Knowledge Management Practices in Automotive Safety Attribute Development

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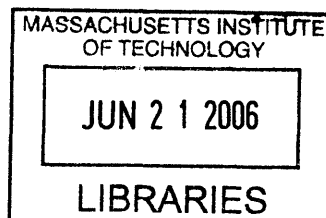
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Abstract

Organizations strive continuously to become efficient. Over the years many of them have tried to attain this through streamlining or reengineering their product development practices. While some of them succeed others are less successful. Product development organizations within automotive enterprises are not different in this regard.

Most reengineering efforts seem to concentrate on tasks and schedule. Detailed schedules are cascaded while the identification of enablers on delivering to the new schedule is left to individual teams in the organization. At the working level, the reengineering process is misunderstood as abandonment of things gone right from past practices. This sometimes results in teams reinventing solutions to similar problems from the past. The purpose of this thesis is to demonstrate that a key enabler for success in any reengineering effort is to understand existing knowledge management practices and reuse them in the context of proposed changes. To do so, existing practices would have to be captured in usable formats.

Proposed changes to existing product development process within an automotive product development organization are studied. Comparisons are made between existing and proposed product development process. To focus this comparison and understand the changes better, the development tasks undertaken by a safety attribute team within the product development group is studied in detail. An analysis of the development process undertaken by the safety team to existing schedule is performed through case studies. Based on this analysis scenarios are developed for the proposed changes.

From the case studies it is apparent that formalized knowledge management practices in formats usable by development teams will help in reducing iteration time through cascade of robust targets. Recommendations are made to build upon and sustain recently implemented knowledge management practices within the safety attribute team. An implementation roadmap for the new knowledge management frame work is provided.

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1. Introduction

1.1 Motivation and Problem Statement

The author has lived through process reengineering efforts before in product development organizations. The reengineering efforts addressed the product development schedule while the process knowledge was not addressed. Moreover, existing knowledge and practices on how the tasks were executed were not given importance. The reengineering efforts merely appeared to be rearrangement of existing tasks. Motivated by these past experiences, the author undertakes an effort through this thesis to study the changes instituted to streamline existing product development practices at Ford Motor Company. Through this study it is hoped that an understanding may be gained towards the challenges facing the product development process in a large enterprise as it strives for continuous improvement.

Automotive product design and development is iterative and time consuming. When faced with demands to reduce the product design and development cycle time, it is imperative to increase the chance of success from individual iterations. So, how can past process knowledge and its reuse help reduce waste by making design and development iterations effective? How can engineers and their managers avoid reinventing the solutions to similar problems across several vehicle lines? Can the find and fix process to design be changed through incorporating robustness in design? Can formalized knowledge management practices aid knowledge reuse among product development teams? Can specific design practices derived from years of expertise be drawn into formats usable within program timing? Is this a reasonable framework that could be adopted

within existing culture and help teams transition to a new process? This thesis hopes to address these questions.

1.2 Scope

The scope of this thesis is limited to the study of knowledge management practices existing in safety attribute engineering at Ford's North American product development organization. The need for knowledge management practices within this attribute team to deliver program tasks is analyzed. A knowledge management framework is proposed for adoption within safety attribute program team structure. The aim is to aid this attribute team in its transition from current product development process to the new process. It should also be noted that vehicle safety includes a broad range of requirements dictated by market and regulatory bodies. The safety attribute referred in this thesis corresponds to impact safety or passive safety requirements for passenger cars, light trucks and sports utility vehicles.

The organizational issues pertaining to staffing, experience, incentive structure for workers and existing culture are important issues whenever a big change is undertaken. But this thesis will not address their effect on proposed product development process transformation. Safety attribute team member reactions in adapting to proposed changes are reported. Team communications within safety attribute in creating their best practices are also discussed. Since this study relates to the safety attribute which is only a small part of the North American product development organization, the team behavior reported need not be indicative of the overall organization.

1.3 Roadmap and Thesis Structure

Early chapters will help the reader understand general product development terminologies. The evolution of product development practices will be discussed

along with the design paradigms that exist within product development. Since this study is on knowledge management practices within a product development team, the context and definition for knowledge with respect to this study will be provided.

Following the introductory discussion on product development practices, background details on existing product development practices at Ford will be provided in chapter 3. This section will detail the safety development practices at Ford and an introduction to some of the requirements for safety development. This section will also clarify the context for subsequent safety team related discussions. Knowledge management practices used within safety under the existing process at Ford will also be described.

Chapter 4 will discuss proposed product development changes. This section will then analyze the gaps in existing product development practices. Initial formal knowledge management practices, its evolution and modifications made to it are also discussed in this section. The gaps that existed in the initial knowledge practices will be described.

To understand the past development practices and proposed product development changes, case studies relating to safety development will be presented. Through this case study in chapter 5, it will be explained how past practices on knowledge management have to change to accommodate the proposed product development process. There is a shift in the design paradigm due to the proposed changes to the overall product development process. While the first chapter introduces these paradigms, the merits of this shift are analyzed further within the context of safety attribute development using this case study. Offsite seminars with safety attribute engineering team members, interviews and program team experiences were used in building this case study.

Since proposals in the new product development process encourages commonality and reuse, it is important to understand the challenges facing this issue. Brief discussions on the advantages of commonality to an automotive company and in particular to safety attribute engineering is undertaken in chapter 6. How a commonality strategy may affect the development process is studied. The importance of knowledge management to attain the efficiency expected through the new product development process, to adopt any shifting design paradigms and to ensure commonality will be addressed. Finally recommendations are made to the safety attribute engineering team and also to interfacing groups with this attribute that would help in the transition to the new product development process.

2. Product Development Practices

2.1 Chapter Introduction

This chapter introduces the reader to a general background on product development process and the design paradigm that exists within this process. Later in this chapter the reader is introduced to knowledge management and the context in which this terminology will be used for the rest of this study. Research related to the design paradigms existing in the development process is provided.

2.2 Concurrent Engineering

In today's business world corporations must react to the changing market needs rapidly, effectively, and responsively. They should be able to reduce their time to market and adapt to the changing environments. Decisions have to be made quickly and they must be correct the first time out. Corporations can no longer waste time repeating tasks, thereby prolonging the time it takes to bring new products to market. Concurrent engineering has emerged as a way for these corporations to bring rapid solutions to the challenges faced during their product design and development process[1].

Concurrent Engineering[2] maybe defined as a "systematic approach to the integrated concurrent design of products and their related processes, including manufacturing and support". In enterprises following a concurrent engineering process, tasks required to develop a product are usually done in parallel, to save time taken for the product to reach market. In an engineering setting this development process would include activities from several engineering disciplines working concurrently along with key cross-functional stakeholders from marketing, product management, purchasing, manufacturing engineering,

production, quality etc. In this regard concurrent engineering maybe regarded as opposite to Taylor's assembly line method which is sequential and an evolving process for a product. Design and development engineers as well as academics who have studied concurrent engineering believe that this simultaneous design process can improve product quality, reduce overall development cost and shrink development time[3]. Though concurrent engineering may not be suited for some industries, especially those involved in a "made to order" business, it seemed to suite well for the automotive sector given its market strategy of planned product obsolescence, short product development and delivery lead times.

The early part of 20th century saw the automotive industry attain tremendous efficiency and effectiveness in the manufacturing of automobiles. To attain this efficiency the automotive industry resorted to rigidly defined work processes and specialized technologies to manufacture their products[4]. This standardized production strategy epitomized at Ford Motor Company in the 1920's was even termed as the *"Fordist"* system. As competition grew in the later part of the century, auto companies had to incorporate flexibility in to the system to address the various needs of its consumer. Also, the existing PD practices did not address the need for flexibility in manufacturing. Additionally traditional product development processes in use did not address the auto companies' needs for reducing their long lead times in their design and development process for new automobiles. These reductions in lead times were not only necessary for keeping their existing customers but also in adding new ones. It was also needed to answer the challenges faced at the market place especially from Japanese automakers. Customers began experiencing superior product quality from Japanese automakers in the seventies. They were implementing several practices in their product development processes which later would be termed as concurrent development or engineering.

The decades of the eighties and nineties saw many American auto companies embrace concurrent engineering practices as a way to gain the efficiencies needed in their product development processes to address their market challenges. Concurrent engineering turned out to be the way for attaining reducing time-to market, improving product quality and lowering product development costs[5]. Automakers, especially in North America, restructured themselves through the eighties to operationalize the concept of concurrent engineering[6]. Case studies showed that a particular company was successful in shortening concept-to market time by over one year on a newly designed vehicle, primarily through the use of product-focused, cross-functional platform teams which permitted the early integration of manufacturing personnel into product and process development. While technology played an important role in this transformation to concurrent engineering, organizational and human resource changes were also found to be the great enablers.

Before concurrent engineering practices were implemented in the auto industry, engineering was carried out in vertical "chimneys" which were organized by functional specialization. Engineers were grouped according to the component they specialized in. This made the product development process entirely sequential, with designers throwing concepts "over the wall" to engineering, and engineering tossing the product and process out to the manufacturing plants. What was needed was an organizational system that permitted parallel development of product and process, and that encouraged interaction and feedback among product designers and engineers, manufacturing engineers, and production and trades employees in the manufacturing facilities.

Organizational changes made to implement concurrent engineering established a "reciprocal interdependence" between the designers and the builders of vehicles. This cross functional blending and communication assured that issues of

manufacturing feasibility are considered at the earliest possible stage of the product development process. This made it easier to change a problematic design further upstream, before significant resources have been spent.

2.3 Design Paradigms in Concurrent Engineering

The need for communication and sharing of design information among all participants early in a product's development process is an essential part of concurrent engineering. Participants in the design process are from both within and outside the company. Those from within the company would to belong to various functional groups like marketing, finance, quality, manufacturing etc. Those from outside the company would be suppliers, dealers and sometimes even end customers. Thus communicating across all these layers early in the product development process becomes crucial. While many management researches into concurrent engineering has studied and shown ways to enhance this communication through social and organizational means, equally important are the underlying design paradigms[7] in concurrent engineering. Liker etal describe one of these design paradigms in concurrent engineering as *Point based* concurrent engineering and the other as *Set based* concurrent engineering. Chapter 5 will discuss the merits and challenges of set based practices in an automotive product development process while the next few sections will attempt to describe briefly what point based and set based concurrent engineering are.

2.3.1 Point Based Concurrent Engineering

A point based concurrent engineering may be summarized as a process in which a single solution is synthesized, analyzed and changed to provide a solution to a given design problem. In point based concurrent engineering, design activity begins with the definition of the problem and then followed by many possible solutions to the problem. After preliminary analysis an engineer may select a solution with the greatest potential to resolve the problem and further analyze,

evaluate and modify it until a satisfactory solution emerges. If this solution proves infeasible engineers then embark on a new solution all over again.

A. Traditional Point-Based Approach

Styling

Marketing

System Design

Serviceability

Component Design

Manufacturing

B. Point Based Concurrent Engineering

Design Solution

Styling

Analyze and Critique

Marketing

System Design

Component Design

Manufacturing

Serviceability

Modify
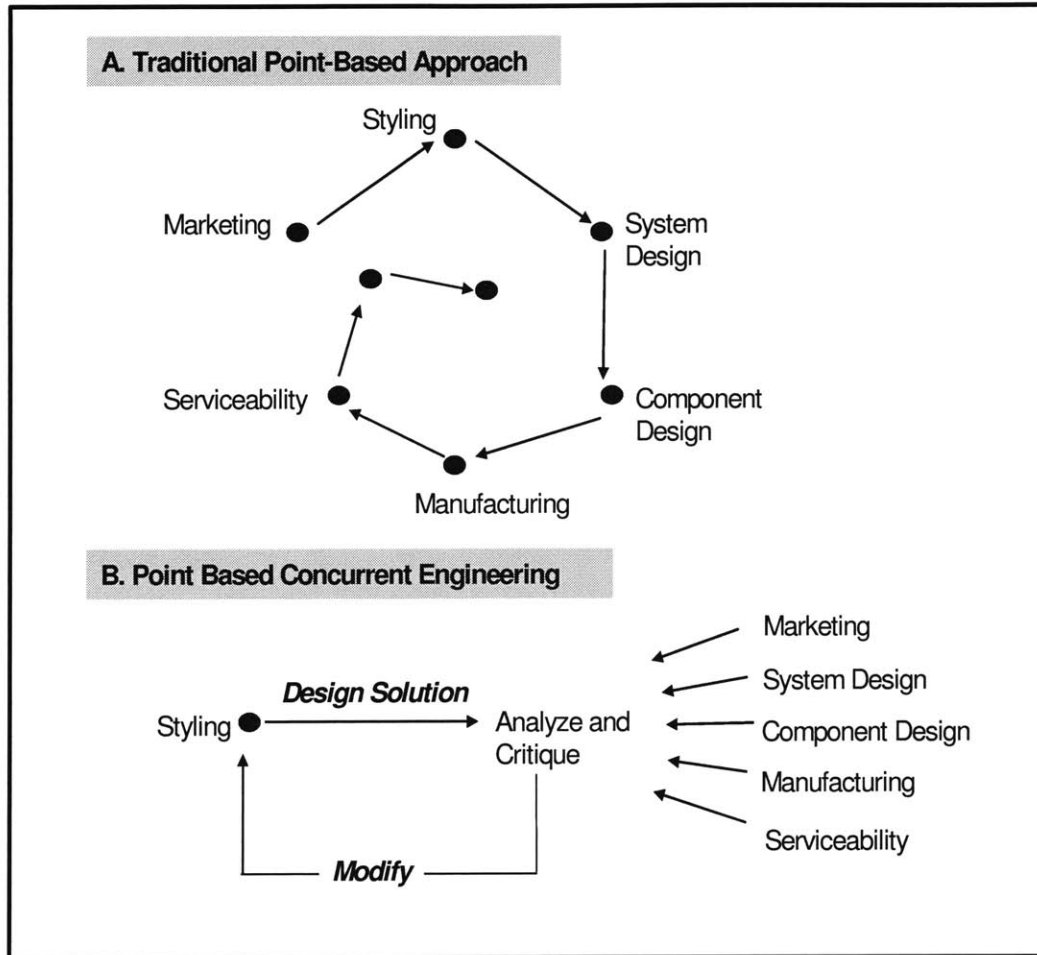
Figure 1: Comparison between point based serial engineering and point based concurrent engineering

In a point based CE environment all activities involved in the development process provide their feedback based on available information. The chosen best alternative proceeds from one part of the organization to another. The design gets analyzed and modified as trade-offs occur between several functional groups

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in the organization until an optimal solution is reached. If changes occur in design then there is a risk of prior design actions being invalidated. Much care should be taken to communicate agreements and decisions on designs between the functional groups involved.

2.3.2 Set Based Concurrent Engineering

In Set Based Concurrent Engineering (SBCE), as in point based concurrent engineering designs also begin with problem definition and idea generation. But rather than choosing an early winner designers consider a broad set of possible solution and gradually narrow down the set of possibilities. The set of possibilities include both a set of discrete designs and/or parameter values.

The narrowing of design sets occurs in a systematic way. Based on information currently available elimination of a possible set occurs when the option is either infeasible or clearly inferior. Information is gathered on a continuous basis based on further development and interaction with all functional groups in the design process. This process continues until the designers converge on a final solution. A simplified sketch of set based iteration is shown in figure 2. Given that designers in a SBCE environment consider several design options, there is explicit communications between participants about reasons for the sets of design alternatives both at the conceptual and parametric levels.

The real difference between these two design paradigms is in the fact that in SBCE more options are analyzed and decisions are left open for a longer period of time. This way when design freeze occurs it is ultimately done so based on development information available from the functional group opposed to "best guesses" from that functional group. Early design freeze based on imperfect information carries the risk of late change. While SBCE may take more time to converge and define a solution it however could move very quickly upon

convergence and onto production without any issues as the set narrowing phase would have considered several possible error states that usually occur late in design.
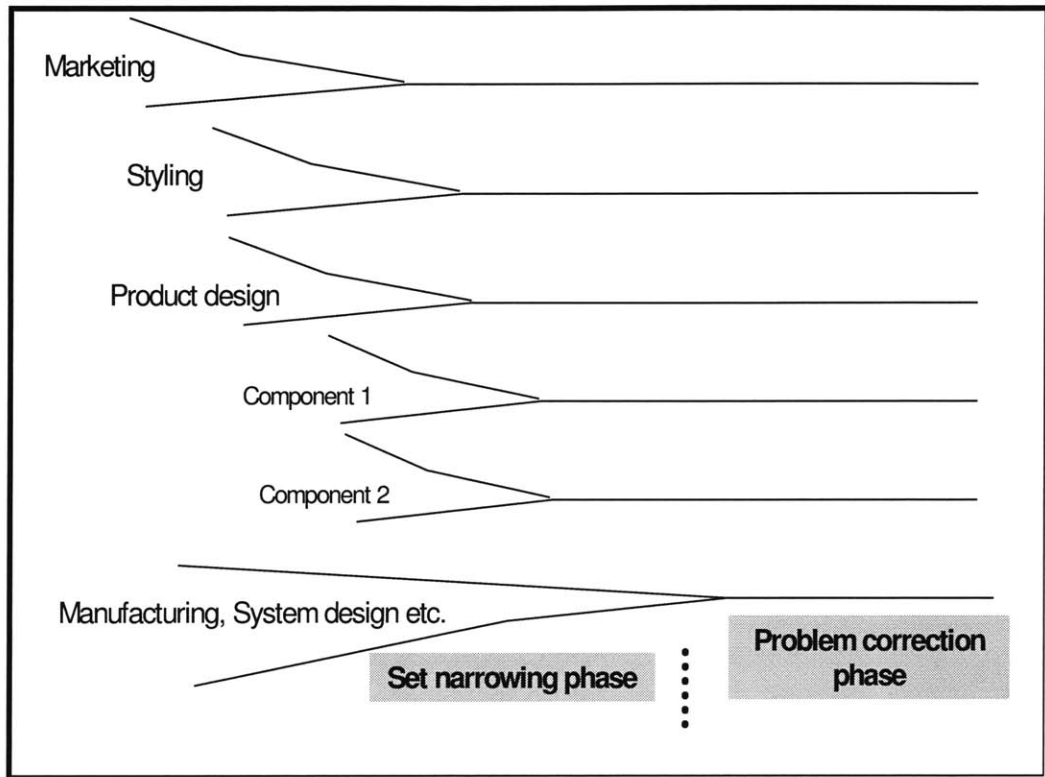
Figure 2: Representation of Set Based Concurrent Engineering

While set based concurrent engineering has clear advantages in an automotive setting, it need not be the best suited concurrent process for all industries. Some examples where point based concurrent engineering is used include Microsoft's "Synch and stabilize" approach, where several iterations and possibly releases of code happens on a weekly basis[8]. Point based process may be successful when product architecture is highly modular. It may also be beneficial to adopt if

iterations are fast and cheap, rework cycle is short and quality of first iteration or starting point is high.

In an automotive setting while some set based CE is practiced, the degree to which individual auto companies follow SBCE will surely vary. Again there is no precise measure to this degree of practice. But Liker etal through their studies argue that Toyota and its suppliers are more Set Based than other automotive companies. The success of Toyota's PDP as well as its manufacturing process is well documented and there is no dispute that they along with Honda are the industry leaders, taking the shortest amount of time it takes to launch a new product. This thesis will not dwell into a comparison of the exact nature of set based practices within Ford and how precisely it differs from Toyota's PDP as seen in literature. However the benefits and need for set based practices at Ford will be discussed in later chapters.

2.4 Knowledge Management

Most dictionaries define knowledge as the accumulation of truths or facts over time. What this thesis hopes to develop is a "contextual" reference with respect to safety attribute engineering in Fords North American Engineering organization. An attempt is made in this thesis to explain as to how this knowledge is created and managed in this organization.

Knowledge is often confused with information[9]. Information usually relates to description or definition and is more perspective in nature answering questions like what, who, when, or where. Knowledge on the other hand comprises strategy, practice, method, or approach to answer questions related to how.

Nonaka and Takeuchi[10] classify human knowledge into two kinds, explicit and tacit. Explicit knowledge involves formal language including grammatical statements, mathematical expressions, specifications, manuals etc. On the other

hand tacit knowledge is informal and hard to articulate with formal language. Tacit knowledge relates to the personal knowledge embedded in individual experience and involves intangible factors such as personal belief, perspective and the value system.

Later chapters will also detail how Fords North American Engineering (NAE) safety functional organization prepares itself for new process changes being cascaded within the company. The explicit knowledge management that takes place within this attribute and how this knowledge management framework aids the transition to this new product development process will also be discussed in later chapters. While this explicit knowledge may have had a tacit underpinning, the study and dynamics of knowledge evolution from tacit to explicit within the organization under consideration is beyond the scope of this thesis work.

Knowledge management is important as it enhances an organization's[11]ability and capacity to deal with and develop on the following dimensions:

> Mission: What it is trying to accomplish?

> Competition: How can it gain a competitive edge?

> Performance: How can it deliver the results?

> Change: How does it cope with change?

Knowledge management is even more important now at Ford Motor Company as it embarks on a new product creation process GPDS (Global Product Development System). The manner in which product development occurs in different enterprises will differ even if they can be broadly grouped as different versions of concurrent engineering. But how a particular enterprise practices

concurrent engineering and if successful how it can build on its own practices is precisely related to the knowledge management activities within this firm.

Prior thesis work by Qi Dong[12] have captured the fact that only 30% of a companies system level knowledge was usually recorded in documents while the rest was based on interviews with engineers. The need for this recorded knowledge and how a team may record it is the knowledge management context for this thesis. It is hoped that by recording the best practices in a usable format will help future teams in their development effort. Hence an attempt is made in this thesis to explain the framework in which knowledge management occurs within the NAE safety attribute as it prepares to adopt the GPDS schedule and processes. Through case studies in later chapters it will be shown how these knowledge management practices helped in quicker problem solving and reduced development time and cost.

2.5 Related research: Development funnel and Controlled convergence

Engineers pursuing a feasible design in a development process are usually encouraged to try several options. The process of considering multiple alternatives is fairly common place. Authors like Wheelwright and Clark, Ulrich and Eppinger have discussed in detail how the "development funnel" is used to narrow down feasible solutions as design matures from concept to implementation stage.

Multiple alternatives provide "flexibility" during development process. This flexibility is essential especially in an unpredictable and rapidly changing business environment[13]. Flexibility in development process should be such that it provides for making design changes as late as possible in the overall development process with little or no penalty at all. It may after all be this flexibility that makes set based concurrent engineering attractive to automotive firms. For example when

product styling becomes a "hit or miss" only after it reaches the end customer, teams involved in styling would like to base their decision on best available data from customers opposed to guesses and single styling themes. In such scenarios carrying multiple styling themes or sets late into the development process is a flexibility that affords for best decisions late in the development process with little penalty.

The process by which the development funnel may be narrowed is provided by Pugh through his concept on "controlled convergence"[14]. Pugh Concept Selection allows for alternating convergence (analytical) and divergence (synthesis). This process improves upon the beginning concepts, usually creating a final hybrid concept usually of higher value that was not one of the original concepts. The following steps detail this concept:

➢ Pugh evaluates each system-level concept against a common baseline, which is either the current product design, or a surrogate. This eliminates conflicts in determining how much a concept is better than the DATUM.

➢ Unlike a true set based concept where there is no limit to the number of comparisons, Pugh minimizes the number of comparisons that must be considered. The comparison is not to the product specifications. The comparison should not be numbers based, as this tends to create a focus on the numerical values instead of the possibility of innovation.

➢ Selection criteria should be chosen to differentiate between the concepts, not show that all the concepts are the same for a given attribute. This will allow for a more straight forward comparison that takes less time. Pugh also stresses examining the negatives of a given concept to reverse

them and strengthen the concept. This would not be evident if a numerical approach was taken.

➤ Every participant in the design process should have a clear, consistent understanding of each concept. And this understanding improves (along with an understanding of the problems) as the process progresses. The team's judgment is used to interpret the results of the comparison.

➤ The process works regardless of product or technology type. This is because it minimizes constraints on creative thinking and provides a stimulus for creative work.

Generic Selection Matrix						
Selection Criteria	Reference System	Alternatives				
		A	B	C	AB*	AC*
criteria 1	D	s	+	s	-	+
criteria 2		s	+	-	-	+
criteria 3	A	+	+	-	+	+
criteria 4		-	s	-	+	+
criteria 5	T	+	s	+	+	+
criteria 6		+	-	+	s	+
criteria 7	U	s	-	+	s	-
criteria 8		s	-	+	s	s
criteria 9	M	s	-	-	+	s
	Σ +	3	3	4	4	6
	Σ -	1	4	4	2	1
	Σ s	5	2	1	3	2
+ = better than, - = worse than, s= same, * = hybrid						

Figure 3: Example of Pugh selection matrix

2.6 Chapter Summary

This chapter provided definitions for concurrent engineering and the two paradigms that exist in the concurrent engineering based product development process, point based and set based concurrent engineering. Though concurrent engineering involves several functional teams, the scope of this study is limited to a few teams in the early stage of the product development process. Also defined in this chapter was the knowledge management context. It was important to provide this context as the word knowledge is very generic and broad. Next chapter will describe the existing product development process at Ford's North American operations. A broad description on product development tasks were provided in this current chapter. This will help the reader to understand the following chapter where a narrower focus on specific development tasks is provided.

3. Current Practices

3.1 Chapter Introduction

This chapter introduces the reader to existing product development practices within Ford's North American operations. The team structure within the product development organization is described. The safety attribute team's interaction with other product development team is described in detail. Also provided is a general description of the roles and responsibilities of the product development teams and in particular the safety team. Existing knowledge management practices within safety attribute team is also discussed.

3.2 FPDS – Introduction

The Ford Product Development System (FPDS) documents the process tasks and deliverables necessary to define, design, verify, and launch a vehicle. It provides a logical sequence of processes and events which optimizes the use of available skills, technologies, and facilities to produce a vehicle in a minimal period of time. The FPDS Process consists of milestones and team events which are timing points for FPDS deliverables. Milestones differ from team events in that they require management reviews. Milestones are defined to communicate progress at various points throughout the product development process. FPDS is utilized by the following brands within Ford Motor Company: Ford, Lincoln, Mercury, Jaguar, and Land Rover. Mazda and Volvo each utilize a unique product development process.

The FPDS Process timing depends on the scalability of the vehicle program. Scalability refers to the level of complexity of a vehicle program. It ranges from S1 to S6. An S1 represents a vehicle program with very little change, such as new

stripes, decals, badging, and body side moldings. An S6 represents a vehicle program with a new platform.

The generic FPDS Process starts at the Kick-Off <KO> milestone which is 50 Months Before Job 1 (MBJ1) for a large scale program and ends at the Job 1 <J1> milestone signifying vehicle launch. Three months after J1, the Final Status <FS> milestone occurs. There are several milestones and team events in between <KO> and <FS>.
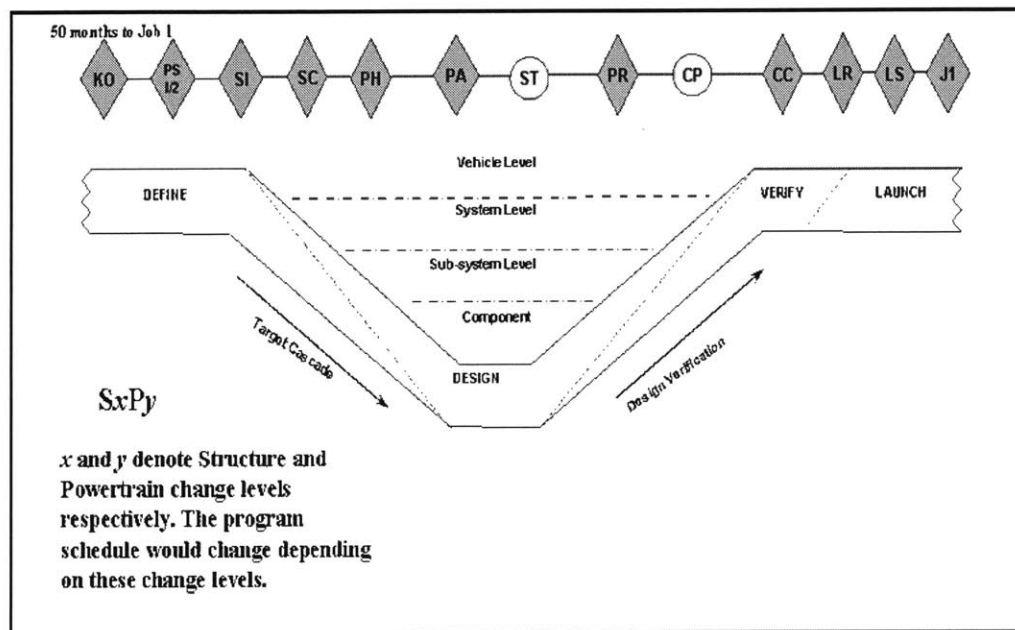
Figure 4: Generic FPDS milestones and system V representation

The tasks involved in executing the PDP to FPDS schedule give this system engineering framework its name, the "system V". Simply put, the vehicle is composed of systems which are composed of subsystems which are ultimately composed of components! This denotes that the entire system is defined and then designed starting from the whole vehicle down to its components. Once the

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definition and designing phases are done, the verification commences starting from the component back to the vehicle level.

The entire vehicle development process is kicked off with the issuance of a product definition letter (PDL) which denotes the "intent" and "content" of the vehicle to be designed. Through the early "define" phases or milestones the vehicle architecture is refined and made compatible with the PDL. Once the vehicle level target compatibility is confirmed, targets are then cascaded from vehicle level to the sub system and then to the component level. The confirmation of component level target compatibility coincides with the program approval milestone or stage gate. After this event design confirmation commences starting at the sub system level and then reaching the full vehicle level starting with the confirmation prototype (CP) team event. Once designs are verified it is then released for production through the engineering sign off milestone events. Finally formal production commences at J1.

What was discussed is only a high level synopsis to explain FPDS. Each milestone has detailed deliverables and associated tasks. There are several hundred tasks and deliverables across all the FPDS milestones that program teams would have to complete the design and launch of any vehicle. It is beyond the scope of this thesis to analyze and explain these tasks. It may also not be appropriate given that these are company confidential and proprietary information. But when the need arises, a particular task may be explained and care would be taken not to violate proprietary information.

3.3 Historical background - The Need for FPDS

While concurrent engineering practices became prevalent through the 1970's in the North American automotive industry, it soon became apparent that these automotive enterprises needed a formalized process framework to integrate

different functional groups within its enterprise. A systems engineering framework was needed that would enable the integration of all concurrent engineering activities. Ford in 1995, as part of its reengineering effort dubbed Ford 2000, embarked on Ford Product Development System. This system engineering framework had its roots in the aerospace industry. The aerospace industry around this time was well underway in using system engineering tools and framework to integrate its functional groups and processes.

From a business stand point FPDS was needed so that vehicles could be made based on affordable business strategy[15]. This in turn would maximize the company's investment efficiency. Before FPDS products were priced based on classic product development equation where vehicles were priced on how much it costs the company to design and build them. But with FPDS Ford began following the affordable business equation which worked its way back. That is, vehicles were priced based on how much the customer is willing to pay. Then depending on this price target, it was then decided how much design change may be made to the vehicle.

3.4 Program team structure in North American product development

At the center of Fords North American product development activities are the Vehicle Program Teams. It is the responsibility of this team to undertake and manage all the tasks required by FPDS for a given vehicle program from <KO> to new vehicle launch at <J1> milestones. Vehicle program teams are further divided into Program Steering Teams, Program Attribute Teams, Program Module Teams and Program Action Teams. The responsibilities of these teams are described briefly below:

> ➢ **Program Steering Teams (PST's):**

o Provides program direction for product, investment, quality and process

o Administers program timing and the targets process

o Monitors the status of team deliverables and milestones

o PST's are chaired by the Chief Program Engineer and the participants are listed in the flow chart (figure 5)

➢ **Program Module Teams (PMT's):**

o Broken down by few major systems; Body interior, body exterior, chassis, power train and electrical

o Manages the design, release, and manufacturability of the specified vehicle system, subsystems and component to meet the quality, cost, functional, weight and timing targets (QCFWT)

o Discusses activity status, identifies issues, and discusses required updates pertaining to design and release of the system.

➢ **Program Attribute Teams (PAT's):**

o Around fifteen attributes are responsible to deliver the vehicle performance. They are listed in the flow chart (figure 5).

o The role of the PAT is to manage the attribute development and performance that affect multiple PMT's.

o   Cross attribute tradeoffs and optimization for a given vehicle program is the responsibility of program specific vehicle integration or vehicle engineering teams.

> **Program Action Teams:**

o   The role of the program action team is to design and release components belonging to the PMT's. For example the restraints program action team is affiliated with the body interior PMT. Its job is to design and release passive safety components like airbags, seat belts and related components, steering wheels and crash sensors.

Each individual PMT and PAT's has their own internal organizational structure headed by dedicated functional chief engineers. Thus several PMT's or PAT's performing the same function would be organized under one such chief engineer. For example all body exterior PMT serving the truck platforms would have a dedicated "truck" body exterior chief engineer. Similarly a functional group like safety is headed by a dedicated safety chief engineer. There is however minor modifications to this structure. Some attributes such as Noise, Vibration and Harshness (NVH) or Durability would be organized under a chief engineer who may have responsibility for both the attributes.

Engineers from these functional groups are assigned to dedicated vehicle program teams. This collocation forms the basis of Fords matrix organizational structure for North American product development activities. This generic matrix organizational structure was created around 1995 during the Ford 2000 reengineering efforts. Over the past decade this matrix structure has undergone several iterations to serve the needs of the PD process at any given time. For

example resource or logistical issues may have created a sub organization. This still would be at the working level opposed to the management level. Still with these changes the underlying theme of a cross-functional matrix organization dedicated to program teams remain the same. Even though manufacturing is an equally integral component of the concurrent process its organization structure is not discussed as part of this thesis.

In a vehicle program setting PAT's provide targets to the PMT's. Each PMT receives targets and system level requirements. The PMT's are then decomposed into various Design Verification Teams which receive requirements cascaded from the PMT's and from other sources, depending on the scope of the design verification team (also termed as DVP teams). An example requirement would be safety PAT teams cascading steering column stroke requirements in the form of load vs. deflection characteristics to Chassis PMT which then cascade it to the steering column DVP team or program action team.

3.4.1 Safety team structure in North American Product Development

A brief description of the safety attribute in Fords North American Engineering organization is provided in this section. Later chapters will deal with the knowledge management and product development activities within this attribute. Safety is one of the program attribute teams. Over the years Safety PAT formed a strong working relationship with certain PMT's like Chassis and Body (interior and exterior). This is due to the influence exhibited by the components and sub-systems from these PMT's on the crash worthiness of a vehicle. Some of the major chassis components and sub systems are frame, sub-frame, suspension, fuel sub-system. Body structural members include component and sub-systems like pillars, floor, dash, doors, roof etc. All of them play a crucial role in the structural crash worthiness of a vehicle.

While this at the PMT level, safety PAT's interact strongly with certain Program Action Team's under the PMT umbrella like the Seat, Restraints, and Instrument Panel. Safety teams additionally work with other attribute groups like Package engineering, styling studio and other cross-functional attribute teams like NVH and durability.

Vehicle Program Team Structure

Program Steering Team (PST)
(Vehicle Line Director; Chief Program Engineer; Project Mngr; Body Mngr.; Chassis Mngr.; Electrical Mngr.; PTSE Mngr.; Vehicle Engineering Mngr.)

Program Attribute Team (PAT)
(Cost; Customer Life Cycle; Customer-Visible Electrical Features; Emissions; Interior Climate Control; NVH; Package/Ergonomics; Performance, Fuel Economy & Drivability; Product/Process Design Compatibility; Safety; Security; Styling/Appearance; Thermal/Aerodynamics; Vehicle Dynamics; Weight)

Program Module Teams (PMT)
(Body Interior; Body Exterior; Chassis; Electrical; P/T)

Program Action Teams (PAT)
(example: EE, Body, CC, DI, Restraints, P/T)

Figure 5: Vehicle program team structure[16] showing the attributes involved in PDP.

As with PMT's the interaction with certain Program Action Teams are stronger than others mostly depending on the needs of the program and based on the components that are changing for that particular vehicle line. Organizationally Impact safety teams are coupled with the Restraints design teams, to signify the close working relationship needed between these two teams (Figure 6). Strong

working relationships between safety PAT's and related PMT or action teams are denoted by solid lines in figure 6.
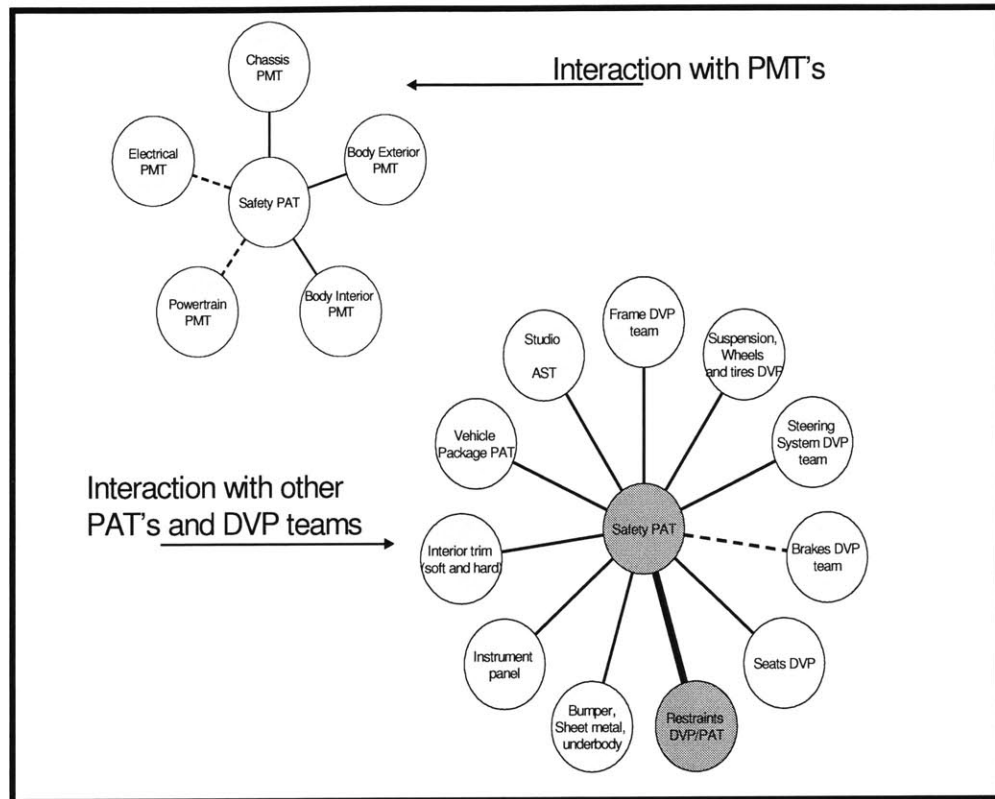
Figure 6: Interaction between safety PAT and other activity teams represented pictorially.

3.4.2 Impact safety requirements in United States

Automotive safety may be divided into impact and non-impact safety. All references to safety in this thesis indicate to the impact safety attribute of an automobile. References to non impact, if made, will be called out specifically. The crash safety requirements for an automobile in the United States are regulated through the National Highway Transport Safety Administration (NHTSA) which falls under the Department of Transportation. These safety requirements are

listed under the Federal Motor Vehicle Safety Standards (FMVSS). All automobiles depending on their weight class would have to meet certain set of FMVSS requirements. FMVSS standards regulate every aspect of an automobile pertaining to impact and non impact safety. While impact safety deliverables is the responsibility of the safety attribute team, non impact safety requirements are the responsibility of the individual PMT to which the regulated component or sub system belongs. The flow chart below shows this decomposition (figure 7). Requirements exist for system, sub-system and component level of a vehicle. Appendix 1 shows some of these examples.
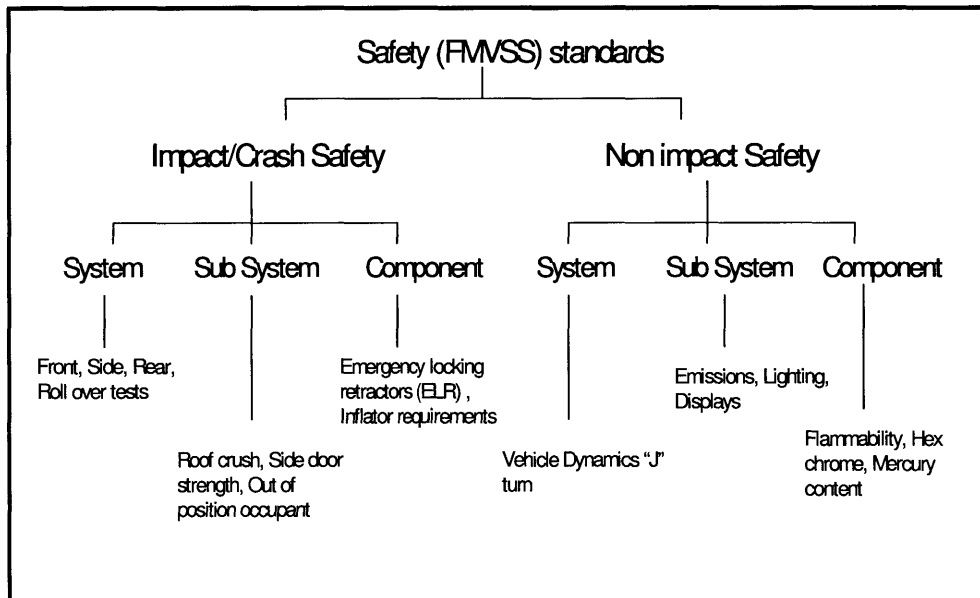
Figure 7: Roles and responsibilities of the attribute teams divided based on regulatory requirements

An example of impact safety requirements in FMVSS is a 30mph full frontal impact of a passenger car (under 5500lbs) into a rigid wall where occupant injury numbers for a 5th percentile female and 50th percentile male Anthropomorphic

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Test Device (ATD or HYBRID III Crash dummy) shall be below a specified values. An example of non impact safety requirement would relate to head lamp standards. Another example would be brake standards which would dictate minimum stopping distances.

3.5 Safety Attribute Knowledge Management Practices Followed in FPDS

Starting in 1995 when Ford adopted the FPDS process, several attribute teams were also reorganized to better facilitate the goals of FPDS. For safety engineering this brought the Computer Aided Engineering (CAE) simulation, testing, development and restraints program action team's closer together under one organization. It was also at this time that the power of CAE simulation to quicken the product development cycle was being recognized by development teams. Reciprocally, CAE engineers were now able to relate to development and project management efforts happening in program teams and were able to interact better with program teams.

However no formal knowledge management practices existed. In interviews with technical specialists within the safety organization it was gathered that prior to Ford 2000 development engineers usually stayed in their jobs longer and this was one of main reasons for not having any explicit documents or formal knowledge management practices. System knowledge was mostly tacit and given that engineers stayed on their jobs longer no formal documentation was required. Also, compared to today, crash safety standards were not many. Sub system and component standards were being populated to ensure system robustness. While the requirement "what's" were being documented, requirement "how's" were not. Dividing up the vehicle into system, sub system and components was just beginning in safety. Sub system design specifications and component design specifications were being formulated and cascaded to the PMT's. But these requirements did not tell engineers how to proceed with design.

A few years prior to Ford 2000, Finite Element Methods[17] and Rigid body codes[18] were used for simulating sub system and full system crashes. CAE engineers were beginning to discover how they may correlate their simulation models to actual crash test. From these correlated models design iterations and changes were being made. At this time confidence in CAE simulation was not high for CAE to "lead design". But the knowledge gained by CAE engineers was being documented. This knowledge related to how they were able to correlate models better to test so that they may recommend design changes and the best assumptions to make in simulation code to produce the right trends that can then be duplicated in design. Best practices relating to recording of necessary parameters from test to be incorporated in models later were all being documented formally. This happened through published internal engineering reports, weekly design reviews among CAE team members across different program teams, technology reviews between advanced research CAE teams and program teams and best practices design reports published by crash simulation CAE community.

3.6 Related research – FPDS, Team Structure and Safety Attribute Product Development

Chatawanich and Rush[19] performed a detailed organizational study pertaining to Ford's organizational culture. This study also details the evolution of Fords organization over the past hundred years. It provides a good insight and information on Ford's matrix structure, program teams and cross functional organizations.

Khan[20] performed a detailed study on safety product development and provided a systematic approach to safety design and product development in FPDS. It uses design structure matrices to study system level interactions specific to safety. Based on this work teams can decide to develop for the worst case test mode identified through the DSM analysis[21], design sub systems for those specific tests

modes and be assured that other test modes would easily conform to this design. This study has a detailed background on how safety requirements came about in United States as well.

Thomke[22] describes "how crash simulation works" in his book on experimentation. The success of many auto companies in using crash simulation to come up with better design is also discussed.

The discussion in section 3.5, safety attribute knowledge management practices, is based on the authors personal observations over several years working in the safety attribute. Also, the practices described are specific to the NA safety attribute engineering. Technical specialists and safety program supervisors were interviewed to supplement personal knowledge on safety knowledge management practices.

3.7 Chapter Summary

Team structure, their roles and responsibilities explained in this chapter will help the reader understand the development process undertaken with in safety attribute. This will also be pertinent to the case study undertaken in chapter 5. The detailed description provided on tasks involved will help the reader understand terminologies used in the discussion on knowledge management practices in the next chapter. It will also help the reader understand the differences between FPDS and changes proposed to the product development process which follows in the next chapter.

4. New Practices

4.1 Chapter Introduction

In this chapter the reader is introduced to the proposed changes in Ford Motor Company's product development process. Comparisons are made between present and future product development practices. Early knowledge management practices undertaken by the safety attribute team in FPDS and its evolution as Ford transitions to the new product development process is also described. To make these comparisons effective gaps in existing practices are identified.

4.2 GPDS - Introduction

GPDS or Global Product Development System is a product development process that Ford will transition to for programs commencing 2005. While most brands in Ford Motor Company use FPDS, Volvo and Mazda use their own unique PDP. GPDS will integrate all these three existing processes. The roots of GPDS lies in Mazda's development process which is considered to be among the fastest in the auto industry. The time taken by some automakers in their product development process to move from "design Freeze" milestone to launch is shown below (figure 8). Toyota is considered the industry leader and comparisons are normalized to their number. Overall time to market data from program kick-off to start of production may not by itself provide an objective measure as the OEM's may have different definitions for program kick off.

The system "V" concept of cascading targets from system down to the component level seen in FPDS may not exist on paper with GPDS. This does not mean that Ford is moving away from this powerful system engineering frame work. Instead for the system to work now, solutions will not only be cascaded

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top down but also from bottom up based on available sets of components and subsystem. Figure 9 attempts to clarify this concept.

OEM	From Design Freeze to Launch
Toyota	Industry leader – 1.0
Honda	1.2
Mazda	1.2
Nissan	1.26
Ford	1.66
Renault	1.73
DaimlerChrysler	1.86
General Motors	2.0

Figure 8: Time to market benchmark – normalized values[23]

GPDS has been mapped out to be more set based than FPDS. GPDS is geared around the parallel exploration of sets of alternatives. A prime alternative is identified after each alternative is thoroughly assessed in a variance-based manner. In GPDS development process can be represented as a funnel starting with early consideration of a wide set of alternatives. Later sets of alternatives are progressively narrower. Decisions are cadenced based on development lead times (e.g., platform, wheel size must be decided very early; Seat Design, Interior Trim, etc. can wait until later). The core principles governing GPDS are structured and repeatable process leading to timely and binding decisions. Another repeated theme in GPDS is that product and processes will be executed with a high level of reuse and commonality. A concept diagram of GPDS milestones showing the funnel narrowing leading to design stability is shown in figure 10.
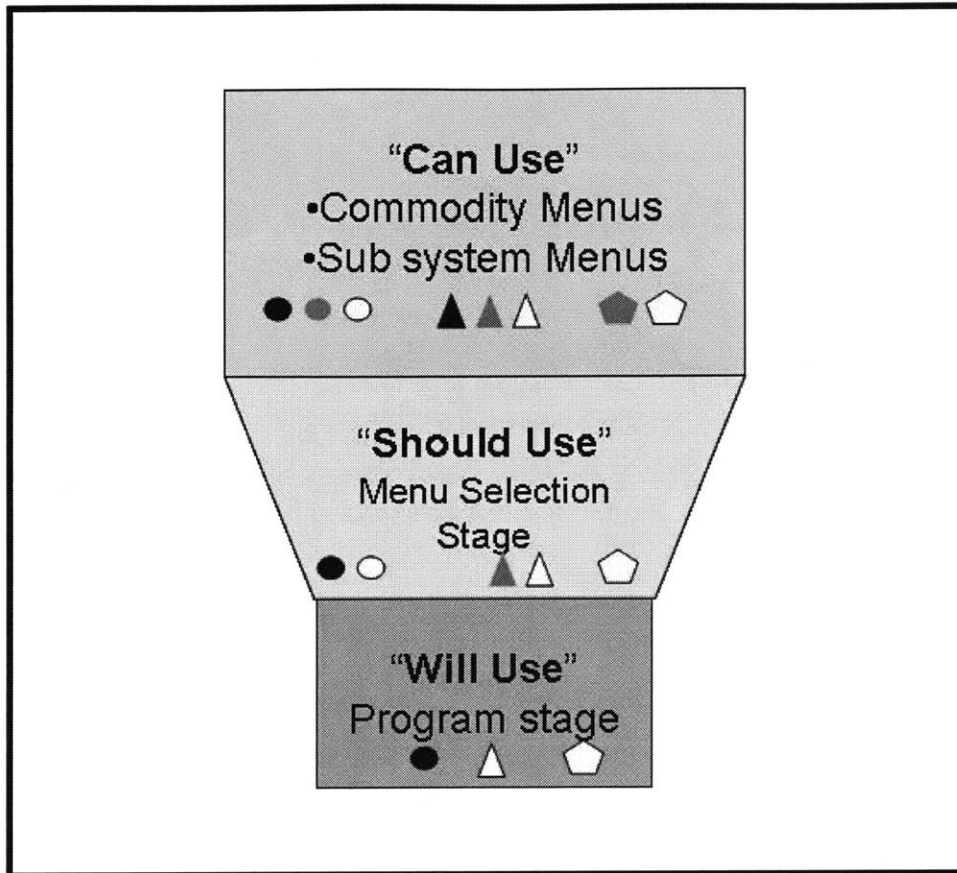
Figure 9: The menu concept where teams are expected to choose from sets of available solutions

4.3 The Need for GPDS

Companies have always tried to provide value to their customers. One way was to reduce product related investments by streamlining their product development processes and pass the savings to customers. This streamlining may take the form of commonality of parts between different product lines and creating product platforms which then can launch multiple products or designing components that use existing manufacturing facility.
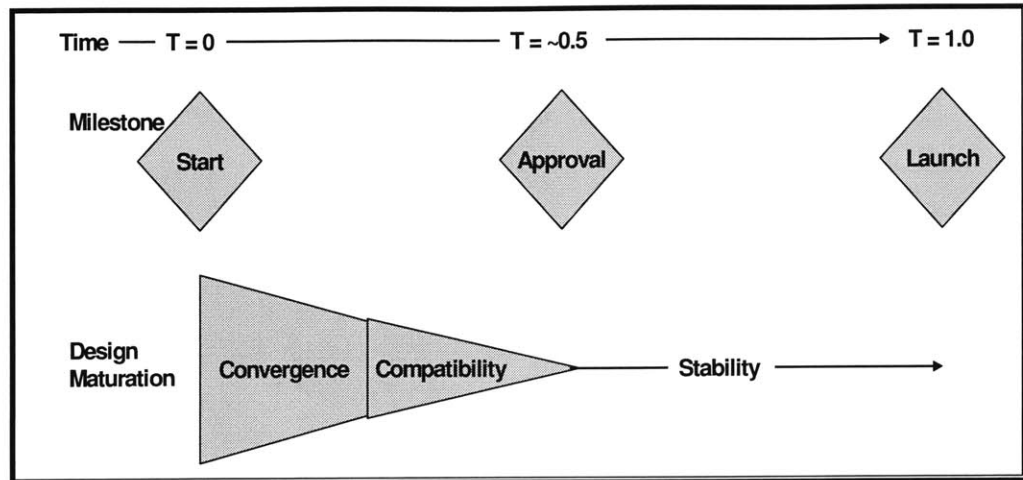
Figure 10: PDP time line indicator and set
narrowing phases

While these objectives are not new, the challenge has always been to balance the
PD effort that tries to maintain commonality and at the same time preserve the
differentiation required in the market place. We also saw the prior table where
Ford is at a competitive disadvantage with respect to its PD timing and time to
market. Additionally it is known that Ford's competitors are continuing to
improve on their own baseline, again through reuse and architecture
commonality. One of the major expectations from GPDS is that it should be
faster and more efficient than FPDS. Following sections will analyze how design
and development efforts may contribute to this.

4.3.1 Gaps in FPDS

Over the years there have been several reengineering processes at Ford. Some of
them would include Design Approval Process, Concept to Customer, World
Class Timing, World Class Process and the current process FPDS.

In retrospect, each of these initiatives had its value. They were good engineering ideas and at that time each one was a better way of structuring work than its predecessor. But they did fall short as time progressed. It is important to understand why they fell short and address the gaps with the next one. It may not be possible to compare all the different process listed above with one another. However based on interviews with both suppliers and resident experts some of the shortcomings in FPDS have been summarized below:

➤ Scope Creep – Lack of discipline to milestone deliverables; system commitments were not required during <KO> milestone and changes were allowed including late styling changes.

➤ Lack of prioritization – Lack of attribute funding; misaligned objectives between attribute and program teams; Chief Nameplate Engineer not empowered to prioritize; conflict between initiatives and customer requirements.

➤ Lack of vehicle identity or clarity - cherry picking from segment competitors and adding additional features to program.

➤ Ineffective benchmarking – No centralized source or activity for benchmarking and its coordination; no consistency on the type of data required by programs from benchmarking.

➤ Staffing and experience – On going resource constraints; waiting for prior launches to ramp down; team experience, many first timers in the team;

➤ Target setting gaps - Target process "Not rooted in reality", teams "Defending the indefensible"; process for developing targets is highly variable between teams; lack of continuity in personnel eliminates or

prevents developing fact based targets; targets are more program centric and no focus on commodity;

> Lack of commodity focus – A Supplier commented that many OEM's rely on being experts in their commodity strategies, and use the programs as simply the tools for implementation of those strategies. But at Ford, teams seemed more program focused. In his opinion, the balance between commodity and program focus was missing at Ford.

The interview summary listed above has both organizational and structural issues pertaining to FPDS. The organizational aspect pertaining to staffing, resources and experience level is complex and beyond the analysis of this thesis. The study undertaken by Chatawanich and Rush referenced earlier deals specifically with these issues.

Scope creep, lack of prioritization and target setting gaps may be due to a lack of adherence to process disciplines. There may be organizational issues involved here as well where functional departments may not be aligned with program or project teams. While the program chief engineer should help in resolution of such issues, the chief engineer's lack of empowerment could have been the root cause why this issue persisted.

The term "commodity" is introduced in the prior section. In future sections, the term commodity is interchanged with component. Both refer to a collection of elemental parts brought together to deliver a function. When assembled with other commodities or components, this collection of commodities forms a sub system. A collection of sub systems forms the system. A few systems compose the full vehicle. As an example, the driver airbag module is considered a commodity or component. The driver airbag itself may be composed of several

elemental parts, like airbag inflator, the airbag fabric material, the retainer or housing, the molded plastic cover, the squibs needed to ignite the inflator etc. The airbag, along with seat belts and crash event recognition sensors forms the occupant restraints sub system. The occupant restraints sub system is part of the interior system. Other sub systems that form the interior system would be seats, instrument panel, trim etc. The interior system along with the exterior system, power train and electrical system forms the full vehicle. A decomposition chart shown in figure 11 provides details of this vehicle-system-sub system and component break up.

The issue of commodity strategy or the lack of it arose in the interviews conducted. The context in which it was used is that in FPDS to deliver system targets, engineers in attribute and functional teams assumed that a new commodity or component design would have to be undertaken. Teams did not check to see if there were commodities available from other vehicle lines that would be compatible in the new system. Several factors including sourcing decisions made were cited as possible reasons for a lack of coherent commodity strategy. Also cited were engineering reasons. It includes the lack of a centralized benchmarking activity which could easily determine compatible solutions from several available commodities. While a physical facility was available at Ford, the need was for readily available commodity performance data that would help in quick comparisons. Such performance data were not readily available.

In FPDS attribute and functional engineers were usually associated with a single program or vehicle line. Even though many engineering groups operated under a matrix organization involving both functional and program teams, intra attribute team interaction in some functional groups was less. Being program focused did not permit engineers to easily gather broad knowledge on similar commodities available from their counterparts on other programs. While engineers and their

teams understood their specific vehicle or system targets well, program focused attribute teams shifted the balance away from acquiring broad commodity based knowledge. This may also have prevented functional engineers to undertake compatibility studies. A compatibility study would allow an engineer to investigate commodities already available on another vehicle program to be used in the new vehicle line without significant redesign. This allows for commonality and reuse of components. The case discussions in later chapter will address the topic of compatibility.

Comparisons will be made to GPDS and changes proposed through GPDS will be analyzed to see if some of these concerns listed above can be answered.

4.3.2 Proposals in GPDS to fix the gaps from FPDS

Recurring themes in the interviews done to assess drawbacks in FPDS were late changes to program assumptions, that design solutions were program specific and unrealistic targets. But in GPDS teams would be moving from a focus on development per program with limited re-use to an annual process that delivers possible solutions to be used by the program and attain targets. Reuse will happen on architectures, systems, parts, and CAE model fronts. To enable this from a commodity level, Ford recently announced that it would be working with fewer, more competent and efficient commodity suppliers.

Too often, given the current process by which programs are resourced for staffing, design actions commence only after programs are kicked off. If the same trend continues, teams would be unable to develop commodities that are common across multiple programs. Hence commodity designs have to happen and be "futured" outside of program process. GPDS explicitly calls for such an annual process. This annual process will be a product planning process incorporating technology and commodity plans, resulting in a more stable,

compatible, and robust program at kick off. The annual process as part of its charter will not allow book shelving of new technology or commodities unless compatibility is assured between both cycle plans and all existing vehicle program targets for which the commodity is intended. This will avoid commodity usage conflicts between programs already in the product development pipeline and those that are still in very early planning stages. The importance of "futuring" will be analyzed through case study in chapter 5.

Unlike FPDS, in GPDS early compatibility to targets is established through reuse of available system solution alternatives. This will prevent incompatible targets and late changes in both business case and content to compatible targets.

Another structural issue with FPDS was the unsynchronized prototype phases. Several prototype phases existed serving the needs of individual attribute teams. Based on prototype test results if a particular attribute made changes to its targets, it was never captured by other attributes in their prototype phase and this sometimes would lead to late changes in design as proper cross attribute trade off optimizations were not conducted. In GPDS design and validation will be developed discretely in a two-phased development process. This would lead to a synchronized development process. Cross-functional verification (virtual and physical) of countermeasures from prior development phase can now feed into the next phase. This will also address some of the target setting gaps encountered in FPDS.

To enable a single point release to signify design completion of all systems and components a senior management design review event will be conducted. This will ensure stability in design development and data release in GPDS. In FPDS changes were accepted through out the process until very late in the PDP. This will not be the case with GPDS. Stable engineering data following a single design

release should also allow tool and manufacturing to commence later in the process resulting in reduced lead time.

Overall, GPDS is being planned to be a manufacturing led process where the pre program activities would define and design the product around manufacturing's requirements to maximize reuse and minimize fixture and tooling investment. While there are significant changes to the operations and organization of PD "factory", given the nascent nature of GPDS it may not be suitable to discuss all of them in detail. But the above details were necessary to understand how commodities and the systems that incorporate them would be designed in such an environment.

4.4 Knowledge Management Evolution in Safety Attribute

4.4.1 Background – Early Knowledge Management Practices

Through the nineties safety attribute teams in Fords NA product development grew in size as more product lines were introduced. Additionally the impact safety requirements increased over the years. Flow chart in Appendix 2 shows a snapshot of the increase in requirement since 2004 in frontal impact alone. The nineties also saw increased awareness in the market place to requirements introduced by public agencies like the Insurance Institute for Highway Safety[24]. The regulatory agencies were also planning to introduce new test modes in side impact, rear impact and roll over protection.

From a safety project management perspective, teams had to ensure that no critical tasks were missed in the development of vehicle. There were no formal task lists existing within the teams. The work breakdown structure were known to the experienced engineers but still not documented. As discussed in chapter 3, most of the knowledge on how and when to conduct an analysis or development project was still tacit. Additionally the ballooning of requirements and product

line ushered in several new engineers into the attribute. Faced with these challenges, safety management in NA product development decided to streamline their development process around 2002. A working team was formed under the leadership of a technical specialist. A detailed checklist was created based on work breakdown structure. The team created this detailed checklist based on their personal experience and interviews among the department members.

The structure of the checklist followed the FPDS schedule. Upper level tasks were initially identified based on generic FPDS deliverables. A simple Gantt chart was used to map the upper level deliverables. These deliverables were divided into three major groups and color coded accordingly. They were Product and process definition tasks, detailed design and optimization tasks and finally testing and verification tasks.

The product and process definition tasks in this checklist mainly pertained to safety planning, scheduling and developing a strategy to enable the vehicle to meet market requirements. It also included tasks for team members to collect and analyze legacy and benchmark information. Based on the information collected safety strategy was provided to the program teams. The product definition letter, a document that details the vehicle content, is then populated with the safety's needs and wants. The second set of tasks that the upper level Gantt chart identified were based on detailed design and cross attribute optimization work that would have to be carried out. The time to start and end the tasks was identified. These design and optimization works were mainly CAE in nature. Finally, when design work was completed the high level schedule identified the test and verification sequence.

These upper level generic tasks were then sub divided into lower level tasks and binned according to the milestones in which they have to be completed. This

format allowed for management reviews as well. In creating the tasks the team realized that they were documenting mostly "what's" rather than "how's". As such this initial checklist was mostly a schedule rather than a "process". The way in which the tasks were arranged followed the system "V" breakdown from the full system to the component level. The schedule for verification conducted starts from the component back to the full system level culminating in system design sign-off by crash safety attribute.

4.4.2 Lessons learnt from early knowledge management exercises within safety attribute and modifications made

The initial document created was extremely verbose and tried to accommodate engineers of varying levels of experience. Even though the initial versions were released for engineers use, the team was continuously challenged by the safety manager to improve upon the checklist. The technical specialist in the team then decided to simplify the verbose format and instead change the structure of the checklist to a more direct short question and answer format which then could be reviewed during the managers design review meetings. It still contained several line item questions and was exhaustive (snapshot provided in appendix 3). The feedback from engineers who were being asked to review this checklist in their daily work was mostly positive. But there were also complaints that the checklist was overwhelming. Experienced engineers felt that they did not require this level of detail while the fresh engineers were left searching, clearly confused by the detailed nature of the questions. However despite the complaints recognition was that finally there was a database which now had all the tasks needed to be undertaken by the safety engineer. It had never existed before in such an explicit manner.

While creating the checklist the team members involved including the author began reflecting on the safety development process and realized that the major

shortcoming of a Gantt format was that it never provided a way to capture the iterative nature of the development process. In essence what we drew up on paper looked like a "home run" plan and not the iterative exercises carried out in our daily work. Hence to overcome this situation team members decided based on informal survey to include safety factors to the time required to perform certain tasks. For example a sub-system cross attribute optimization may require a week of analysis time. Based on team member's experiences, the number of iterations that would be performed in a week was known. The total number of new sub system design that a new program typically underwent was considered. Total time for a task was then calculated based on the above factors for the entire sub system optimization work. Then looking at the FPDS schedule, approximate start and end times were determined so that design requirements may be cascaded to other program teams and provide these teams outside of safety to react to our proposals. The hope from our safety team working on documenting the tasks was that the high level Gantt charts we created would then be used by safety PAT leaders to create the attribute work plans which then could be cascaded to PMT's or PST's and incorporated into the overall program timing plans.

To address the lack of "hows" in the checklist, our technical specialist[25] decided to draw up a system decomposition chart (figure11). This decomposition of a vehicle into system, subsystem and components was the attributes first attempt to quantify the hows. While this decomposition was generic and used in practice either to classify requirements and or determine organizational structure in the auto industry for a very long time, it however was the first time for safety attribute at Ford to use this format to collect, store and present our knowledge, information and practices.

Program specific information

Vehicle—system—sub system-component breakdown

Engineering parameters important to crashworthiness that are influenced by respective vehicle—system—sub system- component

Existing system engineering lessons (links to website repository)

Figure 11: Decomposition chart used to capture process knowledge

The thought behind this decomposition was straightforward. The parameters and targets needed by PMT and/or other attribute team members from the safety PAT are usually engineering metrics. These are needed to design the parts for safety or maybe to come up with design consensus through cross attribute optimizations. Examples of these metrics may be material properties like yield or fracture strength, geometric shapes of components so that they can be packaged in a vehicle environment that it is not detrimental in crash etc. Lessons or

knowledge existing in the company related to a component and the related parameter was assigned to the intersecting cell between the component and parameter.

For example the steering column sub system is an important component during frontal crashes. As the occupant rides into the column during crash, the column must stroke forward in vehicle and absorb energy imparted into it by the occupant. This energy absorbing mechanism of a column is usually specific to a vehicle. This energy needed to stroke a column is determined through a force-deflection characteristic determined by the safety team through an analysis of the vehicle structure in frontal impact condition. In using the VSSC chart, if the safety team wishes to learn how they may proceed with a particular column design, they would search for the steering sub system, cross reference it with the engineering parameter (in this case force-deflection) and proceed to the appropriate cell. Since this was a web based application, when engineers click on the cell they would be able to access generic lessons on how to go about designing for optimum stroke characteristics in a vehicle. So for the first time instead of just a schedule, engineers now had a process to work with. But this was just the beginning. In a program setting depending on the level of changes, engineers would be accessing several such cells to secure information related to their component how's.

4.4.3 Preparing for GPDS

When the VSSC document was mapped out it became apparent to team members that we really did not have adequate "formal" system engineering lessons documented that would aid in our daily work. There still was significant resident knowledge with which safety design work was done but this knowledge was mainly tacit. The mapping of the VSSC document highlighted the urgency among safety team members for the need to put down in writing what they have

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been practicing in developing their system for years. There were more empty cells in the VSSC document signifying a lack of lessons or safety practices. But this was not the case as vehicles continued to be designed to meet regulatory requirements and excel at the market place. The emphasis here is that some of the lessons on how to approach design was not documented which in turn would result in increased iteration time for development. The VSSC document also brought about a change in the thinking of the engineers. Team members began having discussions among themselves in terms of component and building it up to the system. Before it was always the top down approach to system engineering and development, i.e. what components need to be designed to deliver my system requirements? Now the role of components in delivering system requirements was being better understood as engineers began to "build up" to the system. Awareness of component functionality increased as team members began experimentation with components and sub systems instead of full vehicle crashes. The results from component tests were studied and the transfer function needed to apply these results to full system was also understood.

Prior to this mapping safety engineers complained about the lack of formal sub system tests. They expected the results from different sub system tests to add up to provide full system performance. But when the results didn't add up or when the transfer functions were not clear, further studies at sub system levels were abandoned. Iterations were then made at the full system level which was more time consuming. When a component centric view imposed by the VSSC mapping set in, engineers now looked for repeatability in the component characteristics during the component rig tests. If variations were noticed the root causes were understood. This was followed by team members examining the fact that if this component exhibited such a performance variation in full system tests what would the counter measures be? Instead of trying to understand the components role in delivering system targets through summation of different component

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performance engineers began to study the hindrance or variations a component may cause in delivering system performance. Then countermeasures were applied for the elimination or containment of noises generated by components. This type of thinking lead to the origination of "design disciplines" in safety attributes. GPDS is structured such that there is a dedicated pre program phase which is expected to deliver mature system architecture to program teams. This allows program teams to adjust individual component performances and eliminate ways by which some components may hinder overall performance. A basic design group is set up organizationally to deliver mature upfront architecture. If a mature architecture is not delivered then iterations would be similar to FPDS, which would involve a more top-down approach.

In later sections it will be argued that this design discipline based knowledge management framework will be the corner stone of "knowledge reuse" in GPDS. Thus team members began to realize that at the lowest operational levels, formal process may not be enough to address daily needs. They realized that attribute and commodity knowledge that go beyond "years of experience" was needed. The generation of component and sub system based design discipline was the starting point in knowledge management within safety attribute which should prepare us better for GPDS.

4.5 Chapter Summary

This chapter provided comparisons to present and future practices. High level gaps in FPDS were identified. The proposals in GPDS were compared to existing practices. This chapter also saw a detailed description on existing knowledge management practices within safety attribute engineering and why the knowledge management frame work is needed to capture the knowledge and also to help this attribute as it transitions into GPDS.

One of the questions posed under problem statement was that can knowledge management framework aid in the reuse of past knowledge? This section described what knowledge practices worked and most importantly those that did not. While parameter based knowledge that helps in engineering hows were welcome, checklist based engineering whats were not widely adopted. This may be due to the fact that the engineers within the safety group may have felt that they have a good handle on their tasks and schedule and decided the checklists were cumbersome. This also gave some insights into the adoption of best practices within a team structure. The creation and adoption of best practices has to be "grass roots". Engineers prefer knowledge nuggets that will help them think rather than binary commands that may be viewed as eliminating the thinking process. The detailed question and answer checklist is a "checking" tool and not a tool that will "assist" an engineer gain design knowledge. The next chapter will describe how these knowledge nuggets or usable formats of best practices originate through a case study. Readers will also understand the specific product development tasks pertaining to safety better through this case study as it involves the development of a component to meet safety requirements.

5. Safety Attribute Case Studies

5.1 Chapter Introduction

This section discusses details of commodity development in safety attribute as part of the overall vehicle system development using the FPDS process. A steering wheel is used as an example. The choice of this commodity as an example was mainly due to data availability from recent vehicle program experiences. Additionally the system requirement considerations for safety and the importance of cascading it down to the component level could be better explained using this example. The program in which this design and development activity occurred will be referred as "program A" to maintain confidentiality. While there are several attributes involved in the development of commodities, the specific role of safety attribute in development is discussed. The aim of this study is to highlight existing knowledge management practices under FPDS. The high level requirements expected from other attributes are also discussed below but mainly to clarify the context in which safety development occurs. This example also highlights several concurrent engineering practices used in the development of an automotive system. Using available information on GPDS a hypothetical development exercise for a steering wheel for the same program A is also undertaken in this chapter. This is done to highlight the differences between FPDS and GPDS.

Later in this chapter an additional example for passenger airbag development from program B is provided. This case is from a vehicle program which is an early adopter of GPDS. This example will discuss how parallel exploration of multiple themes at the sub system helps in design and development flexibility. This example will provide a context to discuss set based engineering practices.

5.2 Commodity development for safety attribute in FPDS

5.2.1 Cross-functional requirements and teams involved in development

The steering wheel along with transferring the displacement input from the driver to chassis sub-system is also considered an important "passive" safety component. It should perform to its designed safety functions in a crash situation such as providing a reaction surface to the deploying driver airbag and energy absorption in a crash event when an occupant may load the steering wheel indirectly through the airbag. Additionally during low speed collision when the need for airbag deployment is minimum the steering wheel is required to prevent any injury to the occupant, if the occupant were to impact the steering wheel directly. This condition usually happens when the occupant is unbelted or sitting too close to the steering wheel. While these are a few of the safety related attributes that a steering wheel must possess, there are several other attributes that a steering wheel must deliver. Some of them are listed below.

The styling of steering wheel is an important characteristic that a customer considers during the purchase of a vehicle. The styling theme in a wheel conveys the all important vehicle "image". For example, if the vehicle's overall theme is "sporty", it usually has a three spoke steering wheel. If the vehicle belongs to the family sedan category then the styling is usually conservative and these vehicles tend to have four spoke wheels. Luxury segment vehicles usually have wood (decal) finishes. Automakers also offer leather wrapped steering wheels to convey an upscale image within a certain line itself. This allows for product variety in styling within an existing vehicle line allowing marketing teams to offer multiple options to customers. Given the importance of wheel styling to an automobile the studio departments in charge of this attribute pays close attention to the development of the styling theme in a vehicle. Several steering wheel themes or sketches would be developed to gauge customer reaction by studio and marketing teams during the early stages of a vehicle program.

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The customer comes in direct contact with the steering wheel. There are only a few other interior components that the customer interacts with during normal operation of a vehicle (e.g.) seats, switches, pedals and gauges. Since the customer interaction is high with steering wheel, the Noise Vibration and Harshness (NVH) characteristics of the wheel are also critical. Shake and rattle felt by the customer during driving may arise from either the road conditions or from the automobile itself.

2005 Ford Mustang

2004 Hyundai Tiburon

Steering wheel styling form sports car showing a common theme – Three spoke steering wheel
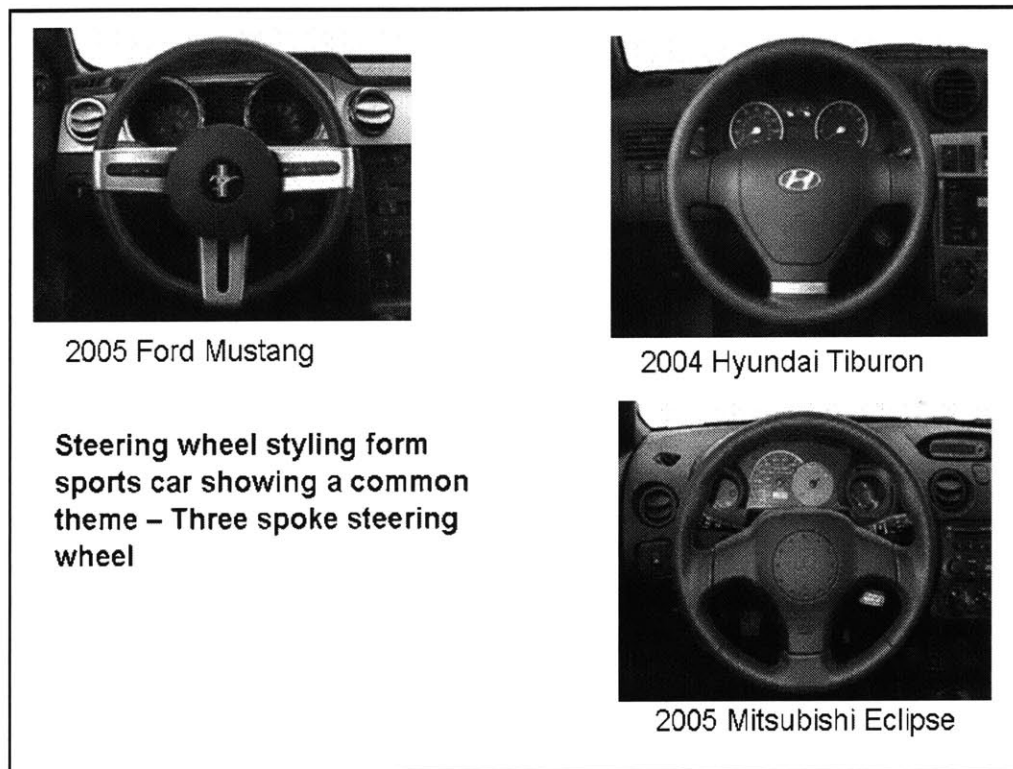
2005 Mitsubishi Eclipse

Figure 12: An example for steering wheel styling theme

To isolate this noise steering wheel would have to meet certain component NVH characteristics like normal mode natural frequency targets. Sometimes "dampers" are incorporated into steering wheel to isolate shake and vibrations.

The armature of a steering wheel is the metal insert or frame inside the urethane foam covered surface of a steering wheel (figure 13). This insert or armature is made from steel tubing, die cast aluminum or magnesium alloys. Along with the attributes listed above, the steering wheel should also be designed for armature durability over the useful life of the vehicle.
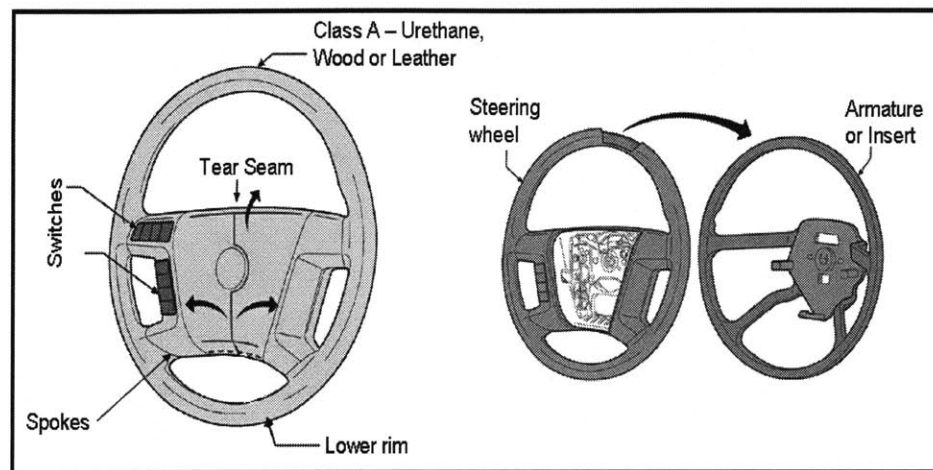
Figure 13: Steering wheel part description

The steering wheel would have to withstand component durability requirements like cyclic fatigue along multiple axis loading and "rim roll" tests during the wheel development process. During the rim roll tests the armature is imparted through a cyclic loading along the wheel rim by a loading device which rolls on the surface of the armature. The armature is expected to maintain its integrity throughout the entire loading cycle which may last several thousand cycles.

Steering wheel package inside a vehicle interior is also considered during the program development stages. It should be ergonomically designed for the customer such that there are no visual hindrance to the gauges (speedometer, fuel gauge) located behind the wheel in the instrument cluster. It should be

comfortable to feel. The diameter of the wheel cannot be too small or too large. While small wheel may have issues with horn package or switch placements, large wheels may hinder with the drivers upper thigh regions during the operation of the vehicle. Large steering wheels may also hinder vehicle ingress or egress.

5.2.2 Team roles and responsibilities during development

From a vehicle decomposition view, steering wheel is the responsibility of the Body Interior PMT. The list of high level requirements that a steering wheel should meet gives an idea of the attribute teams involved in its development. Under the body interior PMT, the Restraints DVP team leads the design and release activity for steering wheels. The engineers belonging to the restraints department coordinate the steering wheel design and release (D&R) functions with all concerned attribute teams, suppliers, manufacturing, purchasing, quality and serviceability representatives for a given program. Targets from different attributes and activities are thus coordinated and balanced under the leadership of this D&R engineer. Each functional group interfaces with the vehicle program team directly to understand the program needs and system level targets. The safety development engineer from the safety PAT would interface with this steering wheel D&R engineer to design the steering wheel for safety related features. The safety development engineer does not "own" the commodity but "owns" the particular safety requirement. This example should also clarify the roles and responsibilities of individual members of the organizational structure explained in chapter 3 on FPDS. It can also be seen from this description the cross functional nature of the development project for this commodity and the need for concurrent or simultaneous engineering practices. Due to the aesthetics and styling involved it is easy to see why the design of this commodity would be subjective. But the importance of a steering wheels "form" to safety, ergonomics and package attributes has made the need for several objective design parameters in the communication between these attributes. In discussing the detailed

development of the steering wheel some of these "form" parameters will be elaborated.

5.2.3 Program specific development

Program A was considered a moderate "scale" freshening and timed accordingly to the corresponding FPDS program schedule. Even though the overall program scale was moderate, it is fairly typical for some attributes to face a much higher degree of change than others. Changes were made to the vehicle interior and especially to the restraints system requiring significant design and development. The steering wheel for this vehicle line was all new. It was also unique and no commonality or reusability for a wheel was identified from other vehicle programs. While the steering wheel was all new, the interfacing components like steering column were reused from earlier models (carry over). Figure 14 shows the FPDS schedule in which some of the events related to design and development of this steering wheel were set to occur.

Safety development tasks begin with understanding the market requirements. These market requirements are usually dictated by the regulatory requirements existing for a given class of vehicle. Safety requirements for a given market may also be driven by non regulatory agencies who act in public interest. Program A was intended for the US and Canadian markets thus requiring certification to FMVSS and CMVSS[26] requirements. Safety requirements for US markets were well understood at the beginning of this vehicle program A. The US requirements for Program A were the same as it was for the previous model year or version of this vehicle. But the Canadian requirements were significantly different with respect to certain occupant injury metrics.

Vehicles are certified based on several objective measures recorded during crash. The objective standards (or limits) are listed under FMVSS (or CMVSSS) as the

case may be. Some of the objective standards based on which a vehicle should be certified are occupant injury metrics recorded through ATD's or HYBRID III dummies. Injury metrics are assigned for each body region, the head, neck, chest, leg etc. The Canadian standard for maximum chest or sternum deflection allowed during crash[27] was significantly lower than the US standard.
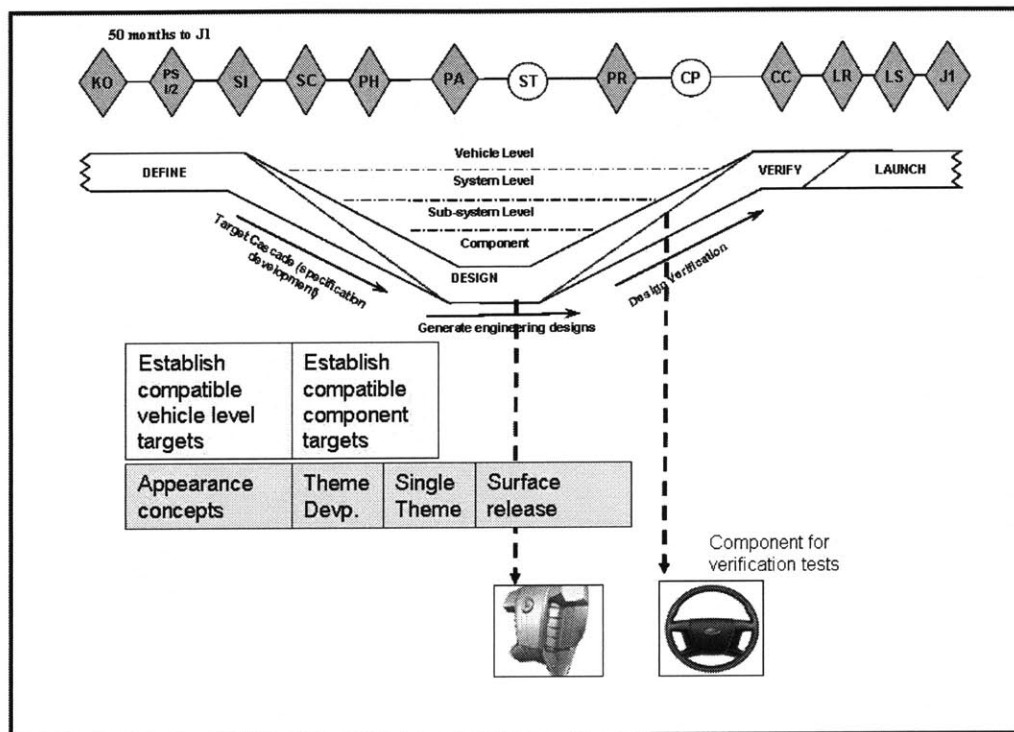
Figure 14: Steering wheel development schedule in FPDS

The safety teams are then expected to compile and understand legacy information. Legacy information for this vehicle line existed from prior model years. If all new vehicle line (FPDS scale level 5 or 6) were to be created, teams would be at a disadvantage for such information and would have to rely on CAE simulations or platforms that are close to the new platform for legacy information. Legacy information for program A indicated that the safety team

would not meet the new Canadian chest deflection standards set for this vehicle if they were to carry existing target ranges from carry over vehicle line for the driver side restraints system. Hence new target ranges for sub systems would have to be established based on new requirements. The vehicle level system responses were considered fairly stable as the chassis or the body exterior did not undergo significant changes for program A compared to the carry over vehicle. The vehicle or system responses were incorporated in Madymo simulations and target ranges for restraints sub system were developed. Target ranges for airbags and seatbelts were established and cascaded to restraints commodity supplier through restraints D&R engineer. Given existing program assumptions, simulations indicated that meeting Canadian chest deflection standards using carry over steering column would be challenging.

FPDS mandates reusability to ensure that affordable business targets are met. Program A did not consider the possibility of significant reuse of restraints commodities as there was a change in commodity supplier from the carry over vehicle line. The new supplier identified would not have any incentive to use parts from the old supplier.

Meanwhile the steering wheel theme development was underway in the styling studio. Initial themes were evaluated by different attributes and appropriate responses were provided back to restraints D&R engineer. In the beginning the role of steering wheel in meeting chest deflection targets were not well understood by the safety team. No existing knowledge (knowledge database) on steering wheel correlated chest deflection standard to the steering wheel. While a tacit knowledge towards the role of steering wheel as a contributing factor to chest deflection was known an explicit knowledge on wheel designs and counter measures were not available. Existing steering wheel design practices helped meet all existing regulatory or Ford internal safety requirement. Challenges arose as

requirements set forth by Canada changed. Full vehicle system responses like deceleration pulse, vehicle cab pitch and drop during crash influence chest deflection characteristics. These characteristics are in turn driven by vehicle architecture. Due to the architectural differences among vehicle lines, other vehicle lines unlike program A did not have difficulty meeting new Canadian standards. Safety team in Program A was also fortunate to have reliable legacy information on full system responses which could be used in determining root causes. The challenges faced were brought forth to the responsible safety technical specialists who had access to cross platform information. Program safety team along with technical specialist identified through fish bone type diagrams different ways to counter the expected chest deflection requirements. The program challenges for reusability, commonality, system response characteristics from carry over sub systems, system complexity were all considered.

The role of the steering system i.e. the steering column along with the steering wheel was considered an important factor in the chest deflection responses. Through simulation it was determined that the steering column or the steering wheel would have to be redesigned to meet the challenging requirements. Changing the steering column would entail significant changes to the chassis sub system and would not meet program goals for reuse and commonality. However as the steering wheel was a new commodity for this vehicle line, safety team decided to investigate opportunities that existed through wheel redesign. Madymo CAE simulations correlated to physical tests indicated that if the steering wheel lower rim stiffness were designed appropriately, then the chest deflection standards for Canada may be met. This is due to the direct interaction of the sternum with the lower rim (through the airbag) in a full frontal collision. Based on studies from ATD responses from various tests, the team developed target range corridors inside which it expected the lower rim stiffness. The theory was

that if the rim deflections were inside this corridor then the ATD sternum would not compress inward thus resulting in lower chest deflection during full vehicle tests .
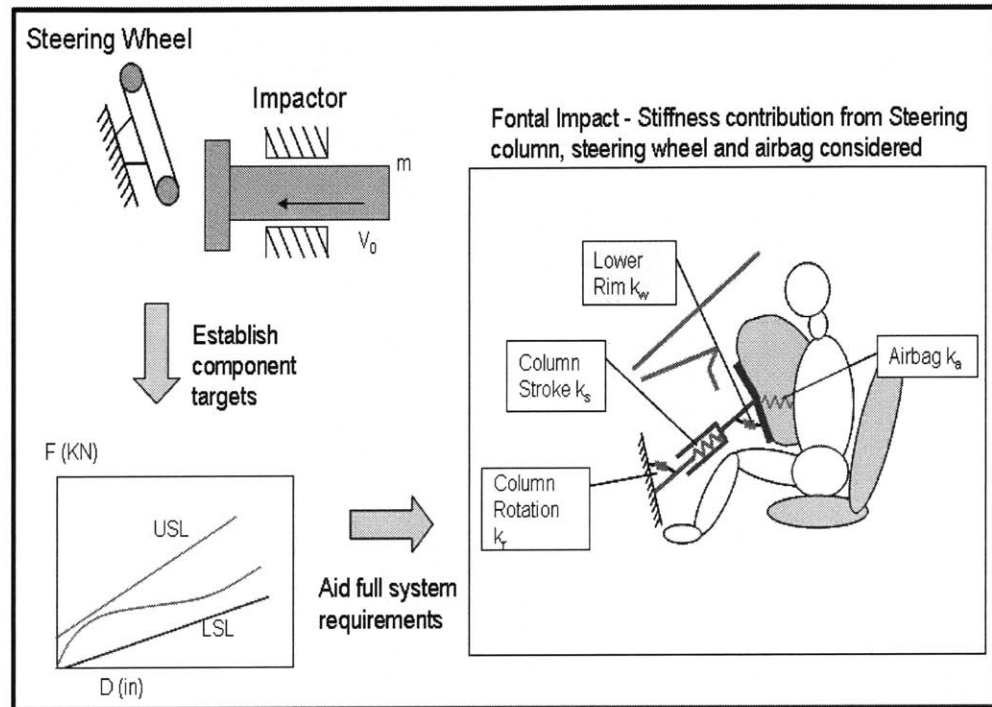
Figure 15: Schematic representation – Steering wheel lower rim deflection targets

The safety team devised a linear impact sub system test to establish and confirm lower rim stiffness targets[28]. Figure 15 explains schematically the test set up used by the program team and a pictorial representation of the corridors which provided target ranges for lower rim stiffness. These target ranges enabled a steering wheel design that delivered full system performance for Program A. The safety targets had to be met along with other component requirements listed

earlier like, rim roll fatigue requirements, component NVH targets, ergonomics targets etc.

To determine feasible solutions, extensive benchmark tests were conducted on competitive steering wheel. The lessons learnt from benchmark exercises were mainly parameter based. The parameter lessons from tests shed light on key design characteristics and enable the accumulation of tremendous steering wheel sub system knowledge. Considerable time was spent by both program safety development team and technical specialists[29] in the development of this knowledge. The solution needed was program specific, i.e. to identify a counter measure to the expected chest deflection standards. However there were no formal knowledge management methods in place to cascade and communicate these lessons across vehicle programs. The ability to reuse knowledge was not in place in a formal manner at this time.

5.2.4 The need for explicit knowledge management

The steps listed as part of the steering wheel development or cross attribute optimizations were known to the safety teams. As discussed in chapter 4, the existing checklist itemized these development tasks. The teams knew "what" to do but not "how". Part of this was due to the fact that the specific system requirement for safety concerning Canadian standards was new and no prior knowledge existed on the contributing factors or design counter measures that would alleviate these system challenges. Also absent was a formal process to quantify the lessons learnt. A lack of formal process could prevent knowledge reuse.

During the safety development for program A it was found that several parameters relating to overall vehicle architecture influenced chest deflection requirements. These parameters include allowable package space for components

inside engine compartment to avoid intrusion against the vehicle cab or green house and the structural energy management during crash as measured by the longitudinal crush distance near the occupant. Fixing these architectural details was not a feasible solution as other major functional targets would have to be compromised. The team also determined that if there was another vehicle line with similar architectural constraints as program A, it would also face similar challenges to meeting Canadian standards. The lower rim standards allow teams to have additional flexibility or range towards parameters listed earlier.

If we were to use this example to study practices in FPDS, the teams knew what steps were needed from a work task list to meet chest deflection standards. These were to conduct full system simulations, gather legacy information, conduct brainstorming exercises, cascade full system requirements to component, develop components to validate full system performance, work with other attributes on cross attribute optimizations, perform full system verification tests and iterate until designs are complete. How the safety team went about doing these tasks was still tacit. The how's, for example formal knowledge relating to the best lower rim sections or rim designs that would enable all attribute targets were known but not documented. Formal documentation on best practices was minimal during FPDS. If a new team from another vehicle line brought a similar concern regarding lower rim stiffness to a technical specialist, the technical specialists through design reviews from program A may know the development details and would ask the new team approaching them to consult with program A. This however is not a formal process that could be sustained over a period of time. It does not allow for easy target cascade or additional improvements to targets. It is not structured for proper communication and cascade in a program team setting. If a scenario arose where the concerned technical specialist changed jobs, it was possible that a new program team would be at the risk of "reinventing" the whole lower rim stiffness development process thus not able to reuse knowledge. The

need for safety teams was a usable format in which this knowledge could be captured and cascaded to design and release engineers or suppliers. The importance of documenting this knowledge will be apparent in the discussions on steering wheel development in a hypothetical GPDS context.

5.3 Commodity Development for Safety Attribute in GPDS

Prior section 4.3.2 detailed some aspects of GPDS and how it will help fill gaps in FPDS. In this section we will compare the product development of a steering wheel in GPDS setting and how it contrasts to FPDS. The need for a knowledge management framework as a launching pad for knowledge reuse will also be discussed.

5.3.1 Development tasks in GPDS

In this hypothetical case study a similar vehicle program like Program A mentioned in section 5.1 is considered. However in this section it is set to the GPDS milestone deliverables and schedule. The tasks involved in delivering attribute requirements for a commodity remains the same. The steering wheel has to still perform all the functions listed in earlier sections for NVH, Safety, Ergonomics, Durability, etc. But when and how are completely different even if what remains the same. First let's have a brief look at the when's.

There is a substantial timing compression from program KO (or Start) to the program approval milestones. This is expected as one of the main aims for GPDS is to shrink the development timing for new programs. Additionally in order to streamline development the timeline is synchronized into two verification phases. Also commodities are binned either belonging to under body or upper body. Underbody commodities would be long lead items as many of them would require platform synergy. The upper body items usually are of trim and ornamentation types where decision need not be frozen early. The

synchronized development phases allows for underbody verification earlier. Results from underbody verification phase will feed into the next verification phase.

In FPDS there was no such synchronization. Attributes would decide the content of their respective prototype phases with surrogate parts that were attribute intended and need not be end design intended. Therefore if safety decided to change the wheel based on its development tests, the actions by safety teams would negate the design actions that would have been in place by the NVH or ergonomics team.

The high level tasks for design and development teams are summarized below;

> Team defines a set of solutions at the system level rather than a single solution.

> Similar sets of solutions are defined at the sub-system level as well.

> Sub-systems are explored in parallel through analysis, design rules and experiments to characterize compatibility and determine a possible set of solutions.

> Analysis gradually narrows the sets to a single solution.

> Once a single solution is established system stability is attained. Solution is not changed and taken to completion.

The important themes in GPDS will be compatibility and completeness. Through this example we will see the difference between compatibility and completeness. Figure 16 below explains the development of a wheel to a GPDS schedule.

One of the key aspects in GPDS is the pre program phase. In this stage multiple themes for steering wheel would be chosen depending on the vehicle segment (family sedan, sporty, truck etc). Each steering wheel will be analyzed in a variance based manner for compatibility. For this each wheel would have to meet individual component performance targets. For example in order for any one the wheels to make it into program A, every individual steering wheel chosen would have to conform to the lower rim target for safety discussed earlier. The design maturation process initially undergoes convergence and then through the compatibility phase. Once compatible designs are identified then the designs are taken to completion.
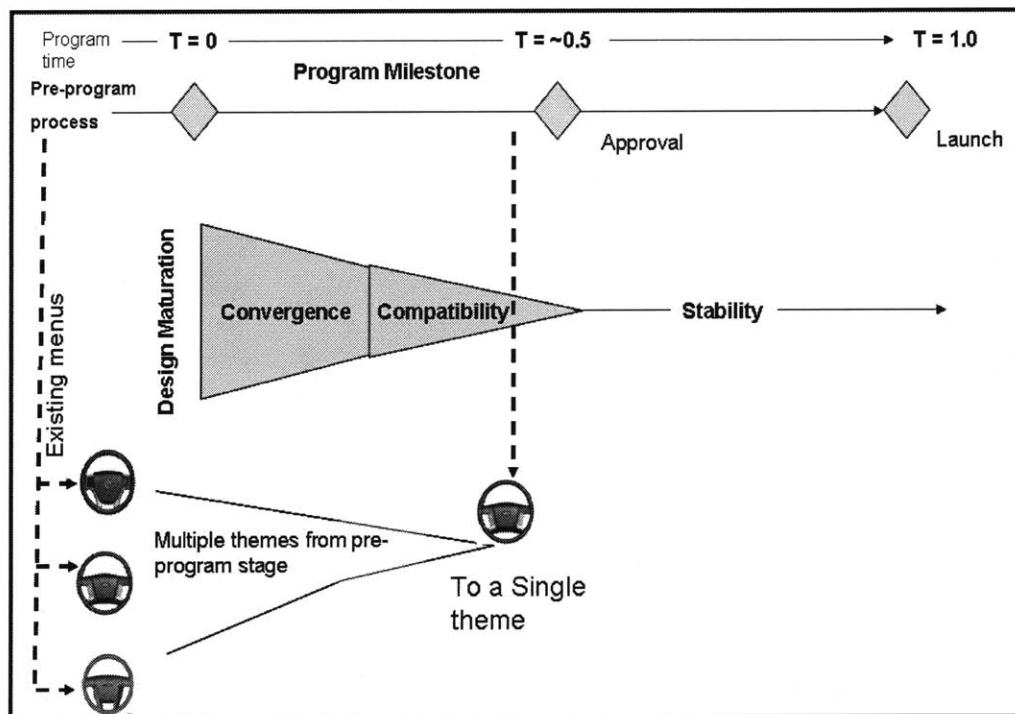

Figure 16: Expected schedule for steering wheel development in GPDS

5.3.2 Compatibility studies

It is important for development engineers to understand and conduct proper design compatibility studies to determine the best design alternative for a vehicle program to use from an existing menu of commodities. Note that earlier section on GPDS described the need for this menu. The process of designing a commodity to deliver system performance will be different from FPDS. In FPDS the target cascade process from system to component level many times resulted in unique vehicle specific components being designed to meet targets. Teams did not undertake extensive commonality and compatibility studies to investigate if parts from other vehicle lines could be reused in a new environment. It would be interesting to understand if this was due to multiple suppliers being used for same commodity? Program experience in safety has been that in most instances commodities could be reused on multiple platforms. Another reason for less commonality could be the fact that engineers may have confused compatibility with completeness.

Completeness is the finalization of all elements of design and validation for a given point. Compatibility is the resolution of interfaces with mating components and subsystems. FPDS schedule emphasized task completion. This was additionally tracked through several project management tools by program teams. The emphasis on task completion could be a possible reason why engineers were more intent on completing their assigned tasks before compatibility with other attributes could be established. Early completion resulted in design incompatibility with other attributes leading to rework and late design changes.

Let's now assume that in Program A, now set to GPDS, the team has to choose between two steering wheels. As shown in figure 17, the safety team would study in CAD the compatibility of the two wheels by overlaying them together. The steering column is also a commodity chosen from commodity menu available to

the program. Let's assume that the team knows which column to proceed with for the program. The wheels are compared to one another for their physical dimensions. Based on the section comparison (about the vehicle coordinate XZ plane) it appears that the two wheels under consideration have comparable diameter. Attribute teams may conclude from this information that both the wheels have similar influence on rim block, ingress-egress and other package features.
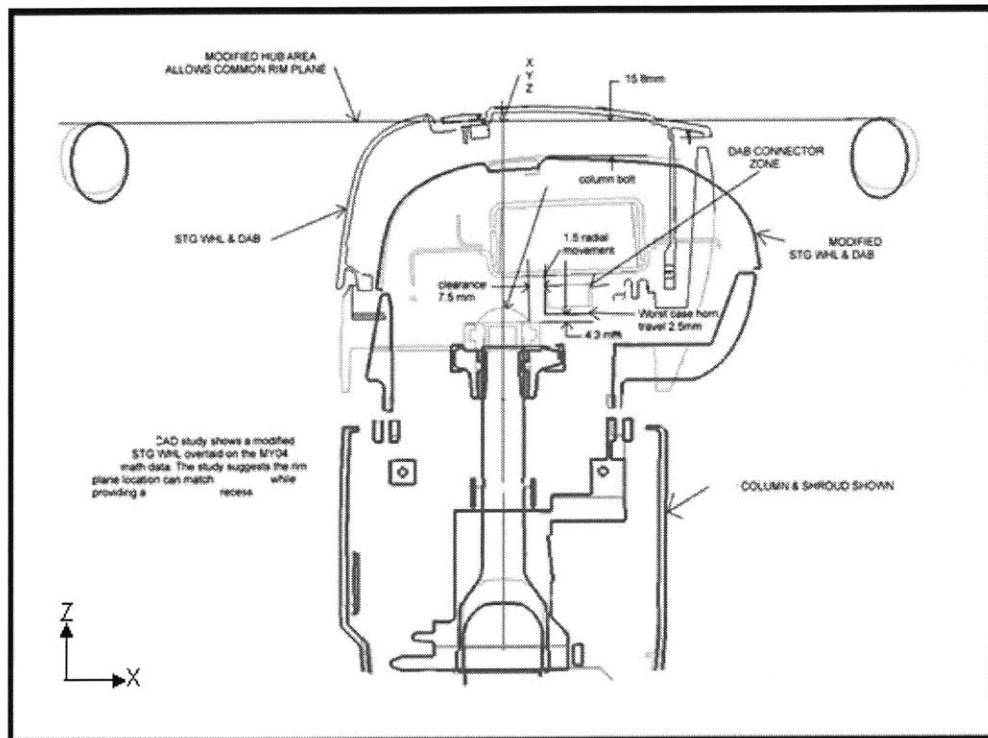

Figure 17: Early compatibility studies between two available steering wheel options for the program

In previous section it was mentioned that steering wheel geometry is an important parameter for safety. FMVSS regulatory requirements phased in after 2004 (Appendix 2) mandates that the deploying bag should cause no risk of injury

to the occupant. This indirectly mandates that the force level of a deploying bag should be controlled[30]. This is verified through component level tests (Appendix 1 shows a picture of the component tests). A feature in the steering wheel that may help this requirement is the airbag module recess from the steering wheel rim plane. So teams when comparing two wheels for compatibility would then take into account the wheel recesses as an advantage for one of the designs. While the other design may not be recessed it may offer other design alternatives like additional package room to incorporate features in module design that can still help the test condition. In other words, there are several alternatives available to teams through such compatibility analysis to meet system requirements. The team may choose these alternatives depending on individual program constraints through a selection matrix like Pugh concepts. Note that during these analyses the team may discover that no matter what design is chosen, it still is not complete. Interface component details such as clock springs to provide electrical connection to airbag squibs, horn package, speed control switches, steering column interface slots may still dictate a new tool for the steering wheel. Including these details is part of the completeness exercise. One of the drawbacks noticed in the FPDS process was that teams were more interested in completing their design tasks opposed to checking for compatibility. When incompatibility in designs arose changes were accepted in designs until very late in the program.

A new steering wheel tool for either urethane covering or the die cast insert if needed in this particular example is still inexpensive compared to a totally new design for the wheel. Reusing existing design in this manner reduces upfront development effort and speeds up the development process. Any flaws or open issues in design may be corrected during subsequent iterations. In interviews with suppliers of steering wheels, it was noted that some of these tools will not result in additional cost to OEM's if the OEM's are able to time their new designs as part of the suppliers regular tool freshening schedule. If Program A were to

investigate multiple themes individually without any formal knowledge of system engineering requirements, it is doubtful if teams can meet their schedule deadlines established under GPDS. Additionally if new requirements arose in the form of new regulations in the market place, given the aggressive timing schedule under GPDS teams may find it difficult to meet their design deadlines. Hence it is important in GPDS that programs adhere to the pre program process where all the requirements may be clarified and solution sets established. Recommendations are provided in later section on how design sets may be created for program teams to use in future.

5.4 Advantages of Multiple Sets – Passenger Airbag Mounting Example

This section describes recent examples from program B. It is one of the first programs at Ford to transition from FPDS to GPDS. All elements of GPDS are not practiced in this program given the transition phase. But there have been significant differences in how attribute teams approach design in GPDS compared to FPDS. This example relates to the passenger bag mounting scheme in the Instrument Panel. In chapter 2 the benefits of carrying multiple options were discussed. The parallel exploration of sets of alternatives at the system, sub system and component levels is an important part of GPDS. Multiple themes at sub system and component levels were not common in FPDS. In FPDS the system theme was frozen early in design process and targets were cascaded down to the sub system and component levels which prevented parallel exploration of system, sub system or components.

5.4.1 Passenger airbag design background

Critical to an airbag design is determination of bag inflator output, to determine volume of gas necessary to fill a bag and how quick an inflator should fill this bag. Schematic shown in figure 17 below is a target inflator characteristic that would be provided by OEM to supplier.

An airbag inflator design requires 'long lead' time and extensive prove out both at the component and full system level. Several component development tests are performed by the inflator manufacturer to ensure propellant integrity and stability in the full system environment. Extensive tests are also required for regulatory compliance demonstration of the inflator. Therefore suppliers to OEM require inflator 'targets' upfront during product development of a new vehicle program to determine airbag design. Safety development engineers provide these targets upfront while full system and sub system requirements are still evolving. However development engineers' assumptions in providing target is based on certain specific assumptions for the vehicle design. Assumptions in vehicle design would include overall architecture (shape and style, body on frame, unitized body), wheel base, Powertrain line up etc. Additionally sub-system assumptions would include occupant seat location, airbag location in instrument panel, airbag module mounting mechanism etc. If any of these assumptions were to change during product development, it would lead to changes in airbag inflator specification. If these changes happen later in program cycle it would result in rework and delays.
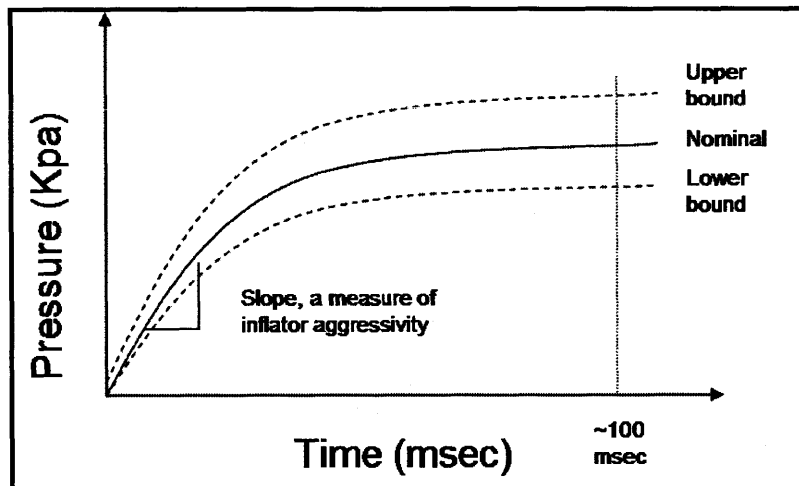
Figure 18: Target inflator characteristics

5.4.2 Program specific passenger airbag development

In program B, the design team's original goal was a top mounted passenger airbag system to maintain commonality with a surrogate vehicle (figure 19). However safety team was informed that this mounting strategy could change. Safety team was informed that a mid mount passenger airbag may be pursued. This new mid mount strategy, if pursued, would serve as "futuring" for subsequent program launching after program B.

The airbag inflator characteristics requirement for a top mounted system compared to a mid mount system are quite different (Figure 20). Since teams were given these possibilities upfront, directions were then provided to suppliers to protect for possible changes.
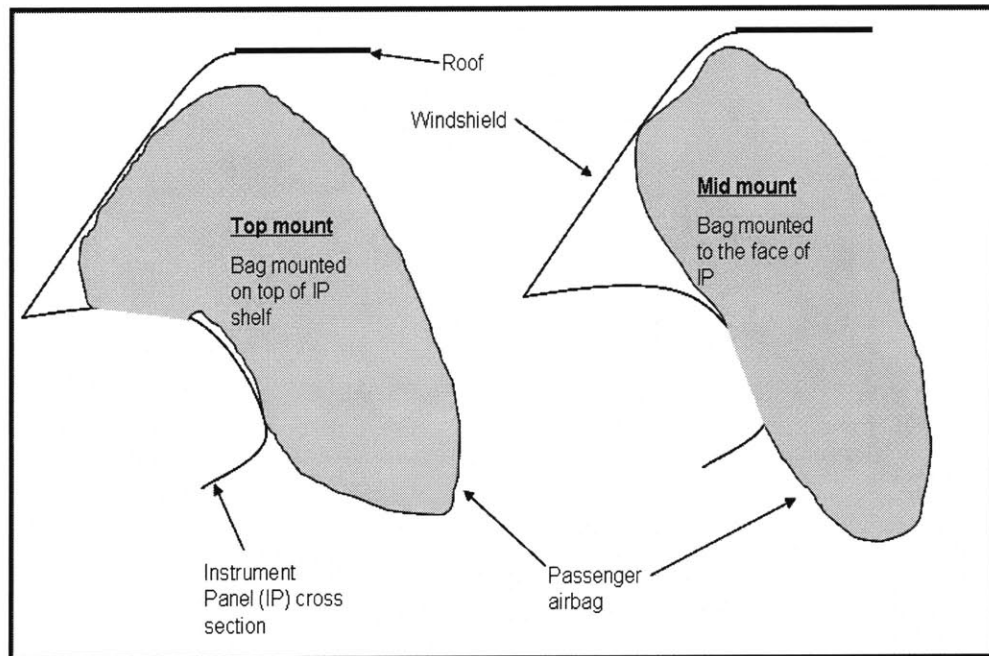
Figure 19: Passenger airbag mounting themes

Suppliers welcome such information and do not consider multiple options as being indecisive on the part of program teams. Conveying multiple assumptions provides suppliers the opportunity to prepare better engineering statement of works. Thus the team ended up exploring multiple sets of alternatives, similar to the set based paradigm explained in chapter one. While this involved additional analysis and development work for the safety teams to analyze two sets of designs, it also prepared them better for downstream design changes.

Figure 20: Passenger airbag inflator characteristic comparison

5.4.3 The use of existing explicit knowledge management practices

During the development process in program B where multiple themes were explored, design discipline documents or "how to" documents created for passenger airbag system was put to use. Lessons were developed at the

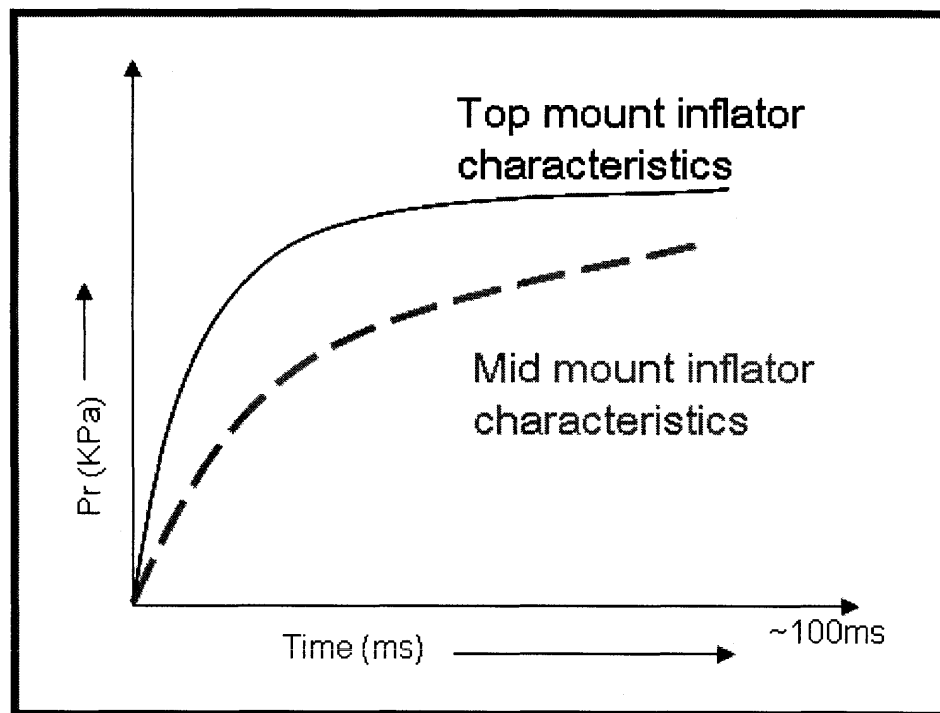component level after studying the system and sub system performances. These passenger airbag lessons are similar to the steering wheel lower rim lessons discussed in the previous section. Best practices relating to inflator characteristics, passenger airbag door design, bag shape etc were put to use. Best practices or lessons from different programs are synthesized to finally provide a design discipline.

Adherence to these design disciplines in program B helped in smooth transition from a top mount theme to a mid mount theme. The design disciplines enabled the cascade of targets accurately for both mid and top mount themes thus providing program teams an ability to carry multiple sets of alternatives. Another reason the safety team was able to do this was that many characteristics of the airbag and inflator design was modular. Thus decisions for most parts could be limited within this module and not allowed to propagate too far into other systems or higher level systems. Thus even at an early stage where safety teams knowledge management practices are still being formalized, their benefits are already being noticed.

5.5 Case Summaries

The Steering wheel development and passenger airbag case studies come from recent experiences in program A and program B respectively. These cases were also discussed in a GPDS related offsite in which the entire North American truck safety department participated in August 2005. Consensus was reached among department engineers that to conduct commodity development in a GPDS setting, safety commodity menus are needed from which engineers may pick depending on program needs. Additionally the need for reuse of knowledge along with commonality of components was recognized as an important enabler for safety development in GPDS. To enable reuse of knowledge it was agreed that working group setting started recently within the truck safety organization

was ideal. Engineers also shared their individual program experiences and the benefits of design disciplines applied to their particular case. The steering wheel example highlights the "compatibility" aspect in GPDS. The passenger airbag example highlights the "set based" aspect in GPDS. In comparing the set based concurrent practices described in section 5.3 with what is described by Liker etal as practiced in Toyota, it may be quiet different. This is set based to the extent that there is a parallel exploration of multiple themes and critical system decisions are delayed until compatibility is confirmed. The ideal state in set based engineering practice is to prove out all feasibility before commitment to a particular design which would include trying out multiple tools.

At Toyota set based design practices are based on more tacit knowledge prevalent in that culture. Another key aspect in Toyota's set based design practice is the expenditure of resources for hard tools. It is difficult to envision at Ford if multiple hard tool commitments would be made and in the end some of these tools are allowed to go unused. At Toyota such practices of developing multiple tools to prove out feasibility are common. What is seen at Ford is the use of virtual tools (like CAE simulations) to evaluate multiple concepts and themes which is much quicker than securing hard tools.

5.6 Chapter Summary

One of the questions posed earlier was if knowledge reuse can help make design iterations faster? Based on the case studies presented it is proven that this can happen. Component robustness can also eliminate the find and fix cycle in product development. Engineers need not reinvent prior solutions on new vehicle lines. But to facilitate all of this an explicit process like the design discipline process should exist. While design discipline addresses reuse of knowledge, a study is undertaken to understand the reuse of commodities in a vehicle in the next chapter. Chapter 6 will also discuss how knowledge reuse is

established among safety teams. The working group forum that promotes new knowledge creation and formalization is also discussed. System behaviors that necessitate the need for design disciplines are discussed as well.

6. Managing the Transition

6.1 Chapter Introduction

In chapter 4 we saw GPDS proposals to address some of the gaps encountered in FPDS. Commonality and reuse of parts and processes was part of those proposals. While reuse of knowledge is the central theme of this thesis equally important is the knowledge required to reuse parts. Hence this chapter will address the part reuse aspect of GPDS. As an extension to the earlier case study on steering wheel, comparisons of steering wheel from another OEM are provided. This comparison will help shed further light on part commonality. Also addressed in this chapter is an implementation roadmap for the knowledge management framework proposed. The role of design disciplines in knowledge management and reuse is also explained in this chapter. A brief discussion on organizational structure used within the safety attribute to sustain this knowledge creation process is also discussed.

6.1 Introduction – Transition Phase

Commonality and reuse strategy is not new to Ford. FPDS also advocated for commonality and reuse. Early in FPDS many vehicle lines were launched from few platforms in Ford's US market. Examples would include the Explorer, Expedition and Navigator SUV's which used existing Pick Up truck platforms. However in subsequent redesigns these same vehicle lines saw less commonality with the platforms from which they originated.

The nineties saw a boom in SUV sales for Ford and other OEM's in their North American market. The demand from the market place forced Ford to offer more SUV specific features. For example independent rear suspension system was introduced in Ford SUV's around the year 2000 to improve ride and handling

features. To accommodate such features commonality was sacrificed with base truck platforms. Unique wants were demanded for vehicle interior as well. Customers expected car like quietness and comfort inside SUV's. This resulted in interior parts like seat sub structure and instrument panel sub structures, which are well hidden from the "A" surface, to become unique between similar vehicle lines.

While customer demand was one of the reasons another possible reason could be the use of multiple suppliers among different vehicle lines either to secure competitive pricing or technology. While the sourcing decisions are not clear the point that is being emphasized here is that these parts like the interior components mentioned above in most instances need not be unique between similar vehicle lines. The subject of commonality within a complex automotive system is vast and cannot be addressed under one section here. However it does offer an insight into the complexity of the development process and the inherent problems that engineering teams would encounter when they try to iterate between multiple themes in a set based environment. Also a benchmark study from Toyota with respect to our earlier case, the steering wheel, is presented. This will provide some insights into this OEM's strategy behind commonality.

Demands from the customer have to be satisfied. If styling differentiation is important then it must be accommodated in design. Given this customer want, if designs were to turn unique between vehicle lines it is only through knowledge reuse that precise targets may be set and more success out of first iterations achieved. Past lessons would help in implementing new technologies as well. If the base architecture is well understood through an established knowledge base, then more attention can be paid to iterations involving new technology. Let's consider an example. An airbag and seat belt together perform the energy management function during frontal collision. Let's now assume that a program

team chooses to introduce a new seat belt technology in a vehicle line and the technology used in airbags is same as before. If lessons learnt through the knowledge reuse process related to Airbag component designs are followed, then the team is assured that this airbag at its commodity level would function as before despite it being new to the vehicle. There would be tuning involved to the airbag design for proper functionality with the new system but this would be minor and predictable. The team's efforts may now focus on the belts which is a new technology to this vehicle line. At a minimum the teams would not be surprised by any unexpected issues from the stable Airbag system thus focusing their resources on developing and implementing the new belt system.

6.2 Commonality and Reuse

6.2.1 Difficulty in maintaining commonality

Product and brand differentiation is an important factor, especially with parts that appear on "A" surface. For example, the customer sees the steering wheel and would pay attention to its styling. At the same time engineering efficiencies can be gained if steering wheels remain same or similar across several product lines. Engineering attributes like safety would not have to undertake extensive design and development work for a new wheel given the steering wheels importance to meet regulatory requirements. This poses a tough challenge to engineering managers at OEM's, balancing between commonality and product differentiation.

Part commonality and product differentiation are opposing forces when it comes to body interior and exterior component styling. This is due to the fact that a customer can see the surfaces on many of the components belonging to this group easily and her decisions to purchase the product are greatly influenced by their appearance and craftsmanship. Components such as seats, instrument panel surface, steering wheel, door interior trim, door exterior have significant influence on safety attribute as well as the styling theme. Significant safety development

effort is required every time a modification is made to any one of them as the occupant in a crash would interact with the "A" surface on these components directly.

There are other forces that impede commonality. Examples are lack of well defined modular sub systems leading to multiple interfaces, lack of organizational structure leading to less coordination among teams, lack of overall company strategy and multiple suppliers for similar commodities. While these are significant system level issues, the focus here is on appearance and its influence on safety attribute engineering. If a vehicle line is successful in maintaining about seventy percent commonality with related product lines in the company's portfolio, it is considered a success. Toyota and Honda have successfully attained such high levels of commonality in their product portfolio. Several OEM's have maintained commonality successfully at the platform level using similar chassis, suspension or body structural members. But Toyota and Honda have reused components which have common "A" surfaces like instrument panel and steering wheels.

6.2.2 Appearance and commonality benchmark

As a follow-up to the case study on steering wheels presented in chapter 5, an extensive benchmark[31] exercise was conducted on steering wheels from Toyota's product lines. This study was undertaken to understand qualitatively how Toyota is able to attain such high levels of commodity commonality. Vehicles sold in the U.S. markets were compared for their steering wheel "A" surface appearance and airbag module design underneath the "A" surface. It was found that among the 2005 model year vehicles compared, Toyota basically uses two fundamental themes in their steering wheel. One is a three spoke wheel and the other a four spoke. The difference between different vehicle lines was only in the A surface. A luxury line like Lexus uses a four spoke wheel similar to a Toyota "badge or

model" vehicle. But the Lexus uses the wood decal on the "A" surface opposed to Urethane in a Toyota badge vehicle. Similarly a sport version Lexus model and a Toyota model would use the same three spoke steering wheel. But the difference again is in the "A" surface appearance only. The Lexus model gets the wood decal while the sporty Toyota badge vehicle would use a leather wrap around the steering wheel. With minor character line differences on the surface, the wheels are practically the same between several vehicle lines compared. So when does Toyota change its wheel design?

A new wheel design was noticed with the 2005 model year Avalon vehicle which is drastically different from the common themes noticed among several Toyota vehicles. Samples of steering wheels used in Toyota are provided in figure 21 including the new Avalon wheel. The details for this new design direction in Avalon's steering wheel may not be known outside of Toyota. However it is known that the Avalon is a vehicle line designed and developed fully in North America. Other Toyota vehicle lines were developed mostly in Japan. Could this uniqueness in styling theme have come from organizational influence or lack of it? Or is Toyota introducing a new family of wheels for the future by package protecting for other components to be included as needed? We can only speculate! However it is well known that Toyota does not change a product design unless there are significant QCFWT improvements through redesign. If the wheel designs are fundamentally sound and deliver attribute targets then Toyota would not seek to change the design. This also brings up an interesting strategy issue.
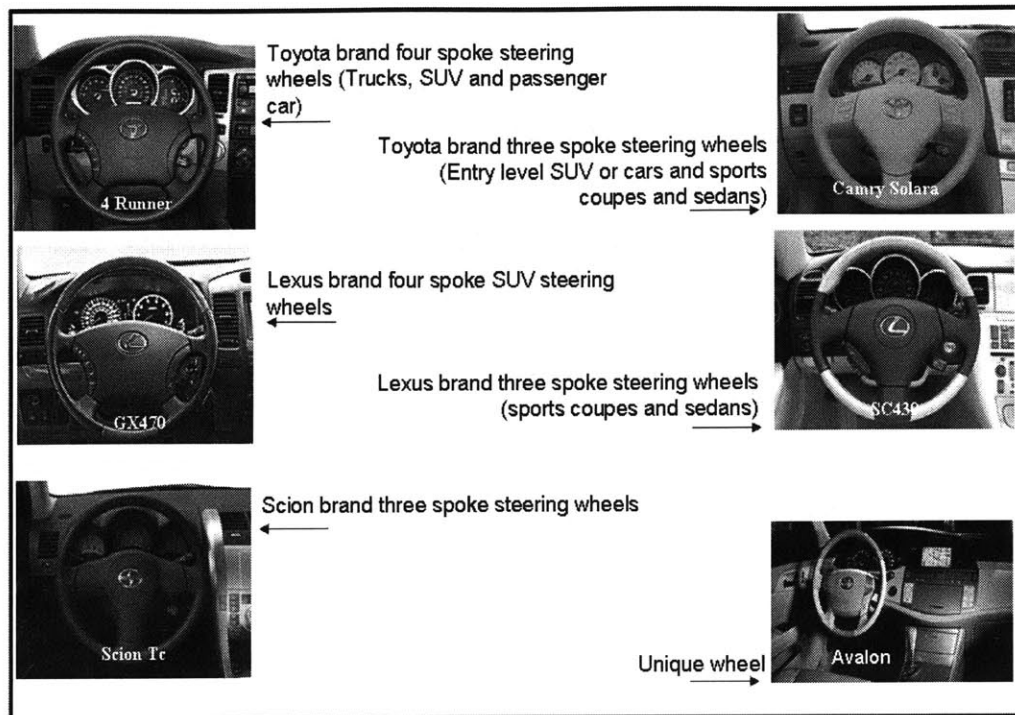
Figure 21: 2005 Toyota, Lexus and Scion
steering wheel benchmark

While Ford believes in unique wheel styling theme among vehicle lines to emphasize its image, Toyota is satisfied with making minor "A" surface changes to their wheel design. Thus we see that to attain commonality more important than engineering enablers is a company strategic vision governing the look or styling themes. The engineering enablers here would deal with such aspects like modularity and standardization of interfacing components. Given that there are only limited sets of options in wheels for Toyota, the interfaces generated with other mating components like switches, steering column or plastic shroud would also be limited and easier to manage.

If commonality is high in Toyota products then how is set based engineering practiced? Based on our study, for steering wheels there are two sets of designs –

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a three and four spoke version. This does seem a limited set if styling variation is required. What is the implication for an attribute like safety? The development, verification and certification for regulatory requirements concerning steering wheel will be swift given the minor differences among them. When the components and airbags inside Toyota's steering wheels were studied there were differences between the vehicle lines. These differences were minor and would be used as tuning parameters to obtain the desired occupant injury requirements during crash. Changes like airbag vent size, airbag diameter, and inflator gas output levels within a family of inflators are examples of tuning parameters that were different from one vehicle line to another. Therefore for steering wheels, set based practices would involve only limited sets of parallel explorations.

An interesting aspect of the Toyota steering wheel design was the "package protection" concept. Package space and features were made available in the steering wheels to accommodate certain components to aid in attribute requirements. This space was available in all the wheels. However the component was present in only a few vehicle lines. For example a NVH damper was in a particular vehicle line. Several other vehicle lines using the same wheel could have used the dampers, but did not. It could be that these vehicles did not experience any vibration problems. But Toyota does seem to have an approach where they have documented lessons on how certain commodities and features may help in delivering attributes. Thus when commodities are designed there is a "futuring" process which makes accommodations for all possible known scenarios. If a vehicle lines sub system property emerges such that attribute may be delivered without the need for a commodity, in this case a NVH damper, it is just not included. By package protecting and keeping designs modular, even commodities become tuning "knobs" in delivering required attributes.

Let's compare two scenarios where futuring exercises are done. One involves futuring as part of a vehicle program while the other is done through a centralized process not dedicated to any particular program team. At Ford, when commodities are designed for a particular vehicle line, given the short duration available to teams for current program and lack of information on future program that haven't yet attained concept status, the vehicle teams would find it very difficult to package protect for subsequent products. Additionally the timing and cost pressures during the program development process would invariably result in teams working on current vehicles to sacrifice the futuring options. Managers in early or lead vehicle teams may not have incentives to absorb costs for future programs. A centralized futuring process would distribute the cost equally among all programs. Liker etal has confirmed these centralized practices within Toyota and Funk[32] has reported similar findings from other Japanese industries. While a centralized process seems beneficial in alleviating timing and cost pressures, there are still some commodities and attributes that need not be futured outside a program as the same ensemble of scenarios may present itself in other vehicle lines. A NVH damper may not be a difficult component for package protection in a new steering wheel environment. Given past histories, future programs may very likely need them as well. But introducing a damper into a legacy steering wheel with very little package protection for it will be very difficult. While protecting for a damper may be relatively easy inside a program, there are other commodities and attributes that would need centralized guidance. Thus it is important for program engineers to have good system knowledge so that they may recognize the futuring ability for their commodities.

6.2.3 Commonality frame work

The "menu" system discussed in earlier chapter is expected to assist program teams in creating commonality and speed up design at Ford. The menus are expected to be created through continuous futuring or annual process exercise by

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the commodity teams. Specific details on menu creation are still being worked out. However early program adopters of GPDS have seen flavors of commonality by being required to choose from a restricted selection of sub systems from either legacy or a few futured commodities. Benefits of commonality include robust design of components, improved quality associated with robustness, time to market and economies of scale. Care should be taken so that sub standard commanization do not proliferate the system in the beginning. If it does then commonality leads to increased cost of change and lack of differentiation among product portfolio. It would also prevent the adoption of better technology in future. New technology is a good area for futuring outside a program. While cost savings are apparent from adopting commonality, it is also inefficient if commonality in enforced at the expense of excess component capability. The company in this case is providing services for which it is unable to charge. As an example, if Toyota provides the NVH dampers inside steering wheels to maintain commonality despite vehicle lines not needing it, then this is clearly an excess. However we saw in our benchmark exercise features like "package space" for NVH dampers but the actual components used only as needed. This preserves the viable business strategy for the company. Commonality should not inhibit innovation. It is easy for stakeholders in the engineering process to shun commonality fearing it will impede innovation. However the aim of commonality is to reduce unique parts across product line. When viewed with this lens it is clear that to attain commonality you have to innovate especially if it has to happen across a complex system.

The aspects of commonality relating to this study on knowledge management are reduction in uncertainty or unknown issues during development, making product development decisions easier. Since the role of a program attribute team like safety is specific and limited to the attribute development for a commodity and

not to the design and release function of that commodity, a frame work alone is presented as to how commodity may be futured and interfaces handled.

6.2.4 Design for Variety

Ulrich[33] defines architecture of a product as the arrangement of physical components, the mapping of functional elements to physical components and the specification of interfaces among interacting elements. The design for variety (DFV) method proposed by Martin and Ishii[34]provides an operational detail as to how product architecture can be done. This method may suit well for a stable product like many sub systems within an automobile where the customer wants are well known. However it may not help in futuring a totally new technology or when requirements are new and still evolving.

DFV method considers two types of variety when developing architecture, one across current product lines termed spatial and another across future generation of products termed generational. Design for Variety method develops two indices to measure product architecture. One is generational variety index (GVI) that measures the amount of redesign required for future design of products. The other is the coupling index (CI) which measures the coupling among product components, stronger the coupling then greater is chance that changes made to one component would need changes to other interfacing components.

The GVI uses QFD[35] type matrix to map customer wants to engineering metrics and then the engineering metrics to the specific components. Then a number rating system is used based on team expertise and judgment for the cost of meeting the most stringent engineering metrics. The higher the GVI for a component the greater is the chance for its redesign to meet future specifications. The coupling index uses a matrix arrangement to map specification flows among components. These specification flows are design information that must be

passed between designers to design their respective components. Design teams estimates the sensitivity of each component to a small change in a related specification. If a small change in specification requires a change to the component, then the component has a high sensitivity and given a higher number rating.
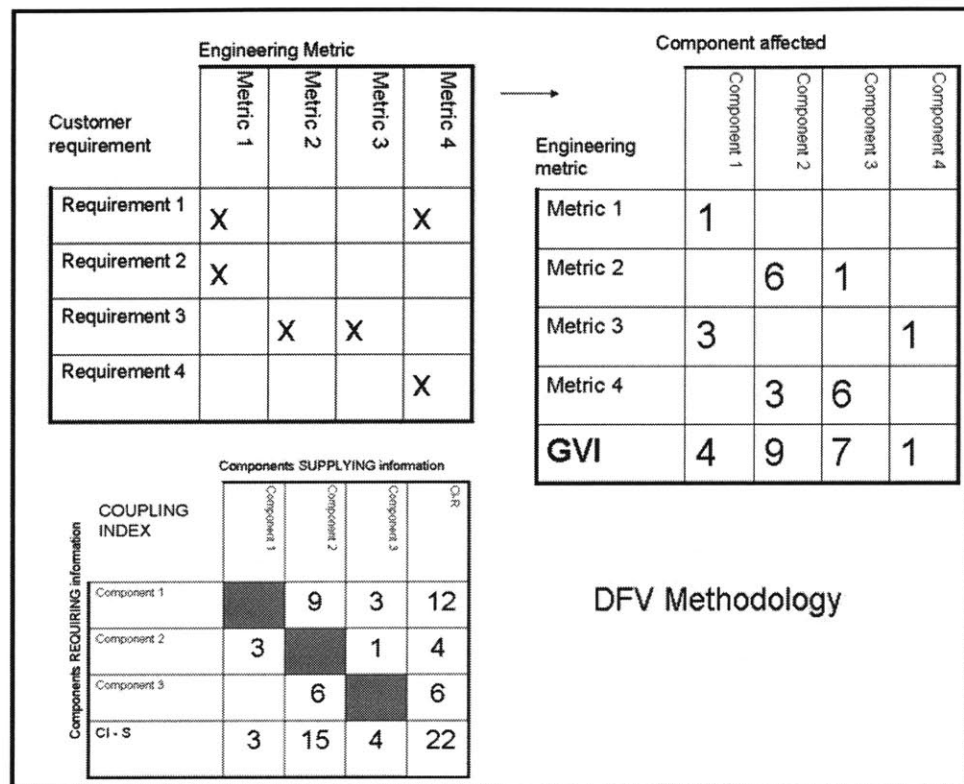

Figure 22: Schematic for DFV methodology for computing GVI and CI

If a large change in specification is required to make a change to the component, then the sensitivity is low and a low rating is given. The assumption in building this matrix is that specification change is linear across all components. The ratings are then summed and coupling index calculated. Based on the matrix, coupling

index can be broken down to CI-supplied and CI-received. Higher CI-supplied indicates that the component supplies a lot of information and change to that will cause more changes to other components. High CI-received indicates higher chances it will change as other components change.

Standardization and modularization strategies may be drawn based on CI and GVI. A fully standardized product would have a GVI and CI-received equal to zero. Fully modularized products where changes can be made to the module to meet customer demand without causing changes to other components would have its CI-supplied zero. Based on these rankings appropriate attention can be provided to the required components. While a mature commodity may be futured using this process, one drawback noticed with this methodology when applied to commodities affecting impact safety attribute is that teams would not know which components have the greatest impact on a new requirement. There is an emphasis on team judgment and past lessons with this frame work. This again brings us back to our central theme which is the importance of knowledge management.

6.3 Managing Emergence

Interactions among elements within a system bring out the system's behavior. This behavior could be termed as "emergent property" of the system or just "emergence". Many times this emergence is not apparent at the element level. System characteristics may not be predictable from the individual characteristics of the elements that make up the system. While several emergent properties are desirable, system designers frequently encounter undesirable properties as well. This is usually due to the fact that a designer would have expected a certain behavior from the system after studying elemental characteristics and was hoping to see some of it at the system level only to find later that it did not materialize. Additionally, in design of systems like automobiles, system characteristics are

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defined much ahead of the sub system or components that make them. For example during development of sub system or full vehicle system for crashworthiness many of the unexpected system behavior comes from unpredictable parameters like imprecise material rapture, unaccountable friction characteristics, stack up among components during crash etc.

The engineering monograph published by ESD-MIT[36] introduces the term emergence management. The question is posed as to how we may get the good emergence rather than the bad or how we may predict the bad? Analytical models using finite elements are used to predict crash behavior during early stages of product development. Models are accurate at predicting most of the system behavior in crash provided the modeling methodology was accurate. These models are still not sufficient to make critical product design related decisions. Also, these decisions have to be made early in design schedule as flexibility to make changes later during product development is lost. One factor responsible for this reduced flexibility later is due to the fact that tooling commitments would have to be made at the component and sub system level before full system behavior is verified. Model correlation is necessary to improve predictability. However to improve correlation you still need full system tests unless reliable transfer functions are available that translate component and sub system performance in bench tests to what may be seen in full system tests.

The first case study on steering wheel is an example of how an undesirable emergent property was encountered during development. Despite crash CAE modeling tools the system responses were not predictable. It wasn't until full system evaluations that the stiff lower rim responses were noticed. While the problem was "found and fixed", the increasing desire to reduce development time will not afford the luxury to find and fix problems as part of future product development iterations. Thus our team involved in the steering wheel project for

program "A" decided to take the exercise further. Once a transfer function was established between component performances in a "bench" environment versus system response in a "full vehicle" environment, it became imperative to quantify these behaviors in a design document. This formalization on how to conduct a component design, in this case a steering wheel, led to the creation of the first design discipline in safety attribute engineering in North America. By not following design disciplines the team would have to pursue other system or sub system level development to avoid the undesired emergent behavior. Without embarking on similar experiments it is unlikely that teams would be aware of any emergent behavior.

6.3.1 Design Disciplines[37]

It should be recognized that design disciplines discussed are different from "standards" or "specification" documents. Standards or specification documents are those specifically drawn to prevent undesired system behavior based on known customer usage pattern. But design disciplines list parameters, features or characteristics that a component must possess so that it has enough robustness to counter any undesirable property that emerges when the system comes together. These design disciplines are also supplemented with common best practices documents which list different possible designs from past experiences, design parameters and development methodology for a given component to meet safety requirements.

Another question posed is that, is emergent management even possible? In theory yes if all possible combinations of the element in the system are tested! However this may be impractical. One way to counter is through knowledge management. Lessons learnt to counter undesirable emergent property from one system need not be revisited again elsewhere in similar systems. The knowledge management framework proposed in this thesis discusses how the interactions

when noticed in a system may be countered using certain design characteristics proven by teams working on similar systems. Simply put, it proposes a formal manner in which teams document and communicate their things gone right! Many engineers and supervisors at Ford when interviewed agree to this notion. The feeling is that more intensive means like additional iterations or analysis and unique design or modifications would be needed when teams are unable to follow design disciplines. Knowing that a team will not be following a certain design discipline is also helpful. It would let engineers and their management knows that extra resources should be allocated upfront during development to address gaps that may arise.

Powerful system engineering tools and frame works such as Design Structure Matrix and axiomatic design[38] helps in capturing possible system interaction. Qi Dong (2002) proposes a frame work in which both these methods are used to predict system interaction especially in the early stages of design when critical decisions have to be made. When formal knowledge on how to design or lack of understanding of how information transfer occurs in the system is an issue, such powerful tools are useful. When knowledge is explicit and the system is mature, then as interactions that occur over time are documented and if followed among these systems designers, such a knowledge management framework is indeed more powerful than any predictive tool.

6.3.2 Implementation Road Map

Technical specialists within safety attribute should lead knowledge creating project teams or working groups. These teams play a key role in sharing their tacit and explicit knowledge. This working group forum produces component or sub system targets for other PMT's or teams to follow. This target setting process may be considered the foundation for design disciplines. This forum also produces "how to" documents or best common practices documents which list

various ways of impacting and delivering designs documented from various programs and benchmark projects. Looking back and comparing the current organizational make up, it is much different from the early days of FPDS where different program safety team's interaction amongst themselves was limited. The core function of the working group should be the need for reusing knowledge, collective learning, repetition of best common practices and preventing the repetition of mistakes.

To prevent any paralysis through analysis, specific projects or vehicle line based experimentation provides a perfect platform for quick prove out. It has been seen several times, even in Ford safety organization, that new vehicle product development is the central location for creating attribute knowledge. To conduct such experimentation companies must maintain a highly adaptive and flexible approach to Product Development, both functionally and organizationally, as it is an iterative, dynamic, continuous, trial and error process.

As there is no room in the product development schedule for excess dynamism or iteration an offline process with similar importance to the actual program schedule is essential. This may be regarded as the pre-program work where the program targets and system level targets are clarified. From a project management standpoint the pre-program and the annual process (section 4.2.2) would have to be adhered for GPDS to succeed.

It is easy to create an attribute centric knowledge that does not account for cross attribute considerations. The technical specialists leading the working groups should help balance the requirements between attributes. Without cross attribute considerations design disciplines will not provide benefit across many vehicle lines.

Finally design compatibility should not be confused with completeness. It is important for safety attribute engineers to undertake broad compatibility exercises along with design and release engineers to explore the design space thoroughly. Coordination with preprogram and core engineering activities are essential enablers for compatibility studies. Both internal and external benchmark results should be included in best practice documents. Balancing compatibility with product differentiation is by no means an easy challenge. Teams may encounter challenges from different functional groups. Teams may have to over design some commodities. Teams may encounter issues where a commodity may just not quiet deliver unless targets are compromised or adjusted. These would require a collaborative effort requiring significant understanding and compromises among the stakeholders.

6.4 Chapter Summary

This chapter saw that part commonality and reuse is more than just an engineering challenge and involves higher level system strategies. While Toyota and Honda may allow common A surface appearance between products, Ford may choose to keep them different. Some components with multiple interfaces will definitely need a greater degree of coordination to attain commonality. Techniques like design for variety methodology may help. If a component is highly modular then maintaining commonality is much easier. No matter if a component is integral or modular, knowledge reuse fits them both in speeding up the design process.

Through cases and past practices the benefits of design disciplines have been proven. An implementation road map for sustaining the design disciple process was provided. Given the grass roots nature of this project it is up to the practicing engineers to sustain it. There is no doubt that if sustained the development process will be streamlined.

7. Recommendations

"An engineer may not take the time to document her steps or put the results of a simulation on the bookshelf and because of that she saved engineering time and did her project more efficiently. But in the long run it prevented us from being able to deploy the reusability concepts that we were looking for."

Repenning and Sterman[39] term the scenario described above as capability trap which is a result of shortcuts. When immediate performance is needed, the team may undertake shortcuts skipping improvements and maintenance. However capability declines in the long run. Time must be allocated to reinvest and improve process capability. If this reinvestment does not happen then the team will always "run like crazy". Any gain made by the team is not efficient. Much energy is expended to gain little. Repenning and Sterman also argue that the ability to generate new improvements is not the barrier, but successfully implementing them usually is.

Similarly sustaining the knowledge improvement process is the key. It is a continuous process with no fixed time frame. The important aspect is the discipline needed to document the knowledge attained, share it among working group members and formalize them through the "design disciplines". The choice of word discipline is in itself interesting. It is not a mandate or regulation nor is it binding in nature. But it is one that has to be believed in and followed, to bring to a state of order the past practices and knowledge. Implementing a new process is not a "tool" problem. Instead it is a systemic one involving the interaction of tools, workers and managers. The working teams within safety attribute at Ford over the past year have created several design disciplines and common practices. Implementing them through programs over the past year and a half have fetched

great benefits as seen in the case presented earlier on steering wheels. The need is several such design disciplines on a continuous basis. It is commendable that the safety attribute management team is not falling into the capability trap mentioned earlier. The strong push given to these actions by the management has helped in sustaining the process. While there are early believers among the working level, whole scale adoption is still essential and would require a fundamental change in working culture.

The past chapters saw discussion on the gaps in the existing product development process FPDS, the proposals from GPDS to fix these gaps, a case study on commodity development for an attribute engineering, competitive assessment on how commodity commonality is maintained and finally through these exercises a case for knowledge management to streamline the commodity development process. To sustain this knowledge creation process and improve on it recommendations are listed below.

7.1 Recommendations for Safety Attribute Engineering

The working group format kicked off at the time of GPDS general cascade to employees has helped to consolidate team experiences from past programs. Sophisticated software tools do not control the knowledge and lessons within the attribute. Instead simple shared disk drives on centralized servers and program web pages are used among members to document and cascade lessons. These are done under the leadership of technical specialists. This process has to continue.

The important lesson learned from initial exercises involving the creation of FPDS checklist is that it cannot be just a rearrangement of tasks. It cannot be exhaustive binary format questions. Several hundred questions constituted the early exercise. A parameter based design document is more welcome. What management needs is an assurance that past mistakes will not be repeated. To this

extent documentation of package and performance details are necessary. These then should have comparison to legacy information. Such simple checklists are better than long questionnaires. The parameter checklists that came out of the offsite meeting within safety attribute should be followed. Engineers should take time in their daily work to document and share lessons. The pressure of daily work relegates such documents to a later date and eventually it may never get done. This should be avoided. The checklists while listing the best possible way to accomplish a desired performance should also talk about challenges that may be faced in attaining them. Though it is the responsibility of the program action teams to coordinate this balancing among attributes, safety team members should also be aware of limitations to design. This way challenges from past are well understood as teams move forward. Finally, checklists are created based on abstractions from experiences and product histories. As such, it will get modified and refined with accumulation of experience. Teams should be prepared for this continuous improvement.

These checklists and books should be shared with design and release engineers. Their trust and concurrence is essential for safety team members to deliver a design to target. Design and release engineers may also insist on similar details from other interfacing attribute and commodity teams. This now enables a wholesome way to understand how specifications flow.

Given earlier discussions, Set based design seems intuitively better. Set based options also supplements existing knowledge base. Unsuccessful sets need not be considered as useless. Unsuccessful sets would supplement existing best practices. While there are already practices in the virtual world through CAD studies and CAE simulations for set based practices, physical experiments should also be encouraged. Through hardware experiments parameter trade off's may be more accurate. The aim of multiple sets along with design disciple is to secure

conceptual robustness. If one function or attribute can create a design that works well with all the possibilities in another function's set, it can proceed with development without waiting for other functions.

While exploring design space during early stages like pre-program, engineers should understand that there are minimal constraints. Compatibility should not be confused with completeness. Compatibility studies should be exhaustive. Also completeness should be pursued only after all interfacing attributes determine the design to be compatible. Once the studies are complete and designs are committed, it is imperative to stay to this commitment. This is why parallel explorations offer a chance to confirm feasibility before commitment. This principle of confirming feasibility before commitment forms the essential core for both set based iterations and design disciplines.

7.2 Recommendations to Interfacing Groups

Design actions should be carried out with downstream implications in mind. Too often package protection for design is confused with implementation of design. When downstream design verification indicates certain features may not be needed for a particular vehicle line, these features are usually removed and package protection negated. Such vehicle centric decisions do not help commonality efforts. Corporate funding should be provided to incorporate future capabilities not used in current programs but anticipated later. Centralized benchmarking activities that allow information flow across all parts of the product development organization should be carried out. Individual attribute teams and commodity teams working on specific program teams or vehicle lines should support these exercises.

The issue of commonality and reuse of commodity is broad. It is an important strategic decision of a company even if the engineering and organizational

challenges can be overcome. It can be done but the effort involved is enormous. But reuse of knowledge is a "lower hanging fruit". It is a must if design and development process has to be streamlined. For legacy commodities which would need updates or freshening the frameworks presented through design for variety may be pursued. The design for variety is a simple extension of system engineering frameworks like QFD already followed with in Ford.

Consolidation of supplier base will help in commonality. A core supply base may also assist in technology development and futuring exercises. However care should be taken that Ford does not shut itself out of innovative ideas from suppliers who are not part of its central group of suppliers. In this regard purchasing strategy is also an important enabler if set based practices and commonality are to succeed. While stability and commitment are required towards a core group of supplier's to ensure commonality, flexibility with outside suppliers is required to advance technology. The flexibility and stability proposed cannot be opposing but should work in tandem to enable broad based parallel set explorations. The purchasing group should assist engineering teams in determining this balance between stability and flexibility. In this regard, proposals in GPDS to include purchasing teams to assist functional engineering teams during the early stages of program should be followed.

Pre program activity was an important part of early program teams in FPDS. As FPDS evolved pre program teams faded away. It may have been due to the fact that they were redeployed within program teams to resolve ongoing issues. Pre program teams are essential to deliver the goals of GPDS. GPDS also emphasizes team continuity from pre program to program phase. While the implementation details are confidential given the nascent nature of GPDS, it is a good sign that this is happening. A central process for futuring commodity is a must. This would also ease the burden on program teams who would have to package protect for

several vehicle lines along with the pressures of delivering a feasible solution to existing program. This centralized process would also remove any organizational conflicts that may arise. In conclusion, as Ford moves forward with its new manufacturing led product development process, knowledge reuse is necessary to launch future innovations and new products in a shorter time to market.

7.3 Future steps

While the recordings of this thesis work are fairly qualitative, quantitative work supporting the design details are specific to vehicle program teams at Ford and hence could not be shared. However the important message that was sought is the reuse of knowledge which was addressed in prior sections. A future study may be undertaken to ensure that knowledge framework process is sustained and quantify the benefits through reduction in product cycle time. It would also be interesting to study any changes in culture within the working groups, if they are able to sustain the knowledge creation process. If working groups are successful in sustaining this process then the evolution of knowledge from tacit to explicit may also be observed. Incentive structure to reward employees may also be studied within this context. Inter team dynamics is important to safety attribute if knowledge management framework can be sustained. A study may also be conducted to explore the extension of this framework to design and release activities.

Appendix I

Pictures of different types of safety development tests conducted by safety attribute teams are shown below. Regulatory tests can be component, subsystem or full system based. In order to conduct several design iterations, development engineers may scale down full system tests to sub system level. Scaling down is for experimentation purposes only and not for regulatory certification. This increases the test turn around time.

Full system safety tests
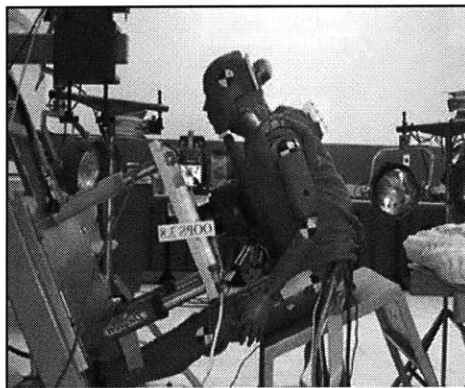
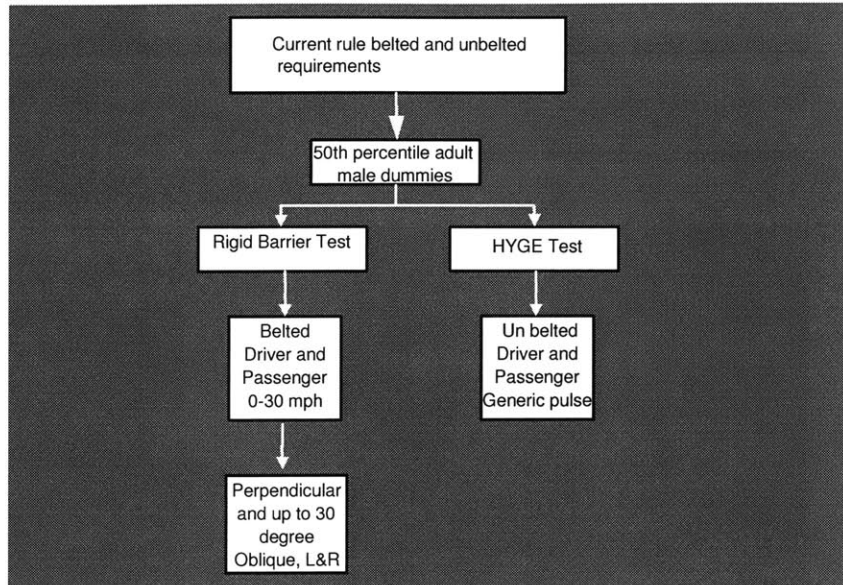Component level safety tests
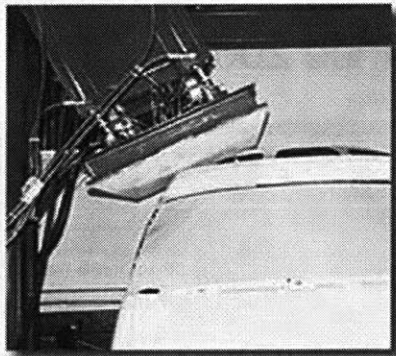
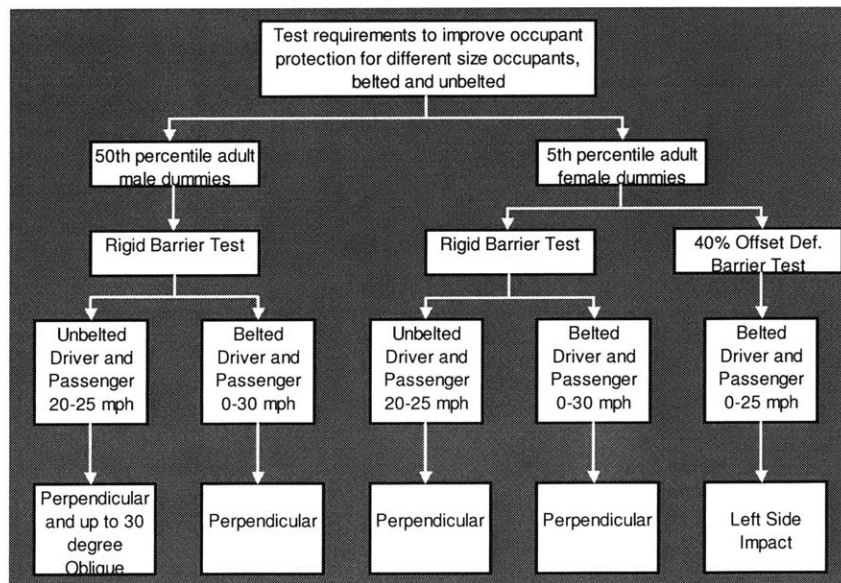Sub system level safety tests

Appendix II

FMVSS requirements for frontal impact before and after 2004 Model Year vehicles.

Until 2004

Since 2004

Appendix III

```
N  Obtained latest PDL
N  Resource needs established v. EFT model
   Saftey PAT established with the following members (invited as needed):
   N  TS
   N  Safety manager
   N  CPE\Vehicle engineering manager
   N  ASO
   N  Restraints D&R
   N  Sled
   N  VEV
   N  PMT Leaders
   N  Suppliers
   N  Packaging
N  Finished creating section website with pertinent posted information\documents
   Final preliminary safety workplan created considering safety pyramid
   (regulations\SDG\Due care\PDG) and future regulations and PD tests:
   N  CAE workplan
   N  AP0 crash testing\development plan based on CAE capability
   Qualitative compilation of competitive and legacy information: Architecture (uni-body v. body on frame)
   / Restraint content (side airbags, curtain, crash sensing system, dual stage airbags, column, STPS)
   N  Competitive benchmark vehicles assessed based on performance and safety content
   N  Compiled Ford legacy information
   N  Compiled Public domain testing information (weblink)
   N  Have communicated acquired information to program and other crash program teams
   N  Have updated PDL content list and containable targets based on acquired information (if need be)
   N  Have posted\archived acquired information for future reference
   Quantitative compilation of competitive and legacy data: Architecture (uni-body v. body on frame) /
   Restraint content (side airbags, curtain, crash sensing system, dual stage airbags, column, STPS)
   N  Continually compiling Ford legacy detailed data
   N  Continually compiling Public domain testing data (weblink)
   N  Currently testing competitive vehicle/system/sub-system/component (VSSC tab)
      N  All final\additional plans and test matricies completed
      N  Potential sub-contracted suppliers have provided quotes for unique component testing
      N  Everest\GPIRS orders initiated for sub-contracted suppier (weblink)
   N  Have communicated acquired data to program and other crash program teams
   N  Have updated PDL content list and containable targets based on acquired data (if need be)
N  Completed providing initial input to appearance theme concepts, which should now include initial CAE
   analysis based on VSSC items studied at <KO>
   N  Closed out tasks\analysis opened at <KO> based on VSSC items
   N  Completed generating revision proposals if theme is unacceptable
      N  Have called proper meetings to start resolving unacceptable items
      N  Have gained agreement upon major issues and design actions\changes are in progress
   Input to details and resolution towards single theme
   N  Continue to attend studio AST meetings and provide input based on VSSC items (and request TS to attend)
      N  Obtained more detailed scans, photographs, drawings and overall theme proposals from studio
   N  Continue updating CAE models for assessing Structure\Occupant performance of proposed
      theme concepts
   N  Based on more detailed information, have proveded input to final preliminary safety workplan
      above, and have adjusted it appropriately
   N  Continued to provide more detailed input at AST meetings as theme(s) is\are refined based on VSSC
      items studied at <KO>
   N  Continually generating revision proposals if theme is unacceptable
      N  Have called proper meetings to start resolving unacceptable items
      N  Have gained agreement upon major issues and design actions\changes are in progress
      N  Have updated PDL content list and containable targets based on acquired data (if need be)
N  Completed providing initial input to package and architecture concepts, which should now include
   initial CAE analysis based on VSSC items studied at <KO>
   N  Closed out tasks\analysis opened at <KO> based on VSSC items
   N  Completed generating revision proposals if package\architecture is unacceptable
      N  Have called proper meetings to start resolving unacceptable items (invited safety management)
      N  Have gained agreement upon major issues and design actions\changes are in progress
   Input to package and architecture concept details
   N  Continue to attend packaging\architecture meetings and provide input (and request TS to attend)
      N  Obtain latest information on frame, powertrain, fuel and suspension package (VSSC tab)
      N  Obtain latest information on program weight swing
      N  Obtain latest visor and A-pillar information (including grab handles)
      N  Obtain latest other VSSC items
      N  Obtain latest manikin\seatback angle and H-point information
   N  Reassess competitive and benchmark information on frame design and performance concepts
   N  Reassess legacy data from surrogate platforms
   N  Continue updating CAE models for assessing Structure\Occupant performance of proposed
      interior\package\architecture concepts
   Start finalizing the following:
      N  The required load carrying capacity of structural members
      N  Required clearances and allowable intrusion of various systems, sub systems, and components
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Picture shows a gateway checklist, documenting tasks for a particular milestone in FPDS, practiced by safety attribute engineering. This documented the tasks conducted in an explicit manner. However it did not describe design details.

End Notes and References

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Affordable business strategy: Customer price or willingness to pay – expected profits = Product cost

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[22] Thomke, Experimentation Matters: Unlocking the potential of new technologies for innovation, Harvard Business School Press, MA 02163, pp51-55

[23] Information obtained from GPDS Phase 2 cascade.

[24] Insurance Institute for Highway Safety, Public Domain agency created by the Insurance Industry in the U.S., www.iihs.org

[25] Jeff Vinton, Ford NA truck safety technical specialist was the team leader who supervised the development of safety FPDS work plan and checklist. His work on the decomposition format presented as the Vehicle-system-sub system and component break up list laid the foundation for future knowledge development work in the form of design disciplines.

[26] CMVSS or Canadian Motor Vehicle Safety Standards are similar to FMVSS and regulate the safety standards for vehicles sold in Canada. The regulating body administering this is Transport Canada.

[27] The crash mode here is a 30 mph full frontal collision into a rigid wall with belted 50th percentile male Hybrid III ATD's. Allowable chest deflection for Canada was 50mm while that for US was 76mm. The reason cited by Transport Canada for tighter standards was mainly to address the driving pattern in Canada. Seat belt usage is high in Canada and Transport Canada was addressing the need for a belted only test. Additionally Transport Canada wished to minimize serious injury or fatality that could arise from sternum deflection as real world accident reconstruction studies showed this to be concern for this market.

[28] Test setup used here is considered proprietary and will not be discussed. While it is important to understand that such component level tests are used to develop the system by engineers, the test set up specifics are beyond the knowledge management frame work discussion.

[29] Steve Kang, Occupant CAE technical specialist within truck safety at the time of this project was pivotal in developing lower rim standards and helping safety teams from program "A" deliver safety targets.

[30] This FMVSS 208 requirement where the deploying force of an airbag plays a significant role in ATD injury metrics is termed as "low risk deployment" by NHTSA. The occupant is placed in an "out of position" condition lying on the wheel and the airbags are deployed. Injury measurements from ATD are the objective measure for the airbag system performance and would have to meet regulatory limits set forth by NHTSA.

[31] Competitive benchmarking of Toyota wheel was done by North American Core Safety Group.

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[37] At the time of this thesis a formal process has been set in motion within Ford safety's core safety group to formalize design disciplines under the leadership of a senior technical specialist. This formal process undertakes the steps listed in the implementation roadmap. It important to note that design disciplines are not necessarily the only means of achieving the required levels of safety performance, are subject to change based on more experience or new technology or new regulations or other factors and are intended to support using concurred on best practices that will save time and resources to allow on target program delivery.

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