A Survey of Front End Modularity as an Automotive Architecture and its Ability to Deliver Value

by

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Abstract

The partitioning of a system can and will dictate the creative space for a designer or engineer. This thesis will analyze how using a new automotive architecture known as a Front End Module (FEM) can affect a limited specific subset of stakeholders.

Through the use of interviews of subject matter experts, literature research and the use of System Design Management tools, an in depth analysis will be done on the FEM and how it affects the craftsmanship, damageability and assembly attributes. It will be shown how the craftsmanship attribute can be improved through the strategic use of FEM's to allow for a feed-forward system where build data are incorporated into upcoming FEM builds. Even with this advantage, the FEM architecture will not negatively impact the damageability attribute or assembly attribute if the proper design cues and strategies are followed.

The FEM will also be intensely analyzed using the tools from the MIT SDM program where it will be evaluated as an architecture itself through the specific and targeted intent and beneficiary breakdown. The analysis will also include an Object/Process Mapping analysis where it will be proposed that the true customer of the automotive front end is not the individual that purchased the vehicle but rather the visual society as a whole.

Finally, a managerial approach will be taken for the analysis of the inherent and inevitable supplier relationship that is required with using this FEM architecture. Interviews were conducted with two suppliers of OEM's and their common road blocks will be analyzed such as lack of holistic thinking or failure to understand the role of the system integrator. Proposed next steps will be laid out to address these barriers in order to open the communication channels between the supply base and the Original Equipment Manufacturers.

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1 Introduction

The automotive industry is under tremendous scrutiny to re-examine the way it is currently creating value for its customers. The majority of the focus has been with regards to the minimization of waste; however other aspects have also been analyzed such as the creation of value through improved vehicle quality or even the perception of craftsmanship as seen by the final customer and how it can generate value within the customer's own perception. This thesis has been kept mostly to the scope of the individual components and how they interface with their surrounding systems. This style of approach is evident in the OEM's heavy cost cutting process where each sub-system is tasked with reducing its individual cost within a specific timeframe. What has not been tapped as of yet is a holistic approach to the vehicle's ability to create value and, even less, the power an automotive architecture can have on the vehicle. Simply re-framing the vehicle through a different architecture can significantly increase the design space of the designer and allow for more ways to create value while not changing the vehicle, or its subcomponents, in a significantly different manner.

Motivation and Objectives

Recent common cost cutting mandates have been able to reduce material costs and stream line designs. While there is always room to achieve deeper cost cuts, a major game changer in cost reduction can only happen through an architectural change. When such a major change occurs, a full stakeholder analysis must be accomplished so that any decisions which are made upstream must take into account and disclose of any downstream implications. Having witnessed personally the intense cost cutting initiatives, it can be seen that the next steps of this cost cutting blitz process is changing the automotive architectures and/or platform strategies. The object of this thesis is to evaluate the next automotive architecture and its ability to deliver value. It will provide a preliminary road map for when the discussions of adapting any future architectural platforms begin as the results from cost cutting measures become smaller.

Definition of Scope

The specific automotive architecture that will be looked at for this thesis is the Front End Module (FEM) and its impact on creating value for the end customer. The FEM consists of building the automotive front end off line, and installing the entire module as one complete assembly on the vehicle rather than building up the front end vehicle component by component. The scope of a FEM is defined by its Bill Of Material (BOM). One OEM could define the FEM BOM in a particular manner while another OEM can define the BOM in a completely different style. Due to this dynamic, the FEM BOM must be defined early on so that no downstream confusion exists when evaluating the FEM. For this document, the FEM BOM will include the fascia, grille, headlamps, bolster and bumper beam. These are the major components that are common across all vehicle architectures and they will be used as the baseline for this analysis. The thesis will explore the advantages and disadvantages of using such a strategy in the areas of craftsmanship, damageability and assembly attributes as they relate to the automobile. The analysis will be limited to these specific attributes as they are deemed to be the most commonly discussed attributes when FEM strategies are talked about. These attributes, though very important, should not be considered the only, or even the most important attributes. However due to the information that is readily available to the author and the time constraint of the thesis, the analysis will be limited to these three attributes.

The FEM strategy will also be evaluated as an architecture using tools learned in the MIT-SDM program. This analysis is meant to be more of an objective and academic exercise to apply an abstract approach in evaluating the power of the FEM as an architecture. It will provide insights behind the intent of the architect on how value is to be delivered to the customer.

Research Design and Methodology

The research will consist mainly of interviews with current industry subject matter experts. The interviews will include different sources from suppliers, OEM engineers, and plant personnel. OEM personnel from the marketing and corporate design groups will also contribute. Plant visits will provide insights into the manufacturing process. Interviews from other industries such as the textile industry or the furniture industry will illustrate how the type of industry can impact the craftsmanship attribute. Some literature research will be done so as to gather certain common knowledge; however the thesis will consist mostly of synthesized information and opinions gathered from industry experts and further interpretation from the author. As a major portion of this thesis involves the evaluation of craftsmanship as an attribute, prior work within the industry will be looked at to see where previous attempts have failed and where they have succeeded.

2 Front End Architecture

A typical automobile architecture is usually partitioned into modules in an attempt to minimize complexity. Ueda (2001)[1] and Fujimoto (2002) [2] have characterized this modular architecture approach as a successful strategy for effectively organizing complex products and processes (Lai, 2005) [3]. The modularization allows for the proper control of the many interfaces between dedicated subsystems. It also allows the overall systemic function to emerge as a sum of these modular sub-components. This chapter will analyze the previously described FEM strategy using Massachusetts Institute of Technology Professor Ed Crawley's "Value Identification Process (VIP)", Professor Crawley's "Object Process Modeling (OPM)" as well as the author's own framework for analyzing System Architectures as it was developed in Professor Crawley's System Architecture course. This breakdown will allow a detailed analysis of the FEM architectural impacts and its ability to deliver value. The chapter will then wrap up with how the proposed FEM architecture can also affect the structure of an organization if the latter chooses to adopt this strategy.

Value Identification Process (VIP)

The VIP process attempts to break down a system into how the external processes operate on the operand in order to deliver value to the beneficiary. It is important to note that the beneficiary is not always the user or the owner of the system. A generic VIP diagram outlining the theory is shown below in Figure 2.1.

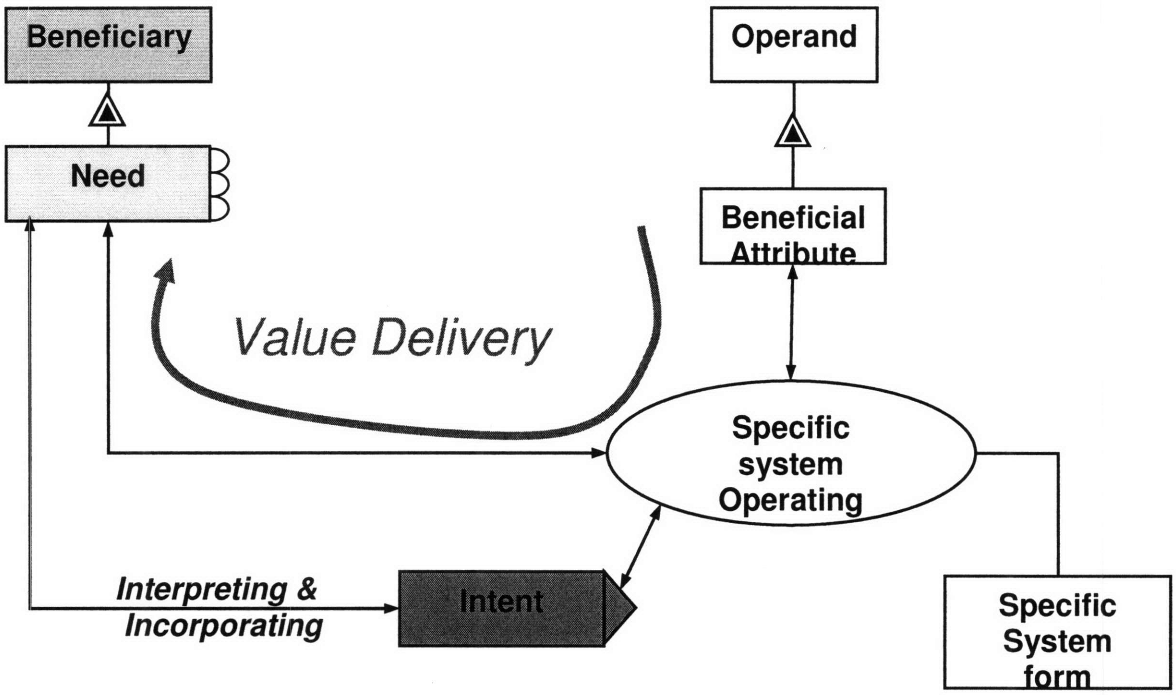


Figure 2.1: Generic Value Identification Process (VIP)
Source: Professor Crawley ESD.34 Lecture 9/8/2006

Figure 2.1 deliberately delineates who the major members of the system are and what kind of interactions the system is managing. What the VIP exercise does is deliberately state the roles and responsibilities of the system as well as documents what interactions occur within the system. For example, the beneficiary has a specific need that needs to be addressed by the system. Based on that need, the system architect must be able to interpret and incorporate what the real intent of the beneficiary is, rather than simply fulfilling his or her needs. After understanding the need and the intent, the architect must use the underlying operations and physics of whatever system is chosen to meet the need and the intent. For example, an aerospace engineer must be able to use transportation to move a traveler from point A to point B. Using the operations and physics of the system, a form is generated by the architect. In keeping with the aerospace theme, the architect can choose the form of an airplane. Finally, the beneficiary attribute is chosen; on which the system must operate in order to deliver value. Such an example can be an airplane gliding through the air to transport the traveler from Point A to Point B.

Looking at the figure, the operand must be explained in a bit more detail as it is often a phenomenon that is overlooked when examining how value is delivered in a system. A system almost always operates on an operand. It is the change in states of an operand that is associated with the delivered value of the product system. The system architect usually does not provide the operand and there is a potential to have more than one. A typical example of an operand is the road for a vehicle. Another more abstract example could be that the US constitution acts on the concept of liberty as an operand to benefit the people of the United States of America.

Another intended function of the VIP diagram is to create a documentation of what the system needs to accomplish. Too often, an architect starts developing a system without much thought on what the system needs to accomplish. This limits the creative space as a solution is arrived at before enough thought has been put into what the need or the intent of the system are. It also helps any downstream architects understand what the thought process was behind the architecture. If any changes are required, the amount of negative effects and their relative magnitude are limited because the current architect is able to fully comprehend why the system was created.

Figure 2.2 shows how a generic VIP diagram could be applied to a vehicle as a whole. Please note the lack of form and generic functionality terms. This portion of the VIP process is to allow the function of the architecture to emerge without providing an immediate solution or form to the problem at hand.

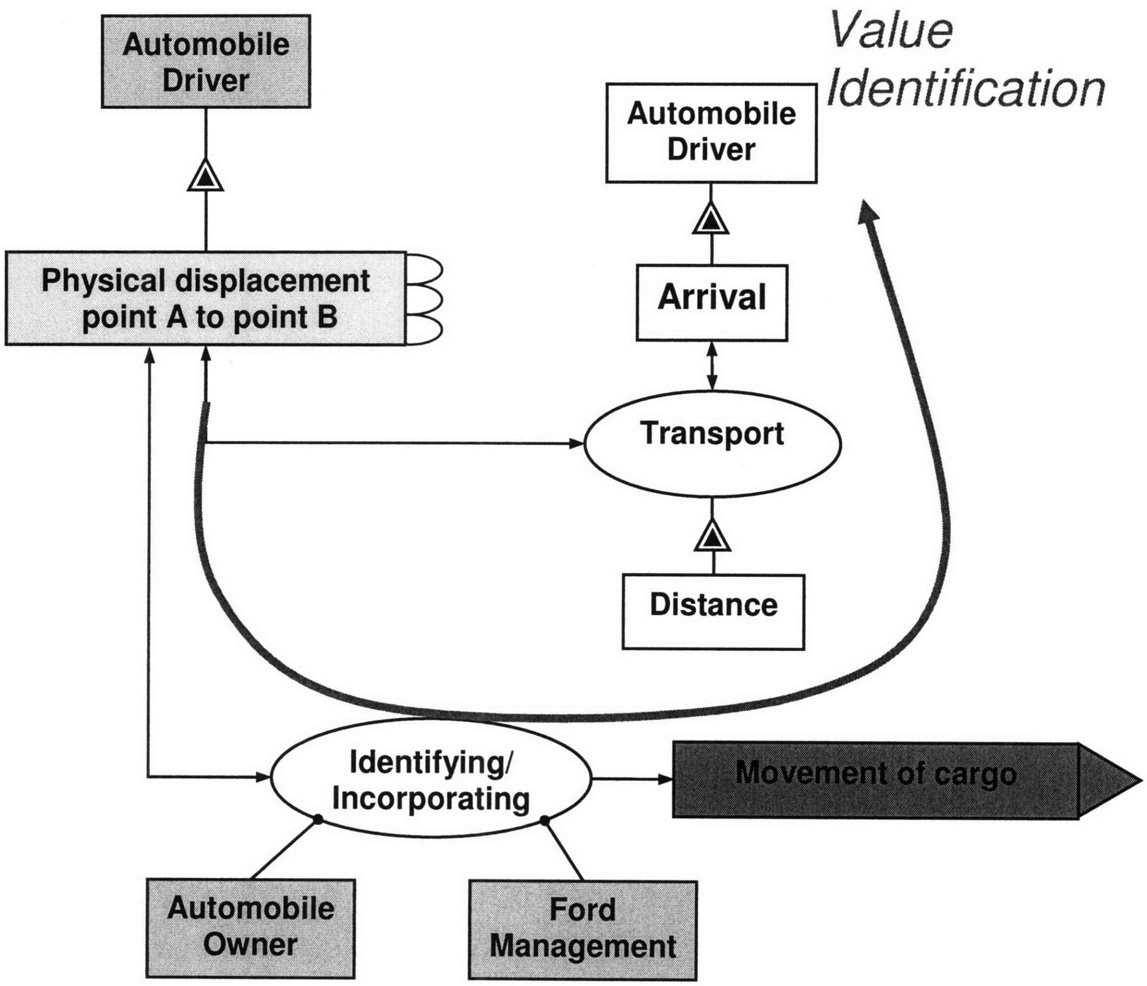


Figure 2.2: Automotive specific Value Identification Process (VIP)
Source: Cravalho, Ybanez, Mahe Opportunity Set #1, ESD.34 Fall 2006

Now that both a generic and automotive specific VIP diagram have been drawn up, what would a VIP look like when applied directly to the front end architecture of the automobile? While the argument can be made that the main function of an automobile is to transport a driver from point A to point B, today's competitive environment has created a secondary set of needs that are becoming so important that they are now surpassing the physical movement cargo requirement of previous years. Displacement has now been surpassed as being a requirement and has become an underlying expectation which must be met by all vehicles on the road today. The value delivery as it pertains to the front end of an automobile has now become a tool to create an emotional attachment from the customer. This point will be expanded further in the craftsmanship chapter (Chapter 3) of this document.

As it pertains to the front end architecture of the vehicle, the architect of the automotive front end has a far greater accountability than simply creating an artifact that is durable and does not fall apart during regular use. His or her *responsibility* is to create an engineered system that delivers all of its functional targets; however his or her *accountability* lies also in creating an emotional attachment not only from the customer but also from visual society as a whole. David Pye best said this in his 1978 book[4]:

> "The scenery most of us live with all our lives was all the work of designers: scenery, I say. We may think we are designing furniture or motor cars, but we are not. If we are designing a motor car for one man, we are designing scenery for fifty thousand others."

Having understood the accountability of the automotive front end architect, it is argued that the automotive front end architecture VIP would look much like Figure 2.3 below.

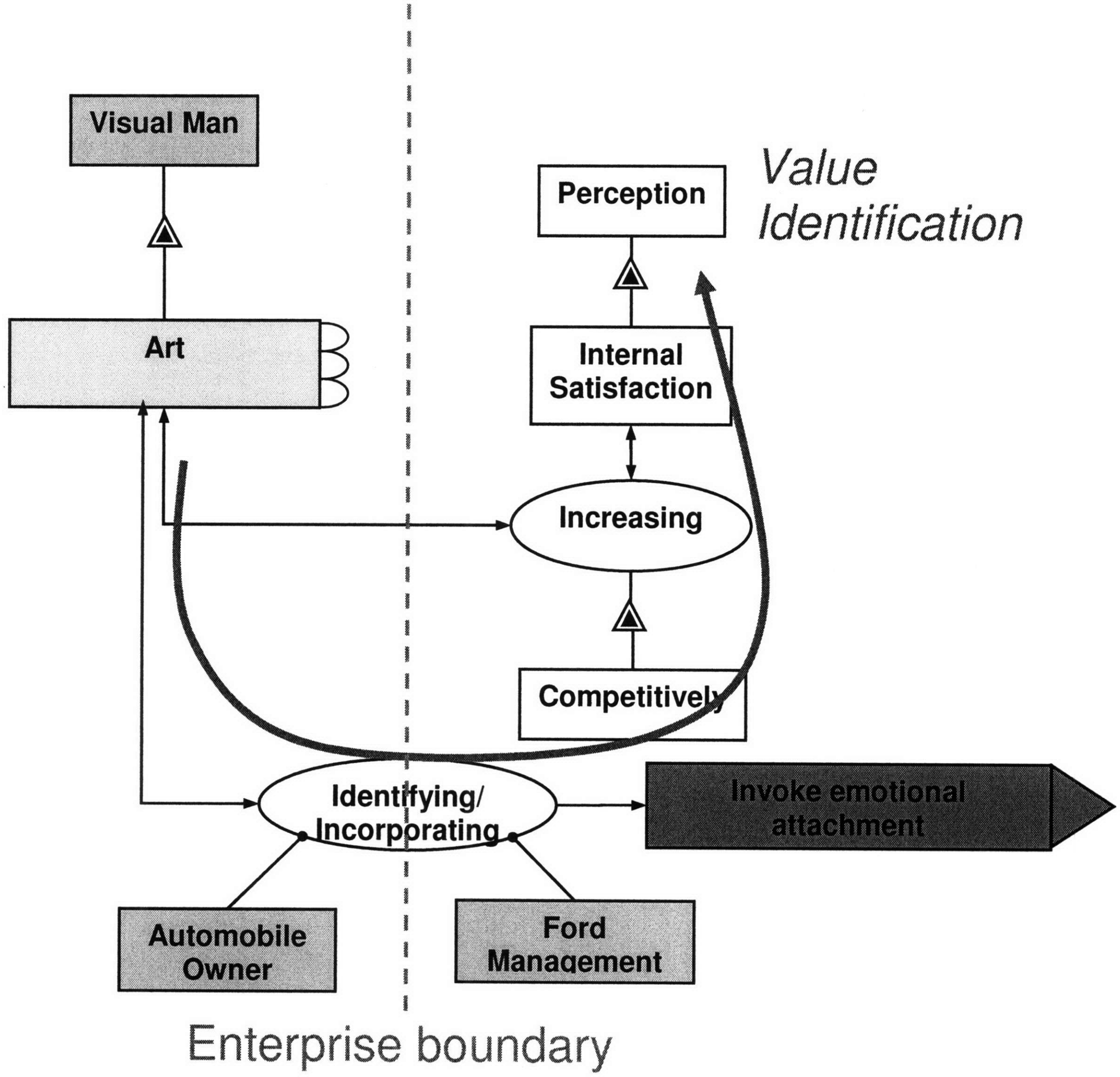


Figure 2.3: Automotive Front End Value Identification Process (VIP)

Figure 2.3 indicates that the beneficiary of the automotive front end is not the automobile owner as one would ordinarily expect but the real beneficiary is the person/group/society that is looking at the vehicle in its surroundings. The vehicle now has become a legacy of art that can be appreciated in motion as well as if it were stationary. The way the automotive front end delivers value to the beneficiary is by increasing internal satisfaction while changing the visual man's perception in a competitive fashion. The automobile driver could be that visual man; however he is not the main beneficiary. The driver does not receive value from the automotive front end while sitting inside and driving the automobile. The visual man outside the vehicle receives that value.

In order for a FEM strategy to work, it must be able to deliver this value while at the same time delivering the functional attribute requirements that have now become expectations rather than a surprise or delight. If the goal of the automotive front end architecture is kept in mind while assigning form to the function during the product development process, the right value will be delivered to the right beneficiary and the FEM strategy will be successful.

Object Process Modeling (OPM)

Object Process Modeling (OPM) is the mapping of objects in the whole product system to processes within the system. The intent is to define a system as a function of its objects and processes so that form may emerge properly. Once again, the key here is to provide a form neutral definition of the system so that the underlying function of the system is captured not only for today's architect but also for any future architects that look at the legacy system years in the future.

In order to effectively create an OPM, the proper definitions must be identified. The definitions of an object and a process are listed below in Table 2.1:

Object	Process
Has the potential of stable, unconditional existence for some positive duration of time	The pattern of transformation applied to one or more objects.
Can be physical. Tangible, visible and stable in form.	Cannot hold or touch a process – it is fleeting.
Anything that can be apprehended intellectually	Takes place along a timeline.
Have states which can be changed by processes.	Is associated with a verb.

Table 2.1: Definitions of Object and Process in an OPM.
Source: Professor Ed Crawley. January 2006 IAP Lectures.

Table 2.1 provides the definition of objects and process so that the function of the system is separated from any form. By analyzing the system in this manner, the creative space is kept as large as possible. For example an object can be an operator and the process can be transporting however the form could be an airplane, an automobile or even a skateboard. The definitions of the object and the process laid out above are to make sure that no form is placed in the architecture before the intent of the system is defined. Having laid out the correct definition of an object and process, the links of how the objects interact with the processes also need to be defined. Their definitions are better listed graphically and are shown below in Figure 2.4.

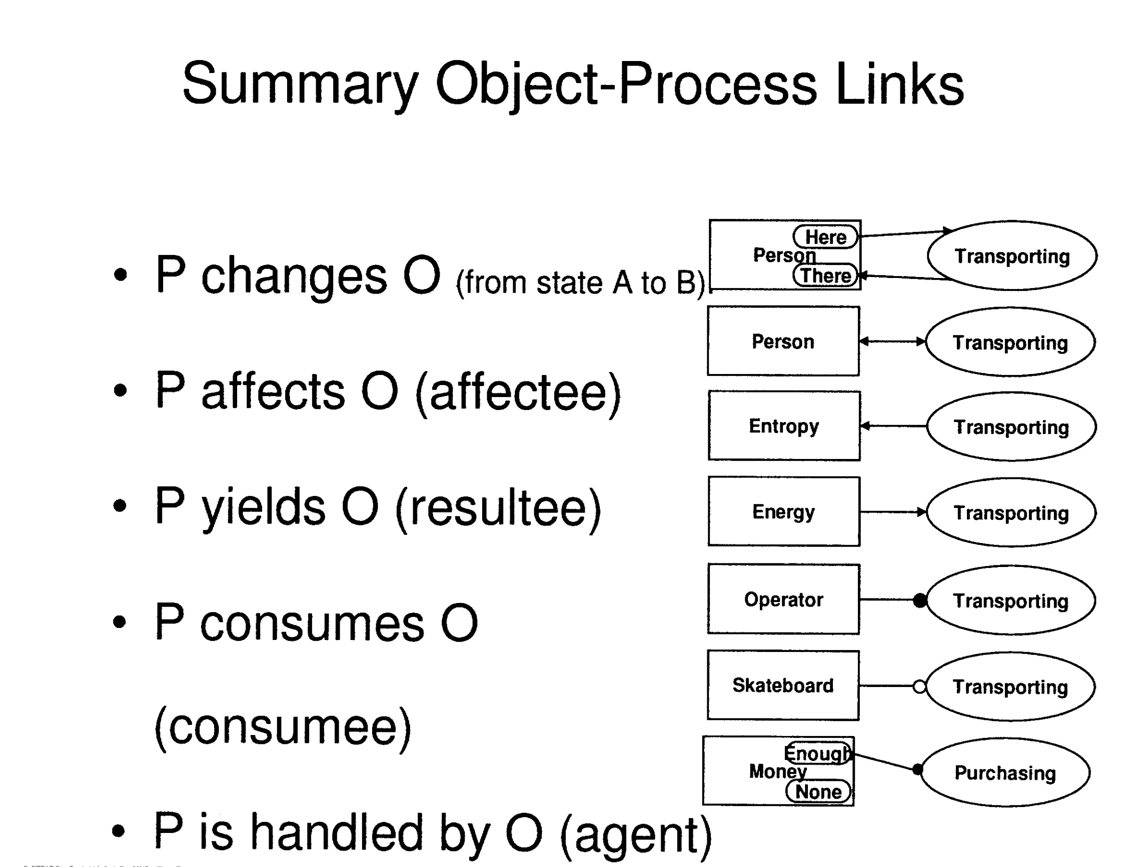


Figure 2.4: OPM Links.
Source: Professor Ed Crawley. January 2006 IAP lectures.

What Figure 2.4 shows is how the objects and the processes relate to each other in the attempt to deliver value to the beneficiary of the system. For example, it can be said that the process of heating consumes the object of energy. It is not made specific what energy is consumed. It could be electrical, thermal or even nuclear but the point is that the underlying process of heating consumes some sort of energy object. Another example could be that the operator object can change from Location A to Location B through the process of transporting. The form of transporting is not mentioned because it could be locomotive, walking or boating. The ties provide the inherent relationship that exists between the object and process that are true regardless of whatever form is chosen downstream. These ties are critical to understand prior to assigning form to the system so that when form is assigned, the proper delivery of value is allowed to emerge rather than having unintended consequences rise to the surface.

In order to illustrate how an OPM can be applied, Figure 2.5 shows the OPM of a relatively simple architecture. Please note that the form neutral processes and objects are shown in the center and left hand side of the OPM while the chosen form is shown on the right hand side of the OPM.

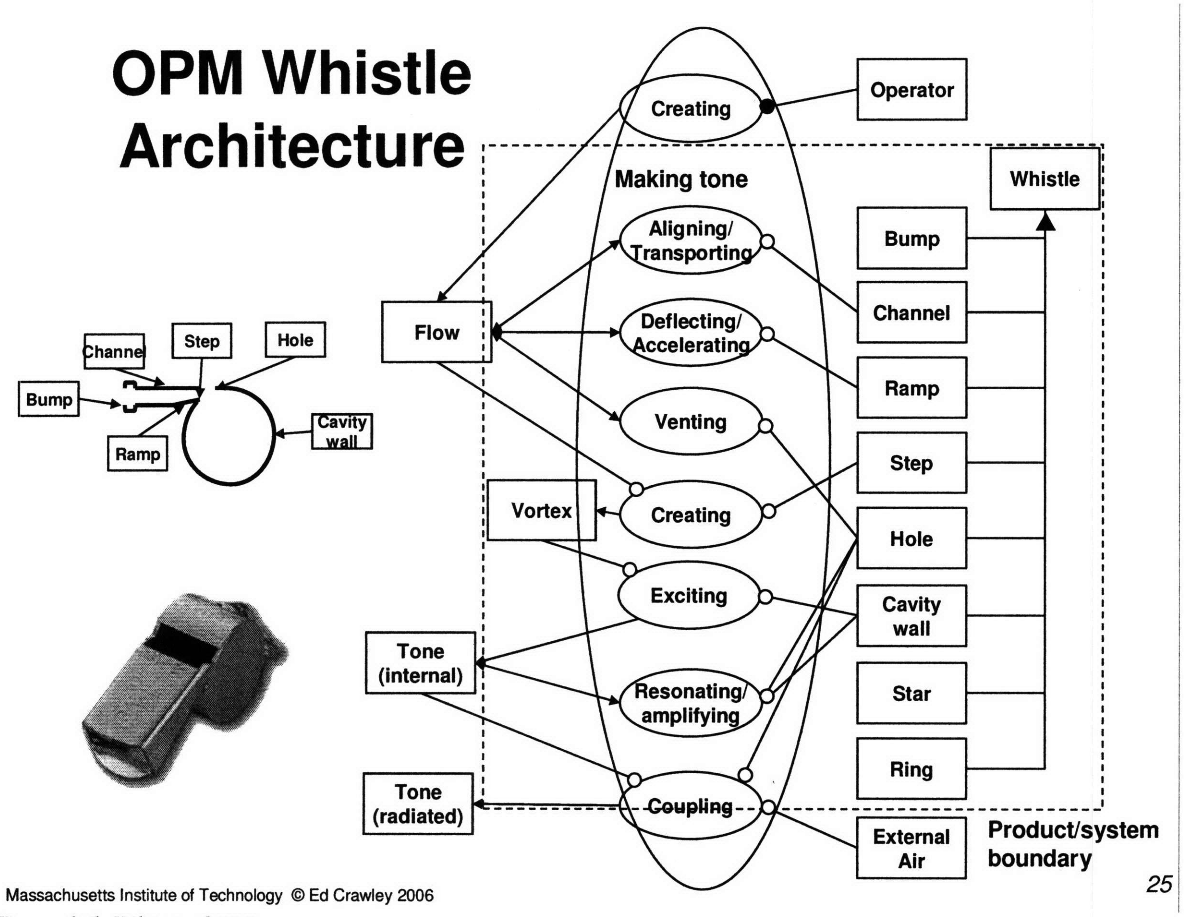


Figure 2.5: Whistle OPM
Source: Professor Ed Crawley. January 2006 IAP Lecture 4.

Now that the process of defining an OPM has been established and it has been shown how it can be applied to a relatively simple architecture, the difficult task of applying to an automotive front end module must be undertaken. The first step taken is to define what objects are to be considered. There are a multitude of objects that could change states or have an unconditional existence for some positive duration of time; however for this exercise, only three objects were chosen. The first was government compliance as without it, no front end would be able to be placed on the market. The second was a set of functional attributes which included, but were not limited to, manufacturability, wind noise, squeak and rattle, serviceability, fuel economy, aerodynamics, etc... Lastly, customer opinion was chosen as an object. It is important to note that "purchase decision" was not chosen an object as it is the contention of this document that the true beneficiary of an automotive front end is not the purchasing customer, but the visual man as a whole. Customer opinion is an object that can change state as it is undecided before the customer looks at the vehicle and decided after he/she sees the vehicle. Whether or not they like or dis-like the vehicle is non-important in this analysis as what really needs to be understood is that either way, the customer will have their opinion decided after seeing the product.

Each object was then tied into a process. Each process was then tied into a physical form of the front end to close the loop to the components of the FEM architecture. The sum of the exercise is shown below in Figure 2.6.

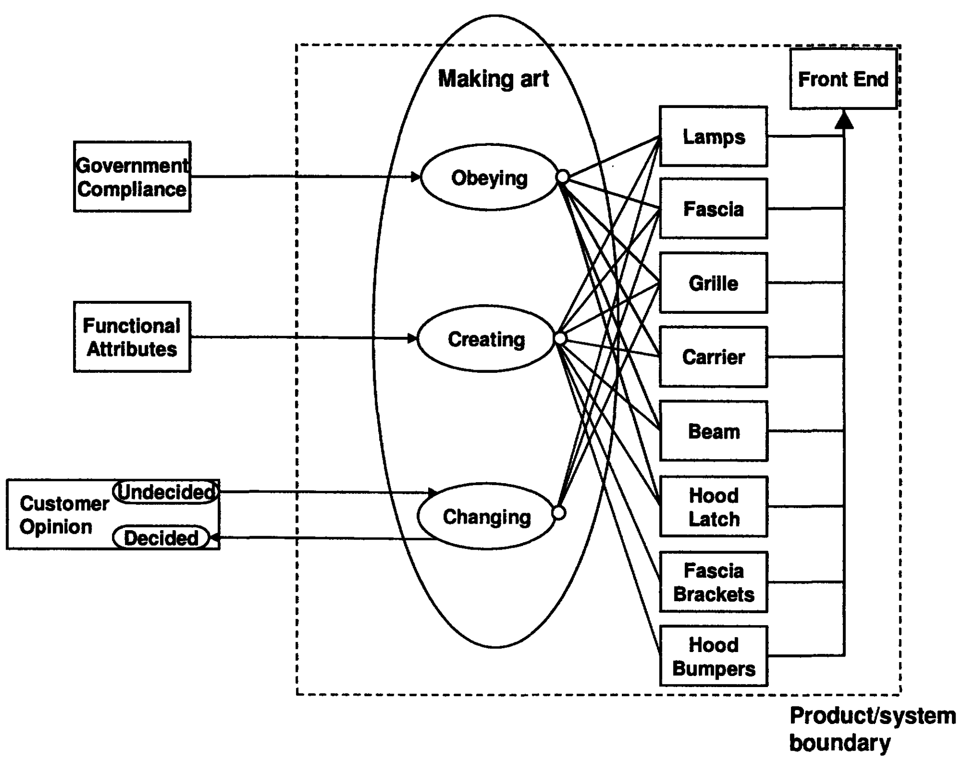


Figure 2.6: FEM OPM

What the FEM OPM show is how interconnected all of the FEM components are and how they are each mapped to the process in multiple ways. While some FEM components do not play much role in the processes, other components such as the lamps, fascias and grilles are related to all of the processes tied into changing government compliance, functional attribute and customer opinion. The FEM OPM graphically shows that FEM is a proper architecture to deliver value to its true beneficiary. It shows how interconnected the components are and shows how it would make sense to tie them into some sort of physical boundary (i.e. module) when developing the front end architecture. This will be explained in further detail in the next section.

The OPM can also be used to show the intent of the FEM architecture. It will guide future architects in downstream decisions in later years. Having this documentation will enable any future architects to understand why the decision was made to physically partition the vehicle in this specific format. The future architects can still choose to change this particular partition; however their choice will have the documentation showing the intent of the original architect, so that their downstream decision can be made as an educated one.

Having established the intent of the FEM system through the use of abstract concepts using the VIP and the OPM tools, it was shown who the true beneficiary of the FEM architecture is. We were also able to document what the architecture needs to be in order to deliver value to the beneficiary. While this documentation is necessary, it does not evaluate the FEM as architecture itself. It does not evaluate whether or not the system was created with full efficiency, or if it employed the best use of form that was applicable for the system. In order to evaluate the FEM as architecture, a specific framework is required.

Framework for analyzing System Architecture – Generic Overview

The architectural framework that will be used to evaluate the FEM architecture was developed in a joint effort between Nick Cravalho, Serge Ybanez and Vince Mahé during the ESD.34 course at MIT as part of the 2006 System Design Management

Program. The analysis is broken into three levels of abstraction. The first level, "the holistic musts," outlines the features that are absolutely required to have a successful architecture. The primary focus of this analysis is on the needs and goals of the key stakeholders. A good system architecture is one in which not only the needs of the key stakeholders are met, but so are the goals. However, it is important to note that the converse of this analysis is not necessarily true. Successfully passing this level does not necessarily mean that the architecture is a success.

The second level of abstraction is called "the good is in the details," (play on the words, the devil is in the details) and it outlines the key features of the end product design that separate a good design from a great design. These design features are the intangibles of the product, the features that can't easily be seen or touched. A critical assessment of all the –ilities is necessary. Furthermore, the competitive advantages of the system will be analyzed.

At the final level of abstraction, "WCHB...what could have been," it will be determined what other concepts the architect could have used to create this system. It is possible that the architect met the needs and goals of the primary stakeholders (Level 1) and the final system was architected perfectly (Level 2), but the chosen concept was not the "right" one. The concept of a "right" or "better" solution that would have delivered a simpler, cheaper and/or better performing end product will be explored. The three levels of abstractions are best summarized in the Figure 2.7.

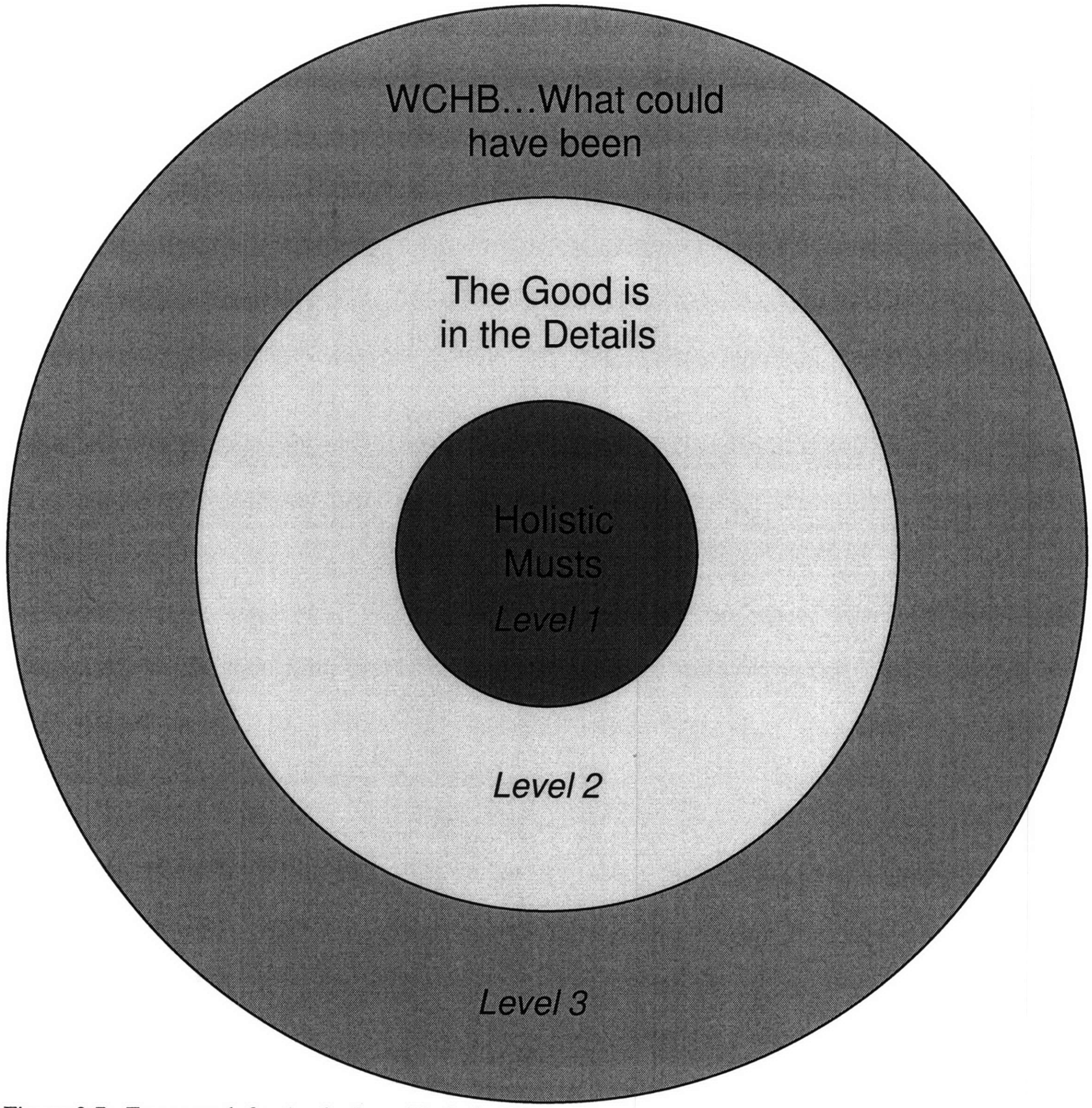


Figure 2.7: Framework for Analyzing a Technical System.
Source: Cravalho, Ybanez, Mahe Opportunity Set #3, ESD.34 Fall 2006

The Holistic Musts (Level 1)

The starting point for the framework for analyzing technical system architecture is the same starting point as when creating a system, namely stakeholder needs. When architecting a system, an architect must fully understand the needs of the stakeholders and customers. Once the needs are understood, then the architect must always keep them in mind when architecting the system for the system can be useful only if it meets the needs (expressed or latent) of these for which it was designed. The needs to be analyzed include the following:

Need Analysis

- Beneficiary
- Users
- Agents
- Enterprise
- Society
- Other Key Stakeholders
    - Regulation
    - Government
    - Environment

It is a difficult task to architect a system which meets the needs of all stakeholders. However, if a key stakeholder need is not met, the project cannot be a success. For example, if the basic need of the beneficiary of an automobile is to be transported safely over the entire desired route and the need is not met, then the system is a failure and the analysis of the system is terminated because no value would be added to analyze the rest of the system. It is similar to a movie that has no sound and a scrambled picture. It is not worth the movie critic's time to analyze the entire movie since it didn't meet the underlying requirements. A less obvious case is when the need of a regulation group is not met, then the system is also a failure because the system will not be allowed to be used to its desired level.

Assuming that all the basic needs of the stakeholders are met, the next level of analysis within the "holistic musts" is the goals of the system. The goals are the requirements not only explicitly stated by the customer and other key stakeholders, but are also implicit goals identified by an experienced architect in the field. These goals tend to reflect the performance of the system since most requirements are performance based (system must meet this speed target or must cost this amount, etc.)

Goals

- Performance
- Boundary (physical)
- Value met...benefit at a cost
- Beauty (if required)

The four main factors in the goals are (1) system performance, (2) system boundary (size of the system) (3) Value of the system and (4) the aesthetics of the system. System performance includes all variables identified by the customer that if met, can lead to a successful system. These parameters vary greatly for each industry and even for each company within a particular industry. Everyone has a different view of what is required (high level) for a successful system. In the end, only the market can give the definitive answer to the question of what is the "right" design. The second parameter is the system boundary. If the system is not right size and/or weight, then regardless of the performance, then the system is a failure. The boundary can also be determined as to where the architect decides to end their design. If a builder does not put a roof on a house because they have decided to limit their responsibility of the system to the vertical structure, the underlying needs of the home buyer have not been met. Thirdly, the system can meet the stated performance requirement and physical boundary, but if the cost of the end system exceeds the perceived value by the customer, then again, the system is a failure. Finally, the aesthetics of the system does matter but the evaluation is subjective. This is a point that is further explained in Chapter 3. The system could give the user great value with amazing performance, but if it does not meet the styling needs of the customer, they will not purchase it and thus the system is a failure.

If the needs and the goals of the system are met, then the system is acceptable. Most likely it will be accepted by some customers in some of the desired markets in the short term. However, there are other considerations (the intangibles) that must be analyzed before the system (and thus the architecture) is deemed a long term success.

The Good is in the details (Level 2)

What separates a good architecture from a great one? The answer lies in the long term potential of the system. Level 1, the "holistic musts" answered the question of what is an acceptable architecture for today. It was a static analysis that considered only the system in the "as is" state. In Level 2, the system will be analyzed to see if it has any long term potential. The framework to analyze the long term potential is the "–ilities". This level is much more subjective than the last level. Since most of these needs are not stated by the customer or other stakeholders, it is up to the critic, to determine what is acceptable for the given system architecture.

-ilities (Primary)

- Flexibility
- Modularity and Interfaces, for product portfolio
- Reliability
- Manufacturability
- Supportability

The subset of –ilities listed above is by no means comprehensive. The level of importance of the –ilities will vary from product to product. However, the –ilities listed above are always necessary for a system in the long term to be successful. By adding flexibility to the system, by having clearly defined interfaces or making the system more modular, the chances that the system will be long term successful are greater. Similarly with reliability, the system must not only be robust today, it must be robust throughout its life cycle. Finally, since most systems are comprised of products that need to be manufactured and supported in the field, the ability to be easily manufactured (AFM) and supported (AFS) will better increase the chances for long term success of the system.

The final section in Level 2 is "sustaining competitive advantage."

Sustaining Competitive advantage

- Use of technology
- Platform architecture
- Exploit supply chain

If the system is going to be a long term success, it must have a sustaining competitive advantage over the competition and future competition. By using advanced technology, incorporating platform architecture and exploiting the supply chain, an architect can give the system a sustaining advantage over the competition.

WCHB...What Could Have Been... (Level 3)

If the architect met the customers and stakeholders needs and goals (Level 1) and had excellent architecture (Level 2), that would give the system longer term market potential, hence increasing the changes that their architecture is deemed a success. However, that doesn't mean that it is great. To be great, the architect must have selected the "best" architecture for problem solving. In this level, "WCHB" (Level 3) the framework will analyze what the architect could have done. It will analyze whether the concept selected properly mapped the function to the form. In addition, it will be seen if the right concept was selected given the context of the problem. There are a myriad of potential solutions, but did the architect chose the "best" one? Other architectures will be evaluated to see if they could have led to a system that was cheaper and or better performing while still meeting the underlying needs.

Exploring the options

- Did the Concept properly map the function to the form?
- Right Concept selected for the given context

Framework for analyzing System Architecture – Applied to FEM

The Holistic Musts (Level 1)

On the surface, it seems that a FEM strategy does address the need of the primary beneficiary in detail. The ability of the FEM architecture to quickly change front ends, to aid in final line assembly and to control better gaps and margins will be discussed in more detail in later chapters however all of these attributes do show a tendency to address the needs of the primary beneficiary which was described earlier in this chapter as being the visual man. Other stakeholders' needs are addressed in the FEM architecture as well such as government regulations which will be discussed in detail in Chapter 4 regarding damageability.

The goals, as defined by the framework, involve performance, physical boundary, value and beauty. The value equation was already discussed in detail earlier in the chapter so no additional time will be spent on this goal. The performance will be discussed in later chapters such as damageability, Noise Vibration Harshness (NVH), Squeak and Rattle (S&R) and assembly at an OEM. The esthetics portion will be discussed in more detail in the craftsmanship chapter. The only item that will be discussed in depth here is the physical boundary goal. A FEM, by definition, includes a specific Bill Of Materials (BOM). It is specifically cut off to include only a specified list of front end components. This is where the traditional front end automotive architecture starts to fall short in the architectural framework analysis when compared to a FEM architecture. The FEM architecture takes advantage of the dynamics of having multiple components come in as an assembly to a final line, rather than having different components come in individually. This architecture takes advantage by moving the physical boundary of the system from the components to the entire front end module, and allows different dynamics to emerge as a result of separating the system from the automobile. Having the FEM come in as an assembly allows the module to perform better as a system rather than a sum of its components. Tighter tolerances are allowed since the parts are fixtured to each other rather than having them assembled separately. Contentions that would not be allowed due to final assembly manufacturing tolerances could now be done without damaging the quality of the product. Entire front ends can be changed without having to account for multiple line space that would be required if the components came in to the line by themselves rather than coming as an assembly.

Obviously, traditional component based front end architectures meet the goals and needs since they have been used over the last 100 years however, the goals and needs must not be considered static targets. What may be a satisfactory level of performance today might not necessarily meet the target tomorrow. When compared to each other, both types of architecture meet the goals and needs of the customer however it seems that the FEM architecture has a much larger potential when discussing the physical boundary goal.

The Good is in the details (Level 2)

There is no doubt that a FEM architecture addresses the modularity aspect of the framework analysis. Reliability, flexibility and supportability are somewhat more subjective and arguments can be made either way, for or against, a FEM architecture. One of the –ility that a FEM architecture might fall short in is serviceability. For this -ility to be successful, significant design work must be done in order for the FEM to match a typical front end architecture. If the proper design work is not done, the FEM architecture has a large potential to fall short in this attribute. How much value does a modular and esthetically pleasing front end deliver if it takes a repair shop two hours to replace a light bulb because the entire front end must be removed to access the back of the lamp? The component architecture, by its very definition, is serviceable since the components must be attached by themselves. That being said, some component architecture designs have shown serviceability to be an issue, so the risk does exist regardless of which architecture is chosen; however, if the serviceability details are not taken into consideration carefully, this is an attribute where a typical component front end architecture performance can surpass a FEM.

The competitive aspect of a FEM strategy was briefly touched upon early in the chapter where it could be used to develop a platform architecture. Similar vehicles could be going down the same line and have completely different front ends simply by attaching different FEM's at the same assembly point. This amount of flexibility is huge in today's market where OEM's no longer can produce vehicles at 400,000+ annual volumes. In today's market, business cases must be made where capital needs to be split across 50,000 annual volume vehicles. Having a FEM strategy would allow for differentiation the same way vehicles have side differentiation in the use of wheel lip moldings. Simply instead of changing the side appearance, which is limited by the greenhouse styling of the vehicle, the vehicle can now receive an entirely new appearance by having a different FEM. Fender cutlines do not even need to be common as long as the attachment styles (i.e. snaps, bracket, bolts, hardware, etc...) are common. Assembly line switch overs could be reduced since a vehicle could be refreshened by simply switching the FEM assembly line rather than re-allocating the main line.

This FEM strategy will also exploit the use of the supply chain however this will be discussed in more detail in Chapter 6.

WCHB...What Could Have Been... (Level 3)

At this step of the framework analysis, different architectures are pitted against each other in order to evaluate which one is truly the best. While there are no definite answers, it seems that the traditional front end architecture is really driven towards the internal customer (i.e. engineering and purchasing) while the FEM addresses the needs of the beneficiary (i.e. visual man). The drive towards the internal customer is most likely done in order to simplify the internal organizational structure. While it is simple to have a purchasing director in charge of several purchasing account managers, it would be more logistically difficult for a system integrator to be in charge of a purchasing account manager. It seems a shift in stakeholder analysis must occur in order for this to become apparent. It must be understood that the automobile has become more than a reliable means of transportation. The exterior appearance of the vehicle can be compared to the fashion industry where the appearance of the vehicle not only has become a measure of social status but is just as fleeting as a seasonal wardrobe. With such small, fleeting product life cycle, a component based typical front end architecture must be changed to allow flexibility in the ability to change exterior appearance at a much faster rate. It seems that a FEM strategy would be able to accommodate those needs in a better fashion due to its flexibility and modularity. While the engineering time and effort to deliver the parts might remain the same for a FEM architecture as opposed to a component based architecture, the flexibility aspect comes from being able to differentiate an entire vehicle line by simply changing the FEM assembly point as opposed to having to change the entire main assembly line.

Organizational Architecture Impacts

One aspect of the FEM architecture that must not be overlooked is the impact that it has on the organizational structure of the company that is implementing the strategy. Conway's law states that "Any piece of software reflects the organizational structure that produced it"[5]. The very same argument can be made with how the automobile is partitioned. Today's automobile is usually partitioned by the upper body (exterior and interior), lower body (chassis) and powertrain (engine). Ironically enough, this also matches how Ford Motor Company is organized as well. Having a FEM architecture will have a significant impact by placing more and more responsibility and accountability on fewer groups as the shift in resources goes from a component based style architecture to a modular architecture. To think that a FEM architecture will only affect the automobile is short sighted, and it must be understood that there will be a significant dynamic change in the organization as it goes from a traditional component based front end architecture to a FEM.

Summary

Three tools were used in this chapter to analyze the FEM architecture and its ability to deliver value. Each tool provided different insights as to how FEM's were able to achieve this goal. The Value Identification Process (VIP) showed how one of the main beneficiaries of the FEM is not the owner or customer of the automobile but the visual man as they are the ones that see the work of art the automobile represents, whether or not the vehicle is moving. The Object Process Model (OPM) outlined how each component of the FEM represents the form that must interact with the underlying processes of the system as a whole. It also serves as documentation of the intent of the original architect so that any future architects will not lose sight of why this particular architecture was chosen. These two tools provided a baseline for us to continue evaluating the FEM as an architecture. They made sure that the needs of the beneficiary are addressed and that a form-free evaluation of the architecture can be done. Having provided the intent of the FEM architecture and how it interacts with the underlying processes to deliver value as baseline, a more factual and objective evaluation was provided by using a framework to critique the FEM as a form to deliver these needs and intents.

This framework was used in detail to show the shortcomings as well as the advantages of the FEM architecture when compared with the traditional component based front end architecture. The FEM's shortcomings with regards to serviceability were discussed as well as the FEM's advantage in shifting the physical boundary of today's component architecture to take advantage of system level dynamics. Lastly, the impact of a FEM architecture on a company's organization was quickly touched upon and compared to Conway's law in the software industry. The impact of a FEM partition will most surely create a shift in a company's organization to match the vehicle's new partitioning format.

3 Craftsmanship

Many products in the commercial market have often been classified as failures not due to their inability to deliver function, but because of their inability to appeal to the customer on an emotional level. This appeal the customer's emotion is often referred to as craftsmanship. It can be best defined as an attribute which has the ability to create a human connection between the customer and a material object. One of the most interesting features of this attribute is that it is mutually exclusive from the actual product's function. One can create a product that delivers the intended function perfectly while, at the same, completely fail in creating an emotional tie to the customer through craftsmanship.

Unfortunately the concept of craftsmanship as an elusive and ethereal target has been proven true as long as human kind has been inventing products. How does one define "craftsmanship"? Is it influenced by culture/background? Can it be learned? Or is it something that emerges out of proper planning on behalf of the designer? Does the definition change across different industries? Keeping general questions in mind, how does a FEM strategy address this attribute (if it even addresses it at all)? Literature research has been abundant in the matter of craftsmanship however it has not been conclusive. This is to be expected from such a nebulous characteristic. We will attempt, however, to answer each question individually and see how the concept of craftsmanship can be tied back into FEM.

How does one define craftsmanship?

Webster's online dictionary defines a craftsman as "one who creates or performs with skill or dexterity especially in the manual arts". Scotland and Williams define it as "involves the visual, touch, sound and smell" (Scotland, Williams et al. 2005). Other definitions include "the perception of quality experienced by a customer, based on sensory interaction and emotional impact" (M. Williams 2005). It is important to note the use of the word 'quality' in Williams' definition. Quality is another word that is widely associated with a positive regard; however when pushed for a definition, a similar clarity exercise emerges from an individual with the same difficulty as when one attempts to define craftsmanship. While many people understand quality and what it stands for, they find it difficult to express it in words, let alone objective targets. Another very important word used in Williams' definition is 'perception'. It seems that Williams is acknowledging that quality does not have one absolute definition and that a good technique to practice in delivering proper craftsmanship is to appeal to the customer's definition with no regards as to whether or not that definition is correct or not. One of the more interesting definitions emerged from Harris and Lipman; it state that craftsmanship is in the fusion of pleasure and work (Harris and Lipman 1989).

The common threads of the various definitions listed above all have an attachment of high esteem towards both the nature and the practice of craftsmanship. This word elicits an ability to synthesize all of the human senses in order to generate a moving human response from an inanimate object. Craftsmanship can be thought of as an emotional bridge that attaches or connects the customer to the product so that additional value is generated. This value is in addition to the functional value it already delivers, and it provides worth on more than just from a product sense. This is easily seen by how some individuals in the IT industry get easily attached to a particular software because they appreciate how the well the architecture and functionality are incorporated. Another example is how a customer will pick a specific brand of furniture over another even though they have similar prices and have the same functionality. It is important to note that this emotional connection can sometimes supersede product functionality in terms of delivering value to the owner. There are plenty of examples where customers will sometime choose a product simply because of the emotional connection it creates rather than the function it delivers. The shoe industry is an ideal example of this experience.

Numerous shoes have been purchased even though their functionality of protecting the feet from harm is dubious at best.

Webster's definition attaches an elitist element to craftsmanship and implies that it cannot be practiced by everyone. Using the word dexterity also entails that the practice must be learned. This will be talked about in much more detail later in the chapter. Using the above definitions, craftsmanship will be defined in this paper as "***the ability to create an emotional attachment to a product via the proper use of the targeted customer's senses.***" This definition encompasses all key attributes from each source. It allows the craftsman a larger design space to come up with an acceptable product solution that will emotionally appeal to the customer while simultaneously does not propose a way of accomplishing it since each customer's definition is different. Providing a cookie cutter method implies that there is a target. By saying to a designer "follow method X and it will provide customer Y with craftsmanship" implies that craftsmanship is a final destination however the literature seems to imply that craftsmanship is more a journey rather than a final destination. As with any functionality targets, craftsmanship targets are constantly changing. There is ample literature that discusses how a product can meet all of the functionality requirements the customer requested at the on-set of the project; however, the product would fail when introduced because the customer did not really express what they required. Craftsmanship behaves in the same way where the target is mobile and must constantly be checked with the customer base, so as to keep up with their expectation.

A final attribute of craftsmanship that must be addressed in its definition is the notion of a holistic approach. The literature documents the importance of cascading craftsmanship targets to the entire team. Scotland and Williams discuss the importance of communicating smaller targets to the supply base but these targets do not apply to the vehicle as a whole (Scotland, Williams et al. 2005). The issue with taking this approach is that the concept of craftsmanship involves a systemic evaluation that sometimes cannot be carried out to the component level. The progression of partitioning a large complex system into smaller sub-systems naturally leads a design team to cascade sub-system targets accordingly. However the essence of the system performance can sometimes be lost in this transition. Keeping this dynamic in mind, the definition of craftsmanship that was previously developed can be altered to be "the ability to create an emotional attachment to a product via the proper use of the targeted customer's senses through a holistic use of the properties inherent to the product."

Is Craftsmanship influenced by culture/background?

Keeping with the idea that craftsmanship is a perceived characteristic, it would only make sense that it is heavily influenced by the background and culture of the targeted customer. Loeffler has gone into extensive research to find out just how significant a customer's cultural background can influence their own definition of craftsmanship (Loeffler 2002). He hypothesizes that customers base their automotive purchases on the vehicle's quality and the customer's emotional tie. Loeffler's research shows how German and Italian brand definition changes when applied to automotive products. His research emphasizes how foreign brands can generate different perceptions from a customer's point of view based solely upon the market in which the brand is being evaluated. For example, Loeffler was able to gather data which shows that

> In France, Germany, Italy and Spain foreign automotive brands have positioning disadvantages with respect to quality related product attributes when lacking the 'domestic make' label and compared with domestic judgments. Quality is perceived to be less convincing in foreign markets. (Loeffler, 2002)

This implies that even if the vehicles have equal attributes related to quality, the foreign brand will be deemed inferior simply because of brand's country of origin. In fact, "In Germany, the lack of the 'domestic make' label results in a positioning advantage with the respect to the dimension 'emotions': foreign cars in general are judged to be more sporty and fascinating." (Loeffler, 2002)

There are two critical points that must be addressed in Loeffler's research. One is that the emotional tie from the customer to the product is labeled as 'quality'. Earlier in the chapter, it was discussed that most firms/industries equate craftsmanship with quality. It is assumed in Loeffler's research that the two terms are synonymous. The second critical point in the research has to do with the statement "*foreign automotive brands*". Please note the exact terms that are being used. This implies that a foreign brand, *regardless of where the automobile was manufactured*, will be judged less favorably than domestic brands. A vehicle could be built domestically but its quality will be judged based upon the brand's nationality. "Even in Europe which is growing together, brands are evaluated very differently in the various countries." (Loeffler, 2002) This confirms how important a brand image is in a product, and will not be addressed in this chapter; however the research clearly shows that there is a cultural aspect to the definition of craftsmanship.

Can Craftsmanship be learned?

The notion that craftsmanship can be a learned skill is a well accepted concept in both the literature and the industry. Bill Pyritz discusses this learned skill concept at Lucent technology where the ability to produce software of superior craftsmanship can only be done through the efforts of highly skilled software craftsmen. (Pyritz, 2003). He even goes a step further in that he submits that craftsmanship is actually a side effect of the focused training and the development of the long-term employees. By taking the time to provide new engineers with a remedial training program, a company is able not only to establish consistent processes across its entire workforce, but also to create work habits and disciplines that are consistent with the company culture. An individual engineer or designer entering a new industry cannot be intuitively aware of all of the craftsmanship intricacies of the product at hand nor should they be expected to. By establishing a training program, a company can make all employees aware of what it deems are critical craftsmanship targets that are particular to that industry/product. The engineering community is able then to incorporate these targets early in the product development process. In this way a proactive, rather than reactive, approach is taken towards the craftsmanship attribute.

While it seems clear that having a standardized system can teach craftsmanship specific to an industry, one can go a step deeper into the analysis to show how much waste can be prevented by following such a path. One of the most important aspects that Pyritz discusses is how much resources are being wasted in re-inventing the wheel. What he proposes is that much of the resources within an established company are spent in re-inventing technology that has already been developed rather than using that established technology as foundation to build a 'tradesmen' workforce. Many of the industries that produce commercial products in today's economy do so with already established and proven technologies.

It is not being proposed here that new technologies do not arise every day. In fact, one only has to open a newspaper to see that new technology is being developed every day; however the methods used to produce most of today's commercial products have varied little over the last several years. For example, major technological innovations have been made in the computer hardware industry via new hard drives and micro-processors; however code is still needed by software designers in order to run the computer system. Another example can be seen in residential houses which are built every day with old materials such as wood, bricks, copper or even new materials such as lightweight concrete; however houses are still put together by carpenters, plumbers and electricians. New hybrid powertrain systems have risen in the automotive industry over the last twenty years; however the vehicle is still put together with nuts and bolts the same way Henry Ford built the

Model T back in the 1910's. What Pyritz contends is that rather than wasting resources such as time, money and energy in re-developing these foundation blocks of the established industry, companies should be spending time in developing their engineers and designers to become craftsmen within their own area.

Apprentices should be learning from senior engineers as to what design cues are required in certain applications. They should be learning how to execute specific interfaces in order to maximize the customer emotional connection with the product. They should be learning how to write code in a structured fashion, so that the debugging process can be accomplished in a shorter time. The history behind design and craftsmanship guidelines should be revisited with the creators of the guidelines; so that the inevitable turn over inherent to the aging workforce does not create a vacuum for the guidelines to be sucked into. The above are examples where a company can spend its resources in establishing an army of tradesman, as opposed to spending resources re-establishing how business is being done every day.

While the literature has shown that craftsmanship can be learned, the true challenge lays in the ability and willingness of the company to take the time and patience to train their employees to the point where the company can reap the fruits of its labor. Establishing a training program not only takes time but it takes significant resources. Using these resources requires long term thinking to both, establish the program in the first place and then defend it over time to prevent the program from being extinguished as a result of short term thinking. The short term thinking process of taking away resources dedicated solving long term issues creates a firefighting mode where all of the emphasis is placed on solving today's issues rather than developing and nurturing long term architectural solutions.

Does the definition of craftsmanship change across different industries?

Earlier in the chapter, it has already been established that craftsmanship can be influenced by cultural background. Knowing that culture has such a strong effect on the interpretation of craftsmanship, one has to ask if the type of industry in which it is practiced also plays a strong role on how it is carried out. A further study was conducted into this possible phenomenon through industry interviews. It was thought that the surveys would serve as more contemporary state of the industry as opposed to literature research and the interviews would also be free flowing. A standardized questionnaire was given to each industry so as to keep the questions consistent. A copy of the questionnaire can be found in Appendix A.

Office Furniture

The first industry that was surveyed was the office furniture industry. Teknion is an international designer, manufacturer and marketer of award-winning office systems furniture and related storage and seating products[7]. It focuses on the mid to high end segments of office furniture products. It has over 3,800 employees located in North America, UK, Europe, Latin America and Asia/Pacific Rim. It operates much like the automotive industry with centralized manufacturing sites and serving its customers through a dealership network. Bruce Beamer is an engineering manager at Teknion and was able to provide great insights into craftsmanship as it pertains to the world of office furniture. At the risk of repeating a previous definition, craftsmanship at Teknion is defined as quality. What is most interesting is how Teknion defines quality. They define it as the cumulative sum of durability, function, fit/finish and *warranty*. The extra emphasis is added on the last attribute as Beamer indicates warranty is one of their top deliverables especially in the light that they offer lifetime warranty. This definition falls right in line with the literature research previously discussed however, as noted with the extra emphasis, that definition is altered by the company's business model which includes the lifetime warranty. Therefore, as it pertains to this particular company, the definition of craftsmanship is, in part, defined by the corporate environment rather than focusing on customer's senses.

By looking at the four aspects of Teknion definition of craftsmanship, one has to wonder how an emotional attachment is created with the customer. All four attributes Teknion has chosen to focus on involve the customer in some emotional aspect although certain attributes have a more direct connection than others. It can be argued that the durability and warranty functions provide a sense of comfort to the customer with regards to the product not failing either early or late in its life, but it seems that the warranty attribute is more influenced by the monetary benefit that it provides to Teknion as a corporate entity. Function fulfills the expectations of the customer, so that no negative emotional impact is created during the user's experience through a non functioning product. These three attributes are relatively easily defined and measured. The fit/finish attribute, on the other hand, is more complex and deserves a deeper analysis.

Further discussion with Mr. Beamer revealed that fit/finish can be further broken down into comfort which then plays into ergonomics. During an interview, Mr. Beamer specifically stated:

> Ergonomics and comfort are critical attributes to the company. All revolves around the customer interface with the product. An ergonomics engineer is assigned to each product and is expected to be the VOC (Voice Of Customer) at all times. He/She has the responsibility of refocusing the team when it shifts to satisfy some of the internal stakeholders (i.e. Product Development, Manufacturing, Marketing, etc...).

It is clear that through its relentless pursuit and attention to ergonomics, Teknion is able to create an emotional attachment to the customer rather than simply creating a product that meets its function. In this sense, Teknion is supporting the definition of craftsmanship given earlier in the chapter.

Teknion has established a deliberate attempt to create an emotional tie with the customer by the methodical use of their senses. That being said, Teknion does recognize that some aspect of their strategies may need improvement to enhance their connection with the customer. The PD process as it stands today is not as standard as it should be, especially when considering the lifetime warranty policy. According to Mr. Beamer, drawings, processes and design standards are not as explicit as they should be when compared to other industries. Craftsmanship targets are addressed as a result of a constant review by the VOC representative but specific targets are not placed up stream so as to limit the number of downstream changes. Also, the use of benchmarking other competitors within their industry for craftsmanship is not only neglected, but the timing is done more reactively than proactively. Benchmarking is a shortcoming that Teknion is aware of and is currently working on bringing it forward into the product development process.

Textile

The second industry that was looked at for commonality of craftsmanship definitions is the textile industry. Lainiére de Roubaix was one of the largest wool and synthetic groups in Europe. They specialized in wool combing, spinning, weaving, circular knitting, socks and F/F sweaters. Their mission statement consisted of supplying medium to moderate fabrics to the men's and women's wear industries in a good quality/price mix. Their manufacturing plants resided in France, Spain, Brazil, US and Columbia. Lainiére de Roubaix Fabric Division had 3 weaving mills for greige goods and yarn dyed-novelty fabrics, and 2 dyeing and finishing mills for yarn dying and piece dyeing. The division had a staff of over 900 people and all the mills were all within 80 miles of each other in the Northern part of France. Unfortunately, Lainiére was sold and broken into different entities in late 2005 as a result of intense overseas competition. The person interviewed was Yves Mahé who was President of the Lepoutre division, which was the second largest weaving mill in France in 1985.

Mr. Mahé stated that the Lepoutre division defined craftsmanship as the combination of the aspect and the feel. The latter was also defined by those familiar with the art as the 'hand' of the fabric. The aspect is described in more detail as the actual pattern of the cloth. Terms such as "defined vs blurred", "clear vs fuzzy" or "colors crossing vs blending" are often used in conversations involving the aspect. All these terms are somewhat objective in their definition, but they are in continuous use throughout the industry and comprehended by all who are involved. In contrast, the hand is much more subjective as it involves the feel of the fabric. Here, terms such as "dry or soft" or "flat or bumpy" are used when evaluating the fabric feel. When the textile industry definition of craftsmanship is compared to the definition proposed in this chapter, it is clear that they are creating an emotional attachment to their fabric by using the targeted customer's senses. This is more pronounced in the feel attribute of craftsmanship than in the visual aspect, although a case could be made that the aspect is fulfilling the visual sense of the customer while the hand fulfills the touch sense of the customer.

There was no dedicated VOC representative for the textile industry as there was in the office furniture industry. Mr. Mahé describes that the VOC is really captured through the orders. The mills usually run production against orders, so there is little finished goods stock inventory. The only time the mills would run without orders was to run small lots for sample fabrics. These samples are provided to the customer as examples of the manufacturing capability of the Lainiére. Armed with these sample coupons, the customer would be able to place orders accordingly upstream. That being said, the VOC was taken early in the product development process but not again until final evaluation of the finished product.

This long lag between the customer inputs can be explained by the inherent dynamics of the manufacturing process. The industry structure, as described by Mr. Mahé, is made up by four distinct processes which are shown in table 3-1.

Process	Description
Spinning	Makes the yarn used for fabric forming.
Weaving and Knitting	Assembles different yarns to create the fabric.
Dyeing	Adds color to the fabric which has been woven or knitted 'greige'.
Finishing	Improves the aspect and feel of the fabric.

Table 3-1: Textile Industry Structure

The first three steps are heavily controlled by a limited number of process parameters. They might include temperature, tension, speed, pressure, cycle time or raw materials; however they are not factors that can be easily tuned or swapped out due to the machines that are being used. The output of these processes can be tuned or tweaked to improve the overall appearance of the product. As such, the last step is the only process where the craftsmanship attributes, the aspect and the hand, can be monitored and altered; however, the operators are limited by the quality of the raw material and the type of finishing equipment they are running.

Even when the operators and supervisors were able to control the appearance of the product, the evaluation was still somewhat subjective. In an attempt to make the process as objective as possible, the craftsmanship control was done by boundary samples which were previously deemed acceptable by the customer. These boundary samples were used by the stage supervisors and operators as limiting examples of what should and should not be allowed to be shipped to the final customer. As such, the customers play a very interesting dynamic in the process. They are asked for their opinion in the beginning of the product development process and not again until they are ready to receive the finished goods. This is very similar to the automotive industry where the customer is often included in the early clay process of the vehicle; however their input is not asked for again until they are ready to purchase the vehicle in the showrooms of the dealers. This is a common theme across capital intensive industries where changing the product mid-stream results in difficult logistics and would come under extreme cost. Another similarity lies in that there is little that can be done to improve the craftsmanship of the product for both the textile industry and the automotive industry once the actual tools and manufacturing process are already established. There is early iteration via the use of 'sample' parts but once the commitment has been made to make the product, the ability to improve the craftsmanship of the part is limited to the ability to alter the existing tools.

Benchmarking is a valuable tool that Mr. Mahé stated was often used in the industry. One of the limiting factors however, was to make sure that the benchmarking was done with an "apples to apples" comparison. The Finishing process is able to alter the feel and the aspect of the fabric within its limiting process parameters. Obviously, the raw material plays a very important process in the final craftsmanship of the product. The finer the fiber, the softer the hand; the cost however would obviously be higher. As such, the textile industry would stick to measuring variables that would not vary regardless of the Finishing techniques. Attributes such as the finesse of the fiber, finesse of the yarn, twist of the yarn are evaluated first to make sure that none of the subjective abilities of the operators are being evaluated. Once a baseline was established on the material properties alone, then the finishing techniques were looked at in more detail. That being said, the textile industry did not benchmark other industries. They kept all of their research internal to their own industry as they felt there would be no benefit to getting outside industries input. Due to the inherent tactile attribute of the fabric, no other industries were looked at. In addition, because the benchmarking was subjective in nature, a certain amount of training was required to provide accurate data. Without this baseline training, the data generated by the benchmarking exercise was not consistent and provide noise into the system rather than giving an objective reference point.

Automotive

The automotive definition of craftsmanship varies significantly according to the environment that is being evaluated. Each part of the vehicle appeals to different senses of the customer and a proper strategy needs to be chosen accordingly. The interior of the vehicle focuses greatly on the sense of touch and smell. The use of "switch-feel" technologies for the upcoming 2008 Escape[10], or the material selection for seats, or even the infamous new car smell show how designers and engineers are focusing on the sense of touch and smell. The interior designers are pushing the envelope even further by going after the visual sense of the customer with an innovative use of interior lighting. "The (2008) Escape features the first use of Ford's signature Ice Blue interior lighting, which presents a cool, crisp, easy-on-the-eyes light for night driving" (Laforce, 2007). While a book can be written analyzing the interior craftsmanship attributes of the automotive industry, this chapter will focus only on the exterior of the vehicle and how it relates to definition of craftsmanship.

In keeping with the industry data collection process, interviews were held with different automotive designers and engineers to obtain a definition of craftsmanship. Rick Nelson is a craftsmanship supervisor at Ford Motor Company and was able to provide insight into how craftsmanship was seen within Ford Motor Company. Mr. Nelson was tasked to improve the front end fits of the North American product line through the in-depth research of how customers view craftsmanship and how it would translate into the purchasing decision. Mr. Nelson first started tackling the issue through a Black Belt 6 Sigma approach. He decided to tackle the data regarding customer complaints through Ford's Analytical Warranty System (AWS) which collects all warrantable items that were charged back to Ford Motor Company. The idea behind this approach is that there is no better way to get a customer definition of 'craftsmanship issues' than looking at what customers found objectionable enough to take the time to return the vehicle for service. This is especially powerful considering these issues do not affect the function of the vehicle in any way, and only deal with the esthetics of the product.

The following are the three most frequent complaints from the VOC that Mr. Nelson's team were able to extract from the data:

1) Vehicle exterior panels lacked parallelism from side to side (from left to right).
2) Vehicle exterior panels were not properly centered.
3) The exterior radii's were not sharp enough.

From this information, it would seem that the most important customer sense that the automotive industry must pay attention to when trying to create an emotional connection is the visual sense. This conclusion falls in line with common expectations that a customer evaluates the exterior of the vehicle from a purely visual and tactile stand point.

Once Mr. Nelson was able to determine what the expectations of the customer were, his team proceeded to benchmark the competition heavily in a methodical way. Each exterior margin was checked for gap, radii and parallelism. The 50+ vehicles benchmarked were documented, and nominal targets were created out of this benchmarking activity. These targets were then made into specifications that all future programs were forced to meet in order to proceed through program approval. This project shows how dedicated the Ford management team was to create an emotional connection with the customer by using the targeted customer's senses which, in the case of exterior system related to parallelism, panel centering and radii.

Even though Mr. Nelson's team focused heavily on benchmarking, that was not the only tool they used in their search for a customer definition of craftsmanship. They developed a survey internal to Ford Motor Company asking specific and poignant questions in order to determine at what point a joint, margin, gap or radii became objectionable. Some sample questions are listed below in Figure 3-1.

Please answer the following 2 questions pertaining to headlamp fit to hood.

1 Please pick the picture that the margin between the lamp and hood becomes objectionable.

There will be a series of pictures of a fusion with increasing margins between hood and headlamp

2 Which one of the following pictures do you find the most appealing for fit and finish?

There will be pictures of shingled and non shingled hoods to headlamp.

Please answer the following 3 questions pertaining to hood and fender margins.

1 Please pick the picture that the margin between the fender and hood becomes objectionable.

There will be a series of pictures of a Fusion with increasing hood to fender margins.

2 Please pick the picture that the margin between the fender and hood becomes objectionable.

There will be a series of pictures showing different levels of margin parallelism between the hood and fender.

3 Please pick the picture that the margin between the fender and hood becomes objectionable.

There will be a series of pictures of a Fusion with different levels of left to right margin imbalance.

Figure 3-1: Sample of Internal Ford Motor Company Craftsmanship Survey

One of the most interesting results that emerged from the survey was that customers actually tolerated a certain amount of 'imperfection' in specific joints before the overall opinion became negative. This implies that there is a window of opportunity where the designer and engineer can miss the target but yet still create an emotional connection with the customer. The results from the survey were also included in the target setting process and helped determine the level of acceptable variation in the targets.

Summary

After studying two industries other than automotive for craftsmanship definition, their respective attributes are summarized into table 3-2 and compared to the automotive industry definition of craftsmanship as defined above. Also listed are the enablers and the road blocks pulled out from the interviews in each specific industry. Please note that the features which were common across the industries are shown in bold.

Industry	Definition	Enablers	Road blocks
Furniture	Quality (Durability, Function, Fit/Finish, Warranty)	1) Numerous product iterations 2) Dedicated VOC representative on each team. 3) Flexible PD	1) Lack of formalized PD Process 2) Insufficient benchmarking 3) Lifetime warranty
Textile	Aspect Feel ("the hand")	**1) Formalized and heavy up front PD process.** **2) Intense and detailed benchmarking.**	1) Lack of downstream ability to alter product. **2) Lack of planned iterative process.** **3) Subjective evaluation of end product by multiple stakeholders.**
Automotive	Gaps, Margins, Radii's (Exterior)	**1) Intense and detailed benchmarking.** **2) Formalized and heavy up front PD process.**	**1) Lack of planned iterative process on a component level.** 2) Large teams provide numerous inputs into system. **3) Subjective evaluation of end product by multiple stakeholders.**

Table 3-2: Industry Comparison of Craftsmanship

As shown in the above table, the textile industry and the automotive industry share very common attributes with respect to their enablers and roadblocks. As previously mentioned, this might be due to the fact that both industries are very capital intensive and do not allow for much flexibility in the product as readily as the furniture industry.

How does a FEM strategy address this attribute?

Now that an acceptable definition of craftsmanship has been proposed and supported with examples of different industries, how can a FEM strategy address this elusive emotional connection with the customer's senses? If one were to follow the concepts provided in table 3-2, it would be wise to execute as many enablers as possible while avoiding the roadblocks which were also listed.

A FEM execution would most likely be accomplished by a member of the supplier family (this topic will be discussed in greater detail on Chapter 6). This would mean building the entire module outside of the OEM assembly walls. Having the entire module built off line and shipped in as assembly will allow the supply base, or even the OEM if the construction is done in house, to have multiple iterations without requiring the entire vehicle in order to assess the customer's emotional attachment to the product in relationship to the front end craftsmanship. This strategy would fall inline with the furniture industry where iterations are not only expected, but they are a welcomed source of knowledge to get continuous feedback on the craftsmanship attribute of the product. The usual road block with evaluating the craftsmanship of an automobile is the large amount of capital and logistical work required to build the full body prototypes. These prototypes are then evaluated for all attributes, performance and function only when they are completely built and finished. By having the entire front end built as a separate entity, the cost of construction is greatly reduced while the customer can still evaluate what looks to be a full vehicle from a front end perspective. The module can be analyzed without having the need to be built on a vehicle since the module is coming built up from the supply base.

Best of all, the module would be built using production tools and processes rather than relying on the engineering and manufacturing community to mock up front ends for interim reviews not associated with a specified build phase. This allows for build variability to be included in the system early in the production system. Since the prototype builds are limited in nature due to the high capital required to build the vehicles, specific build events are created and kept on a schedule. There is very rarely any time to build an entire vehicle outside of that specific build schedule. As a result, engineers rely on other tools to evaluate craftsmanship and fits/finishes. Figure 3-2 shows how plants typically evaluate parts for craftsmanship. Each plant has a full body fixture where vehicles are evaluated against a perfect body where specific portions of the vehicle are set at nominal dimensions with no variation into the system.

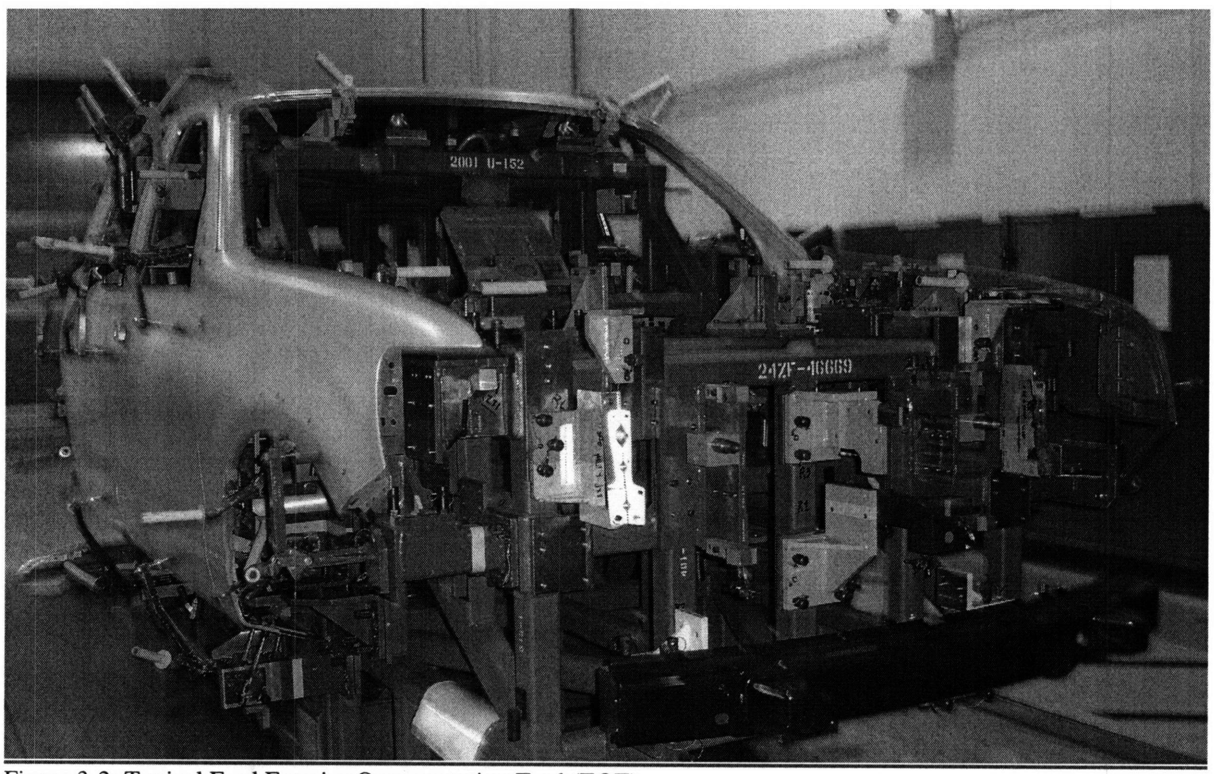


Figure 3-2: Typical Ford Exterior Ornamentation Tool (EOT).

This tooling fixture requires engineers and operators to install the parts one at a time with bare hands, non production tools and not with production processes. Once a craftsmanship issue seems to be resolved, the final check is made at the next prototype build so that the parts are built as they would be in production. Having a

FEM strategy would eliminate this secondary check since the evaluated front end would come off of a production process. The expectations of the customer would not only be fulfilled without building an entire vehicle, but the module would be production representative without even being attached to the vehicle!

Another advantage of the FEM strategy would be that the large number of stakeholders who are required to sign off on the craftsmanship appearance of the vehicle could do so based upon the module itself and not have to wait until full production to assess the final appearance of the vehicle intended to the customer. If we put aside the systemic issues appearing once two sub-systems are placed together, in this case the FEM and the attaching body substructure, the problems of interfaces of the components within the FEM would have been resolved through significant built iterations prior to the module even getting on the full vehicle. This concept was talked about earlier in the context of capital costs and logistics (build coordination); however the physical location of the module was not discussed. The module could be transferred anywhere without the need to be attached to a vehicle, and can serve as boundary object for the entire team to focus discussion around much like in the way the clay in the studio process operates. Having this boundary object be present in numerous physically different locations early in the manufacturing process allows for the numerous stakeholders to input their requirements or subjective opinions early in the process when there is enough time left in the program to act upon those changes.

There is a well known precept by Aristotle that states "What we have to learn to do, we learn by doing"[12]. Having the ability to iterate so much more by using a FEM strategy allows the entire team to understand and learn from their mistakes. It allows the team to understand issues in a much easier fashion and with less pressure by building the FEM off line than if vehicles were moving off the line at the rate of 80 vehicles an hour. This concept ties back to the learning aspect of craftsmanship. By creating a nurturing learning environment in building the module off line and via numerous iterations, the engineering, design and manufacturing teams are allowing themselves some breathing room to learn how the system operates in a controlled environment rather than relying on building the prototype for the first time on a moving vehicle with the entire vehicle variation coming into play.

With all of the benefits a FEM would provide towards the execution of an emotional connection with the customer, there still exists some draw backs. The most notable one is the styling limitations of the FEM. Since the FEM would come in as an entire module and be attached to the vehicle in one single step, certain cutlines would be dictated in the Studio clay feasibility process. This is not such an easy task as these cutlines are often the subject of much debate. Aram Kasparian is a Design Manager at Ford Motor Company and he states that cutlines play a key role in the development of a vehicle's theme[13]. Depending on how critical these lines are to the overall look, they can act as anchors and are non-negotiable in order to deliver a specific look of the vehicle. Stylists start their sketches with these cutlines as the defining elements of their idea or concept and, while they understand that the surfacing of the parts is very important in communicating a quality execution, people often read cutlines as much as exterior surface. Most stylists' initial sketches revolve around vehicle proportion, and overall graphic layout of windows, lamps, grille or other exterior components which is why cutlines play such a key role. Benchmarking also plays a big role in setting up the cutlines. Certain styling cues can be influenced from competitors' vehicles and inspire designers to create specific appearances.

Based upon the loading strategy at the end line of the FEM, a vertical or horizontal cutline would be required to attach the FEM to the body structure. How that cutline gets executed might negatively affect the craftsmanship attribute of the overall vehicle. If the designer's vision of the vehicle conflicts with the current manufacturing state of the FEM, emotional and lengthy debates will occur. The solution will be either a compromise of the vehicle styling or an increase capital expenditure to achieve the desired vehicle appearance.

Summary

In this chapter, the argument was made that craftsmanship could be defined as "the ability to create an emotional attachment to a product via proper use of the targeted customer's senses." This statement was supported through the use of literature research and surveys across three different industries. The literature research supports that not only is the idea of craftsmanship influenced by the culture of the evaluator but it is also something that can be learned and practiced by the designer and the engineer. The three chosen industries, the furniture, textile and automotive industry, all shared common ideas of subjective evaluations of the product by the customer but only the textile industry and the automotive industry had a heavy emphasis on detailed benchmarking within their industry but not outside their industry. It is also important to note that both of these industries share a lack of a planned iteration process but, in contrast, this is a common practice in the furniture industry.

The FEM architecture was then evaluated against what emerged as the enablers and roadblocks of the three industries. The heavy benchmarking will not be affected by the use of a FEM as an architecture however what a FEM does bring is an ability to evaluate the product without the need to build up the entire vehicle which is what is required today. Instead, the module can be built outside of the limitations of the program schedule and the entire front end can be built off of supplier production lines and operators which allows inherent build variability to be incorporated earlier in the product development cycle.

With all of these benefits, there still exist certain limitations as the specific design cues will be limited to the Design Studio personnel. Due to the manufacturing process of the FEM both at the supply base and the assembly plant of the OEM, there will be limitations to how the FEM interfaces with the vehicle. In today's world of design leadership, this is a very large obstacle to overcome as designers do not welcome cues that stifle the creativity required to generate an automotive concept.

4 Damageability

Energy management during collisions is a key attribute for any automotive architecture. One of a vehicle's main purposes is to provide safety and protection to both its occupants and individuals that come into contact with the vehicle during any impact event. Ever since the first automotive related death occurred in 1899[1], a strong emphasis has been placed on the automobile as an important factor in the safety equation of public transportation. Requests have come from many public interest groups, including government supervision, and have resulted into wide variety of regulations. But the first time the automotive industry was truly regulated came with the National Traffic and Motor Vehicle Safety Act of 1966.

While the government standards were first used as the industry maximums[2], there has been a major shift in the attitude towards vehicular safety. Automotive OEM's have greatly increased internal safety standards and they often exceed government standards. The automotive industry has embraced these new safety standards, and often has become a trend setter in establishing new safety requirements.

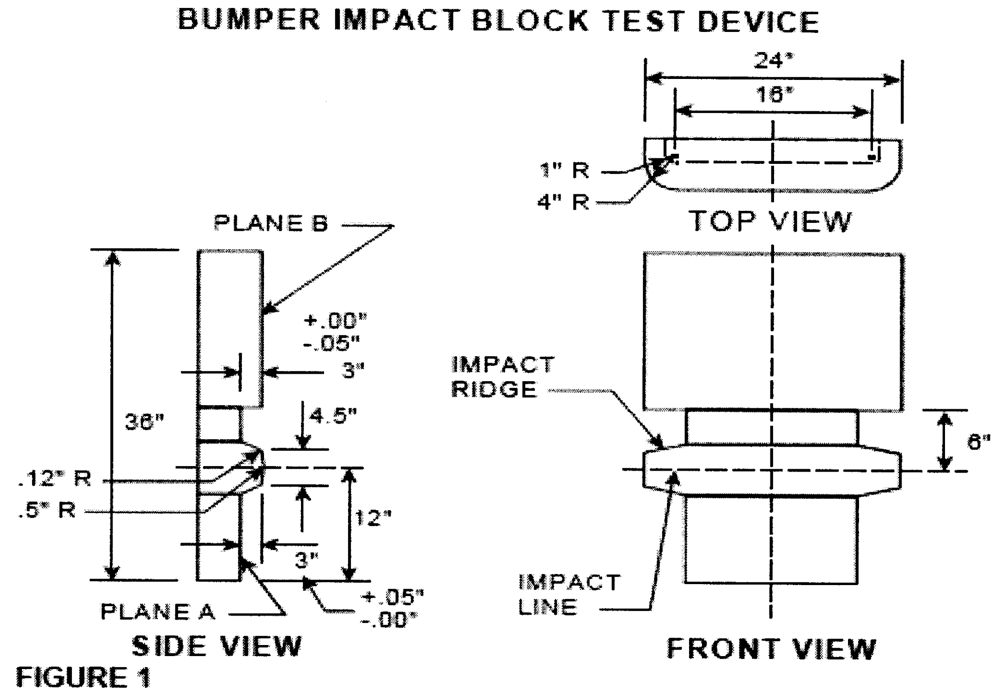
A vehicle's ability to absorb energy is determined by a number of factors which include type of impacts, materials and part geometry. This chapter will concentrate on specific impact patterns that are more affected by the front end architecture. The types of impacts which will be analyzed in this chapter will include the low speed damageability (U.S. Part 581 and Canadian Motor Vehicle Safety Standard 215), high speed damageability and the new Pedestrian Protection which is coming out of Europe. Component materials will not be looked at in depth for this analysis because the same materials can be used for a FEM, partial FEM or even a completely separated front end. Therefore, materials will not provide either an advantage or disadvantage as they relate to the choice of whether or not to use a FEM strategy. Finally, part geometry/front end architecture will also be looked at as it relates to the ability of the vehicle to absorb energy.

Type of impacts

Part 581 (CMVSS 215)

The Part 581 Consolidated Federal Requirements is a series of impacts required for all passenger vehicles sold in the United States. The Canadian 'cousin' is listed under the Canadian Motor Vehicles Safety Standard (CVMSS) 215 which is slightly different in the impact patterns, energy and the damage criteria a vehicle must meet. The difference will be discussed in more detail further in the chapter. Both requirements consist of several impact patterns that must be run in a specific configuration to determine the damageability performance of a vehicle when impacted at low speed impacts that range anywhere between 5.0 mph and 1.5 mph.

There are two types of barriers used in both the Part 581 and the CMVSS 215 impact series. They consist of a pendulum barrier and a flat barrier. The latter is rather self-explanatory in that it consists of a vertical barrier that provides a rigid vertical surface all the way down to the ground. The pendulum is more indicative of what a vehicle-to-vehicle impact would be, in that the pendulum simulates a vehicle bumper beam by having a surface protrude from the flat barrier. The Part 581/CMVSS 215 beam is shown in Figure 4.1 below:



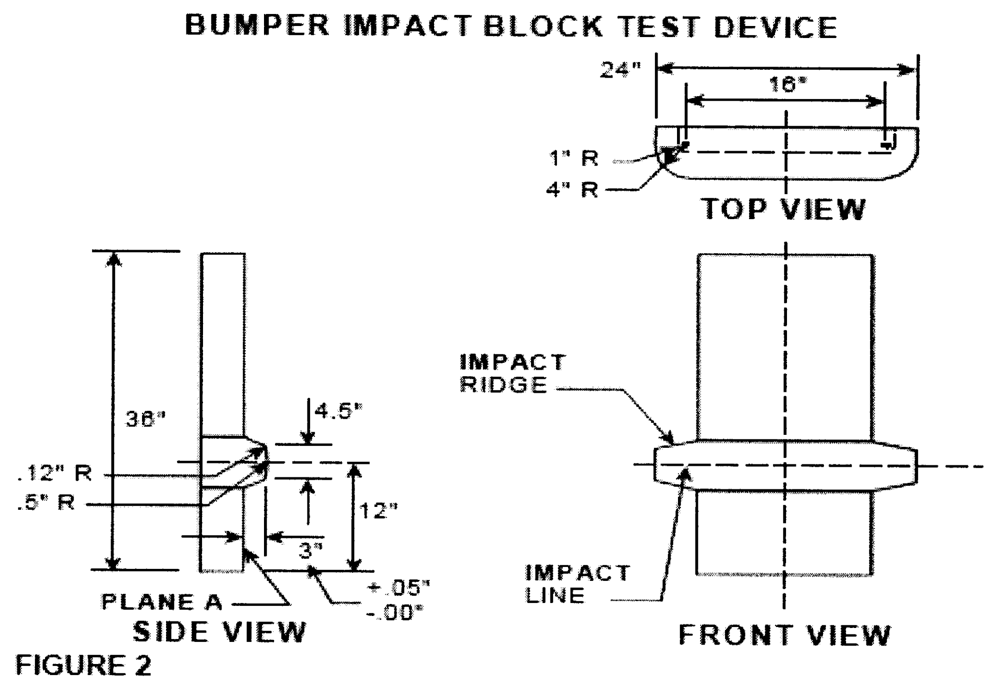


Figure 4.1 – Part 581 Schematic
Source: Department Of Transportation 1990.

As seen by Figure 4.1, the pendulum has the intent to simulate a vehicle-to-vehicle impact condition which could promote either 'over ride', a condition where the pendulum goes over the impacted vehicle energy absorption beam, or 'under ride', where the pendulum goes under the impacted vehicle energy absorption beam.

The impact series for the US Part 581 consists of the following cumulative series:

1) Longitudinal 2.5 mph pendulum impact at the centerline of the vehicle anywhere between a height of 16 and 20 inches off of the ground.
2) 2.5 mph pendulum impact offset of the centerline of the vehicle anywhere between a height of 16 and 20 inches off of the ground.
3) 1.5 mph 30 degree corner pendulum impact at 20 inches off of the ground using the Plane B pendulum.
4) 1.5 mph 30 degree corner pendulum impact at any height between 16 and 20 inches off of ground but must be done on opposite side of impact #3.
5) 2.5 mph flat barrier impact at centerline of vehicle.

The high/low test configurations are left to the discretion of the testing engineer; however the engineer has to show due diligence in proving that the testing configuration was run at the worst case scenario if a legal action raises the issue. The 30 degree corner impacts are explained by Figure 4.2 where the barriers are placed at a 30 degree angle from a pure cross-car location in order to simulate an angular impact.

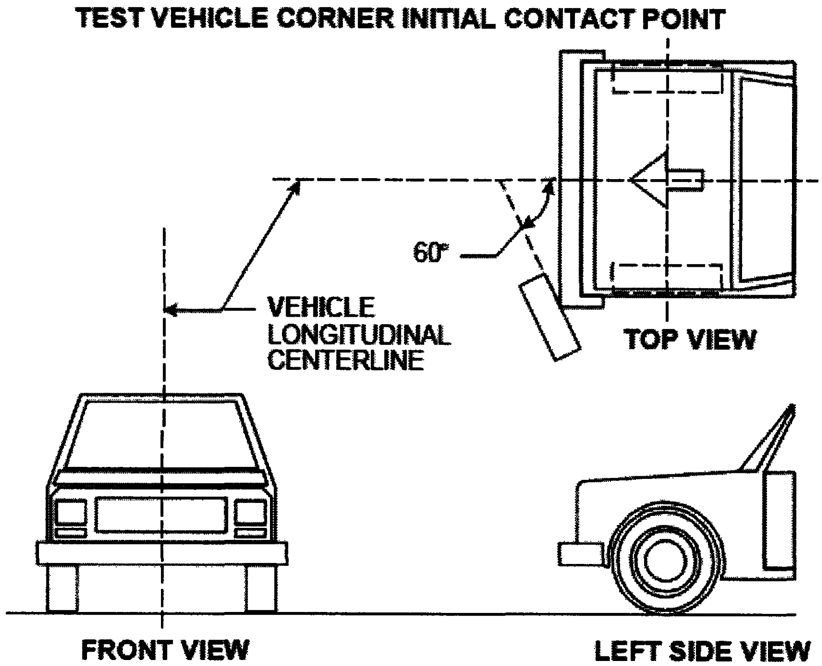


Figure 4.2 – Part 581/CMVSS215 Corner Hit Location.
Source: Department Of Transportation 1990.

The CVMSS 215 test procedure is different from the US Part 581 in that it consists of 4 cumulative impact series which are listed as follows:

1) 5.0 mph pendulum impact at the centerline of the vehicle anywhere between a height of 16 and 20 inches off of the ground.
2) 5.0 mph pendulum impact offset of the centerline of the vehicle anywhere between a height of 16 and 20 inches off of the ground.
3) 3.0 mph 30 degree corner pendulum impact at 20 inches off of the ground using the Plane B pendulum.
4) 2.5 mph flat barrier impact at centerline of vehicle.

Please note the speed differences of the two different tests. While someone might think that a 5.0 mph impact does not carry a tremendous amount of energy, the kinetic energy of the vehicle is tremendous if you take into account the vehicle weight which is anywhere between 3000lbs to 5500lbs.

The intent of these tests is to make sure that no functional damage is made to the vehicle during a low speed impact. Essentially, a customer should be able to drive away from the impact without having to worry about a loss of powertrain or safety related function such as broken headlamps or pierced radiator. The US requirement however is more stringent in that it does not allow damage to any sheetmetal (i.e. hood or fenders) and sometimes, will not allow damage to non energy absorption material (such as cosmetic grilles or badges). This gets extremely tricky in that some grilles are contacted by the pendulum ridge but because they serve no energy absorption function, they cannot be cracked or damaged. These laws were written in the 1970's so some of the damage criteria might seem too stringent however this is a law that must be met and sets a threshold that the designer must account for when developing their models.

Keeping in mind these passing criteria, certain geometries become critical in order to pass the regulation. One of the most critical geometries is the beam overlap with the pendulum during impact. If the pendulum overlap is kept to a maximum, the chances of over riding and under riding are minimized and the intrusion of the pendulum into the vehicle architecture during impact is reduced. The intrusion, known in the industry as stroke, also sets up the distance that other componentry must stay clear of so that they do not get damaged during the test series. The beam must also be flexible enough to not drive energy into the frame rails as the intent of the regulation is to keep the damage to the bumper system only. That way, a customer will only have to replace the beam after a low speed impact and the rest of the vehicle architecture is not affected.

Now that a quick overview of the regulatory test has been provided along with the passing criteria and the critical geometries, how would a FEM strategy/design address this particular impact mode? Low speed damageability is meant to keep damage to only the energy absorption material. Most of the time, this includes the bumper beam, the fascia cover and the energy absorber. The fascia cover is the front esthetic cover of the vehicle and is often made out of thermoplastic olefin (TPO). The energy absorber (EA) is material that is kept between the back face of the fascia cover and the beam. There are a variety of materials that could be used but they often include EPP foam, Xenoy (PC/PBT) or Thermoplastic Olefin (TPO) and they often include intricate geometries in order to maximize the energy control in the package space provided. An exploded view of a typical fascia is shown in Figure 4.3.

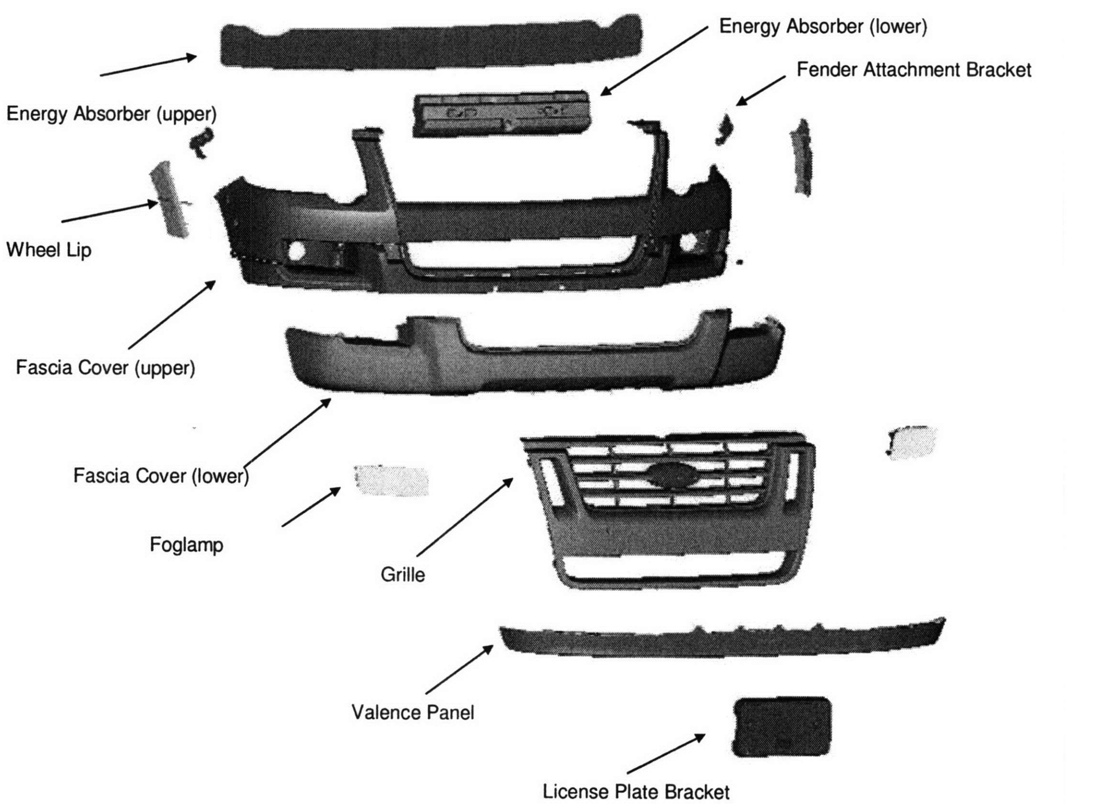


Figure 4.3: Exploded View of Typical Fascia System.
Source: Ford Motor Company

As previously explained, a FEM design would encompass the entire front end including headlamps, beam, fascia, grille, EA and foglamps as one complete module. Since the critical geometry for low speed damageability is the placement of non damageable components behind the maximum allowable stroke of the beam, a system's performance relative to this particular impact series can be reached with or without a FEM strategy. Just because the entire front end would come in as a module would not provide any additional advantage in lieu of any other front end strategy with respect to the placement of non damageable parts beyond the stroke of the beam. It is true that the module will provide additional access behind its components, but this inherent advantage will not transform into an improved performance in the low speed damageability attribute. In addition, a FEM strategy would allow for a more repeatable placement of parts because of the access of the components and the heavy use of fixtures; but this minute advantage would not parlay into any additional advantage because the pendulum barrier placement is done in a vertical fashion and when engineers set up their pendulum height, they account for vehicle ride variability. On the surface, a FEM strategy would not provide any sort of advantage over any other type of front end construction when it comes to low speed damageability performance.

High Speed Impacts

High speed impacts involve speeds higher than 12 mph and go up to 55 mph depending on the particular type of impact testing. They include front and rear testing and their main intent is to maintain the safety of the interior occupants. This includes the prevention of internal injuries such the movement of organs within the body or the breaking of bones as well as exterior injuries such as trapping of body components or prevention of fuel leakage. Out of the three types of damageability that are being examined in this chapter, the high speed damageability is definitely the most critical in today's litigious society.

As mentioned earlier in the chapter, ever since the first car related death in 1899, there has been a strong social movement to regulate the crash and accident avoidance features of an automobile. The National Traffic and Motor Vehicle Safety Act of 1966 created the first attempt to regulate by generating the Federal Motor Vehicle Safety Standard (FMVSS) on March 1 of 1967. The regulations that control the crash worthiness features of an automobile are listed under the Part 571 of the

FMVSS[4]. As expected, numerous components are involved when evaluating a vehicle's crash worthiness performance. As such, numerous regulations/standards were created. Items such as Head Restraints (Standard 202), Seating System (Standard 207) and Roof Crush Resistance (Standard 216) are only a subset of the twenty four standards that are used to evaluate a vehicle. For this chapter, we will concentrate on Standard 208 which is the Occupant Crash Protection.

Because the complex text of the Standard is rather lengthy, table 4.1 attempts to summarize the impact series that are required for compliance to the FMVSS 208. It is not meant to be an exhaustive listing of the entire impact series that is required for certification but, as with the other damageability explained throughout the chapter, it illustrates the magnitude of the impacts that today's automobile must be able to endure.

Barrier Type	**Speed**	**Dummies**	**Dummy Placement**
Rigid Barrier	0 to 30 mph	1) 5%ile female 2) 50%ile male	Driver Side and Pass. Side
40% Offset Deformable (belted)	0 to 25 mph	5%ile female	Driver Side and Pass. Side
Rigid Barrier (unbelted) 1) 90 degree flat 2) 90 degree flat 3) 30 degree left 4) 30 degree right	20 to 25 mph	1) 5%ile female 2) 50%ile male 3) 50%ile male 4) 50%ile male	Driver Side and Pass. Side

Table 4.1: General Summary of the FMVSS 208 Impact Test
Source:
http://www.mgaresearch.com/products_and_services/Testing_Services/FMVSS_Testing/FMVSS_208.htm

It is important to note that these tests do not include any of the other development tests which are required to calibrate the crash sensors or any OEM internal specifications. Recent court cases such as the Explorer/Firestone recall have shown that meeting the government requirements might not necessarily protect a corporation from judicial action even if the OEM's have set higher internal standards to show due diligence in their design.

Also, Table 4.1 does not list all of the impact series required for the New Car Assessment Program (NCAP) which "provides consumers with vehicle safety information, primarily front and side crash rating results, and more recently rollover ratings, to aid consumers in their vehicle purchase decisions. The rating results are relayed to consumers via an easily recognizable star rating system – from 1 to 5 stars, with 5 being the highest." [5] Customers have already been exposed to this system through OEM's marketing strategy to promote safe cars.

As engineers are putting these vehicles through their respective impact series, they are constantly looking for a few key elements in order to obtain a positive rating. As one would expect, these elements all have to do with occupant protection. Elements such as Head Impact Criteria (HIC), Chest G's, Chest Deflection, Femur Load, Hip (H) Point Displacement, Upper Neck Tension, Upper Neck Compression, and Neck Injury Criteria (NIC) are examined with the utmost attention so as to meet the dictated criteria. These thresholds are established by either the government or internal OEM standards. Because of proprietary reasons, these standards cannot be shared at this time; however the data of already built vehicles is available to the public and shows some of the standards the government is forcing OEM's to adhere to. Figure 4.4 shows how 2003 Toyota Corolla and the Chevrolet Silverado Pick Up comply to the FMVSS 208 50%ile male dummy test series.

RESULTS OF COMPLIANCE FMVSS 208 CRASH TESTS ON
2003 MODEL YEAR VEHICLES USING 50TH MALE DUMMIES

MODEL	HIC (15) 700 max.		CHEST G (60G max.)		CHEST COMPRESSION (63 mm max.)		LEFT FEMUR (10000N max.)		RIGHT FEMUR (10000N max.)	
	Drv	Pas	Drv	Pas	Drv	Pas	Drv	Pas	Drv	Pas
Chevrolet Silverado PU	132	94	47	41	33	14	6433	6773	7643	6915
Toyota Corolla	93	76	39	32	25	8	5129	3412	3821	5462
ND = No Data										

MODEL	HIC (36) 1000 max.		CHEST G (60G max.)		CHEST COMPRESSION (76 mm max.)		LEFT FEMUR (10000N max.)		RIGHT FEMUR (10000N max.)	
	Drv	Pas	Drv	Pas	Drv	Pas	Drv	Pas	Drv	Pas
Cadillac Deville	445	343	47	47	23	23	3781	3372	5636	4070

Figure 4.4: Sample Vehicle FMVSS 208 Compliance.
Source: http://www.nhtsa.dot.gov/cars/testing/comply/fmvss208/2003crashtest_50thMales.pdf

When dealing with such high speeds and large magnitudes of kinetic energy, it is not expected that the vehicle exterior and internal frame components will go through the crash event without damage. This was re-iterated during an interview with Jody Raval who is a Crash Development engineer for the Ford Motor Company. Essentially, a crash team evaluates a vehicle's crash worthiness by the amount of crushable space from the forward most point of contact at the front of the vehicle to the point of contact to the occupant dash panel. This might seem like a generous amount of space when looking at today's vehicles however one must keep in mind that the energy that must be absorbed is dependent on the vehicle's weight and that the engine does not count as crushable space[6].

The crushable space is most easily controlled by the form of the front rail structure forward of the dash panel in a vehicle. Intensive FEA analysis is done to create bend points and break initiators in order to actively and correctly manage the energy during the event. How these rails are tied into the rocker panels underneath the doors is also vital as the impacts are so violent that they sometimes bend the vehicle at the pre-determined hinge point under the B-pillar of the vehicle. For those who are not familiar with the construction of the vehicle, each pillar is marked by a letter and begins at the front of the automobile. The forward most pillar by the windshield is called the A-pillar. The next one between the front and rear door is called the B-pillar and so on.

Also, the way the front rails are tied together is critical to the performance especially during the off-set crash testing. The intent is to keep the two front rails tied together during the impact so that the load is spread across both rails rather than relying on only one rail to manage the entire energy. That is why the front bumper beam design is critical to maintain integrity between the two interdependent front rail systems.

Now that the impact series, passing criteria, and general geometry for high speed impacts have been briefly discussed, how would a FEM strategy address these issues? Because the front end components are not expected to survive the crash event without damage, front end geometry does not play as vital of a role as it does for the low speed damageability events. That being said, the front bumper beam is critical to a vehicle's ability in maintaining front end structure during the event. Since the current direction of Ford Motor Company FEM strategy is not to have the bumper beam as part of the FEM, this should not be an issue however if future strategies include having the front bumper beam part of the FEM module, there must be significant consideration put into the design of the beam as well as its interface into the rest of the front end module.

In addition to the front bumper beam consideration, one must understand how the tie-ins of the module itself to the front rails and the engine compartment are planned. Some of the critical design dimensions for the FMVSS 208 crash events are the location of fuel lines and the battery placement. Both dimensions must be looked at in a dynamic environment when the high speed strokes are taken into account. A FEM strategy will not be any different from any other type of front end construction since the components would be the same as well as their placement in vehicle position. If thought is placed in the design of the battery and fuel placement has been properly done, that should not be an issue.

Pedestrian Protection

Pedestrian Protection is a new set of impact patterns developed by the United Nations Economic Commission for Europe (UNECE) which are designed to protect an individual (both adult and child) when being struck by a vehicle going 40 kph. The European Parliament first passed Directive 2003/102/EC on November 17th, 2003, requiring European automakers to meet the pedestrian requirement in the form of two rolled out phases with the second phase being more stringent that the first[7]. While there are still significant discussions taking place as to whether or not this legislation will come over to the US market, North American OEM's are taking a pro-active step in designing for this requirement since their vehicles are being sold to a global market, and need to meet each all local market laws.

There are two types of impacts that the legislation tries to protect pedestrians from. These are called head form and leg form protection. The head form protection band tries to minimize the damage done to an adult or child head as it impacts the hood of the vehicle. The intent is to diminish as many hard contact points as possible such as contact to the fender attachment rail or any powertrain components as these items are not compressible and therefore do not absorb any energy. The second type of impact is the leg form, which simulates the impact a vehicle would have on an individual's leg. The intent is to minimize the load seen in the femur and reduce the shear seen in the individual's knee joint. Figure 4.5 shows the typical types of impacts simulated with both the head form and the leg form.

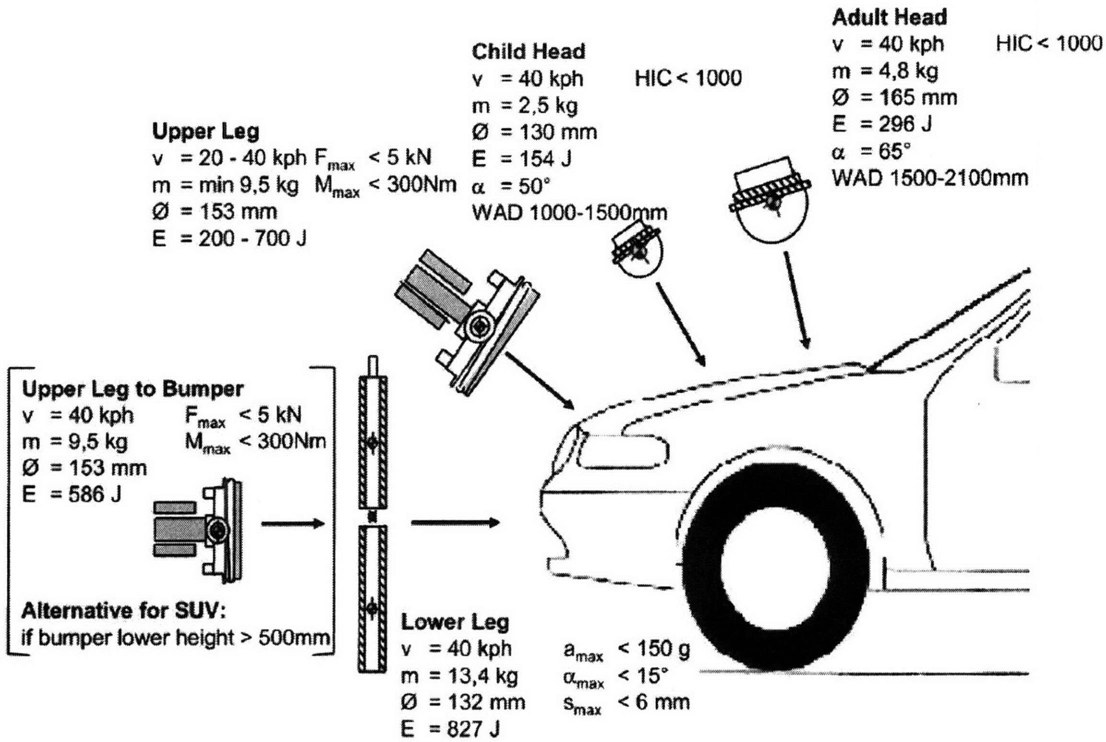


Figure 4.5: Typical impact hits for both the head form and the leg form hits.
Source: Ford Motor Company

Once again, the geometry of the vehicle plays a key role in evaluating the performance of a particular vehicle for pedestrian protection. As evident in Figure 5.5, we will only concentrate on the leg form portion of the test procedure as a front end strategy would not impact the headform performance. Those results are dictated by the material of the hood and the position of the hood/fender cutline as well as the position of the wiper arm pivot points. What is not evident from Figure 5.5 is how the plan view sweep of the front end comes into play. The legform is only allowed to be hit inside of a certain area that is dictated by the sweep of the front end. The more angular the front end is the less surface area the legform can be impacted unto the front end.

The criteria to meet pedestrian protection involve measuring the loads going into the legform as well as measuring the shear that occurs in the middle of the legform. Contrary to what Figure 4.5 seems to indicate, the legform impact module is not completely stiff but is designed to bend in the middle much like a human knee would during impact. It simulates the human knee as if a pedestrian was struck from the side, which means that if too much shear is experienced it would result in a severe injury on the struck pedestrian. Figure 4.6 shows how a legform module would respond during an impact.

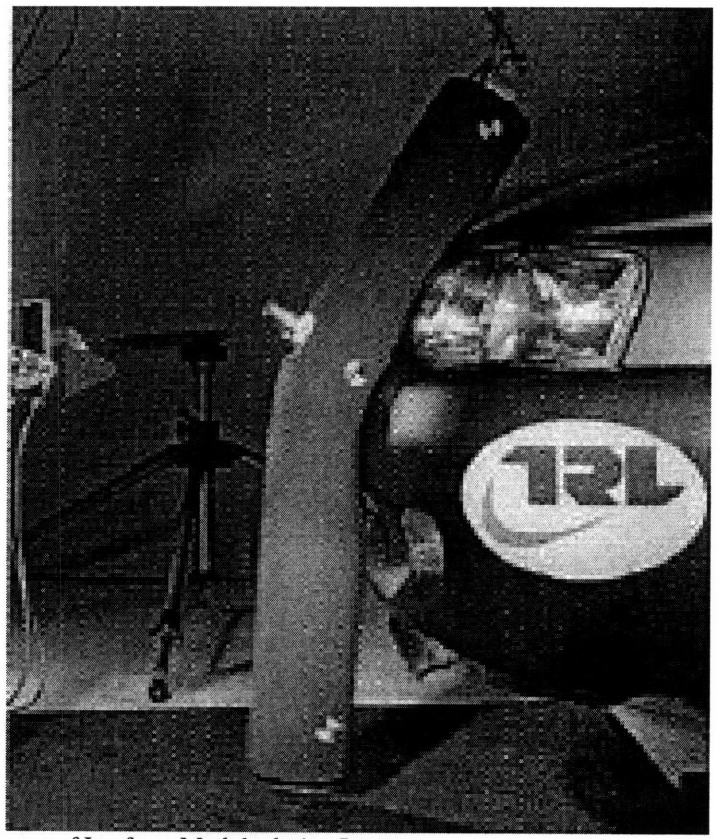


Figure 4.6: Typical Impact of Legform Module during Impact.
Source: Hardy/Lawrence/Carroll/Donaldson/Visvikis/Peel, 2006

While the legform shown above does indicate the vertical impact with relationship to the vehicle, there is also a cross car component of this impact series that must be taken into account. There is an impact band that is set up relative to the geometry of the vehicle very much like it was set up for the low speed damageability pendulum. Figure 4.7 shows how that barrier is set up.

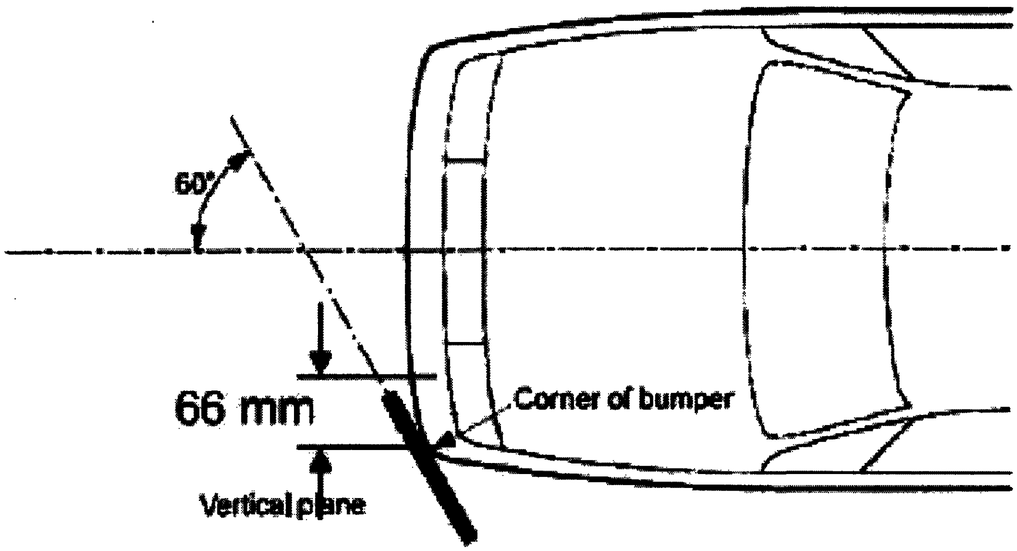


Figure 4.7: Maximum outboard position of the Legform Module.
Source: Ford Motor Company

A 60 degree plane is drawn true grid to the vehicle and moved forward until the first point of contact. Once that point has been established, another vertical line is drawn 66 mm's inboard. Please note that this is done on both sides of the vehicle. The legform module is allowed to be placed anywhere in between those two outboard lines but it must be kept in mind that the testing engineer must show due diligence by testing the worst case scenario. This is similar to the due diligence that to be shown during the low speed damageability testing scenario.

Energy management once more comes into play. Making the front end soft in order to reduce load into the legform will result in high shear loads seen by the knee joint. On the other hand, making the front end stiff so as to reduce the shear loads into the knee will translate into high loads into the legform module. While this might seem like a no win situation, there are certain alternatives which bumper and front end engineers can use in order to meet pedestrian protection requirements.

One of the first things front end engineers do is try to make the front end as flat as possible. This allows the load of the impact to be spread out on as large an area as possible thereby reducing the chances of having high energy point loads. Also, it is to the advantage of the engineer to align the front end contact points with the center of gravity (CG) of the lower and upper legform module. This energy management strategy allows for minimum independent rotation of the upper with relationship to the lower portions of the legform module. Another strategy that is also often used is to make the upper portion of the front end have a softer spring constant than the lower portion. What this does is to force the pedestrian to rotate up onto the hood by swinging the bottom portion of the leg from underneath them. This strategy does have its issues in that it forces the pedestrian onto the hood; however it is assumed that the rest of the vehicle meets the headform requirement and therefore minimum damage is forced unto the pedestrian.

Both of these energy management strategies involve the use of stiff chin spoilers which were not required in previous designs. Figure 4.8 shows a typical chin spoiler that allows for the proper energy management listed in the above scenarios.

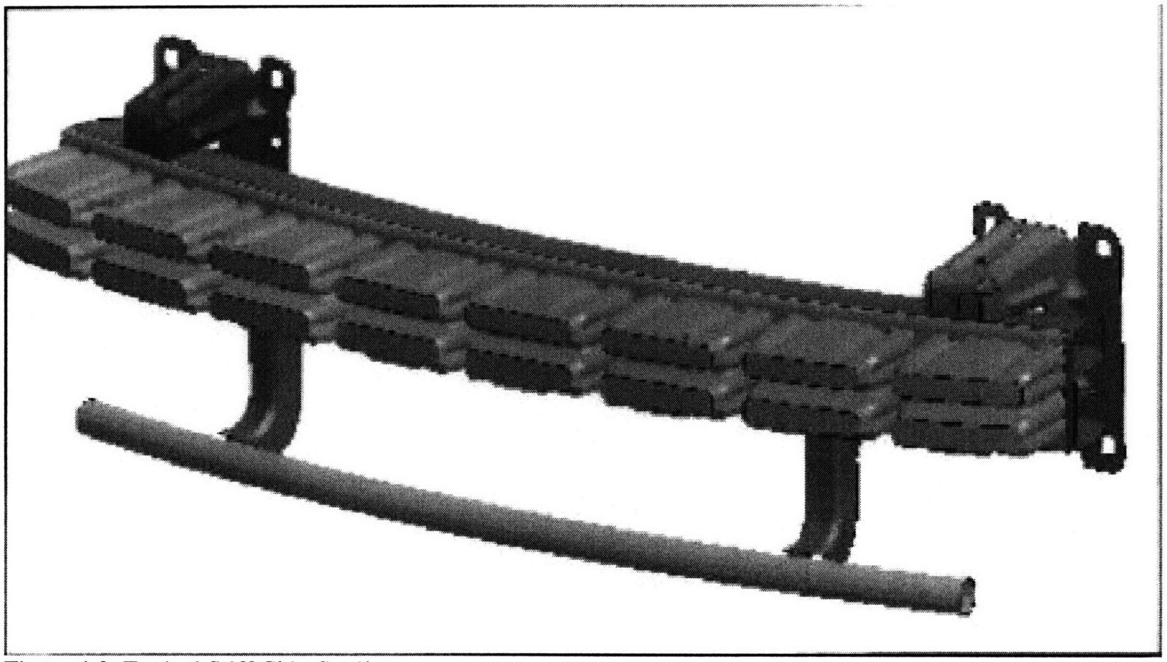


Figure 4.8: Typical Stiff Chin Spoiler.
Source: Ford Motor Company

Please note how the lower chin is brought forward in vehicle position so as to increase the surface area of the energy absorption material and prevents the upper and lower leg from rotating independent of each other. If the independent rotation occurs, there is a higher risk of failing the shear requirement of the pedestrian protection legislation.

Now that the impact series, passing criteria, and general geometry for pedestrian protection have been briefly discussed, how would a FEM strategy address these issues, if it should even address them at all? Much like the low speed damageability, the energy management of the system is really dependent on the geometry of the overall front end. The key factor for pedestrian protection is that the critical damage must now be limited to the pedestrian rather than to the componentry of the vehicle itself. As previously explained, one of the key factors for the proper pedestrian protection energy management is the ability to control the independent rotation of a pedestrian's upper and lower leg. The use of stiffer lower chins would imply that a FEM strategy could provide some benefit to address the protection requirements;

however it does not imply that any other strategy, if well executed, could not deliver those same results. The use of componentry and its placement can be done regardless of what type of front end assembly strategy is done.

However, having a FEM strategy entails a Single Point Of Contact (SPOC) approach in which responsibility is given to an individual accountable for the entire FEM and its performance. What this does is create a system engineer position that is able to understand the overall system performance of the front end as it relates to pedestrian protection. This only offers a minor advantage as a perfectly integrated team could ultimately come up with the same design solution if their communications are seamless. The argument could also be made this would be also applicable to the low speed damageability impact series however it could be argued that the low speed damageability requirements are so dated that no major innovation is required to meet the targets, which is not the case for pedestrian protection, which requires new methods of energy management on a systematic level.

Also, pedestrian protection testing can be completed on a front end module basis by itself. Instead of having to test an entire vehicle, a FEM strategy will allow testing to be developed and completed on only the components that are required. This greatly reduces the costs of testing since engineers would no longer require entire vehicles to test or even have to deal with the logistics of traveling proprietary vehicles in public areas. This strategy could also be applied to the low speed damageability since the impact series do not generate damage beyond the front end.

Summary

In the chapter, three types of damageability that are most relevant to the front end structure were discussed. They are the low speed damageability, high speed damageability and pedestrian protection. As each type of impact has specific ways to handle energy into the system, the key geometric enablers were also presented. The argument was made that since high speed damageability mostly deals with occupant safety and does not concern the ability of front end architecture surviving the impact (other than contacting fuel lines), low speed damageability and pedestrian protection are the areas where design and execution of the front end are key and where the benefits, of a FEM execution can be leveraged.

An overall summary of the findings are listed in Table 4.2 shown below.

Impact Tests	Key Requirement Criteria	Key Geometrical Dimensions	FEM Strategy Advantage
Low Speed Damageability	1) No damage to any non Energy Absorption componentry. 2) No Functional Damage to safety components (CMVSS 215).	1) Beam Overlap to pendulum barrier. 2) Placement of front componentry out of stroke zone.	1) None. Critical geometry can be achieved with any strategy. 2) Front end testing can be completed on a modular basis.
High Speed Damageability	1) Occupant Loads 2) No opening of closures systems (i.e. hoods, doors, liftgates)	1) Crushable Space. 2) Rail position and tie-ins 3) Placement of fuel lines and battery.	1) None. Front beams are not included in FEM strategy. 2) FEM or not FEM construction should not be a consideration if design consideration is played into key geometrical dimensions.
Pedestrian Protection	1) Headform loads 2) Legform loads	1) Dependent upper and lower leg energy management. 2) Proper CG alignment.	1) Systematic solution that allows for innovative use of geometry controlled in one module. 2) Legform testing can be completed on a modular basis.

Table 4.2: FEM Performance with Respect to Damageability.

The table shows that a FEM strategy shows a minor improvement over other types of front end architecture. The key enabler for a FEM strategy is the Single Point Of Contact (SPOC) approach where responsibility and accountability lie in one source of information. Also, a FEM strategy allows for a systematic approach to the new pedestrian protection regulation coming out of Europe. Finally, a FEM strategy can allow for early development testing to be completed at a component level rather than using entire vehicles for testing.

On a last note, it was also shown that although various front end architectures other than FEM's can accomplish this same performance for low speed damageability and pedestrian protection, the SPOC approach truly drives a system level performance. Vehicles have passed the Part 581 test without the use of FEM's for many years; so it cannot be argued that a FEM strategy will resolve the issues. However a FEM strategy with a SPOC might be able to alleviate any downstream changes because the performance of the entire system relies on one single point of contact.

5 Assembly at an OEM

The manufacturing of an automobile is a very dynamic environment as the whole plant operates under the precept that time is money. There is a strong emphasis on keeping the line moving to continuously build product and ensure that the product is constructed with high quality the First Time Through (FTT). In order to meet the high time and quality standards, an assembly plant uses numerous factors as methods to control or maintain the product fabrication and quality. These methods or processes are measured and modified in order to keep the plant assembly line moving while still making a quality product. The methods and processes used include product design, operator training, tooling fixtures, serviceability and even assembly aids. Most of these methods were already discussed in previous chapters as they relate to the FEM as an automotive architecture. The product design, for example, was discussed in the Architecture and Damageability chapter along with the serviceability attribute. This chapter will focus on a specific subset of attributes that the Final Assembly Plant (FAP) uses, and on the role a FEM architecture can play in the FAP dynamic. The attributes that will be looked at in detail will be the online adjustments made at the FAP, the Material Planning and Logistics (MP&L) group and the In Plant Vehicle Repair (IPVR). The analysis will include an overview of each attribute, the potential pitfalls that are commonly faced within each attribute and a list of possible resolutions on how to circumvent the pitfalls. Each analysis will conclude with long term implications that each of the solutions present. The chapter will then wrap up with a list of additional attributes that would need to be looked at in more detail. As laid out previously in the document and in more detail in the subsequent Supplier chapter, a FEM architecture requires a holistic approach in order to truly assess its potential. To limit the discussion to only the three attributes listed above would be short sighted and would not follow the spirit of this analysis however it is a necessary constraint for this document.

Online Adjustments at the FAP

Fit/finish is a major deliverable of the FAP. A vehicle is continuously judged on its appearance and that appearance is often equated to quality (see Craftsmanship chapter). One of the major deliverables of the FAP is its ability to consistently provide a product that meets the craftsmanship standards established early on during the launch of the vehicle. While the ability to influence the fit/finish of the vehicle is somewhat limited by the design of the componentry, the FAP has a certain latitude to meet the established targets through the use of On-Line Adjustments (OLA's).

One who has not walked the plant floor would not believe the amount of variation that can be seen in a vehicle. A common public mis-conception is that all vehicles are built the same; however after walking the line, one can see that OLA's are common throughout the FAP line, and affect almost all aspects of the vehicle. Hoods, decklids (otherwise known as trunks) and doors are all hand fitted at the end of the line once the vehicle is completed. This fitting is not only necessary for craftsmanship reasons but also for water leaks, as decklids require a proper seal to close out any potential water paths, or NVH, as doors require the right sealing to prevent air entry into the cab. This phenomenon was observed by the author at a multitude of Final Assembly Plants at Louisville (KY), Wayne (MI), Chicago (IL) and St. Louis (MO) where both Body-on-Frame vehicles and unibody vehicles are built. These OLA's are common across both vehicle architectures and do not differentiate between a car and a truck. On the vehicular front end, OLA's mostly consist of mean shifting componentry based upon the available data of the front end structure. The body structure of the vehicle is measured on a continuous basis for any trends. This data is used for trouble shooting any fit/finish issues or to check for quality control of the structure as it leaves the bodyshop. The practice of an OLA on the automotive front end would require shifting some componentry structure, such as moving a lamp housing outboard by x mm's, based upon a front end bolster consistently building inboard by that same x mm's. It is a systemic approach that is more reactive than proactive as the change often occurs after the vehicle is already built. The FAP would prefer making the change in the tooling to make the OLA not operator dependent however the OLA is often made by an operator in order to keep the line moving and making the product on time.

There are several issues that emerge as a result of using OLA's. The first is that some OLA's are operator dependent as previously mentioned. Using an operator for any process introduces variability that would otherwise not exist in the system. Worse, that variability will not be consistent for the simple fact that a human operator is doing the work. While operator training can alleviate this issue, the inherent variability that humans bring about will never go away. The way to reduce this variability is through the use of Gage Reproducibility and Repeatability (Gage R&R). Gage R&R's will allow an individual to accurately measure what kind of variability will be seen by implementing the OLA and how it will also provide an insight into how that variability will change across multiple operators. This will allow the FAP to include the measured variability in the design of the OLA up front. Even with the use of a gage R&R, there will always be residual operator variability, especially if the OLA relies heavily on operator accountability (i.e. use of hand pressure across a taped surface rather than using a hand applied roller).

The second issue that OLA's introduce is that they can hide the root cause. OLA's are often used as Band-aids to resolve a build issue that pops up on the plant floor. That is done to keep the line moving because any minute of line down time results lost revenue. Of course, that assumes that every built vehicle can be sold for a profit. While these Band-aids are good at resolving the immediate issue at hand, they sometimes are used as permanent corrective action and require additional labor to be built into the process, rather than fixing the issue through quality actions. One must be careful not to allow a sense of complacency with the use of OLA's. Otherwise, additional labor will be built into the product rather than fixing the design issue at hand. One method to prevent this pitfall is to enforce a shelf life on the OLA. By instituting a countdown clock on the OLA, it puts pressure on the team to either implement the permanent corrective action through the use of labor or force a design change to eliminate the need for any adjustability. This process drives accountability of the FAP staff and creates a sense of responsibility in order to accurately process the OLA.

The final issue with OLA's is the potential to create new issues downstream that were not envisioned when OLA's were implemented on the line. This is a common phenomenon where the plant floor is so focused on resolving the issue that they have blinders on which prevents them from seeing any future downstream repercussions. A holistic approach must be taken when implementing OLA's. One can prevent these downstream failures by implementing 'red rabbit' trials in which heavy iterative trials can flush out any downstream failures prior to full OLA implementation. The OLA would be implemented on a trial basis, so as to make sure no operation or process downstream is affected. The reason these trials are called 'red rabbits' is because any failure of the trial is brought to the attention of everyone, and essentially has the appearance of an unforgettable red rabbit. While red rabbits will prevent any downstream actions exhaustively, a more efficient method of testing the change can be developed as long as the engineering team goes through the implications of the change thoroughly.

How would a FEM architecture address the use of OLA's? As previously mentioned, front end OLA's consist mainly of mean shifting componentry according to how the vehicle front end structure is building during a particular timeframe. This data is usually available a couple of days prior to the vehicles being built in the assembly area due to the paint lead time. Using a FEM architecture would allow the data to be fed upstream to the supply base, and have the modules come in with the componentry mean shifted through the use of fixtures and jigs at the supply base. This would result in a feed forward system that is proactive rather than reactive.

This saves the OEM from having to spend money in expensive tooling change to mean shift the componentry parts themselves. The FEM architecture could accommodate the front end variability by shifting the components in the assembled front end itself and not physically change the componentry tooling at all. One important nuance that must be grasped is that the FEM modules would have to come in Just-In-Time through a process called In-Line Vehicle Sequenced (ILVS). This is nothing new to the automotive industry however in order for this mean shifting strategy to work, it is imperative that the FEM's come in ILVS, so that there is enough lead time in the supply chain to mean shift the FEM at the supply base assembly area or the OEM assembly plant depending on how the FEM is being assembled.

Using a FEM strategy will not eliminate hiding the root cause of an issue by using an OLA. No architecture can address this procedural failure. It can, however, drive the OLA away from the FAP and entirely out of the hands of the OEM if the FEM is built at the supply base. By moving this potential downfall out of the hands of the OEM, the OLA or design action is being driven to a less complex interface. Instead of doing an OLA at the FAP on a larger Work In Progress (WIP) product, the OLA is done on a module that contains fewer parts and, in case the module is damaged, the replacement cost is less than it would have been had the OLA been done when the vehicle is built. Therefore, while the fundamental dynamic of hiding the root cause is not necessarily addressed by using a FEM architecture, the risk of using an OLA is less considering the OLA is being done on a less expensive WIP than if it were implemented on the vehicle at the FAP. This logic could also be used for the potential pitfall of downstream effects of implementing OLA's. Since the trials are first done on the module by itself, having a FEM architecture would facilitate trials on multiple levels. The interfaces of the FEM are limited and if the OLA or design change to eliminate the OLA is kept internal to the module itself, a full vehicle trial would not be necessary in order to implement the OLA or design change. By using a

FEM, the overall system interfaces are reduced, and the system is made less complex.

It is important to note that the advantages of a FEM architecture are based upon a feed forward system which has, for its roots, the concept of a lead time between the availability of front end structure dimensional data and the delivery of the FEM to the FAP line. There is a long term implication that must be considered when using this feed forward system. While this lead time is acceptable in today's environment, most, if not all, OEM's are trying to switch to a Just-In-Time strategy which continuously forces a reduction in assembly lead time. As OEM's force their FAP's to build vehicles in a matter of hours and not days, the FEM architecture loses its advantage over standard end item component architectures as the FEM supply base cannot be fed the necessary data in an appropriate timeframe to take action. When this occurs, the number of OLA's at the FAP can increase unless the design reduces or eliminate variability in the area of fit/finish.

Material Planning & Logistics (MP&L)

The MP&L attribute of a FAP is extremely complex. The MP&L group must organize the delivery of over 5000 different components and manage their transport all the way up to the assembly line so that the entire vehicle is built in one smooth, continuous motion. When done correctly, this work is overlooked and taken for granted but when any part of that value chain fails, the failure is seen by everyone from the line worker to the plant manager. The ordering and delivery of the components involves dealing with not only the requirements of the FAP but also those of the supply base. Items must be ordered with a minimum lead time to properly support the assembly line, but also with a maximum lead time that would prevent extra inventory from building up and create a buffer or even worse, part obsolescence.

Unfortunately, the most common pitfall that an MP&L staff falls into is that an inventory build up is often created to compensate for the fluctuation in the assembly line production schedule. This has a detrimental effect as the componentry inventory build up creates an artificial demand upstream at the supply base. This is often known as the 'bullwhip effect'. The artificial demand is generated by creating an inventory buffer which drives variability in the demand upstream. The artificial demand is created because extra inventory is needed to fill the inventory buffers in the system and is not used to generate finished good product. The bull whip effect is exemplified in Figure 5.1 below.

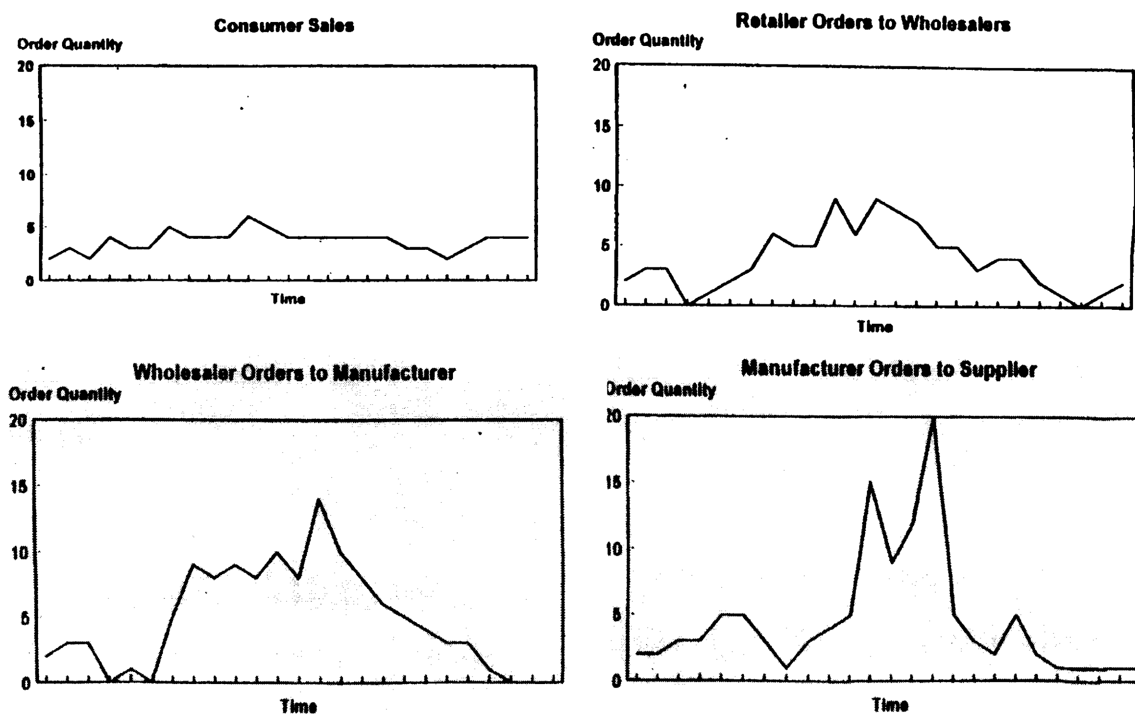


Figure 5.1: Variability of Orders throughout the Supply Chain.
Source: Lee, H, P. Padmanabhan and S. Wang (1997), Sloan Management Review

Figure 5.1 shows graphically how the orders vary tremendously the further and further away they are from the finished good product itself. What this dynamic creates is a sense of urgency to force the supply base to deliver product in far greater amounts than what the customer and, in this case, the FAP requires. This, in turns, always creates obsolescence to a certain extent as the supply chain can never truly get rid of its entire stock. Even worse, if the supply base uses a LIFO system (Last In, First Out) instead of a FIFO system (First In, First Out), the risk of obsolescence is increased even further.

Given the inevitability of the bullwhip effect, one must have a proper strategy in order to reduce it. According to MIT professor Martinez de Albeniz, the ways to cope with the bullwhip effect are to[1]:

1) Reduce variability and uncertainty.
2) Reduce lead times.
3) Create alliance arrangements.

Knowing these mitigating techniques, one can develop a strategy to minimize the impact of the bullwhip effect.

A FEM architecture will not affect the bullwhip effect. This is a dynamic that is not affected by the architecture of the vehicle as much as it is by the MP&L management strategy. While a FEM will reduce the number of overall parts that is ordered by the FAP, the tendency to create an inventory buffer will still exist even if the FAP is ordering only one part. However, looking at the strategies that Professor de Albeniz laid out, a FEM strategy could possibly fall into the "create alliance arrangements" category. This method of coping with the bullwhip effect states that an OEM can reduce uncertainty by creating an open communication channel with its supply base. This includes opening up order schedules, sharing sales figures and even sharing internal price data. All this requires a certain amount of trust between the OEM and the supply base which is a concept that will be explained a little bit further in Chapter 6 - Suppliers.

A FEM strategy will reduce the number of parts an FAP must order, so uncertainty is reduced somewhat at that level. Having such a complex component delivered on a daily basis in an ILVS stream will require some information to be given to the supply base. Also, there are inventory restrictions to the FAP building a FEM strategy since the same FEM cannot be used on the different vehicles. However these restrictions have not stopped some FAP MP&L analysts in the past to build up inventory of ILVS parts. Interviews with Amy Pope from the Louisville Assembly Plant have shown that dimensionally large ILVS components such as fascias, wheel lips, cladding and even roof racks have some safety stock built up to compensate for change in vehicle scheduling or repair[2]. This is done in spite of the large warehouse space required to store these components. If a FEM is introduced in a FAP that already has a culture of building up safety stock, the tendency to continue ordering extra inventory will not change. In short a FEM strategy will reduce uncertainty somewhat for the MP&L at a FAP since the number of ordered parts will be reduced however the ability to reduce the bull whip effect lies in the ability of the MP&L department to effectively manage their stock.

While a FEM strategy does not affect the short term of the MP&L attribute, the long term effects should not be ignored. Having as many as thirty components coming in Purchased In Assembly (PIA) in one module will greatly reduce the number of assembly inputs in the line when they were previously coming in as end items. These assembly inputs are also known as 'streams'. By having only one stream to the FAP line, a plant can reduce their assembly workforce or shift the workforce resources accordingly. If one is thinking holistically, this will not only reduce the number of operators to assemble the part on the main line but also the number of fork lift drivers to bring the parts to the line, or drivers to transport the parts from the supply base to the FAP, or even the number of maintenance folks that service the monitors at each station. Not only does it reduce the work force but it can also reduce the length of the main line itself. The size of manufacturing plants could be reduced as a result of a FEM architecture.

With the potential to reduce the workforce size, a FAP will have some difficulty selling the FEM architecture to a union shop. As a result of the lower volumes that the North American OEM's are seeing in today's environment, NA OEM's will have an especially hard time bringing in FEM architectures. If the FAP is able to take a lean approach to the situation and emphasize that the FEM is here to minimize waste and create value, the FAP can re-allocate the union workforce to other jobs such as Kaizen team leaders. The workforce that is taken off the line must understand that they will be getting new job responsibilities. That will provide the same value to the customer as they were receiving with their old jobs.

In Plant Vehicle Repair (IPVR)

As one can imagine, it is very difficult to have a vehicle come off the assembly line without any physical damage as a result of human interaction. The vehicle is touched more than a thousand times during production by more than a thousand people and such, the human element will always bring a certain amount of uncertainty in terms of slight damages to the vehicle. Common examples of vehicle damage include fenders getting scratched by belt buckles when an operator or engineer leans into the engine compartment or door getting dented when an operator goes into the vehicle to drive it to another part of the plant. An IPVR might even happen as a result of an emerging issue that was not seen before during any of the prototype builds. Even with all of these events, the First Time Through (FTT), some FAP's are seeing FTT's as high as 99% with high 80%'s being the average[3].

There are two major issues with IPVR's that control the quality of the repair work. The two issues are the repair time and the damage to the surrounding components. While it may seem obvious that both of these attributes would affect the quality of the part, they must not be ignored. With vehicles coming off the line anywhere between 30 units an hour to over 80 units an hour, the IPVR shop space can become very crowded in a very short time. When a FAP is producing large trucks, the already small shop size becomes even smaller. Having a long repair time will increase the time the vehicle stays on the IPVR shop floor and with vehicles coming off the line on a continuous basis, the IVPR shop can quickly become the bottle neck of the FAP, thereby affecting upstream processes.

Damage to surrounding vehicle components not only affects repair time, but also has another negative quality effect. There is common saying on the plant floor stating "You will never build the vehicle as good as you did the first time through"[3]. Taking off different components to gain access for a repair will result in degraded vehicle quality, regardless of whether or not damage was done to the components that were taken off. While the design of the components is done deliberately to drive variability out of the system, the vehicle cannot be expected to be built identically every time parts are taken off the entire assembly. This is such a common dynamic that OEM's even put requirements to prevent this failure mode. An example of such a requirement is stated below:

> "All system components which need to be serviced or removed in order to gain access to other components requiring repair or adjustment must be capable of being removed and reinstalled to the vehicle a minimum of three (3) times. The part, mating and adjacent components must not exhibit any dent, crack, scratch and lose function. Margins and gaps variation must not exceed 0.5 mm from the original setting."[4]

The requirement is slated to ensure repeatability of the design during serviceability however, whenever parts are put on and off, material will be scraped away, locating pins will be bent, plastic/metal will be bent not allowing for repeatable results. If the repair procedure is quite intensive and the FTT of a vehicle is rather low, the parts could easily be taken on/off more than twice at the FAP floor thereby already having taken up all of the serviceability variability even before the vehicle reaches the customer's hands.

A FEM strategy will somewhat help out in this attribute. Currently, if an operator has to take off the front end to access the engine compartment, they must take off each individual component separately. After completing the repair, they must build up the entire front end without the use of fixtures or jigs that were used throughout the assembly line. Since these operators specialize in IPVR's, they are not familiar with each individual component, how they attach to the vehicle and other specific intricacies of the designs. This results in additional variability that was not seen during the original build up. Using a FEM architecture will allow the IVPR specialists to take off the entire front end module and have unprecedented access to the engine compartment. Additionally, the build up after the repair will be more consistent as the number of interfaces that were affected will be less than if each component was taken off separately. Once again, the interfaces of a complex system have been reduced. The potential for repair damage is kept to a minimum because the interfaces between each sub-system are kept to a minimum. If only one component is required to be taken off to access other items that need to be repaired, such as a headlamp or a fascia, then the FEM architecture will be susceptible to the same failures as typical individual component architectures are. Essentially, both architectures will be on even ground. This is assuming that the FEM architecture meets the serviceability attribute which was discussed heavily in Chapter 2.

A long term implication a FEM architecture will have on IPVR's is that a re-allocation of the plant floor layout will need to be done. Reducing repair time and damageability of surrounding components will result in a need for a smaller IPVR shop floor. That being said, one cannot overlook the fact that capital must be spent in order to allow the efficient removal of an entire FEM. Damage done to a FEM as a result of a repair will result in a larger repair bill than previous designs as the FEM is more expensive than the individual components. One can probably implement a recycling program where maybe some internal componentry can be saved from the damaged FEM however the potential for full system damage remains unless a proper hoist system is implemented. Some tooling capital will be needed in order to build temporary retention racks and hoists to aid in the proper handling of parts, rather than allowing for the removal and random storage of FEM's. Currently, the IPVR shop floor is allocated right after the end of the assembly line. Long term implications might require for a separate area to be allocated with an intricate hoist and storage system to allow the proper handling of FEM's as they are taken on and off for repair.

Another long term implication that will emerge out of using a FEM architecture is that some common practices on the current plant floor will no longer be tolerated or even allowed. One such practice is to allow the vehicle to continue to be built and go down the line without certain parts. In some instances, vehicles are allowed to move down the line without having completed a specific operation or install. Such examples include not making an electrical connection because a wire harness gets caught up on a stud or a vehicle is built without a headlamp because the operator did not receive a shipment of lamps. These 'un-builts' are allowed and tolerated because the vehicle can still be partially built, driven off the line and built up in the IPVR shop floor. If the FEM includes some sort of cooling module, the vehicle will no longer be able to be driven off the end of the line. This will create a bottleneck as operators must tow these 'un-built' vehicles to the end of the line thereby greatly reducing line speed. With this new architecture, there will be more emphasis to build vehicles right the FTT. Issues that were previously masked by the processes of the plant will now be brought up to the surface and addressed in their own right. This new phenomena will be painful at first since it will drive somewhat of a new culture and new challenges; however over time, it will improve the quality of the overall vehicle as issues are no longer allowed to be masked by internal FAP or organizational processes.

Potential attributes:

There are many attributes that could have been looked at in this analysis. While the focus was maintained on three in particular, it would be beneficial to specifically mention certain attributes that were not looked at but that would play a vital role in the way a FAP operates on a daily basis. Attributes such as the quality control of the vehicle, or operator training occur every day at the FAP. The dynamic of introducing a FEM architecture will greatly affect how a FAP is able to maintain dimensional control and how they train operators with this 'new' way of thinking. The assembly tooling, such as hoists and fixtures, would also have to be looked at when introducing a FEM architecture. FAP capital will be required to deliver parts to the line as well as hoists to install the modules at the end line.

The labor force reduction attribute was briefly discussed in the MP&L attribute; however a great in-depth analysis must be done as there are many variables that affect this complex relationship. Some of these variables cannot be measured and some do not deal with even building a vehicle at all. Such an example is how the surrounding community will be affected by the reduction of work force, if one exists, as a result of introducing a FEM architecture.

Plant flexibility must also be addressed. Having the ability to build similar vehicles and make them look different to a customer was a concept that was talked about in Chapter 3; however multiple streams must be installed at the plant in order to build these vehicles in a flexible manner. This attribute will also place a certain amount of accountability and responsibility on the labor force as they must deal with multiple designs especially if the vehicle architecture or program decisions do not allow for common designs. Even if the FEM is designed in such a way that it requires common operations at the FEM install station, other vehicle componentry might not follow suit. Therefore, operators of downstream operations might be affected because they have to deal with multiple designs.

Even with the four additional attributes listed above, there are a myriad of attributes at the FAP that were left off this analysis. They were not left out because of their relative importance but rather because of the limits of this study. The final assembly plant is a system of its own with many interfaces and sub-systems. A FEM architecture is only a part of the entire system, and its true impact cannot be fully predicted. The most an architect can do is to take a full assessment of the FAP stakeholder and make sure that the right trade-offs are made when the FEM architecture, as a whole, is evaluated with all of its stakeholders' needs.

Summary

This quick survey of the FEM architecture and its impact on a FAP is meant to provide an objective and academic analysis of how an automotive architecture can affect the FAP stakeholder. In this chapter, a brief overview of each analyzed attribute was provided. The common pitfalls of each attribute were laid out to show the challenges that a FAP faces on a daily basis. Whether it was having the OLA's hiding design issues, the bullwhip effect for the MP&L attribute or degrading vehicle quality as a result of IPVR's, all attributes have pitfalls that must be considered. Potential solutions to these pitfalls were provided with the FEM architecture. For the MP&L, a FEM architecture could not provide a solution to the bullwhip effect as that dynamic is more of a result of the ability of the MP&L personnel to handle uncertainty. For the OLA attribute, a FEM architecture can provide a previously unavailable feed-forward system by inputting vehicle body structure data to the supply base prior to the FEM being built. For the IPVR attribute, a reduction of interfaces provided a small relief to repair time and damageability to surrounding components however capital was required for FEM specific tooling such hoists and storage racks. Finally, potential long term impacts were briefly touched on in a systematic approach. The potential reduction of the work force provided by the MP&L attribute was looked at as well as the loss of any FEM advantage for the OLA once the FAP becomes faster at manufacturing vehicles. A FEM architecture would also end the common practice of 'un-built' vehicles to go down the line causing a positive dynamic of bringing issues to light rather than allowing the plant processes of hiding design issues. While a FEM might not provide all of the answers to the pitfalls outlined above, it seems that the opportunity and design space that it can provide should not be overlooked when the FEM is introduced to the final assembly plant.

6 Suppliers

When looking at the value created by the FEM architecture, a holistic approach needs to be taken so that a global optimization can occur instead of having localized islands of success. This process involves looking at the entire value chain of the FEM which, in turn, includes an analysis of the supply base. Suppliers play a critical role in the undertaking of using a FEM architecture. They are just as much stakeholders as the OEM's or even the final customers themselves. Their needs must be addressed in order for the FEM architecture to succeed and this will require some shifts in thinking and culture on behalf of the OEM in order for the relationship to be successful. To address the needs of the supply base, several interviews were conducted with different FEM suppliers so as to ascertain their positions regarding FEM and their inherent relationships with OEM's. The two companies interviewed were Magna International and Hella Behr Plastic Omnium (HBPO), both of whom produce FEM today for OEM's such as Daimler Chrysler, BMW and Hyundai. The interviews were kept free flowing and they did not follow a specific set of questions as the scope of the interview involved exposing barriers and obstacles the supply base is facing when introducing an FEM for the first time to an OEM. The raw data from the interviews can be found in Appendices B and C. This chapter will focus on the findings of the interviews, so that a stakeholder's analysis can be properly explored. It will also include an analytical approach to the frustrations and challenges faced by the supply base when trying to introduce a FEM architecture to an OEM for the first time so that solutions can be proposed to alleviate these pressure points. The intent of the chapter is to inform the reader of the potential pitfalls one will face when switching to a FEM architecture from traditional component style front end architecture, so that they can understand the supply base's position. This will allow for a more informed decision process, as common barriers and obstacles will be exposed as well as the reasons thereof.

Magna International Inc.

The first person to be interviewed was Norm Guschewski at Magna International Inc. Mr. Guschewski is the Director of Module Development and has been working on incorporating FEM's into North American OEM's architectures for the past three years. Magna is the world's third largest auto parts supplier based on 2005 global OEM part revenues ranked by Automotive News[1]. Mr. Guschewski's position can be best summed into three particular difficulties. The first difficulty is described as a lack of direction, push and commitment from OEM upper management to install a FEM architecture. As previously described, changing the front end architecture to accommodate a FEM requires significant shifts in physical geometry of the componentry and in organizational culture. During the interview, Mr. Guschewski specifically stated:

> "Grass roots campaign will not work because of the massive organizational changes required to support FEM.[2]"

As previously mentioned in Chapter 2, the organizational structure of the current OEM can be tied back into how the vehicle is partitioned, much in line with Conway's Law. To breakdown these barriers will require much political clout which cannot come from the ground up. Part of the solution to resolve this issue is to make the issue tangible to upper management. Convincing a CEO is never an easy proposition, but clearly Dieter Zetsche has seen the value created by the FEM architecture as Daimler Chrysler is pushing towards more and more FEM vehicle platforms. How would a company like Magna be able to convince another OEM CEO to switch to this architecture? It can be argued that a grass root campaign may work, contrary to what Mr. Guschewski stated. Having the working level engineers and designers understand the benefits and push these benefits from the ground up may result in, at the very least, visibility for the FEM architecture. A single prong impulsion from the top down will not suffice to expose FEM to the entire OEM organization. In this world of smaller and leaner organizations, pushing from all angles including engineering, designers and even purchasing will result in a higher visibility and increase the chances of exposing the architecture to an agent of change within the OEM. Locating that agent of change is the key to establishing an open line of communication within the OEM, and greatly increases the chances of obtaining a change of mind at the executive level.

The second problem that Mr. Guschewski often runs into is the lack of holistic approach in evaluating the FEM architecture. As mentioned at the beginning of the chapter, a FEM architecture must be looked at on a holistic level to evaluate the true benefit and impact it can have on a vehicle platform. Analyzing only one portion of the value chain will only result in localized optimization and can even negatively impact other portions of the system. This can, again, be tied into the organizational structure of the OEM. This structure creates a culture where cross-communication is difficult across boundaries. Therefore, in order to promote a FEM, the agent of change now must not only talk to the Lighting buyer and engineer but they must talk to a Fascia buyer and engineer. The chimney style organization promotes a reward system that is only tailored to a component style establishment. Players in this system are evaluated on how they optimize their own commodity and not the entire system. Promoting a systemic solution in this environment is very difficult. One approach to address this barrier would be to draw out a value stream map and show how the FEM delivers value to the end customer. This value map would not be limited to the engineering deliverables, but would include items such as Materials Planning and Logistics (MP&L), safety stock inventory and any waste (including items such as multiple part handling or contract renegotiations). Having the map of the current state for the front end system can visually display where the bottle necks for delivering value to the customer are and a proposed state solution in the form of a FEM can be laid out for comparison. Having these visual artifacts will bring to light how effective, or ineffective, the current process of a traditional component style front end architecture is. While there will most certainly be challenges to the definitions and final form of the current state map, the very fact of having the visual map in front of the group will allow for frank and open conversations rather than resorting to dealing with generalities that are not substantiated with facts.

The last problem Mr. Guschewski described in length is the lack of understanding at the OEM with respect to the role of a system integrator. Attempting to not repeat what was previously stated, due to the component style architecture, there is an emphasis on each department to focus only and specifically on their particular sub-system. While this might facilitate the internal organization of the OEM, the customer and the beneficiary of the system, as defined in Chapter 2, do not particularly care for or benefit from the performance of the individual components. What good is a functioning headlamp if it cannot stay attached to the fender on a cobblestone road? What is being evaluated by the beneficiary is the entire front end as a complete module. The only way to control this modularity is by having a Single Point Of Contact (SPOC) who is both responsible and accountable for the module across the existing organizational boundaries or silos. That person cannot be involved in the minutia of each individual component, but they must have the power, the responsibility and the accountability for the entire system. The current status of a system integrator at the Ford Motor Company can be best described with a recent issue that was experienced on the 2008MY Taurus vehicle at the Chicago Assembly Plant[3]. Late during the launch of the vehicle, there was a major difficulty with the front end fit and finish. Because the issue did not emerge until the fascia was installed, it was deemed to be a fascia only issue. During the root cause analysis, it turned out that the major contributor to the front end fit and finish was the relationship of the front end bolster with respect to the fender. The fit and finish problems that emerged after the fascia was installed were only resolved once that bolster to fender relationship was fixed; however due to the fascia being the largest visible component of the front end; the fascia team was charged to root cause what was ended up being another component's issue. This exercise resulted in a fascia task force team to be pulled from their future model year work in order to resolve a current model issue that ultimately ended up in not being a fascia related issue at all. If an integrator had been in place, this issue would have been the responsibility of the system integrator and the extra work force might not have been necessarily pulled off their future model work in order to resolve the issue. "War stories" like this are very proficient at illustrating the need to have a system integrator and a SPOC. They also emphasize how having an integrator can provide a solution to what is today the standard operating procedure.

While war stories are an effective method to illustrate the need for a SPOC, it will be very difficult to surrender the entire SPOC role to an outside vendor since the OEM would be relinquishing immediate control. This step will require trust and transparency between the OEM and the supply base, both of which are not gained overnight. Having an outside SPOC requires the OEM to give up a certain amount of control with regards to the product, which can be very scary if the relationship and trust between the two companies are not solid. Issues such as cost, intellectual property and confidentiality become large crosses to bear. There are no certain and set answers to gain this trust so providing a solution in this context would be incorrect and futile. The ability to gain this trust will have to be delivered over time and will require small successes to be built on top of each other in order to establish the transparency that an outside vendor SPOC requires.

The SPOC concept is not something that necessarily requires a FEM strategy to implement. An OEM could very well re-organize their structure to have SPOC and system integrators; however having a FEM architecture automatically generates a SPOC by shear partitioning of the vehicle. This is a point that was explained thorough detail under the Organizational Architectural Impacts in Chapter 2.

A summary of the problems described by Mr. Guschewski's has been listed in Table 6.1 below along with their proposed solutions. It is important to keep this table in mind as we go through the next part of the chapter, and explore the results of the HBPO's interview.

Point of Conflict	Actual Interview Quote	Proposed Solution
Lack of OEM upper management commitment	"Grass roots campaign will not work because of the massive organizational changes required to support FEM."	Provide input into the OEM from all Product Development angles (i.e. Purchasing, Engineering, Manufacturing, etc...) so as to find internal agent of change and maximize exposure of FEM architecture
Lack of Holistic Approach	"Most business cases are being limited to one particular department. The whole value stream is not being looked at."	Lay out current state value stream as it relates to the end customer to begin systemic discussions. Show proposed state solution.
Lack of System Integrator role awareness	"The concept of a single point of responsibility is scary to an OEM. Requires the OEM to relinquish control over a very visible commodity."	Build trust over years and product. Understand that process is a journey and not a destination.

Table 6.1: Magna International Inc. Interview Summary

Hella Behr Plastic Omnium (HBPO)

The HBPO representatives interviewed were Stefan Schmidgall and Roger Kolasinski. Mr. Schmidgall is the Director of Engineering and Mr. Kolasinski is the Account Manager at the HBPO North American Division. HBPO, a 3-party joint venture based in Lippstadt, Germany, says it supplied 269,000 FEM's to auto makers in 1999, 625,000 in 2003 and 1.1 million in 2004. In 2005, the company says it produced nearly 2 million FEM's for the world's auto makers. The company claims 23% of the global market for FEM's[4]. HBPO is a major player in European FEM's and produce FEM's for vehicle lines such as the Porsche Cayenne, Audi A7 and the BMW Mini.

The interview process revealed four points of contention that are often brought up during the introduction of a FEM to an OEM.

The first point is the changes in front end body structure construction required to accommodate a FEM. As mentioned previously in the chapter, the assembly of the FEM requires open access to the front end structure in order to allow for the proper loading and attachment of the FEM to the rest of the body. The issue that HBPO runs across is that the OEM's often use cross-members to stabilize their front end structure during the assembly process prior to installing the front end trim pieces. The typical cross-member of choice is often the bumper beam which, for damageability purposes, must be in front of the cooling module and headlamps. This implies that it must be installed after these two components or have a vertical loading path. Proposing a FEM architecture means that the vehicle must go through its body construction process and painting process without the use of bumper beams, and still maintain its geometric dimensionality all the way to the trim assembly of the beam *after* the installation of the FEM. The changes to the Bill of Process at each assembly plant to support this architecture not only require capital changes for new layouts and assembly process but also present engineering challenges to maintain front end dimensionality without the use of cross-members for stability. This might not be something new to an OEM but because some OEM's do not have a common Bill Of Process, implementing this across all of the Final Assembly Plants will result in significant challenges.

The second challenge that Mr. Schmidgall and Mr. Kolasinski mentioned is the OEM's lack of wanting to be first to the market. There is an inherent risk with leading the charge in a new technology. It comes with the uncertainty involved with making such a decision. Burden costs are inherent to switching to a new technology. Costs associated with the switching of the front end body construction to be open ended as well as organizational costs associated with staffing the company to deliver this technology must be addressed. These heavy costs must be incurred with no guaranty of success. This why some OEM's prefer to have others bear those costs and prove out the technology rather than assuming that risk themselves. Professor Utterback describes this dynamic of 'not wanting to be first' extensively in his book *Mastering the Dynamics of Innovation*.[5] In his book, Utterback makes the distinction between a disruptive technology and an incremental technology. A disruptive technology is one that causes major architectural changes within the product that creates such exponential changes in product performance that the current technology cannot match no matter how many incremental improvements are made. Examples of disruptive technologies include the use of hydraulics in the construction industry, the invention of the condenser for the ice industry or the use of closed body shell construction in the automobile. Utterback asserts that there is difference in the "first to market" advantage depending on whether or not the technology that is introduced is disruptive or not. If the technology is disruptive, there is an advantage of being first to market. Examples such as the Winchester disk drive, the electronic calculator industry and the transistor all show that for companies that introduce disruptive technology, there is an advantage for early entry competitors. Using this model, the question remains as to how should an OEM (and the industry) define the FEM as an architecture and whether or not is it disruptive? While a FEM might seem to be a significant change in architecture direction, it is still using the same componentry and given enough time and money, a similar performance can be achieved using typical component front end construction. It is due to the very short product life cycle that FEM vehicles see a significant improvement in craftsmanship and flexibility over traditional component front end constructions. Therefore, it can be argued that FEM is not a disruptive technology because a similar performance can be achieved by either the FEM or the typical component based architectures. The true advantages of the FEM emerges only when put into context of the short product cycle times and the flexibility of a vehicle line. Using Utterback's model, it would seem that there is no major advantage to being a first entry into the FEM architecture because it does not alleviate the significant financial risk the OEM is taking by pursuing that strategy. The only way to lessen the apparent risk of being first to market is by showing how other vehicle lines have been successful in implementing a FEM strategy. This is done by showing the vendor portfolio of previous and current production products.

The third obstacle HPBO often has to confront when introducing a FEM architecture is the lack of a holistic approach when evaluating the value equation a FEM brings. Most OEM's are organized into silos where management, engineering, assembly and purchasing are all organized around their own particular commodity, and are limited to their immediate interfaces. Optimization occurs at a component level; rarely is a global optimization looked at and the entire system evaluated for delivery of value. This is a very similar issue that Magna International Inc. has run into and has already been talked to in depth earlier in the chapter.

The final barrier that HPBO has faced is the issue with the legacy contracts that currently exist at the OEM's. The legacy contracts could be as simple as land contracts with the existing assembly plants as discussed in Chapter 5 or as convoluted as United Auto Worker contracts also discussed in Chapter 5. Other examples could include previously negotiated contracts with component suppliers that force directed sourcing to HPBO or even the organization of the OEM which forces specific partitions into the FEM. While these legacy contracts might sometime seem negligible when looked at from an outside point of view, they represent significant barriers preventing the full systematic benefits of a FEM to emerge. Unfortunately, there is no clear cut answer or solution to address each of these legacy issues as they are different in each of their respects. The only process that can be recommended to address this point of conflict is to build a value stream map to show how the FEM architecture delivers value and minimizes waste. The tangible results along with the building of trust over the years can help in weakening the barriers and ultimately allow for a re-shifting of resources to help in delivering a FEM strategy.

A summary of Mr. Schmidgall and Mr. Kolasinski is provided below in Table 6.2.

Point of Conflict	Actual Interview Quote	Proposed Solution
Body Construction Changes	"Very large changes to an existing body shop are required."	Show FEM strategies that exist in the competition today and use that architecture.
Fear of being first to market	"Some OEM's do not want to change the status quo."	Show FEM strategies that exist in the competition today and are often used as benchmarks for other OEM's.
Lack of holistic approach	"FEM require a holistic approach that does not exist in certain companies."	Lay out current state value stream as it relates to the end customer to begin systemic discussions.
Legacy Contracts	"FEM's free up both space and personnel. Some companies cannot handle either with cost legacy system still in place."	1) Lay out current state value stream as it relates to the end customer to begin systemic discussions. 2) Build trust over years. Understand that process is a journey and not a destination.

Table 6.2: HBPO Interview Summary

When comparing Table 6.1 and Table 6.2, it is important to note that there are common elements to both tables. The common theme of a lack of systematic thinking or holistic approaches seems to emerge out of both interviews. The lack of commitment of an OEM to make the switch as was explained by Magna International has really for origin the OEM's fear of being first to market. The Body Construction changes required for a FEM can also be grouped together as part of the legacy contracts that an OEM is forced to deal with based upon previous ways of doing business. All in all, it seems like the common barriers faced by the supply base when approaching an OEM to switch to a FEM strategy can be traced to the lack of systematic thinking on behalf of the OEM and the existing legacy contracts.

Summary

Part of evaluating the ability of a FEM to deliver value is to complete a stakeholder analysis. In this chapter, a quick survey was done with a very important but overlooked stakeholder, the supplier. The supplier/OEM dynamic is often disregarded when there is an emphasis on the cost equation rather than the value equation. The dynamics that cannot be placed in a sort of absolute monetary value quickly fall wayside when other hard numbers with a direct relationship to the bottom line are placed in front of decision makers. This chapter emphasized these underlying dynamics through interviews with the supply base. Common issues seen by both Magna and HBPO such as lack of systematic thinking or holistic approach to the FEM, fear of being first to market and legacy contracts were touched upon and potential solutions were provided to begin a possible mending process to tie the disconnects. The fact that some common issues existed at all showed that there is a constant communication battle being fought between the supply base and the OEM's. Having these barriers out in the open at least provides an attempt to establish a communication bridge between the two parties. Understanding the two point of views and where they are coming from will help out with future communication and creates a self-awareness of the dynamic. The proposed solutions include the use of communication tools such as Value Stream Maps and benchmarking in attempt to create objective data that will make debates less subjective when value is being discussed. Other proposed solutions such as building trust are more progressive and long term, and cannot be established overnight via a standard tool or approach.

7 Conclusion

The aspiration of this thesis was to accomplish a survey of FEM as an automotive architecture and analyze its ability to deliver value across a limited subset of stakeholders. As a secondary deliverable, the thesis was also meant to be an objective source of knowledge using academic tools for the Ford Motor Company as the FEM architecture goes forward in its implementation plan. The advantages and disadvantages of a FEM strategy were explored across the craftsmanship, damageability and assembly attributes as they relate to the automobile. The FEM strategy was also evaluated as an architecture using tools learned in the MIT-SDM program. Finally, the supplier stakeholder was analyzed and dwelled into using numerous supplier interviews. The synthesized data and conclusions did allow for some interesting findings to emerge as a result of the data collection obtained in this work.

Chapters Summary

In Chapter 2, Front End Structure and Architecture, three tools were used to analyze the FEM architecture and its ability to deliver value. Each tool provided different insights as to how FEM's were able to achieve this goal. The Value Identification Process (VIP) showed how one of the main beneficiaries of the FEM is not the owner or customer of the automobile but rather the visual man as they are the ones that see the work of art the automobile represents whether or not the vehicle is moving. The Object Process Model (OPM) outlined how each component of the FEM represents the form that must interact with the underlying processes of the system as a whole. It also serves as documentation of the intent of the original architect so that any future architects will not lose sight why this particular architecture was chosen. These two tools provided a baseline for us to continue evaluating the FEM as an architecture. They made sure that the needs of the beneficiary are addressed and that a form-free evaluation of the architecture can be done. Having provided the intent of the FEM architecture and how it interacts with the underlying processes to deliver value as baseline, a more factual and objective evaluation was able to be provided by using a framework to critique the FEM as a form to deliver these needs and intents.

The FEM's shortcomings with regards to serviceability were discussed as well as the FEM's advantage in shifting the physical boundary of today's component architecture to take advantage of system level dynamics. Lastly, the impact of a FEM architecture on a company's organization was quickly touched upon and compared to Conway's law in the software industry. The impact of a FEM partition will most surely create a shift in a company's organization to match the vehicle's new partitioning format.

Chapter 3 attempted to apply an objective measure to the subjective attribute of craftsmanship. The argument was made that craftsmanship could be defined as "the ability to create an emotional attachment to a product via proper use of the targeted customer's senses." This statement was supported through the use of literature research and surveys across three different industries. The literature research was able to support that not only is the idea of craftsmanship influenced by the culture of the evaluator but it is also something that can be learned and practiced by the designer and the engineer. The three chosen industries, the furniture, textile and automotive industry, all shared common ideas of subjective evaluations of the product by the customer but only the textile industry and the automotive industry had a heavy emphasis on detailed benchmarking within their industry but not outside their industry. It is also important to note that both of these industries share a lack of a planned iteration process but, in contrast, this is a common practice in the furniture industry.

The FEM architecture was then evaluated against what emerged as the enablers and roadblocks of the three industries. The heavy benchmarking will not be affected by the use of a FEM as an architecture however what a FEM does bring is an ability to evaluate the product without the need to build up the entire vehicle which is what is required today. Instead, the module can be built outside of the limitations of the program schedule and the entire front end can be built off of supplier production lines and operators which allows inherent build variability to be incorporated earlier in the product development cycle.

With all of these benefits, there still exist certain limitations as the specific design cues will be limited to the Design Studio personnel. Due to the manufacturing process of the FEM both at the supply base and the assembly plant of the OEM, there will be limitations to how the FEM interfaces with the vehicle. In today's world of design leadership, this is a very large obstacle to overcome as designers to not welcome cues that stifle the creativity required to generate an automotive concept.

The three types of damageability that are most relevant to the front end structure were discussed in Chapter 4. They are the low speed damageability, high speed damageability and pedestrian protection. As each type of impact has specific ways to handle energy into the system, the key geometric enablers were also presented. The argument was made that since high speed damageability mostly deals with occupant safety and does not care about the ability of front end architecture surviving the impact (other than contacting fuel lines), low speed damageability and pedestrian protection are the areas where design and execution of the front end are key and where the benefits, or lack thereof, of a FEM execution can be leveraged.

A table format summary was used to show that a FEM strategy does show a minor improvement over other types of front end architecture. The key enabler for a FEM strategy is the Single Point Of Contact (SPOC) approach where responsibility and accountability lie in one source of information. Also, a FEM strategy allows for a systematic approach to the new pedestrian protection regulation coming out of Europe. Finally, a FEM strategy can allow for early development testing to be completed at a component level rather than using entire vehicles for testing.

Finally, it was also shown that although various front end architectures other than FEM's can accomplish this same performance for low speed damageability and pedestrian protection, the SPOC approach truly drives a system level performance. Vehicles have passed the Part 581 test without the use of FEM's for many years so it cannot be argued that a FEM strategy will resolve the issues however a FEM strategy with a SPOC might be able to alleviate any downstream changes because the performance of the entire system relies on one single point of contact.

Chapter 5 summarized the common pitfalls of each attribute were laid out to show the challenges that a FAP faces on a daily basis. Whether it was having the On Line Adjustment's (OLA's) hiding design issues, the bullwhip effect for the Material Planning & Logistics (MP&L) attribute or degrading vehicle quality as a result of In Plant Vehicle Repair's (IPVR's), all attributes have pitfalls that must be considered. Potential solutions to these pitfalls were provided with the FEM architecture. For the MP&L, a FEM architecture could not provide a solution to the bullwhip effect as that dynamic is more of a result of the ability of the MP&L personnel to handle uncertainty. For the OLA attribute, a FEM architecture can provide a previously unavailable feed-forward system by inputting vehicle body structure data to the supply base prior to the FEM being built. For the IPVR attribute, a reduction of interfaces provided a small relief to repair time and damageability to surrounding components however capital was required for FEM specific tooling such as hoists and storage racks. Finally, potential long term impacts were briefly touched in a systematic approach. The potential reduction of work force provided by the MP&L attribute was looked at as well as the loss of any FEM advantage for the OLA once the FAP becomes faster at manufacturing vehicles. A FEM architecture would also end the common practice of 'un-built' vehicles to go down the line causing a positive dynamic of bringing issues to light rather than allowing the plant processes of hiding design issues. While a FEM might not provide all of the answers to the pitfalls outlined above, it seems that the opportunity and design space that it can provide should not be overlooked when the FEM is introduced to the final assembly plant.

The supplier/OEM dynamic is often disregarded when there is an emphasis on the cost equation rather than the value equation. Chapter 6 completed quick survey with a very important but overlooked stakeholder, the supplier. The dynamics that cannot be placed in a sort of absolute monetary value quickly fall wayside when hard numbers with a direct relationship to the bottom line are placed in front of decision makers. This chapter emphasized these underlying dynamics through an interview process of the supply base. Common issues seen by both Magna and HBPO such as lack of systematic thinking or holistic approach to the FEM, fear of being first to market and legacy contracts were touched upon and potential solutions were provided to begin a possible mending process to tie the disconnects. The fact that common issues existed at all showed that there is a consistent communication battle being fought between the supply base and the OEM's. Having these barriers out in the open at least provides an attempt to establish a communication bridge between the two parties. Understanding the two point of views and where they are coming from will help out with future communication and creates a self-awareness of the dynamic. The proposed solutions include the use of communication tools such as Value Stream Maps and benchmarking in attempt to create objective data in what often becomes subjective debates when value is being discussed. Other proposed solutions such as building trust are more biased and cannot be established overnight via a standard tool or approach.

Future Studies

In limiting the analysis to a specific subset of stakeholders, a more in-depth study was accomplished however it purposefully left room for other future comprehensive studies. The quick answer for any future studies would be to start off with a larger set of stakeholder analysis. While this is absolutely necessary and must be done at some point in order to complete the analysis, throughout the data collection process several topics emerged that can provide more insightful starting points for any future downstream studies.

The first common topic that was brought up as a future subject of study was the potential to develop a detailed cost model to fully evaluate the economical effect of adopting a FEM strategy on a particular vehicle platform. This cost model needs to have a holistic approach as the thesis showed that there are many attributes that affect the cost benefit equation of the FEM. This was discussed most notably in Chapter 5 and 6. The model needs to include items such as reduced labor, increased floor space and supplier mark-up of bought components. Often overlooked costs such as cycle time to the line or lifetime equipment maintenance must also be looked at in order to fully evaluate the impact of using a FEM strategy. Having a standard cost model across a company that could be applied to a vehicle platform will take away a lot of subjectivity when evaluating a FEM architecture and allow a team to make an educated decision based upon hard facts rather than relying on subjective data that, more often than not, comes from outside sources trying to sell a business plan.

The second topic that emerged as a result of this analysis is the impact an FEM architecture can have on a marketing plan or a branding strategy. A FEM brings about the ability to significantly alter the front end appearance of a vehicle by installing a different module at the same point on an assembly line. This type of flexibility allows for a modular approach to be applied to a marketing plan. For example, differentiation across a particular vehicle series could occur by changing around the entire front end of the vehicle rather than today's basic trim changes (i.e. Molded-in-color fascia system versus painted fascia system or painted grille versus bright plated grille). This potential to drive differentiation to a new level must looked at in more depth with regards to the implication it provides on a motor company can handle their product portfolio. Expensive business cases have been built around minor refreshenings on vehicle programs. The power to differentiate at a much larger visual scale with fewer disruptions to the assembly plant must be fully explored.

Another theme that requires more study is the topic of commonality. Having the ability to bring in different modules to the assembly plant end line results in a large flexibility however exploring the design space of commonality can truly enhance the upstream and downstream potentials of the FEM. By being able to not waste resources in re-designing common parts, engineering minds are allowed to explore other system boundaries and designs since they are no longer required to address common issues again and again. Commonality also can impact the overall cost of the components as economies of scale benefits get larger as the quantity of each identical part produced also gets larger. Let's not forget that the subject of commonality is a double edged sword. Being common across assembly plants vehicles and platforms requires a tremendous amount of time, effort and disciple in the upfront design and downstream maintenance since one change on a common component would no longer affect only one particular vehicle.

Last but not least, a Design Structure Matrix (DSM) could have been developed to evaluate the overall complexity a FEM brings to the design space. In chapter 2, it was briefly shown how critical the front end interactions are and how, architectural wise, it makes sense to create a module that encompasses all of the front end components to minimize the interactions between the subsystems. A DSM would be another good tool to graphically represent how the vehicle architecture can be partitioned by clearly showing how the design tasks are interrelated and how an organization can be structured in a way that rework can be minimized. The analysis of coupled tasks can also allow for design tasks to be done in series or in parallel so that unplanned iterations are kept to a minimum. The increase in knowledge of the vehicle design process flow would provide further data in making a decision as to whether or not a FEM architecture will be a proper fit in a specific automobile manufacturer.

Overall conclusion

What was presented in this thesis was an objective evaluation of the delivery of value where the value definition was altered according to the specific analyzed stakeholder. The thesis was structured in a way that each chapter represented a different definition of value. For example, the craftsmanship chapter defined the value received by visual society. The assembly at an OEM chapter analyzed the value as seen by the Final Assembly Plant. The damageability chapter showed how a FEM could deliver value to the various impact regulations required out of an automotive front end. By taking a different approach on each stakeholder and breaking it out into separate segments, the value delivery was not influenced by any negative impacts created by combining other value definitions. What remains to be done, however, is synthesize all of the data obtained into one overall evaluation. In order for this to occur, one question still remains on how to define value at a system level.

When evaluating how a system delivers value, one must first go through the thought exercise on how to define systemic value. This is first done by identifying which stakeholders' needs must be addressed and developing a hierarchy on how to handle trade-offs. It must be understood going into the evaluation exercise that trade-offs are inherent to the process and that certain stakeholders who were identified earlier will receive little to no value by pursuing a specific change in strategy. It might even be said that some stakeholders will be worse off in a future state by adopting a new strategy. This is a necessary evil that must occur when evaluating the value delivery at a system level since not stakeholders will receive value.

Using the limited subset of stakeholders that was analyzed in this thesis, it can be said from the chapters' summary that a FEM is able to deliver value for the craftsmanship, damageability and assembly attributes but that certain trade-offs must occur in order for the strategy to be adopted. After performing an objective and academic architectural review of a FEM as a strategy, a FEM architecture seems to be an adequate form to deliver value to the end purchasing customer. Finally, significant challenges will need to be conquered with supplier relationships in order for a FEM strategy to work at an automotive OEM.

Appendix A: Craftsmanship Interview Guide

To aid in our original discussion, I've taken the time to write down a few questions which are meant to be more thought starters than absolutes. The idea of this document is not to replace the interview itself but rather to generate some ideas as to where you think the conversation should go. I don't want to stay too much on track because I am more interested in seeing where the conversation will end up. The plan is for me to capture a few themes that emerge out of our talk and see how they can (or possibly cannot) be incorporated in an automotive environment.

Questions:

1) Does your current company (or any prior company you have had experience with) have objectives/matrices that attempt to measure craftsmanship?
    a. If so have they succeeded?
    b. If not, was there any attempt to generate these documents?
2) If craftsmanship was a critical part of your business, was there a concentration on the senses of the customer?
    a. If so, which ones were primarily looked at and were they placed in any sort of priority?
    b. If not, were the human senses ever considered as part of "craftsmanship"?
3) How was the Voice of the Customer (VOC) ever incorporated into your daily work environment on a pure esthetics aspect?
    a. Was the esthetic interpretation of the VOC ever been purposely ignored?
    b. Is the esthetic VOC interpretation an iterative process or a deliverable in a milestone (captured once and not looked again until late in the product development cycle)?
4) Was craftsmanship ever incorporated into the upfront design of your current company?
    a. If so, were there any special design tools and/or strategy that were used to address this attribute?
    b. If not, was there an attempt to include craftsmanship as early as possible in your product life?
5) How significant is benchmarking in your product development cycle?
    a. Do you actively benchmark your competitors?
    b. Do you actively benchmark other industries?

Appendix B: Magna International Interview Raw Data

Front End Modularity Discussion with Norm Guschewski
September 11, 2006
Decoma-Magna Corporation **12:40 pm to 1:30 pm**

- **VW started FEM back in 1992.**
- **FEM's are Part of Daimler Chrysler core strategy**
  - Dieter Zetsche saw the benefits of FEM from Mercedes and brought over the knowledge to Chrysler once he came over to the U.S.
  - Provided top down vision, and direction to implement.
- **Major hurdles as seen by Decoma-Magna in providing FEM strategy to Ford Motor Company:**
  - **Lack of direction from upper management. No commitment and no strategy provided from the top.**
    - Grass roots campaign will not work because of the massive organizational changes required to support FEM.
    - Benefits of FEM are not tied into reward system and, as such, no incentive exists for using the new (to Ford) technology on new programs.
    - New roles and responsibilities must be generated for FEM to work and they cannot be created from the ground up.
  - **A holistic business case is not being done.**
    - Most business cases are being limited to one particular department. The whole value stream is not being looked at.
    - Reluctance to review entire value stream (i.e. MP&L, inventory, late changes due to quality for front end appearance, etc...) because of large complexity.
    - Chimney view exists at Ford Motor Company where boundaries are drawn up between commodities.
      - Example: Lighting buyer is different from cooling module buyer which is different than fascia supplier.
      - Situation is only worsened with latest re-organization where specialization is emphasized over systemic knowledge.
  - **Ford Motor Company does not understand the concept and role of systems integrator.**
    - No value is seen by the OEM as evident in the last re-org.
    - The concept of a single point of responsibility is scary to Ford. Requires Ford to relinquish control over a very visible commodity.
      - Relationship between Ford Motor Company and suppliers has been strained due to the cost blitzes over the last five years.

        - Certain transparency is required between the two firms. Transparency is not built over night. The Daimler-Chrysler business for Decoma-Magna was built over many several years of quality production.
    - Ford Motor Company is currently pushing to have everything designed back in house which is not necessarily a bad thing but there still does not exists an emphasis on system integration.
        - The integrator role is somewhat assumed by Ford management that it should fall on the responsibility of the Design & Release engineer.
        - The D&R engineer is too overwhelmed with the systematic issues of their commodity (purchasing, design, studio, vehicle operations, MP&L, program management, verification, Build/Test/Fix) that they are not allowed the time/resources to view systematic issues outside of their commodity.

- **General notes and comments**
    - What are the internal boundaries within Ford Motor Company that prevent from FEM being accepted?
        - Mr. Guschewski can only comment on what he sees as an outside firm.
        - He has some insights from what is seen at meetings but he cannot comment on what is happening behind closed doors.
    - Most people are reluctant to change.
        - Ford Motor Company is in dire straits right now. A culture of fear as spread throughout Dearborn in light of the current business situation.
        - Today's managers and supervisors obtained their positions using certain methodologies that are currently being challenged. Why would they embrace new technologies that challenge what was their promotional path?

Appendix C: HBPO Interview Raw Data

Front End Modularity Discussion with Stefan Schmidgall & Roger Kolasinski
October 11, 2006
Hella Behr Plastic Omnium 11:00 am to 11:30 pm

- **The resistance of OEM's to FEM was summed up in three different obstacles:**
  - **Body Structure**
    - FEM strategy requires a complete open front end body structure.
    - Very large change to an existing body shop.
      - Requires OEM to maintain dimensional stability in an open configuration through body shop and paint shop.
      - Requires elimination of Bumper beams (Cross member can be still part of the body) that were use previously for fixture tools and dimensional control.
      - Will, at specific plants, require changes to the Bill of Process and the re-allocation, elimination or addition of body shop tooling.
  - **Methodology**
    - Some OEM's do not want to change the status quo.
    - Certain OEM's do not want to lead the charge with FEM and would rather prefer following strategy.
      - Do not want to bear burden costs of developing new strategy.
      - Do not see the benefits of FEM as outweighing the difficulties of changing.
    - FEM require a holistic approach that does not exist in certain companies.
      - Certain OEM's are organized in "Silos" that do not allow for discussions across the multiple components that a FEM brings together.
      - An example would be a FEM buyer would have to deal with negotiating for a cooling module, a lamp, a carrier and a fascia. Currently, some OEM's have each buyer split up.
      - Engineering and other white collar positions also fall under this "Silo" trap.
  - **Legacy Contracts**
    - FEM's free up both space and personnel. Some companies cannot handle either with cost legacy system still in place.

        - Allow assembly workforce to limit sourcing based upon their negotiated work contracts (i.e. will force FEM to be built on site rather than at supply base).

- **There are three waves of acceptance an OEM usually goes through when accepting an FEM strategy.**
    - 1st wave: A supplier will build up the FEM with OEM direct sourced components. Essentially, the supplier will be used as an assembly line to deliver the FEM in sequence to the main line of assembly.
    - 2nd wave: the FEM supplier would develop the carrier but would still use OEM direct source components.
    - 3rd wave: Full integration by the FEM supplier where the entire module responsibility and delivery would fall on the FEM supplier.

- **Some OEM's do not want to switch to FEM regardless of the above obstacles.**
    - These OEM's have determined FEM is not a viable strategy due to technical issues even when presented with benefits of FEM.
    - Do not agree with structural integrity of FEM's.

Appendix D: References

Chapter 2: Front End Architecture

1) Ueda, H. (2001). "Modularization and supply of automobile industry." Economics Review **41**(5): 20.

2) Fujimoto, t. (2002). "Japanese type of supply system and modularization: the case of the automobile industry." Tokyo Economic Report: 69-78.

3) Lai, G. M. H., E. T. Oh, et al. (2005). Modular Manufacturing Architecture in Automobile Production.

4) Pye, D. (1978). The Nature and Aesthetics of Design.

5) http://en.wikipedia.org/wiki/Conway's_Law

Chapter 3: Craftsmanship

1) http://www.m-w.com/dictionary/craftsmanship

2) Scotland, R., M. Williams, et al. (2005). Communication of craftsmanship targets to the supply base.

3) Harris, H. and A. Lipman (1989). "Form and content in contemporary architecture: issues of style and power." Design Studies **10**(1): 67-74.

4) Loeffler, M. (2002). A Multinational Examination of the "(non-) Domestic Product Effect. **19:** 482-498.

5) M. Williams, C. T., A. Singh (2005). Integrating Craftsmanship Metric Data from the Automotive Supply Chain into the OEM to Improve the New Product Introdution Process. 7th International Research Conference on Quality Innovation and Knowledge Management.

6) Pyritz, B. (2003). Craftsmanship versus engineering: Computer programming - An art or a science? Bell Labs Technical Journal. **8:** 101-104.

7) http://www.teknion.com/investor/investor_overview.asp

8) Interview with Bruce Beamer, Engineering Manager of Teknion (1/07 - 3/07)

9) Interview with Yves Mahé, VP of Lepoutre (1/07 - 3/07)

10) Laforce, J (2007). 2008 Ford Escape: feel the difference. Ford World 15

11) Interview with Rick Nelson, Craftsmanship Supervisor, Ford Motor Company (6/06)

12) http://www.pennygardner.com/copyquotes.html

13) Interview with Aram Kasparian, Design Manager, Ford Motor Company (10/07)

Chapter 4: Damageability

1) Lee, M. T. (1998). "The Ford Pinto Case and the Development of Auto Safety Regulations, 1893-1978." Business and Economic History **27**(2): 11.

2) Matthew Lee, M. D. E. (1997). Pinto Madness or Acceptable Risk? The Construction of an Auto Safety Issue as a Social Problem. Annual Meeting of the Eastern Sociological Society. Baltimore, MD.

3) Transportation, U. S. D. o. (1990). Laboratory Test Procedure for Regulation Part 581. N. H. T. S. Administration, Office of Vehicle Safety Compliance. **Regulation Part 581:** 69.

4) http://www.nhtsa.dot.gov/cars/rules/import/FMVSS/index.html

5) http://www.safercar.gov/info.htm#iq1

6) Interview with Jody Raval, Crash Development Engineer, Ford Motor Company (5/07)

7) BJ Hardy, G. J. L. L., J A Carroll, W M S Donaldson, C Vivifies, D A Peel (2006). A Study on the Feasibility of Measures Relating to the Protection of Pedestrians and other Vulnerable Road Users, TRL Limited**:** 282.

Chapter 5: Assembly at an OEM

1) "Bullwhip Effect" ESD.763 - *OPERATIONS and SUPPLY CHAIN MANAGEMENT*. Lecture 7, June 20th, 2007.

2) Interview with Amy Pope, LAP Part Control Manager, Ford Motor Company (4/05).

3) Interview with Jon Stein, LAP New Models Launch Supervisor, Ford Motor Company, (5/05).

4) Ford Motor Company, Grille System Design Specification. September 14, 2007

Chapter 6: Suppliers

1) http://www.magna.com/magna/en/investors/

2) Norm Guschewski interview on 9/11/2006.

3) Dale Darkowski interview on 6/21/2007.

4) Murphy, T. (2005). "Front-End Module Demand Just Beginning." Ward's Auto World. April 1st.

5) Utterback, J., *Mastering The Dynamics of Innovation*, Harvard Business School Press, 1994.