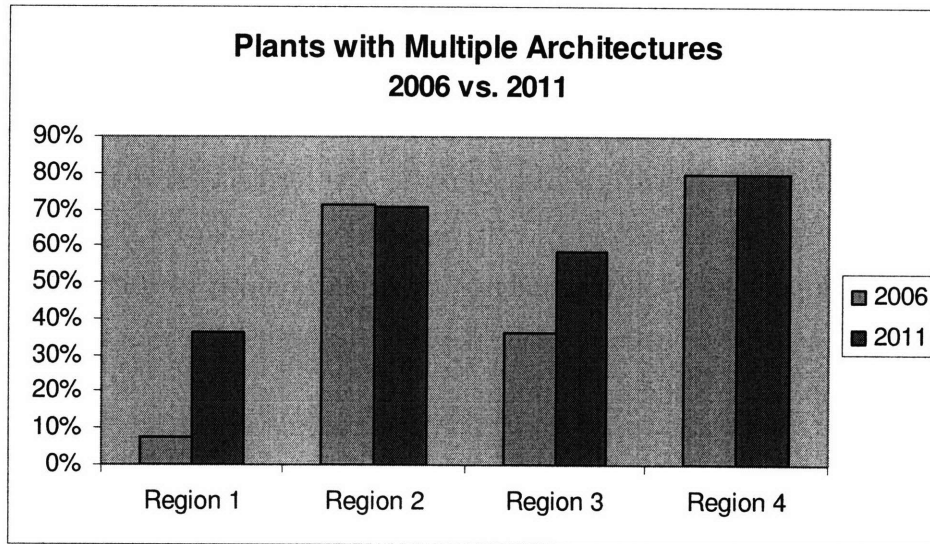


Figure 1: General Motors Flexibility: Plants building Multiple Architectures

Unfortunately, General Motors has to contend with a number of factors that disallow this level of built-in flexibility. Below are listed some of the key challenges to obtain flexibility, both for GM specifically, and for industry as a whole. Continued implementation of interbuildability and flexibility will begin to alleviate these issues, some in the short term and some in the long term.

GM Specific Challenges:

- ❖ Limited cash availability
- ❖ Legacy facilities
- ❖ Legacy architectures
- ❖ Labor Union agreements
- ❖ Evolving standards: BOP, BOE

General Industry:

- ❖ Shifting customer demand
- ❖ Government regulations
- ❖ New technology
- ❖ Program cost structures
- ❖ Global demand trend

General Motors must develop its interbuildable products and flexible production lines with these complications in mind. Limited cash availability requires solutions to balance the immediate requirements with the resources available and the need to accommodate future products. Integration into legacy facilities is also necessary for the same reasons. Legacy facilities may use non standardized equipment and procedures to produce non-standardized architectures. Even

the GM standard processes, the Bill of Process (BOP) and Bill of Equipment (BOE), which will be described in chapter 5, are being improved over time. GM must develop flexible processes to accommodate this evolving standard.

To control program spending and cash flow, each product is developed for performance and manufacturability on a case by case basis. GM uses the extensive set of tools it has in place to ensure flexibility and to serve as checks and balances as a product goes through the development process. As a product is developed, it is certain to encounter roadblocks that stem from the factors listed above. It is important for GM to have a robust process that will indentify interbuildability and flexibility violations and resolve them in a timely manner. This thesis will discuss GM's tools, study some cases in which flexibility enablers have been violated, and where appropriate, follow the process through resolution.

2.5. Summary

Chapter 2 summarized the definition of manufacturing flexibility and interbuildability. A review of flexibility metrics in industry was conducted, and a discussion of interbuildability and architecture commonality followed. The final section took an initial look at how General Motors approaches manufacturing flexibility and product interbuildability. Chapter 3 will look at globalization at General Motors, and explore how the current global strategy accommodates flexibility and interbuildability. Chapter 4 will explore the General Motors organization through MIT Sloan's three-lens framework and Chapter 5 will discuss the specific tools GM has in place to define processes and ensure flexibility and interbuildability. Chapter 6 uses a case study approach to take a closer look at specific examples in which flexibility has been challenged, in order to understand the reasons that flexibility may be compromised, and the process by which issues are resolved. These chapters are followed by observations of what is working well and recommendations for improvement.

3. Global Strategy: Role of Flexibility in the Global Enterprise

3.1. *Globalization, and Strategically Managing a Global Business*

This section will discuss implications of a globalizing industry as well as the application of Global Strategy principals to the design of a global organization. General Global Strategy focuses on development of an intricate, balanced, and strong organizational plan. The global nature of a company must include general business and functional management along with the ability to adapt to local markets. Most important, though is the appropriate management of the linking mechanisms between global entities.

Globalization of the automotive industry has brought many new players into the market and created an entirely new playing field. Increased competition has created a very difficult environment for all competitors in this industry. “The globalization of the industry has left carmakers with few sheltered markets while requiring the serious players to establish a global footprint of their own. The inevitable result has been huge structural change, a major ratcheting up of competition led by Asian producers, and huge pressure on the margins of carmakers and their suppliers.” (Griffiths, 2006, p. 1) “The inevitable consequence of all this activity has been to bring into much sharper focus the burden of overcapacity in the industry.” (Griffiths, 2006, p. 1) This overcapacity was driven by a generally inflexible structure, which meant a drop in the demand for a specific style resulted in idle time at the subject facility because other vehicles could not be incorporated into the assembly line without tremendous time and cost implications. “Desperate for competitive advantage, carmakers are also putting themselves under more pressure by using flexible design and manufacturing technologies to create or explore many more market niches than in the past.” (Griffiths, 2006, p. 1) Increasing manufacturing flexibility helps alleviate overcapacity and enables efficient production of lower-volume niche vehicles.

Bartlett & Ghoshal have developed a rationale for management of a global firm. They claim “effective competitors need to build strong business management with global product responsibilities if they are to achieve global efficiency and integration”. (Bartlett & Ghoshal, 1987, pp. 43-44) Their paper highlights three important corporate management competencies,

and a later paper, (Bartlett & Ghoshal, 1992/2003, p. 102), highlights the resulting strategic capabilities.

Competency 1: Strong geographic (country) management: This manager has the ability to read and respond to the diverse needs of different markets.

Strategic capability: National-level responsiveness and flexibility

Competency 2: Strong business management: This manager is a champion for manufacturing and product standardization, and global sourcing.

Strategic capability: Global scale efficiency.

Competency 3: Strong functional management: This manager builds and transfers core competencies throughout the business.

Strategic capability: Cross market capacity to leverage learning on a local basis.

To balance these effectively, a multidimensional organization must be formed. A good manager recognizes the sometimes asymmetrical and ambiguous nature of this balance, and adapts tasks and responsibilities as necessary. More successful companies challenged a general assumption of the need to institutionalize decision making mechanisms and simple means of exercising control. Instead, they differentiated tasks and developed complex methods for coordinating organizations.

Bartlett and Ghoshal determined that the organizational structure that is created is important, but the management of the structure and linkages within is what drives competitiveness. Success in today's international climate demands "highly specialized yet closely linked groups" of these three types of managers. A company needs a "managerial mindset that understands the need for multiple strategic capabilities, that is able to view problems from both local and global perspectives, and that accepts the importance of a flexible approach". (Bartlett & Ghoshal, 1987, pp. 102, 14)

Hansen and Nohria also emphasize the importance of linking mechanisms on the softer side of organizational development. "For multinationals... future advantage will go to those that can stimulate and support interunit collaboration to leverage their dispersed resources." (Hansen & Nohria, 2004, p. 22) The major management levers identified are Leadership, Values and Goals, and Human Resources procedures.

“While companies can’t use the same strategies in all developing countries, they can generate synergies by treating different markets as part of a system.” (Khanna, Palepu, & Sinha, 2005, p. 14) Ideally, as a company enters an emerging market, it will retain its core business strategy across all global locations or groups, but adapt to exploit local competencies or fill local gaps. Perhaps, on a large enough scale, the company will be able to even influence the local context.

During the continued globalization of the automotive industry, it is critical that large companies adapt to take advantage of scale, but stay nimble enough to understand and exploit local advantages. As GM builds and expands development centers abroad, the company will be faced with continued pressures. The following chapters will discuss GM’s organizational structure, and linking and aligning mechanisms used to implement its Global Strategy.

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4. Three-lens Framework: Business organization and responsibilities

This section will explore the methods by which General Motors operates to understand the way change can best be achieved. General Motors' business will be described based on an MIT Sloan framework that views an organization through three separate lenses, structural, cultural and political. (Carroll, June 2006) First, the organizational structure will be analyzed. Then, the lines of political influence will be discussed. Finally, the General Motors culture will be explored. Each of these three lenses will help evaluate the decision making process at General Motors, and how flexibility fits into the organization as a whole.

4.1. *Strategic Design Lens*

4.1.1. GM's organizational structure

General Motors is considered a "basketweave" structure; grouped into four world regions, and twelve functional areas. Unlike other matrix organizations where one manager is assigned to each of the sides of the matrix, GM assigns dual responsibility to its leaders. In this way (Figure 2), employees underneath this organization don't report to two separate managers, rather each manager is responsible for more than one organization (Garvin & Levesque, 2006).

GLOBAL PROCESS LEADERS	REGION PRESIDENTS			
	GM North America	GM Europe	GM Asia Pacific	GM Latin America
Product Development				
Manufacturing and Labor Relations				
Sales/Service/Marketing				
Quality				
Powertrain				
Human Resources				
Planning and R&D				
Purchasing				
Communications				
Finance				
Legal/Public Policy				
Information Systems and Services				

Figure 2: GM 2004 Basket weave Organizational Structure (Garvin & Levesque, 2006)

Structurally, GM is separated into two distinct groups: Product creates vehicle designs, and Manufacturing creates the production systems to build the vehicle. Historically, it has been difficult to bridge the gap between product and manufacturing. Through structural changes and leadership support, this is improving quickly. High level leaders are adopting more of a ‘one company’ approach. Specific and standardized tools have been created to help link these at many points through the development process.

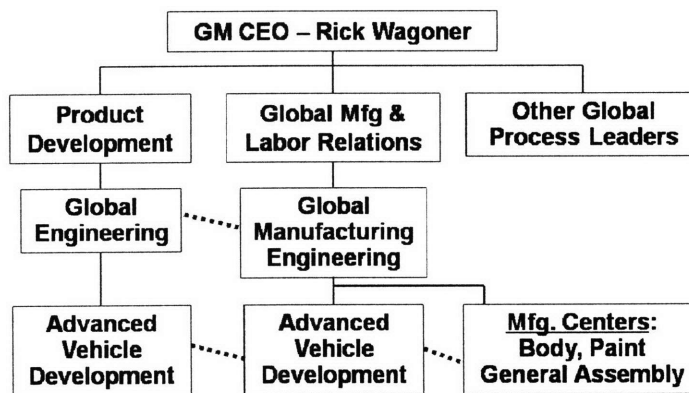


Figure 3: GM Basic Organization

4.1.2. Architecture Development and Local Specialization

GM's size and scale have historically led to many design and manufacturing redundancies. The addition of a Vehicle Line Executive position and the creation of Global Homerooms have allowed the organization to consolidate its vehicle development system. The Global Homeroom strategy is a major alignment mechanism, centralizing the development of major architectures and giving decision making authority to one specific geographic region. It also facilitates one point of contact for teams developing the styles based off that architecture. (Phelan, 2007)

In addition to localizing architecture designs, GM is taking advantage of regional expertise. GM opened a new design studio in November of 2007 in Bangalore, India. This is one of 12 global centers that will be used to develop designs for vehicles around the globe. The Bangalore center will focus on interior designs. GM is not targeting the cheaper labor, but developing and exploiting the design expertise in these different regions by developing collaborative research labs with the India Institute of Technology in Kharagpur and other world renowned universities. (Yee, 2008) This is just one of many examples in which General Motors is expanding its global influence and developing specialized local talent.

4.1.3. Linking

Because GM is becoming more global, constant and fluid communications across all regions of the globe and each of the functional areas is required. GM is the 'Mother of the Process' and has established many linking mechanisms to help facilitate communication and effective vehicle development. Standard cross-functional meetings are held at specific times. These meetings are used to address regular agenda items as well as a roundtable forum for individuals to raise specific issues. A global time zone meeting calendar highlights acceptable times for standard and ad hoc meetings, so all relevant parties across the globe can be included at reasonable times of day. (Although, several dedicated employees are willing to attend 2am meetings when necessary.)

Technical Integration Engineer (TIE) roles ease the transition between product design and manufacturing. Global Manufacturing Centers such as body, paint and general assembly (Figure 3) house functional experts who understand the intricacies across all plants and platforms.

Informal linking mechanisms are created by the employees themselves. The tendency of employees to stay with GM for the majority of their careers results in a large, intricate, and deep social network. GM also hosts bowling leagues, golf tournaments, family activities, holiday parties, car shows, and concerts.

GM has many other methods for aligning the global organization. Standard processes developed over many years facilitate exhaustive problem solving and help to ensure commonality. Some of these include the Bill of Process (BOP), the Bill of Equipment (BOE), standardized product development processes, and GM Manufacturing System (GMS). These will be discussed in Chapter 5. Employees use checklists and online databases to ensure best practices are being utilized and no opportunities or issues are missed. Scorecards are used as tracking devices with green, yellow, and red ongoing status for key metrics and deliverables. A central training organization, General Motors University (GMU) houses technical and non-technical training in any subject that can be accessed by employees worldwide, both online and in the classroom. The incentive system is based on both corporate and individual goals. The individual goals are determined as the organizational strategy is rolled down through each level.

4.1.4. GM Global Common Goals

The challenging competitive environment in which GM finds itself is positive in that it unites the employees to achieve success for GM. Employees are generally very self aware of GM's challenges in the auto industry, and what needs to be done to help fix the problems. GM's corporate goals are listed on the website: "To provide the finest vehicles possible to every customer in every market around the globe"³. This is apparent in working with the employees at many levels. The focus is on excellent quality and delivery of what the customer wants.

³ <http://www.gm.com/corporate/>

General Motors sets organizational direction through a vision statement, subsequently rolling down more and more tactical goals throughout the entire organization. Customer enthusiasm is a key phrase heard throughout the company, and this must be translated into tangible, measurable metrics. Figure 4 shows an example of the types of goals at each level. In the following sets of goals, flexibility is one metric that has been driven down through the organization.

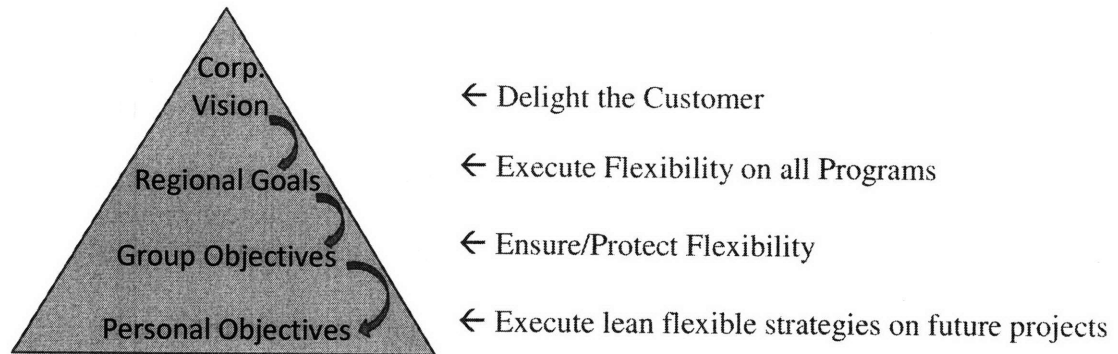


Figure 4: Cascade of goals throughout GM

GM's corporate vision is: "To be the world leader in transportation products and related services. We earn our customers' trust and enthusiasm through continuous improvement driven by integrity, teamwork and the innovation of GM people."⁴

The Group Vice President of Global Manufacturing and Labor, Gary Cowger has responsibility for all manufacturing. His 2008 priorities are designed to achieve the global vision by more targeted means⁵.

1. Attain GM corporate goal of targeted structural cost as % of net sales a year early
2. Execute manufacturing flexibility/product interbuildability on all programs
3. Institutionalize GMS
4. Successfully launch global programs
5. Improve quality through the entire process
6. Share and implement best practices globally
7. Close global competitiveness gap – globally

⁴ http://www.gm.com/corporate/careers/life_at_gm.jsp

⁵ Internal GM documentation

Going another step down through the organization, the Global Manufacturing Engineering Guiding Metrics mention flexibility in point number two⁶.

1. Operate the business globally by leveraging the talent, knowledge and expertise of the entire organization.
2. Protect the manufacturing flexibility & interbuildability of our products & architectures.
3. Achieve Process Driven Product Designs by working in parallel and having an equal voice with Product Engineering & Manufacturing Planning.
4. Be strategic and take risk to achieve investment and operating cost targets.
5. Conduct Peer Reviews to drive lean investment, maximize asset reuse initiatives & incorporate lessons learned.
6. Benchmark our competition to develop common, lean processes & standards that represent the lowest cost global solution.
7. Drive the elimination of waste through Standardized Work & Continuous Improvement.
8. Leverage the cultural diversity of our employees through open communication and create the opportunity for new ideas, personal development and organizational growth.

The ME 2008 Top Priorities boil down to the following initiatives within ME⁷.

1. Flawless Launches
2. Manufacturing Flexibility Strategy
 - a. BOE 4.0 Development & Implementation
 - b. Centers & ME Chiefs ensure flexibility between the Major Global Architectures
3. Execute Manufacturing Footprint
 - a. Greenfields
 - b. Brownfield Conversions - Assembly & Stamping Optimization
4. Targeted Structural Cost
 - a. Lean Investment Focus
 - b. Continue migration of ME Structural Costs
5. Integrated Global ME Organization
 - a. Global HRM Structure (Performance management, Compensation & Headcount Planning)
 - b. Global Budget Structure focusing on Work Sharing
 - c. Workload Model Tool Implementation

Personal Goals that flow down from ME are reviewed twice a year in GM's Performance Management Planning (PMP) process. Goals and objectives are set at the beginning of the calendar year, and then reviewed mid-year and at the end of the year. These include strategic and tactical plans. An example of personal goals is listed below.

⁶ Internal GM documentation

⁷ Internal GM documentation

Metric / Strategic Initiative:

Expand and accelerate manufacturing flexibility

Plan to Improve Performance:

Continue to improve ME input to manufacturing footprint

Centers continue to develop lean M&E/tooling solutions that enable flexibility

Develop manufacturing and operational practices that enable flexibility

This listing of goals throughout the organization, from corporate goals to individual initiatives, shows a consistency of purpose and use of tactical tools and resources to assist in execution.

4.1.5. Conclusion

GM's strategic design has evolved over the years to facilitate the management of hundreds of thousands of employees, long design cycles, and capital intensive production. The tools that GM has implemented to manage flexibility, such as Manufacturing Requirements and Flexibility Enablers, work hand in hand with the other tools and procedures used throughout the organization. The group and subsequent individual goals incorporate the most important strategic and tactical objectives. They are enforced through linkages with coworkers who have similar goals as well as a monetary incentive system. Yearly goal setting and evaluation serves as a closed loop process to keep track of what has worked well and what should be changed.

4.2. Political Lens

The key external stakeholders to any automotive company are the media and the consumers. Generally, consumers can be divided into the emotional and the practical. To those who buy for practical reasons, features such as safety rating, gas mileage, and price are of key importance. Those who purchase emotionally may also consider these features in their decision, but generally less tangible metrics such as handling, performance, and style are the most important. Consumers get their information from a number of places, including word of mouth and media.

Auto manufacturers must design vehicles to fit the needs of the consumer. Qualitative features such as handling and style are very difficult to define and execute. Quantitative features such as gas mileage and storage space are easier to design, but may not be a source of value for the

product. Product development at GM is under intense industry pressure to deliver both style and quality.

Product has historically held the power in the organization, partially because it can directly effect the top line. The decisions made by the Product group have a direct effect on sales to the customer. Product is responsible to design to new regulations and identified customer needs. It is responsible for the weight, handling, and size in addition to many other product requirements. Manufacturing is looked upon by Product as a cost center. To the Product teams, Manufacturing's processes add cost and complexity to the vehicle without adding value to the top line, besides the actual process of putting the parts together.

The increase in price pressure and intense competition in the Automotive Industry has highlighted the need for improved efficiency and lean production. This shift in strategic focus has given the manufacturing side of the business more voice in the development process.

Program teams are also a large source of power within GM. Both Product and Manufacturing employees are assigned to Program teams, which work on one vehicle through its development. Programs teams responsible for high price vehicles (traditionally trucks) have more power than teams responsible for price-sensitive vehicles, such as small car.

Program teams influence the functional areas within the Manufacturing side of the organization. To produce a vehicle that is 'best in class' each program must comply with requirements from all stakeholders. The Program team has to justify its business case, meet the customer defined vehicle specifications, government regulations, and manufacturability requirements. When a program team does not comply with manufacturing or design standards, its options are to re-design, get approval for the deviation, or initiate a change in the standard. Often, one of these metrics will take precedence over manufacturing requirements.

Power at GM also comes through authority. GM's size means many management layers in which people are divided into a large number of discrete tasks. With each person responsible for such a small piece of the larger organization, it is difficult for any one person to affect change. This often leads to deferral of decision making to managers up the chain. The higher in the

organization, the more broad decision power a manager has. People underneath this authority tend to follow their leaders' direction, as long as it is compliant to their best interests.

The evolution of politics at GM shows that Manufacturing is gaining power within the organization, giving this group more leverage to negotiate for the process improvements necessary to be competitive. Each organization is tasked with executing its specific goals. While these goals may not always be aligned with flexibility in the short term, a more holistic view of global flexibility over many years gives Manufacturing more leverage to insist that flexibility is incorporated into the business strategy.

4.3. Cultural Lens

GM is in a time of transition – trying to keep some things consistent (quality) while dramatically changing others to be more competitive. There is a divide in the people at GM – some are old-school thinkers – in the box, do my job, go home at 5. These people believe that management will lead them in the direction that should go in order to keep GM around. Others have embraced change, and want to do everything possible to help GM turnaround. These people still focus on their job responsibilities, but have been given the directive to challenge the status-quo. Others have embraced the fact that things are changing around them. They do not fight it, but are not willing to migrate with this change. These people steadily leave the company through retirements and downsizing.

People here value fair treatment and respect. The UAW has fought for fair treatment of its workers over the years and salaried, non-UAW employees have benefited from these agreements. Employees enjoy a very comprehensive benefits package, many vacation days, and general job security. While GM has negotiated plant closings and down-sizing with the union, both union and non-union employees receive generous separation packages. Fair treatment like this is hard to come by in other industries.

People at GM value respect at all levels. These are people who have a lot of pride: pride in the product they produce and pride in their contribution to that product. GM employees are used to producing products known and discussed all over the world, for what was once the largest

company in the world. While all are well aware of the challenges GM is currently facing, the employees are looking for respect on large and small scales. GM knows that it has to regain respect for its products. Each employee values the personal respect he receives from his peers as an expert in his silo of responsibility.

4.4. *Three Lens Summary*

The Strategic, Political and Cultural lenses combine to form a composite view of the General Motors organization. The Strategic Lens identifies the organization's strength in structure, process and procedure. The Political Lens shows the challenges that are faced due to the organization's size and legacy programs. The Cultural Lens highlights the underlying traditions and customs that are evolving alongside the other two.

This Three Lens analysis, in conjunction with a more in-depth look at GM's toolbox and specific case studies will form a complete picture of how flexibility is approached by the organization. Because responsibility for flexibility is ingrained in the culture of GM, it is important to understand how it is managed, both from the substantive, goal oriented position as well as subtler political and cultural perspectives.

The following chapter will discuss in more detail the tools that have been developed as part of the strategic design of the company, which serve as the best way to execute many of the major operations within the organization.

5. Current State – Tools used to Ensure Flexibility and Interbuildability

5.1. Standardized Products and Processes

GM is executing its initiative to reduce complexity by consolidating architectures and assigning a global homeroom to become a center of excellence for that architecture.

As discussed in Chapter 3, this strategy requires geographic, business and functional management and coordination. To help with coordination GM has put into place key processes and procedures that document best practices, and facilitate communication between teams.

GM has incorporated these initiatives into the development tools to help standardize and align the organization. Both the product engineering and the manufacturing organizations have developed processes to help align the business and aide in flexibility. The next few sections will explore some of these processes.

5.2. Product Engineering: Global Vehicle Development Process

The Global Vehicle Development Process (GVDP) is a high level process used by the engineering organization to outline the key metrics that should be common across all vehicle development programs in all regions⁸. Each regional program then drives these core elements on the critical path down into program specific tasks and functions. A GVDP council manages this process and approves any changes or amendments.

...We've created a new Global Vehicle Development Process, because being the best right now includes having the best development process, one capable of world-class performance standards. This process captures the best features of all our regions. We have agreements in place for a globally common VDP, which is a key enabler for global architecture sharing.

R. Lutz – Global Leadership Conference, March 2004

⁸ Internal GM documentation

The GVDP answers strategic process imperatives such as globalization, resource limitations, lead time reduction, and alignment of corporate architecture and program governance. Manufacturing process driven product design is one of the underlying GVDP philosophies. This highlights GM’s structural realization that early involvement by manufacturing and the incorporation of manufacturing requirements into the design process is critical.

The GVDP, as an overarching process, is aiming to improve flexibility and interbuildability.

5.3. The House of Flex

The vision for GM’s flexibility strategy is a common, global, world-class, flexible manufacturing system to deliver high quality at competitive cost exceeding customer expectations⁹. This House of Flexibility, Figure 5, depicts the relationship between GM’s set of tools. The foundation is based on GM specific Competitive Work Practices and the Global Manufacturing System (GMS). Tools such as the Bill of Process (BOP), Bill of Material (BOM), Bill of Equipment (BOE) and Manufacturing Footprint are crucial to the support of Global Manufacturing Flexibility. Each of these components will be discussed in the following sections.

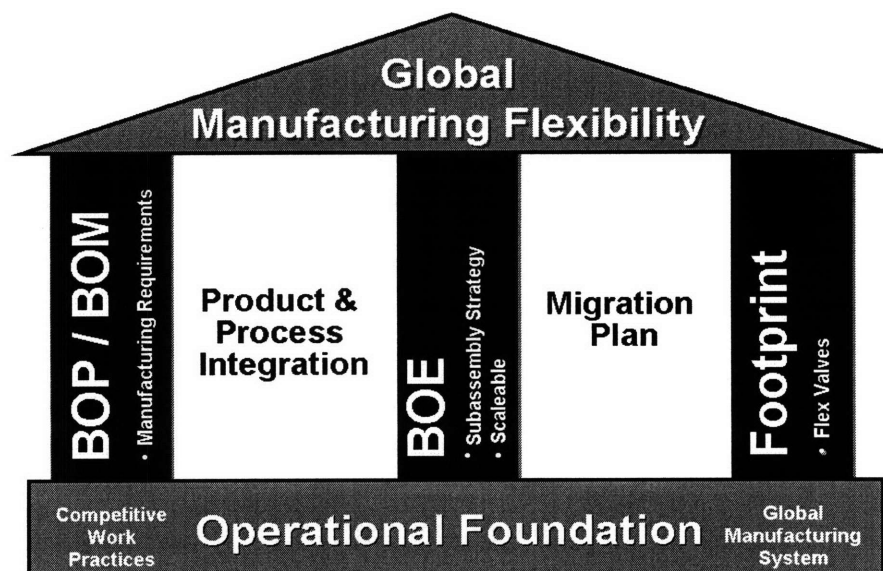


Figure 5: House of Flexibility

⁹ Internal GM documentation

5.4. The Operational Foundation

General Motors has defined a standardized set of principles for the manufacturing process, called the Global Manufacturing System (GMS). Employees are trained in the same GMS elements and associated tools and methods all over the world, in an endeavor to unify the culture and thought process of the entire global organization. GMS focuses on People Involvement, Standardization, Built-In Quality, Short Lead Time, and Continuous Improvement, with specific activities identified to help focus on these important principles¹⁰. This commonality could be compared to the Toyota Production System, as it is a set of values and way of thinking for the entire organization.

Competitive work practices result in fewer job classifications, and allow production operators to work outside the given job scope, performing tasks like simple maintenance.

5.5. Bill of Process (BOP)

The Bill of Process is a common, documented approach to manufacturing and assembling vehicles. The BOP defines requirements for both the product engineering and the manufacturing sides of the organization. The BOP defines the build sequence, subassembly design strategy, major interfaces, and other items critical to flexibility.

The common assembly sequence defines which major steps are done in what order. This ultimately allows for easier incorporation of alternate models into any BOP-compliant plant. It also takes into account major best practices for vehicle assembly, such as a doors-off assembly process.

The BOP is built on the premise of a short main line and modular subassemblies. Bringing a completed subassembly to the main line drives differentiation off of the main line, shortens the most expensive line, and helps reduce variability in quality and cycle time. Because the BOP defines specific subassemblies, their components, and a common interface requirement, it is also

¹⁰ Internal GM documentation

easier to accommodate design changes and address assembly issues. Subassembly build strategy is not defined by BOP, but evaluated on a case by case basis.

GM's goal is to design product architectures and manufacturing lines that are BOP compliant. From the BOP come both tactical and strategic tools to help achieve this goal. Tactical Manufacturing Requirements (MRs) have been developed to help guide each program as it executes its design process. Strategic Flexibility Enablers have been put in place to identify product features that could have global flexibility implications.

5.5.1. Manufacturing Requirements (MR)

Manufacturing Requirements are a manifestation of process driven product design. The MRs are a set of requirements adhered to by the Product Engineers as they design a product. These MRs incorporate program manufacturing requirements into the design process.

They are program specific product specifications that include body, paint, and general assembly requirements to implement the BOP.

The MRs help to highlight the voice of manufacturing early in the design process and aide communication between the two separate organizations of Product Engineering and Manufacturing. The resulting forethought given to the product design enables implementation of manufacturing processes that are best practice and globally common.

As both product and process are developed, the MR status must be tracked. Any deviations from the MRs require a deviation approval. If this cannot be resolved, then the issue is escalated.

5.5.2. Flexibility Enablers

Flexibility Enablers are strategic product design requirements based on the Bill of Process product attributes. The key product characteristics in this list have been identified and agreed on by the global centers. Each product characteristic identified has a significant influence of the global interbuildability of General Motors' architecture portfolio. All products that are

approved during the product development process must adhere to these enablers. A product driven flexibility enabler violation has many implications. The production of the current design would incur significant cost and time investment, including investment to alter processes, change equipment, or hire additional people. The violation could affect the ability to allocate the product to a specific plant, or the allocations of current products with the violating product. It is in the best interest of vehicle development teams to comply with the Flexibility Enablers.

5.6. *Bill of Equipment (BOE)*

The Bill of Equipment enables global use of common equipment, incorporating industry best practices and regional considerations¹¹. Specific to manufacturing, this tool defines the type of equipment and tooling that will be put into a plant to manufacture a specific product.

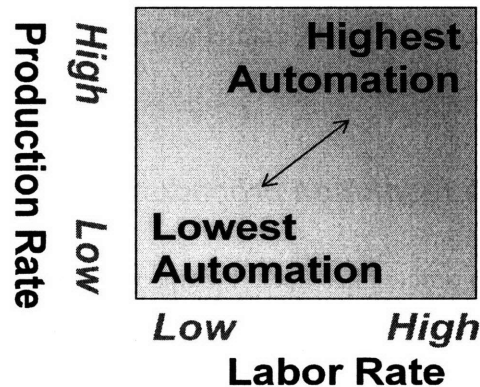


Figure 6: Bill of Equipment nine-box

The BOE was developed as a partnership between all the global regions. Best practices were identified and rolled into the Global BOE, which is to be applied to all programs. The use of globally common equipment and tooling reduces purchasing and maintenance costs and allows vehicle build in multiple plants with minimal cost impact.

¹¹ Internal GM documentation

The content of the BOE is dependent on the plant's geographical context. Factors affecting BOE automation level include production rate and local labor rates in the region, as illustrated in Figure 6. The lower the production and labor rates, the less capital intensive are the requirements for the plant. As a product is being developed and the target facility is identified, the program is allotted capital commensurate with the upgrade required.

5.7. *Manufacturing Footprint*

The manufacturing footprint marries the future product plan with the manufacturing allocation. The future product plan is based on a master architecture plan¹². Product plans are then developed based on the given architectures. A manufacturing allocation plan is developed taking into account current plant capabilities, which are tracked according to the BOP. As a vehicle progresses through the product development processes it is matched with the capability of the manufacturing facility to determine the optimal assembly site. One of the major challenges in determining the manufacturing footprint is incorporating legacy architectures that are not BOP compliant, yet still in production. A lack of product interbuildability makes the manufacturing footprint allocation much more complex.

5.8. *Flex enabler issue resolution procedure*

The flexibility issue resolution process has been documented and includes methods to identify and escalate issues as they arise. Flexibility issues are generated by program teams and manufacturing centers during the advanced vehicle development stage, as the vehicle design and manufacturing process is developed. Each issue is documented on a Flexibility Issue Reporting Form and communicated to the Technical Integration Engineer (TIE), who is responsible for flexibility in the organization. If an impact on flexibility is expected, then the Center that is affected will conduct a study that looks at the issue in depth, identify possible resolution options, and report cost and timing impact. The flexibility TIE tracks issues, coordinates studies and acts as the interface with other parts of the organization to aide in resolution. If the issue is deemed to have an impact to program cost or timing, then the issue is escalated through the organization.

¹² Internal GM documentation

The regular Global Joint Engineering and Manufacturing Strategy (GJEMS) meeting, which includes the Global Vice Presidents of Manufacturing and Engineering, is the final authority on issues of flexibility. Issues escalated to this point have high level strategic implications.

5.9. Conclusion

General Motors has developed many standardized processes and procedures which create an exhaustive network of linking and aligning mechanisms. These procedures have been developed over time and continue to evolve to incorporate best practices. This evolution has resulted in the identification of key Flexibility Enablers, and product and process requirements that are necessary to help ensure a competitive position both in product cost and quality. As issues arise that violate these flexibility enablers, team members are required to follow a process of resolution, with the tools described above as a guide. The following chapter describes a few specific cases in which issues were identified and resolved. The purpose of these case studies is two-fold; first, to better understand the basis of the issues that arise, and second, to identify the actual process of resolution, and understand how it varies from case to case.

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6. Case Studies

6.1. *Research Methodology*

The author spent seven months at the General Motors Tech Center in Warren, Michigan scoping and studying the issues that affect manufacturing flexibility during product and process development. Throughout this period, the author gathered data, attended meetings and conducted interviews.

Meetings provided insight into team interaction, and the relative importance of factors that were being discussed and negotiated. Interviews were initially conducted with Integration Managers, to determine a laundry list of flexibility issues that were in the process of resolution. This list was then pared down to a list of four key issues that had a strategic impact on flexibility over time and across the entire organization. These four issues were further studied to gather a deeper understanding of the problem and resolution process.

To complete the case studies, interviews were conducted with key team members in both the Product and Manufacturing organizations. Interviews were held with technical specialists, engineers, managers, and chief engineers. The specific parties involved in the case studies are listed at the beginning of each section, labeled Issue Escalation Process, within the case studies themselves. Standard interview questions were used at the beginning of each interview, but centered on free dialogue and questions specific to the issue at hand. Some specific questions included: What tools do you use to do your job? What works well now, what doesn't and what would you change? What metrics are you measured on? What issues are of most importance to you? General interviews and meeting observations were also conducted with senior leaders to gain an understanding of the strategies and priorities in the GM organization.

6.2. Case 1: Cockpit 1.5 Flex Enabler

6.2.1. Background

The strategy behind a flexible General Assembly shop has evolved to include a short main line, into which subassemblies are introduced at the level of common interface. The cockpit is such a subassembly. It is built by a separate entity either in a separate part of the plant or by an outside supplier, and then inserted into the vehicle on the main line as one entire unit. The common interface is the cross vehicle beam, to which each subassembly is hung.

The Flexibility Enabler that calls out the cockpit subassembly defines both the specific content waterline of the subassembly as well as the process of its assembly into the vehicle. The Flexibility Enabler reads: “Cockpit 1.5 structural design which is loaded through the door– product capable”¹³.

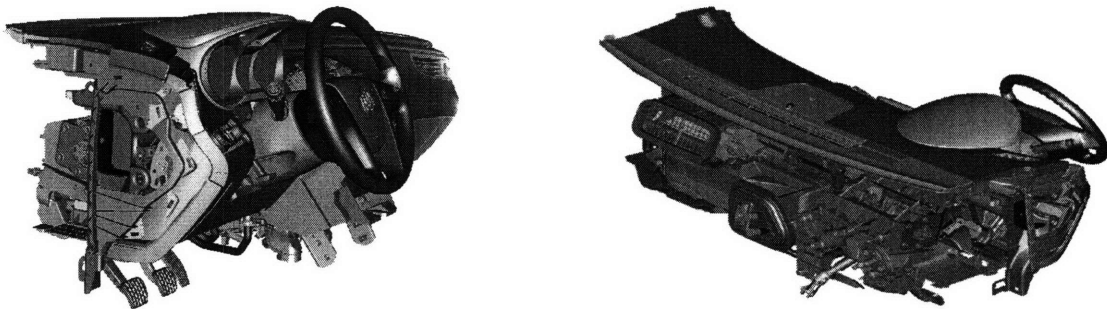


Figure 7: Cockpit Content

The definition of the Cockpit, with respect to content, has changed over the years. Historically, the content contained in today’s cockpit was manufactured as a layer build, in which components were assembled to the vehicle while traveling down the main vehicle assembly line. This resulted in a longer line and made line balance more difficult. The subassembly concept moved assembly of all cockpit content to a separate line which included cockpit build and functional subsystem test. This completed cockpit was then installed to the vehicle in one station on the main line. As vehicles were designed and

¹³ Internal GM Documentation

launched using this system, the content of the subassembly evolved into the content defined by Cockpit 1.5, as shown in Figure 7. This definition included the Cross Vehicle Beam, HVAC, 'mod' plate with pedals attached, Instrument Panel (IP) assembly, and Steering Column assembly. As new architectures are developed, Cockpit 1.5 has been challenged and adjusted to meet flexibility, program specific, functional, and assembly requirements.

6.2.2. The Specific Issue: A Decontented Cockpit 1.5

The Chevy Aveo and Opal Corscia were the first vehicles based on the small vehicle architecture, launched in 2001. The small car architecture was unable to comply with a fully contented Cockpit 1.5. In this case, the entire cockpit assembly, including brake booster and pedals, could not fit through the door opening during the installation process. Because the pedals were attached to a 'mod plate' in the existing Cockpit 1.5 definition, the mod plate was removed from the requirement. An alternative assembly process was identified. Instead of attaching to the cockpit subassembly, the brake booster and pedals were assembled to the vehicle (front of dash) as part of the main line. Ultimately, the cockpit content rules were altered to include the pedal assembly, but allow the brake booster to be included ad hoc, for each program. This new subassembly is referred to as the 'Modified Cockpit 1.5 content'. Vehicles based on the small car architecture continue to violate the original Cockpit 1.5 definition.

6.2.3. The Specific Issue: Small Car vs. Compact and Mid-size

The manufacturing plan for the most recent small car architecture targeted a facility which built the compact and mid-size architectures. Concern arose when it was noted that the small car cockpit content and subsequent manufacturing process required was not compatible with the other architectures. The compact and mid-size solutions are BOP compliant. They are built so the pedals are installed as part of the cockpit subassembly. The brake booster is assembled on the main line, after cockpit installation.

Product Engineering designed this new Small car to be built with the pedals assembled to the vehicle on the main line, prior to the cockpit subassembly installation into the vehicle. Although this was not BOP compliant, this was a logical progressive decision for Product

because this process was 'mainstream' for the legacy small car architecture. This solution also met Product's requirements of lower piece price, and was a better fit with legacy product. Manufacturing direction diverged from this process, and recommended the pedal assembly be installed as part of the cockpit subassembly, to be interbuildable with the compact car.

6.2.4. Product Concerns

Product designed the cockpit for the new small-car to include the same basic content as previous vehicles in this architecture family. In this context, the brake booster and pedals were an integrated design, and had to be connected to each other. Product viewed the additional engineering and content that was required to comply with BOP as wasteful, because it meant increased weight and complexity.

Product is concerned with the satisfaction of the end customer. Noise, Vibration, and Harshness must be minimized. This means that the design of the cockpit must be robust. Safety for the passenger is also a key concern. The interfaces between parts in the design of this major subassembly can affect the energy transfer in the event of a crash. The design was meant to avoid loading of the brake booster and subsequent load on the pedal, pushing back towards the driver.

6.2.5. Manufacturing Concerns

Manufacturing concerns drove the change in design and manufacturing of this vehicle, based on the recommendation that the small car architecture be built in the same manner as the other architectures. While BOP deviation had less impact on the product side, manufacturing costs would increase substantially based on the need to facilitate high volume, mixed architecture production.

Mixed architecture production would increase the labor and training required to complete two separate installation processes. Additional space and tooling on the main line would be required for only the small car architecture, impacting the overall build efficiency of the assembly line. For instance, an assembly worker responsible for the installation of pedals on

a small car could be left idle when a vehicle based on a different platform passed by. This process also complicated the order of the processes, affecting the order in which other components could be placed. Material handling complexity would increase substantially due to the high volumes of each of the products. Ergonomic concerns also arose with the mainline pedal assembly and subsequent process changes.

Benchmarking showed that no competitors install pedal box as part of the entire cockpit assembly on equivalent sized vehicles.

6.2.6. Issue escalation process

The Global Technical Integration Engineer (TIE) who is responsible for the cockpit subassembly is tasked with ensuring commonality across architectures. He attends status meetings across programs to drive commonality and stay informed of program issues.

The MECE raised this particular issue and had his team do case study analysis. He worked with his counterpart on the Product Development side of the organization. Disagreement on general strategic direction resulted in the issue being raised to the Vehicle Line Executive (VLE). The VLE didn't agree with Manufacturing's recommendation to deviate from PD design.

The issue was then raised to the General Assembly enterprise group, in preparation for going to highest level, GJEMS, the group vice presidents of Manufacturing and Product Development. Group VPs gave direction to comply with BOP regardless of cost implications, keeping with set strategy. As a result, vehicles based on the small car architecture will be produced in the same manner as Compact and Mid-size, the vehicles it will be built alongside. The pedals will be included in the cockpit subassembly, as required by BOP.

6.2.7. Implications

In the market for a small car, customers are very sensitive to price and not willing to pay for differences in a manufacturing process. GM management had this to consider when making

the decision to incur additional cost to keep the architecture BOP compliant. This also shows management's consideration of the entire value chain, weighing the direct increase in product cost for a BOP compliant design with the cost of manufacturing complexity and degradation of flexibility and interbuildability that would result from violating BOP.

Enforcement of the BOP and Flexibility Enabler resulted in a number of improvements. It commonized the solution with Compact and Small car, allowed common assembly processes, eliminated ergonomic challenges, minimized manufacturing inefficiencies, and improved future flexibility. In this case the solution was not technical, but strategic. This issue was escalated to GJEMS to provide direction for a decision that could have short term implications, but long term benefit.

6.2.8. Conclusion

In this case study, the issues of BOP compliance and architecture commonality were mostly strategic. The people involved in the escalation of the issue recognized the implications; it was apparent early on that it would be raised to the highest level, GJEMS, to give upper management the opportunity to reiterate the strategic priorities within the organization. In the end, this issue was resolved with approval to incur additional product development cost in order to maintain product and manufacturing commonality.

6.3. Case 2a, 2b: Body/chassis marriage

Body/chassis marriage is performed on the main line in the assembly plant. In this process, the painted body is transferred on carriers from the paint shop, to join the partially completed chassis which is traveling along the main assembly line.

The process for body chassis marriage varies depending on the assembly plant, and is based on a number of factors, including the BOE. In an automated marriage procedure, the body and chassis are brought together and fastened in a cell with absolutely no operator involvement.

In a semiautomatic marriage process, a hydraulic lift lifts the chassis up into the body and operators on the line remove interferences and execute fastening procedures. In one case, the body and chassis cease forward movement in a 'stop station', while the marriage is performed. In another case, the body and chassis continue forward movement along the main line, but synchronize their relative movement as they are married together. In either case, the product requirements for marriage are the same.

6.3.1. Background

General Motors is creating a brand new architecture aimed at a very specific target market. For the purpose of this paper, the architecture will be referred to as KX. The first vehicle being designed with the KX architecture as its base is critical to GM's globalization process and development of the brand; it is the pioneer vehicle program for this architecture. According to a GM employee on the team, "our team is committed to delivering a vehicle that exceeds its targeted competitor".

The KX architecture just recently passed through a very early phase gate in GM's GVDP, a gate at which the essential elements of the architecture are established. At this point, the architecture framing is complete and the Engineering and Execution stage of the GVDP begins. The program based on this architecture also passed through the Program Framing

Initiation (PFI) Gate. At PFI, customer requirements are translated into technical requirements, and engineering solutions within the context of the architecture begin to form.

In order to successfully develop this breakthrough vehicle, the KX development team has been given a directive to challenge the status quo of the current development process when necessary. This challenge is meant to test the rigor of the current development process and associated tools, and result in an optimized architecture definition with respect to real constraints.

6.3.2. Case 2a: The Specific Issue: Stepped Engine Load

The manufacturing BOP requires a direct vertical load of the chassis into the body. Current body/chassis marriage processes are performed as a vertical load. The Flexibility enabler reads: “Vertical load (marriage) of powertrain, front and rear suspension components without compound motion”¹⁴.

Size, weight, and handling are all primary concerns for the business case of the new vehicle. The engine performance requirements for KX result in a design that creates a no-build manufacturing condition in the body chassis marriage process. The resulting solution that is studied in this case study is an indexing of the front part of the chassis with respect to the rear and the body, as shown in Figure 8.

¹⁴ Internal GM documentation

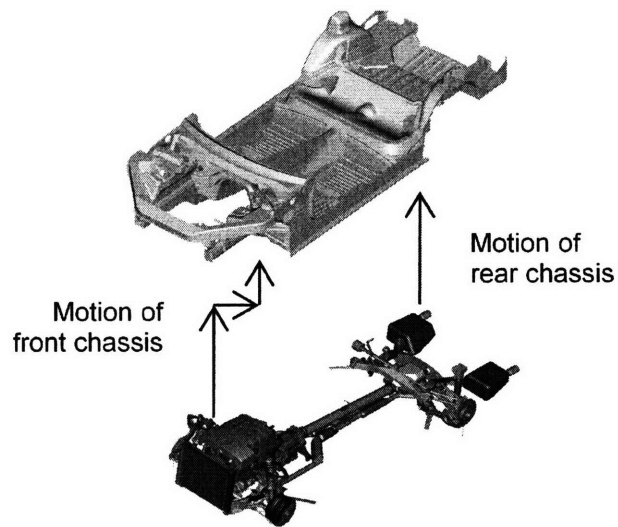


Figure 8: Body Chassis Marriage - Indexing of Chassis

This proposed solution has both product design and manufacturing implications. Changes to the vehicle design and manufacturing process to accommodate this solution could affect current legacy production, the future production allocation of KX architecture-based vehicles, and future allocation of other architectures alongside the KX. Each team must keep these consequences in mind while searching for a solution.

6.3.2.1. Product Concerns

Pegging the architecture's definition to a specific product market translates to stringent global customer requirements, specifically vehicle target size and performance. As development progresses, every design and manufacturing decision that deviates from these two goals is challenged. During development, the Product team must balance the vehicle program requirements while still complying with MRs.

An implication of new architecture development above and beyond standard vehicle development is importance of architecture optimization. Typically, due to complications throughout the development process, vehicle specifications inflate, and the vehicle design becomes bigger and heavier. Because this is a new architecture, off of which future vehicles will proliferate, the team responsible for this the KX architecture cannot allow this to happen.

The KX architecture team can take advantage of a clean design slate. While they must incorporate Corporate Common Components (CCC) into the design, they have no legacy parts or designs to incorporate into their vehicle definition. If a better solution or process arises, they have not only the ability, but the responsibility to challenge the current methods and tools.

Vehicle size and performance metrics are closely linked to each other. A third related metric is vehicle handling. Vehicle handling performance is directly affected by weight distribution of major vehicle subsystems. In addition to size, performance, and handling the Product team is also concerned with engine power and fuel economy standards.

The critical measurement that drives the minimum vehicle length is the powertrain to dash distance. This and the handling and subsequent weight distribution metrics require the powertrain sit as close to the dashboard as possible. As a result, space inside the engine compartment is a premium. This KX program is set to minimize engine compartment space. As product selects the components that will fulfill vehicle performance and weight requirements, the program team must negotiate internally just to result in a viable product package.

An auxiliary fuel pump attached to the engine is required to meet performance metrics. This aux fuel pump creates interference during a strictly vertical body/chassis marriage. The only product based solution to this issue was to increase the distance between the powertrain and the dash, allowing clearance for the aux fuel pump, and effectively lengthening the entire car. This is a cardinal sin in architecture development, because it is always easy to increase size and weight at the expense of performance.

Product could comply with the vertical load requirement, but the resulting increase in minimum architecture length, degradation of vehicle handling and increase the minimum architecture weight was unacceptable. If the Product team followed this solution, it would have to compromise its key product requirements, and put the entire architecture business case at risk. As a result, the product team pushed back on the Manufacturing Requirements, and asked that Manufacturing perform and evaluation to better understand the manufacturing process implications of their design requirements.

The resulting stepped marriage solution that was proposed required that Product incorporate the capability for a small longitudinal propshaft slip. Suppliers are nervous about this design because such a change opens many powertrain performance implications.

6.3.2.2. Manufacturing Concerns

The marriage process at any facility requires extensive investment in equipment and tooling. This process is considered a “monument” because it is large, complex and expensive to alter. Thousands of pounds of steel must be brought together, aligned and fastened within only millimeters of tolerance, in a few seconds of time. Once the marriage process is located within an assembly facility, other processes are planned around its position and function. Any change to a monument such as body/chassis marriage would be expensive to duplicate in other plants and would have implications for legacy vehicles. To the manufacturing team, it is a given that this equipment or tooling cannot be changed for the sake of one vehicle. However, there is room for change within the processes of the body/chassis marriage.

Manufacturing is evaluating a few alternative marriage options:

1. Index and lift: Shown in Figure 8, page 49. The front chassis begins to index forward with respect to the rear. The chassis is lifted into the body cavity, almost to the final vertical position. Then, the front chassis is returned to its initial position, and the chassis is lifted the remainder of the way into the correct position. This will allow the chassis, including powertrain, to edge around the body as it is fit into place. This procedure will require product to re-design a portion of the chassis/powertrain system to create a joint with longitudinal slip, so that the front of the chassis can index forward with respect to the rear.
2. Angle and lift. As the chassis is lifted, the front rises higher than the rear. The front is then angled into the body, avoiding interferences. The rear chassis is then lifted to its final marriage location. At the time of this case study there was no conclusion that this solution would be viable, but if it worked, it could remove the need for alteration to the product itself. An evaluation using computer based computational tools was done for initial assessment.

These potential manufacturing process solutions have product design implications. Manufacturing has asked Product to look at altering a portion of the vehicle design that does not have the same architectural footprint increasing implications. But, both these development options will be evaluated concurrently.

The manufacturing team is also concerned that a change to the product, the manufacturing process, or both, will make it more difficult to allocate vehicles from the KX architecture to any other plant without a large investment and machine alteration, thus affecting manufacturing flexibility.

6.3.2.3. Issue escalation process

Parties Involved

Compartment Design Integration Engineer (CDIE)
Compartment Integration Team (CIT)
Vehicle and Process Integration Review meeting (VAPIR)
General Motors North America (GMNA)
Advanced Vehicle Development (AVD) Executive Director
Manufacturing Chief Engineer (MCE)
Program Engineering Manager (PEM)
Architectural Manufacturing Integration Manager (MIM)
General Assembly (GA) Manufacturing System Integration Engineer (MSIE)
Manufacturing Engineering (ME)

December 2006. The requirement for a stepped engine load was identified in underhood packaging work by the CDIE. It was reviewed at both CIT and VAPIR meetings. Both the GMNA AVD Executive Director and MCE were notified of the issue.

The Product and Manufacturing organizations discussed options and alternatives for resolution of the issue. It was agreed that the Product team could not reasonably change the engine compartment space, so Manufacturing requested permission to explore the potential for a 'stepped' or 'staggered' engine load.

January 2007. The Architectural MIM facilitated a review at the targeted assembly plant with Product engineers, Manufacturing engineers, the PEM, and the MCE. As a result of this meeting, both Product and Manufacturing committed to evaluating the feasibility of a stepped engine load. Each group had to evaluate the resulting impact on current product and process

design. Product identified design enablers required to facilitate a stepped engine load and began analysis. Manufacturing agreed to pursue revision to the current Automatic Guided Vehicle (AGV) tooling plate system for an off-line evaluation test.

Spring/Summer 2007. The GAE TIE obtained funding through ME Adv Tech Work project leadership team for development of a tooling plate system. A contract was formed with a tooling supplier.

September/October 2007. The Program team, including GMNA-AVD Executive Director and MCE, agreed to approve two of the GVDP phase gates with the marriage process as an open issue, coded yellow¹⁵.

December/January 2008. The revised tooling shipped to the assigned assembly plant to be tested. The GA MSIE conducted a trial/workshop with appropriate Product and Manufacturing representatives. The goals of this test were:

- ❖ Level set both design and integration stakeholders on the proposed marriage process.
- ❖ Identify product design enablers.
- ❖ Affirm design owners' buy-in to support and subsequently deliver the enablers.
- ❖ Identify and capture improvement ideas for the proposed marriage process.

January 2008 update. The common intent of both Manufacturing and Product Engineering to continue development of a stepped engine load has been noted in all Program team gate reviews and Manufacturing Engineering leadership updates since issue was discovered. The architecture and parallel vehicle development process is moving forward with the stepped engine load as the anticipated solution.

6.3.2.4. Implications

The architecture development team and other stakeholders must have an understanding of which plants will build this architecture in the future. The ultimate solution should involve a manufacturing process that does not involve extensive modification of legacy tooling. The product should be interbuildable with other architectures so that future plant allocations can be

¹⁵ A yellow code is defined as "Moderate risk; known recovery plan".

accommodated. Even if the KX architecture is slated to be built in only one or two plants now, a change in plan has the potential to invalidate the business case for the product design.

This issue will be resolved without escalation to GJEMS, because the strategic implications are understood by managers. Manufacturing and Product development are working together to develop a technical solution that works within the BOP.

6.3.2.5. Conclusion

This Body/Chassis marriage issue can be viewed as a technical issue with basic strategic flexibility implications. At the time this case study was completed, the resolution had not yet been reached. However, the team had a plan in place to resolve the issue without impacting the overall flexibility of the assembly process. In this case, Product and Manufacturing work hand in hand to come up with a compromise that will be the best for GM as a company.

6.3.3. Case 2b: The Specific Issue: Vertical Fastening

During the body/chassis marriage process, the chassis cradle attaches to the body with six separate fasteners, three on each side of the vehicle. To remain standardized for both manual and automated marriage processes, vertical fastening is required. This helps with standardization of tooling, product and process. The Flexibility Enabler reads: “vertical fastening (marriage) of powertrain, front and rear suspension without compound motion”¹⁶.

Through concurrent development, the new global KX architecture team identified a substantial weight savings and more robust management of crash loads if one of the three bolts on each side were fastened perpendicular to the chassis, rather than directionally vertical. Figure 9 shows the proposed dual fastening design. As shown in this illustration, the number 3 fastener is inserted perpendicular to the body frame.

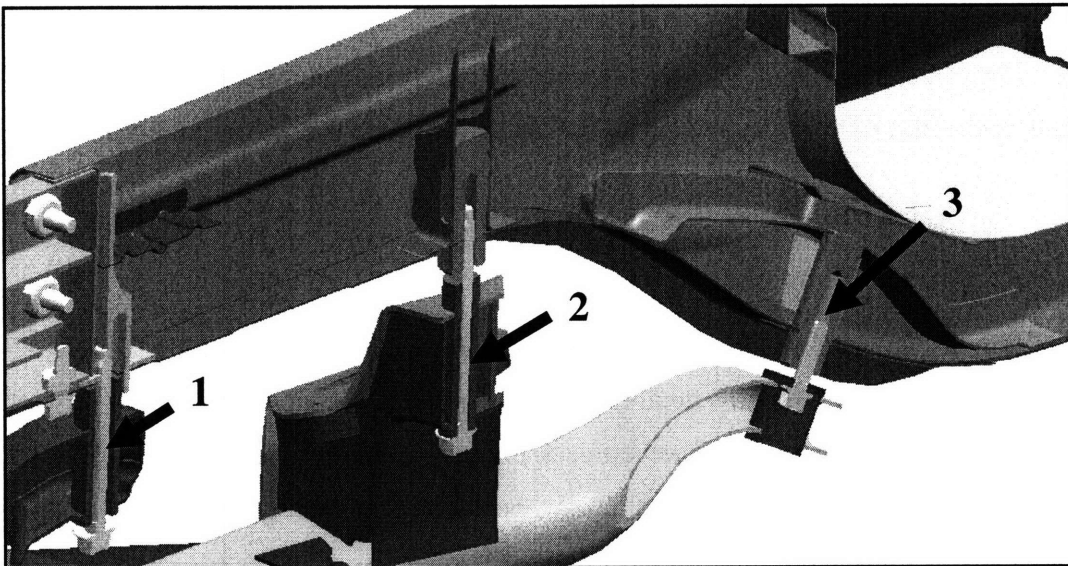


Figure 9: Body/Chassis Dual Direction Fastening Design

Manufacturing flagged this design as a violation of the Flexibility Enabler, and an alternative design was developed. In Figure 10, the proposed vertical mount design is shown. The three fasteners are identified by black arrows.

¹⁶ Internal GM documentation

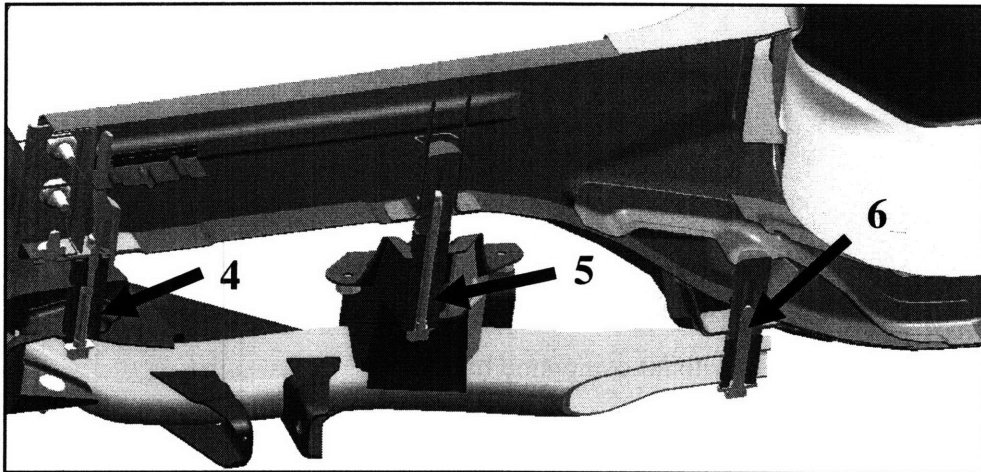


Figure 10: Body/Chassis Vertical Fastening Design

The new design complies with the Flexibility Enabler, so all the fasteners are directionally vertical. To accomplish this, the design had to accommodate the curvature of the body frame member. As a result, the design for fastener number 6 required an additional bracket. This additional bracket introduces added complexity that the global architecture team would like to avoid. At the time of this case study, the KX architecture team planned to use the cost and load improvements of the bracketless design to support a challenge of the vertical fastening flex enabler.

6.3.3.1. Product Concerns

The dual direction fastening design is robust from a design perspective. Incorporation of a purely vertical mount in order to meet a flexibility enabler is a suboptimal solution. The additional bracket required to accommodate vertical mount has a large impact on overall product weight and increases part count. This vertical design also reduces the ability of the body and the chassis to efficiently distribute crash loads.

6.3.3.2. Manufacturing Concerns

Each marriage process, (fully automated, partially automated with stop station, and partially automated with constant movement), is affected by this proposed change in a different way. Because the Body/Chassis marriage process is mostly automated, any non-vertical bolt

attachment design violates flexibility requirements and is considered a RED issue¹⁷. In a partially manual marriage process, both with stop station and with constant movement, operators use torque tools supported by a swiveling arm for ergonomic assistance to bolt the chassis and body together. The design of the tools limits the operator to fasten only in a vertical direction. Acceptance of a non-vertical fastening position could require alteration of automated tooling, alteration of operator tooling, or movement of the fastening process to a different point in the assembly line. In the partially automated marriage process the ability to adjust is much more feasible than in a fully automated process.

6.3.3.3. Issue escalation process

Parties Involved:

Architectural Manufacturing Integration Manager (MIM)
General Assembly (GA) Manufacturing System Integration Engineer (MSIE)
Manufacturing Chief Engineer (MCE)
Manufacturing Engineering (ME)
Design Release Engineer (DRE)
GMNA AVD Executive Director
Technical Integration Engineer (TIE)

September 2007. The Architectural MIM and GA MSIE raised the enabler violation at the Manufacturing Health Check meeting, just prior to the Architecture Definition gate review, as part of the standard program assessment. The ME functional team directors and MCE made the decision to designate the current non-vertical cradle bolt attachment design as a RED issue due to manufacturing flexibility requirements. At the time of the case study the magnitudes of design impacts such as mass were not yet defined.

The Architectural MIM was responsible to inform the Chassis and Body team about the requirement for a design change. As a result, the Chassis and Body technical team developed the details of the non-vertical design in order to estimate the mass impacts of the two different designs.

December 4, 2007. By this date, Body engineering had completed the preliminary designs for both conditions, and understood the specific cost and mass impacts of both designs. Body DRE requested another review with the Body Architecture leaders, the GMNA AVD Executive

¹⁷ A red issue is defined as “Significant risks and no recovery plan or high uncertainty”

Director and the Architectural MIM, to present the significant weight impact that would result from the design change. The DRE recommended a second look at the decision to incorporate the vertical fastening design with the bracket, in order to comply with Flexibility Enabler. The Architectural MIM agreed to reevaluate proposal with Manufacturing team.

December 6, 2007. The Architectural MIM had the MCE review both the designs and impacts with the DRE and obtained the support of the MCE.

December 7, 2007. The Architectural MIM, MCE, and GA-MSIE took the proposal for the dual design into the GAE leadership review, a monthly review on Architecture, and requested support and approval for the modified, partially vertical design. The Flexibility TIE was in attendance to ensure understanding from a flexibility issue resolution and requirement standpoint. The GAE leadership, the director and EGMs, approved the proposal. As a result, a revision of the flex enabler verbiage is under consideration by the GAE. The altered Flexibility Enabler would include a requirement for four (of six total) bolts to remain vertical within the marriage station. This will allow two of the six total bolts to be fastened as required by the product design.

December 10, 2007. The GA MSIE informed the Program team of the decision that was made. The issue is closed.

6.3.3.4. Implications

This decision was made with thought to future allocation of tooling and production, as well benchmarks of other current designs. The automated body/chassis marriage process is expected to continue in some GM plants, and possibly proliferate to other plants, so leaders took into account the need to incorporate a design that could be manufactured in either a fully automated or semi-automated marriage process.

In making this decision, the stakeholders were confident that the existing automated process could still be utilized. This is a standard six bolt cradle design, with three bolts on each side. Four bolts are vertical and two are not. In an automated marriage process, only the four vertical bolts would be fastened, or 'hard mounted', during the marriage. This process would allow the four bolts to locate and adequately secure the cradle to the vehicle body prior to removal of the marriage tooling support. The remaining two bolts would be fastened at a later stage in the

assembly process, most likely by operators with hand tools. There were no significant dimensional concerns on alignment of holes for the additional two non-vertical bolts.

The team validated this decision with benchmarking of other similar processes. Another similar platform is produced with this separated fastening process. This is also a six bolt, hard mounted cradle, but all six bolts are vertical, compliant with BOP. In this manufacturing process, four bolts are vertically installed during the body chassis marriage process and two additional bolts are driven in the following workstation, after removal of the marriage tooling. This process alteration was done to meet cycle time requirements in the body/chassis marriage cell, but shows that the separated fastening process can be done successfully.

As far as application to the global manufacturing environment, other plants with an automated body/chassis marriage process in Europe currently build only very similar architectures. To bring in a vehicle similar to the KX architecture, additional processes will be required in the station(s) following the body/chassis marriage process. Therefore, with the incorporation of new processes required to accommodate the KX architecture itself, a workstation design similar to the one in the States could likely manage installation of two non-vertical cradle bolts.

In summary, the rationale for agreement was 1) only four bolts would be fastened at the marriage station, 2) The remaining two would require a new tool and 3) The fastening of these remaining two could be accommodated in another station. Based on internal studies done, and benchmarking of other processes, this was a feasible solution.

6.3.3.5. Conclusion

Resolution of this issue was achieved through data driven analysis, benchmarking of current processes on other architectures, and compromises by both Manufacturing and Product organizations. Both showed an inherent concern for flexibility, considering both the current and future implications of their decisions. The resulting conclusion called for a revision of the existing flexibility enabler, to make it more specific and thus allow for increased flexibility in the design and manufacturing process.

6.4. Case 3: CO₂ Refrigerant for Europe

6.4.1. Background

The European Union has passed legislation banning R134a for use in vehicle cooling systems, effective 1/1/2011 for all 'new type' vehicles, and 1/1/2017 for all new registrations.

GM has been anticipating this new regulation and studying alternatives to the current R134a cooling system. The new regulation requires the Global Warming Potential of the refrigerant to be less than 150. GWP is "a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1)." (Wikipedia: Global Warming Potential) The GWP for R134a is 1300, while CO₂ is 1. R152a, another refrigerant that was being considered, has a GWP of 120. This would meet the new GWP<150 requirement, but would most likely become obsolete after any future emission reduction requirement changes.

While research has been done to identify other alternatives besides CO₂, OEMs have decided to collaborate through SAE¹⁸ to make CO₂ the new mainstream refrigerant. VDA¹⁹, SAE, and JAMA²⁰ have formed a cooperative to develop global processes for Lifecycle analysis. The new system provides an open approach with sharing of development information. (International Energy Agency Workshop: "Cooling Cars with Less Fuel", 2006)

6.4.2. Product Concerns

A new CO₂ system will impact standard vehicle cooling system components. A CO₂-based system requires an accumulator, so under hood packaging must accommodate this new structure as well as the legacy, receiver based, R134a structure. System components must also be designed to withstand the higher pressures required in a CO₂ system. In addition to design challenges, developers must also accommodate service and safety concerns. Technically, this

¹⁸ SAE is the Society of Automotive Engineers

¹⁹ VDA is Verband der Automobilindustrie, a German quality standards organization.

²⁰ JAMA is the Japan Automobile Manufacturers Association

means additional sensors and control logic, and additional equipment such as a heat exchanger, more fan power, and better baffling.

A decision also has to be made between two major options. To allow a vehicle program to design for

1. A flexible dual system that accepts either CO₂ or R134A, or
2. A vehicle that can accommodate both systems simultaneously

Product would like to design parts to be interchangeable.

A new system will also add weight to the vehicle, changing its fuel efficiency rating, handling and many other vehicle characteristics.

The use of CO₂ also requires more energy. Therefore, fuel efficiency is reduced in comparison to R134a, mainly in warmer climates.

Noise, Vibration and Harshness (NVH) is also a concern for the product team. To address vibration concerns, appropriate mounting of the compressor will be important. The high pressure of the CO₂ system will also require the team to address 'hiss' and 'thump' noises that could violate NVH requirements. This could also lead to leakage issues.

The implications for product development stemming from this regulation change are considerable.

6.4.3. Manufacturing Concerns

Manufacturing must put into place additional assembly space and more complex processes to accommodate a CO₂ based system. The additional parts required for the CO₂ system will have an impact on the assembly sequence and line balancing, not only for plants that have to support CO₂ systems, but plants that have to support both old and new systems. Facilities that will produce only CO₂ based vehicle systems would remove the standard evacuation and fill process and incorporate the new CO₂ installation and fill process directly on the main assembly line.

Incorporation of a CO₂ based system installation process into a manufacturing facility has a substantial impact on the global footprint, as well. Facilities that build only vehicles in the EU for the EU can be converted completely to a CO₂ based system installation. However, it will be much more difficult to allocate an EU-bound vehicle to any facility that produces vehicles for non-EU countries. To remain flexible, a facility producing both EU and non-EU-bound vehicles will have to develop an assembly, fill and test process that can accommodate both systems. This could result in a substantial cost and timing impact.

Another key concern is the location in which the system will be filled and pressurized. Shipping cars with highly pressurized systems involves some level of risk. A few different options are considered. First, the system could be filled and pressurized at the plant. Second, a 3rd party could be contracted to fill and pressurize after the vehicle is assembled, before it reaches the dealer. Lastly, the dealer could have in place a method to fill and pressurize the CO₂ cooling system. Outside contractor intervention would deviate from current BOP and First Time Quality Standards.

The pressure required for the CO₂ system also has to consider increase in potential leaks due to the larger number of joints in the system. The joints must be accessible for leak tests after fill as well as service in the field.

6.4.4. Issue escalation process

2005. The CO₂ proof of concept was completed. Global Central engineering developed CO₂ parts and integrated them into Corporate Common Components (CCC) list.

February 2006. At the Global Engineering Leadership Team Review a recommendation was made to diverge on HVAC refrigerants for Europe to meet the new standards, but keep the current R134a refrigerant for non-European vehicles.

May 2006. The team is continuing to work to minimize resources needed.

In this case, issue escalation was minimal. The issue was identified at a high strategic level and the regulatory changes were anticipated and tracked. Because this change was driven by the European regulatory environment it was generally understood that a solution was required, not optional. Management kept abreast of the status although no flexibility specific escalation was required.

6.4.5. Implications

Cost implications for such a requirement are broad and large. First, an increase in design resources is needed to address the initial design and development of this new system.

Upcoming vehicle programs will require concurrent development to accommodate one or both systems. Infrastructure will need to be incorporated into manufacturing facilities to accommodate either one new, or both systems. Dealers who sell and service the vehicles would have to acquire tooling and educate employees on fill and service of the new system. Suppliers would have to alter and update tooling.

CO₂ has been identified as the best chemical to address the European regulations. However, R152a is also being researched as an alternative. Manufacturing has several viable alternatives for addressing the CO₂ requirement.

Globally, there is no consensus on a way forward for automotive refrigerant regulations. Therefore, all future global vehicles must be designed to accommodate either system. European competitors are expected to launch CO₂ earlier than requirements dictate. R134a is expected to remain mainstream refrigerant for all other regions besides Europe. North America will likely not follow CO₂ direction (currently restricted in some states). Japan has stated opposition to CO₂ (JAMA requested EU to delay implementation). Cost sensitive markets are unlikely to adopt the additional structural and piece part costs required to introduce the new refrigerant.

6.4.6. Conclusion

The CO₂ refrigerant issue has broad implications for both Product and Manufacturing. This issue was identified early, and will continue to be evaluated and resolved as a multi-stage process, for many years. Although flexibility is a major concern of the team exploring possible options and solutions, there have been no flexibility specific issues that have arisen. It is in a case such as this that all the team members involved must keep flexibility requirements in mind when making decisions, so as not to compromise the flexibility of the system as a whole. This will be an interesting case to follow as decisions continue to be made.

6.5. Case 4: Paint Issue – Liquid Applied Sound Dampening

6.5.1. Background

Liquid Applied Sound Dampening (LASD) is a material that dampens the sound from road and body vibrations within the passenger compartment of a vehicle. It is applied to the body of a car and oven baked in the paint shop.

Previously, applied dampening pads were used to meet Noise, Vibration and Harshness (NVH) requirements. These pads had adhesive on one side, which was peeled off and applied to the body during the general assembly process. This adhesive process is labor intensive and required storage of multi-size, bulky pads near the main assembly line. The pads could be ergonomically awkward and generated waste such as dirt and edge trimmings.

LASD is a bulk material that acts like a paste as it is extruded onto the vehicle body by a robot. The LASD application process is completely automatic. Inherently more flexible than the previous method, LASD is agile and can easily adjust the location and thickness of application.

6.5.2. Product Concerns

The application of LASD addresses Noise, Vibration and Harshness (NVH) performance flexibility. Robots can be reprogrammed to apply the 'paste' in many different locations and thicknesses. NVH is a very important factor in a vehicle design when aggressive damping treatments are required. GM incorporates use of applied damping materials and specially treated steel extensively throughout a vehicle to remain competitive.

6.5.3. Manufacturing Concerns

There are many benefits to incorporating the LASD process into a plant. However, manufacturing has to take into account a number of concerns when choosing whether or not to implement it. First, a plant must have the floor space to dedicate to the robot within the paint shop. Because paint shops are monuments (like the marriage process) alterations can be tricky and expensive. It's much easier logistically to put LASD in a Greenfield environment than to

drop it in to an already existing shop. Brownfield investment could be 2-3 times installation cost in a Greenfield plant. The LASD robot itself requires a substantial investment that cannot be justified in all circumstances.

For LASD to be applied, the assembly line must incorporate a stop station. The vehicle must be able to stop long enough for the application process to complete, and then resume normal movement.

Improvements associated with LASD include fewer operators required, reduction in material handling and labor costs, application consistency and specialized placement.

6.5.4. Issue Escalation

A Notice of Action (NOA) was posted in November of 2005 through Global Joint Engineering and Manufacturing Strategy (GJEMS), requiring incorporation of the LASD process into all GM North American assembly plants on all new vehicle programs. This was effective 9/1/2005. Any programs with contract signing after this date were directed to implement LASD “as soon as practical”, taking into account impact to plant and process modifications. The Paint and Polymers Center is given responsibility to determine implementation timing on a case by case basis going forward. Implementation is funded by each individual product program.

The current decision method is based on business case, requiring a specific payback period. The Center director presents the business case, and the product team approves the final sign-off. Deviations from the plan are allowed if implementation cost is excessive, but must be brought to GJEMS by the Program Team for approval.

A sample business case incorporates the following factors²¹:

Labor Savings: material handling for pads, Sealer application, other

Material savings: Damper pads, kit sequencing, additional sprayer material

Investment: Total investment less manual pad investment.

²¹ Internal GM documentation

Total Savings is calculated by difference in labor and material costs less required investment. A simple payback is calculated.

In addition to payback, quality and ergonomics are rated on a +/- scale. Additional comments are included. Comments address consistency of application, flexibility to add automated sealer later, and elimination of ergonomic issues and dirt related defects.

6.5.5. Implications

The decision methodology for implementation of LASD is generally straightforward. Decisions are based on the Bill of Equipment 9-box and business case. Because the paint shop configuration requires advance planning and cannot easily be altered, this decision is generally made early, based on concrete measures, and not debated hotly.

6.5.6. Conclusion

GM has an overarching plan for implementation of LASD across its plants. This plan is based on the business case scenario including cost of implementation, automation requirements, and strategic need.

7. Observations and Recommendations

7.1. Observations

As described in the previous chapters, GM has many specific tools that support product and process development, and subsequent processes to identify and resolve flexibility enabler violations. These standardized tools are critical to operation in a global environment, but it is their practical application that ensures the success of the organization.

The cases described in Chapter 5 all have flexibility implications, and yet the escalation process only required full use in one of the situations. The mere existence of a formal escalation process and the threat of escalation to the level of Group Vice President drive early decisions. Issues taken to that level are strategic in nature and incorporate suggested feasible resolutions. In the case of the Cockpit 1.5 Enabler, the escalation process was used specifically for this purpose, to put a strategic stake in the ground, off of which future programs could make decisions. In the case of the Body/Chassis marriage issue, the Program team was given a directive to challenge the status quo and was able to agree on a process for resolution with an appropriate level of management involvement. This team is working towards a solution that would integrate into the manufacturing process, keeping in mind the need to minimize the impact to flexibility. Both the new refrigerant system and LASD issues have strategic implications for flexibility, and initial strategic decisions were made to move forward with their implementation. However, once strategic direction was given, execution is completed within a lower level of oversight. Implementation of LASD is based on a defined business case, and can be implemented early in development with few strategic implications.

The case studies also illustrate that the tools adapt to the needs of the current product portfolio. The BOP and BOE are constantly evolving. The defined content of Cockpit 1.5 has evolved based on applicability to a broad range of architectures. The Body/Chassis marriage issues have challenged the intricacies of the current flexibility enablers.

Based on the cases studied, the current methods of issue identification, escalation, and resolution are adequate and appropriate. The processes are used consistently, in proper circumstances, and

altered when necessary. The tools, politics and culture in place at General Motors support these processes. The following section will provide recommendations for improvement of the current processes.

7.2. Recommendations

These recommendations derive from a compilation of conclusions based not only on the case studies conducted, but general observation and analysis of the softer side of the organization, including structural, cultural, and political aspects. The day-to-day challenges the engineers and technical specialists faced gave insights into areas that could be improved.

In general, the processes in place at GM serve as a guide to the employees, and as long as the spirit of the process and the overarching strategy of the organization is correctly communicated and understood, the processes can be effective.

In this light, it is continued communication and robust strategic direction that will help the organization continue to operate effectively. These recommendations are meant to encourage GM to continue the parts of the process that have been working well, and improve the feedback loop to monitor the health of the system. In addition, the author recommends that a culture of healthy challenge be fostered in the organization. In a few cases studied, this has helped the Flex Enablers evolve, and an extrapolation of this type of teamwork and challenge would be healthy for the organization.

- ❖ Develop an enabler definition process, incorporating feedback from issue resolution and BOP/BOE changes.

It is challenging to keep enabler definitions up to speed with current process needs, industry best practices, and technology improvements. As the BOP and BOE evolve, the applicability of Flexibility Enablers, which are drawn from these standards, may change. Rather than periodic review of the flexibility enabler definitions, a constant scrutiny and testing would be more effective. Feedback could include more systematic tracking of flexibility issues and incorporation of the resolutions into the enabler list.

- ❖ Encourage challenge of flexibility enablers.

Continuous challenge of the list of flexibility enablers helps to ensure continued legitimacy. The directive given to the KX team to challenge the status quo resulted in small changes to the enablers, but also helped the team define the boundary between which assembly processes could be altered and which were defined by the flex enabler.

AVD management stresses understanding of process rather than blind implementation of strategic alignment mechanisms such as checklists and red/green charts. While these processes are important because they pool best practices and compile a legacy of lessons learned, it is necessary to have in place mechanisms that will test and correct the current processes. A continuous challenge to the enablers should not result in major changes, but more concretely define the enablers.

- ❖ Improve incentives for teams to look at larger picture rather than silo in their own organization.

Concrete incentives for development teams to include flexibility in their decision process are also important. Currently the specialized manufacturing centers and Manufacturing Integration Managers have more ownership over cross-product commonality. Because program teams are measured on the program metrics in general, there is little internal incentive to implement cross-program commonality. The importance of Flexibility is driven through the culture of the organization, but could be more effective if incorporated more concretely within each program.

- ❖ Deliver a consistent strategic vision and message from management.

Strategic direction from management should be consistent and well communicated. Because the escalation process is used to dictate strategic direction, one decision made by GJEMS is used as a guide by lower level managers to make their strategic decisions. Management direction also communicates the importance of flexibility with respect to other program metrics. Because no one person in the organization owns flexibility, each employee is

responsible for including flexibility in his decision process. It is imperative that management continue to elevate the importance of flexibility in the AVD culture.

These recommendations do not insinuate monumental change or try to diagnose one specific major issue. Rather, they are meant to be strategic and incremental. They should act as a reminder for leadership to continue a strategy that is working well, but give incentive to tweak the process to keep the important issues in focus.

8. Acronym List

CCC - Corporate Common Components
GWP - Global Warming Potential
LASD - Liquid Applied Sound Damping
PFI – Program Framing Initiation
VDA - Verband der Automobilindustrie, a German quality standards organization.
SAE - Society of Automotive Engineers
JAMA - Japan Automobile Manufacturers Association
OEM – Original Equipment Manufacturer
NOA - Notice of Action
FTQ - First Time Quality Standards
BOP – Bill of Process
BOE – Bill of Equipment
BOM – Bill of Material
GMS – Global Manufacturing System
GMU – General Motors University
GVDP – Global Vehicle Development Process
MR – Manufacturing Requirements
NVH – Noise, Vibration and Harshness
UAW – United Auto Workers - union
CDIE - Compartment Design Integration Engineer
CIT - Compartment Integration Team
VAPIR – Vehicle and Process Integration Review meeting

Positions and Groups

AVD – Advanced Vehicle Development
DRE - Design Release Engineer
EGM – Engineering General Manager
GA - General Assembly
GAE – General Assembly Engineering
GJEMS - Global Joint Engineering and Manufacturing Strategy
GMNA - General Motors North America
MCE - Manufacturing Chief Engineer
ME - Manufacturing Engineering - group
MECE - Manufacturing Engineering Chief Engineer
MIM - Manufacturing Integration Manager
MSIE - Manufacturing System Integration Engineer
PD - Product Development - group
PEM - Program Engineering Manager
TIE - Technical Integration Engineer
VLE - Vehicle Line Executive

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